March 2014

Charting New Waters

The Road Toward Smarter Nutrient Management in Municipal Water Treatment

The Johnson Foundation AT WINGSPREAD

About The Johnson Foundation at Wingspread

The Johnson Foundation at Wingspread, based in Racine, Wisconsin, is dedicated to serving as a catalyst for change by bringing together leading thinkers and inspiring new solutions on major environmental and regional issues. Over the course of 50 years, The Johnson Foundation at Wingspread has inspired consensus and action on a range of public policy issues. Several organizations have roots at Wingspread, including the National Endowment for the Arts, National Public Radio, the International Criminal Court and the Presidential Climate Action Plan. Building on this legacy, The Johnson Foundation at Wingspread has set a new, strategic mission designed to achieve greater, more sustained impact on critical environmental issues. Launched as part of this new direction is Charting New Waters, an alliance of leading organizations calling for action to avert the looming U.S. freshwater crisis.

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Convening Report

Meetings Convened by
The Johnson Foundation at Wingspread
February 13–15, 2013
October 28–29, 2013

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The Johnson Foundation AT WINGSPREAD

The latest phase of Charting New Waters focuses on water infrastructure. Specifically, this work aims to catalyze the widespread adoption of more sustainable and resilient water infrastructure systems in the United States. It is focused on synthesizing and disseminating information and recommendations that help local, state and national leaders set a course for and navigate decisions regarding the construction, financing, management and maintenance of sustainable and resilient water infrastructure for the future.

Partnership in Action

The Water Environment Federation, the Environmental Defense Fund and The Johnson Foundation worked in partnership to sponsor a meeting at Wingspread in February 2013 and another at Airlie Center in October 2013 on the topic of nutrient management in municipal water treatment. Participants in these meetings represented the diverse interests and perspectives The Johnson Foundation sets out to engage through Charting New Waters, including scientists, researchers, engineers, utility managers, federal and state regulators and members of advocacy groups, along with the implementing partners. The partners are working to elevate the visibility of, and increase the understanding around, wastewater nutrient management issues, to encourage decision makers at the local, regional and national levels to accelerate movement toward sustainable water infrastructure.

Conferences that Inspire Solutions

Letter from the Director

Can wastewater treatment achieve more ambitious goals for the clean water it provides, while holding the line on energy use and greenhouse gas emissions? Along with our partners at the Water Environment Federation and the Environmental Defense Fund, we asked a group of experts to explore this question with us. These deliberations and this latest report, *The Road Toward Smarter Nutrient Management in Municipal Water Treatment*, are part of our Charting New Waters series, which has been expanding horizons and opportunities for U.S. water security for more than five years.

These latest meetings stemmed from our shared understanding that continuing on our current path is not an option. Despite staggering advances in wastewater treatment over the past half-century, effluent from municipal treatment plants continues to be a source of nutrient pollution into our nation's waters. Rather than deflect attention to other sources of pollution, this group took the "can-do" approach of examining opportunities for the water utility sector to continue to contribute to the cleaner water we all want, and took it a step further to examine the potential for recovering nitrogen and phosphorus and returning it to the agricultural cycle.

The range of technological options is exciting, and the dedication and intellectual creativity of those working to develop and implement these changes can't help but give us all encouragement that a new day lies ahead. But the conversations remind us that the solutions are not just about technology; change will require appropriate policies, regulations and markets, as well as data and workforce capabilities. All of these pieces need to work together to achieve the new utility model that many of us seek.

This report provides a glimpse into the stimulating conversations and debates that were held over the course of the meetings, and serves as a placeholder until the more robust product is available from our partners later this year (see p. 5). It will also serve as a springboard for further discussions with an expanding base of partners and stakeholders.

Thank you to all who participated in these discussions and to those who are actively engaged in the solutions ahead. This work isn't easy, but that doesn't mean it isn't necessary.

Thank you for joining us in the journey,

Lynn Broaddus
Director, Environment Programs
The Johnson Foundation at Wingspread

Introduction

Water management is one of the cornerstones of municipal infrastructure, vital to protecting human and environmental health in cities and towns of all sizes. Over the last century, the challenges faced by wastewater treatment facilities across the country have changed significantly as a result of population growth, urbanization, intensified agricultural practices and climate change. One of the primary challenges these facilities face is managing nutrients – specifically, finding ways to meet the demand for cleaner effluent while juggling economic and energy constraints. The Johnson Foundation at Wingspread teamed with the Water Environment Foundation (WEF) and the Environmental Defense Fund (EDF) to ask a group of experts with diverse backgrounds to help think through the opportunities and obstacles associated with addressing the nutrient challenge. This report is an initial summary of those conversations.

Drivers of Change

Population growth and corresponding increases in the demand for food and energy have driven up the use of phosphorus and nitrogen-based fertilizers and the combustion of fossil fuels. These factors have contributed to the most rapid dissemination of reactive nitrogen in atmospheric, terrestrial and aquatic environments in the last 2.5 billion years.[1] Nitrogen overloading causes eutrophication and biodiversity loss from dead zones in estuaries and freshwater systems; increased criteria pollutants and potent greenhouse gas emissions in atmospheric systems; and, through atmospheric deposition, increased acidification and other forms of nitrogen pollution in soils. Similarly, too much phosphorus in our waters contributes to toxic algal blooms and eutrophication in lakes and other aquatic environments, causing significant environmental damage, particularly in freshwater systems.

These types of environmental concerns have resulted in efforts to protect and restore freshwater ecosystems, as well as heightened regulatory constraints on the discharge of contaminants and toxins from wastewater treatment facilities. While a variety of factors have contributed to these nutrient-related water-quality challenges – including agricultural practices, urban stormwater runoff and the deposition of airborne pollutants – effluent from municipal wastewater treatment is a significant contributor in many urban and coastal areas.

Reactive Nitrogen

A variety of nitrogen compounds – including nitrous oxide (N_2O), ammonia (NH_3), nitrate (NO_3) and others – are referred to as *reactive nitrogen*. In water, these compounds can contribute to eutrophication, or the rapid growth of algal blooms that deplete oxygen, hurt fisheries and result in coastal dead zones. Reactive nitrogen compounds also include atmospheric greenhouse gases, and they can increase ozone levels. N_2O in particular is a potent greenhouse gas.[2]

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[1] D.E. Canfield, A.N. Glazer and P.G. Falkowski, "The evolution and future of the Earth's nitrogen cycle," *Science*, no. 330, 2012, pp. 192-196.

[2] E.A. Davidson, et al. "Excess nitrogen in the U.S. environment: Trends, risks and solutions," *Issues in Ecology,* no. 15, 2012. Available online at: www.esa.org/esa/wp-content/uploads/2013/03/issuesinecology15.pdf).

At the same time that our society is demanding cleaner water, new opportunities are being developed to remove these nutrients from wastewater more effectively, as well as to recover them. Although many nutrients can be costly or energy-intensive to remove, they can also be revenue-generating or at least cost-offsetting when recovered. Recovery of the significant quantities of nitrogen and phosphorus in our municipal waste streams could help to stem the growing nutrient imbalances being observed in natural systems, offer a marketable product, and in the case of phosphorus, provide a sustainable source of a finite resource to support agricultural production and food security in the United States and worldwide.

New technologies continue to bring improvements in the effectiveness and efficiency of wastewater treatment systems. Given the dual challenges of increased nutrient loads at wastewater facilities and the growing need to preserve and recycle these nutrients, many members of the wastewater sector believe the time is right for a sector-wide shift away from basic treatment and toward nutrient recovery and removal. Such a shift would complement conventional treatment and disposal and would harvest valuable resources from municipal waste streams.

Many utilities, in fact, are already renaming their facilities. Instead of "wastewater treatment plants," the new term of art is "water resource recovery facilities" (WRRFs),[3] which reflects the new focus on capturing marketable resources such as energy, nutrients and water. While legal and regulatory

Wastewater treatment plants are not waste disposal facilities but are water resource recovery facilities that produce clean water, recover nutrients (such as phosphorus and nitrogen), and have the potential to reduce the nation's dependence on fossil fuels through the production and use of renewable energy and the implementation of energy conservation.

– WEF 2011 Renewable Energy Position Statement

Declining Global Phosphorus Reserves

Scientists worldwide agree that phosphorus reserves are declining. Rock phosphate, the primary source of phosphorus used for agricultural fertilizers, is a limited resource with dwindling supplies. Researchers at the Global Phosphorus Research Initiative – an interdisciplinary collaboration between independent research institutes in Europe, Australia and North America – published a 2009 study describing phosphorus as a "finite resource [with] current reserves [that] could be depleted this century."[4]

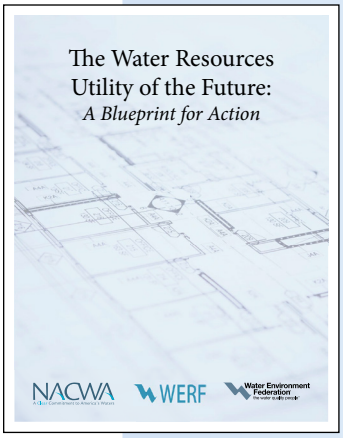
[3] D. Cordell, J. Drangert and S. White, "The story of phosphorus: Global food security and food for thought," *Global Environmental Change*, no. 19, 2009, pp. 292–305.

[4] WEF has adopted this terminology in their Renewable Energy Position Statement. In the context of this document also, "WRRFs" refer to wastewater treatment facilities.

mandates still focus on maintaining public and environmental health, reframing the perspective around resource recovery reflects the ever-increasing awareness that many of these resources are in short supply and have significant value to society. Treatment for nutrient removal and recovery both addresses a critical need and presents a real opportunity for environmental and economic gain.

Water Resources Utility of the Future

In 2013, the National Association of Clean Water Agencies, the Water Environment Research Foundation and WEF released *The Water Resources Utility of the Future: A Blueprint for Action* to define relevant issues, analyze key data and offer recommendations for critical actions for the future of water resources management. Today's clean water agencies are increasingly looking beyond the Clean Water Act as they seek to improve environmental performance, benefit their communities and improve their financial picture. The Water Resources Utility of the Future is defined by today's utility leaders who are pioneering innovative technologies and cutting-edge practices with a focus on resource recovery. The Blueprint presents objectives and goals for the water community to adopt in an effort to achieve a new clean water paradigm, with consideration for energy production, water reuse, green infrastructure and watershed-based approaches.



See www.nacwa.com for more information.

Coming Together to Pursue Smarter Nutrient Management

The Water Environment Federation and the Environmental Defense Fund both recognize the value of incentivizing technology improvements for removal and/or recovery and reuse of nitrogen and phosphorus from wastewater in a sustainable and cost-effective way. The two organizations jointly crafted the following vision statement for the future of wastewater treatment: "WEF and EDF are collaboratively seeking to explore 'smarter' approaches to the management of nutrients from municipal water sources, considering such factors as the potential for resource recovery, overall net environmental benefit, regulatory barriers/incentives and cost effectiveness."

In 2012, The Johnson Foundation, through Charting New Waters, partnered with WEF and EDF to help scale successes from the wastewater sector and catalyze more widespread transformation to improve nutrient management. These three organizations convened two events intended to gather representatives from the wastewater sector, the environmental community, the research community and regulatory agencies to develop practical steps to guide the wastewater sector toward smarter nutrient management while conserving resources, lowering costs and protecting water quality. These convenings focused on the value of addressing nutrient removal and recovery through voluntary approaches rather than through top-down, regulatory means. The meetings were designed to facilitate strategic thinking on the challenges associated specifically with wastewater treatment.

The two expert meetings focused on "Crafting a Future Vision for Nutrient Management in Wastewater Treatment":[5]

- **Part I: February 13–15, 2013, at Wingspread in Racine, Wisconsin**
- **Part II: October 28–29, 2013, at the Airlie Conference Center in Warrenton, Virginia**

This report presents The Johnson Foundation's synthesis of the insights and ideas raised and solutions generated during these meetings and captures opportunities to advance this work going forward. Most of the recommendations from Part I are summarized in the *Setting Goals for Nutrient Management* section that follows; the discussions from Part II are reflected in the subsequent sections titled *A Roadmap for Smarter Nutrient Management* and *Factors Influencing the Success of Nutrient Management*.

As complementary publications, WEF and EDF are developing a draft Strategic Management Matrix to be released in early 2014, as well as a full Nutrient Management Roadmap to be released in early 2015.

Setting Goals for Nutrient Management

The management of nutrients discharged from point sources into the environment – whether done by removal or by recovery and/or reuse – cannot be addressed sustainably without considering tradeoffs. Decision makers must consider the potential environmental effects, operational effectiveness, community impacts and economic factors, or else they may trade one problem for another when developing solutions to remove nutrients from waste streams. For example, the conventional treatment of nitrogen and phosphorus tends to have a significant energy demand and results in potent greenhouse gas byproducts (e.g., nitrous oxide and methane).

To holistically balance these complex and interrelated factors, facility operators and those involved in day-to-day activities at WRRFs can consider developing functional goals. Examples of cross-cutting, functional goals for nutrient management include:

- maximizing the capture and reuse of waste stream nutrients;
- minimizing the energy used to process wastewater;
- minimizing nutrient release into the environment;
- minimizing alterations to the hydrologic cycle;
- minimizing the release of greenhouse gas emissions from infrastructure; and
- maximizing economic benefits.

Image courtesy of The Johnson Foundation at Wingspread

Brainstorming session on nutrient management. Airlie Conference Center, October 2013.

[5] See Appendix A for a list of participants at the two meetings.

All such goals need to be considered within the context of economic realities. Technology has come a long way, but all communities have to contend with finite resources and competing public needs. The purpose of functional goal-setting is to promote the development of co-beneficial solutions and the clear articulation of the consequences and tradeoffs that can be missed in a more siloed approach to operational decision making. Balancing diverse goals within the context of site-specific needs and challenges could illuminate new opportunities for smarter, more economically and environmentally sustainable solutions with multiple benefits.

There is also value in considering long-term aspirational goals, to help anticipate future challenges beyond current circumstances and regulatory mandates. Integrated, long-term goals could describe the "bigger-picture" challenges facing the sector and consider the potential for future opportunity through innovation and strategic thinking. Such aspirational goals can be motivational and resonate with those interested in pushing beyond current common practice, including industry leaders, partnerships and coalitions focused on long-term action and implementation. The following aspirational goal, jointly developed by WEF and EDF, was proposed as an example intended to inspire longer-term transformation of the wastewater sector:

> *The next generation of wastewater treatment has net zero impact with regard to energy use, greenhouse gas emissions and nutrient discharge by 2040. Achieving this goal will require a dedication to overcoming the technical barriers, financial constraints and regulatory disincentives limiting nutrient removal, greenhouse gas emissions reduction and energy neutrality in the treatment of wastewater.*

While the participants in both meetings recognized the value of setting concrete targets for nutrient reduction in both the short and longer terms through functional and aspirational goals, members of each group expressed concern about setting unrealistic expectations for nutrient reduction and about the potential for increased regulatory burdens. There was a sense among some WRRF representatives, for example, that innovative nutrient management could lead to increased regulation, which could eliminate the flexibility required for facilities to experiment with different nutrient removal and recovery technologies. Potential regulatory mechanisms that could provide facilities with the latitude needed to explore these technologies without the threat of immediate ramifications are listed later in the subsection on Regulatory Innovation.

A Roadmap for Smarter Nutrient Management

At the meetings, participants discussed and began to develop a "nutrient roadmap" – that is, a mechanism to help facilities create a near-term, functional approach to smarter nutrient management. This effort, which remains under development, is being modeled after the WEF process of designing *The Energy Roadmap: A Water and Wastewater Utility Guide to More Sustainable Energy Management*, which serves as a guide for utilities of all sizes to pursue a path to sustainable energy management.[6] Similarly, the nutrient roadmap is intended to demonstrate the possible pathways by which wastewater facilities can transition from current operating procedures toward the aspirational goal of sustainable nutrient management. The term "roadmap" is not meant to imply a single destination or route. Each utility will have different needs that must be considered in the context of demographics,

[6] See http://www.e-wef.org/OnlineStore/ProductDetail/tabid/55/ProductId/20487783/Subsystem/INV/ProductCode/P130001/Default.aspx for more information about *The Energy Roadmap* published by WEF. An overview of the project is also available at: http://wef.org/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=12884902042&libID=12884902042.

weather conditions, priorities for the watershed and a range of other factors. Possible management factors under consideration for inclusion in an eventual roadmap include the following:

- Situational analysis to better characterize the challenges, understand the ecosystem factors and set goals
- Management considerations, including an evaluation of public values
- Evaluation of resource-recovery opportunities
- Assessment of nitrogen-treatment alternatives
- Assessment of phosphorus-treatment alternatives
- Process and product balance that includes carbon management, air emissions and dewatering
- Identification of marketable products from resource recovery

Each utility's challenges are influenced by the facility's stage of evolution. The roadmap will take into consideration that utilities evolve along a continuum of change – from optimizing legacy systems to implementing new, transformative systems. Regardless of where a facility is along the continuum, improvements can be made in pursuit of the ultimate goal of increased sustainability and resilience in the face of a changing climate.

The roadmap will provide different options and tools to help WRRFs make short-term and long-term improvements in their nutrient management practices and move toward the utility of the future.[7] Change is most often incremental but not necessarily consistent or linear. The roadmap will take these stages of development into consideration and reflect the mechanisms for catalyzing widespread movement along the continuum of transformation.

WEF and EDF have initiated the process of developing the nutrient roadmap, which will be published in early 2015 and based in large part on the discussions from these meetings.

Factors Influencing the Success of Nutrient Management

The diverse experts around the table at the February and October 2013 meetings expressed interest in a range of topics complementary to the tools and technical guidance that will be covered in the nutrient roadmap. Particular topics of interest included: regulatory innovation, technological advances in nutrient removal and recovery, watershed management, carbon management and better information for better decisions.

Regulatory Innovation

In considering options for smarter nutrient management, it is critical to account for the range of regulatory landscapes in which WRRFs across the United States operate. The extent to which specific nutrient loads are regulated varies widely based on geography and watershed characteristics. A relatively small percentage of facilities are regulated to meet water-quality standards in their receiving water body using specific numeric criteria for nutrient concentrations in their treated effluent. For example, facilities located in particularly sensitive watersheds such as the Chesapeake Bay face increasingly stringent effluent requirements under

[7] See *The Water Resources Utility of the Future: A Blueprint for Action*, National Association of Clean Water Agencies, Water Environment Research Foundation, and Water Environment Federation, 2013. Available online at: http://www.nacwa.org/images/stories/public/2013-01-31waterresourcesutilityofthefuture-final.pdf.

the Clean Water Act. Some facilities are required to meet technological criteria, but not numerical criteria, while others are subject to numerical criteria that are not particularly stringent. Still other facilities are regulated for one nutrient but not the other. For example, WRRFs that discharge into salt water are not typically regulated for phosphorus, but can be heavily regulated for nitrogen.

Regardless of the regulatory conditions they currently face, many facilities have opportunities to reduce their nutrient loads through relatively straightforward measures.

Facilities across the spectrum of regulatory contexts are aware of shifts in thinking about the regulation of nitrogen and phosphorus. Regardless of the regulatory conditions they currently face, many facilities have opportunities to reduce their nutrient loads through relatively straightforward measures. Meeting participants noted that, even among facilities not currently regulated for specific numeric criteria, many have the capacity to remove as much as 20–50 percent of their current nitrogen load through minor process changes that require little capital investment. There was some disagreement among participants as to whether or not operators would be willing to use excess flow capacity for nutrient removal and recovery processes, since many eventually hope to expand into that capacity. However, flexible permits that do not penalize utilities for temporarily using excess capacity to implement low-cost nutrient removal and recovery techniques could help incentivize the more widespread adoption of these practices.

Many of the plants that currently bear significant regulatory burdens have already implemented processes to reduce their outflows of nitrogen and/or phosphorus and are more likely to engage in nutrient removal and recovery. Getting other utilities – those not governed by stringent regulations – to voluntarily improve their nutrient management practices is a significant challenge, in part due to cost constraints and a lack of understanding of the need for, or value of, nutrient reduction. That said, facilities with and without current regulatory pressure are concerned about the prospect of more-stringent permit requirements if they are successful in reducing their nutrient loads. Particularly in service areas with growing populations, more-stringent load limits may limit facilities' ability to accommodate increasing capacity needs.

A deeper conversation about the evolution of the regulatory environment and opportunities for innovation would be beneficial to:

- encourage utilities with less regulatory pressure to adopt the pioneering practices that highly regulated WRRFs are undertaking;
- identify innovative solutions to the difficulties regulated facilities face in cost-effectively meeting permitting requirements;
- address tensions between the desire to reduce nitrogen loads overall while also allowing for capacity to meet population growth demands;
- anticipate the establishment of new or more-stringent regulatory requirements; and
- explore opportunities for low-cost efforts, especially those that can reduce operational costs (e.g., adding anaerobic denitrification to systems that nitrify ammonia to nitrate earlier in the treatment process).

Pilot projects could be one mechanism by which to promote innovation, enhance the collective understanding of technological alternatives, and build case studies of utilities practicing or willing to experiment with smarter nutrient management options. Currently, the regulatory environment creates disincentives to take on risks in the interest of reducing nutrients. Several innovative regulatory practices could help to alleviate these disincentives:

- **Safe harbor programs** – i.e., voluntary programs that allow for experimentation with or the piloting of new or innovative approaches with limits on the regulatory disincentives or risks

- **Stochastic permitting**, which uses probability models to consider fluctuating pollutants over relatively long periods of time, rather than using highly prescribed, inflexible limits enforced on a weekly or daily basis

- Approaches to allow temporary use of **current excess permitted capacity for cost-effective enhanced treatment, without triggering lower effluent discharge requirements**.

Technological Advances in Nutrient Removal and Recovery

Technological advances continue to drive progress toward smarter nutrient management. A wide array of nitrogen- and phosphorus-removal tools exist for WRRFs across a spectrum of sophistication and capital costs. These tools range from nitrogen management techniques for upstream sources (e.g., urine separation, water conservation, pre-treatment and protein recovery) to various plant-scale, treat-and-control approaches (e.g., conventional nitrification-denitrification, nitritation-denitritation or nitrite shunt, and deammonification or partial nitritation-anammox). Techniques for phosphorus removal have a similar range of considerations and options.

Technologies have also been developed that can recover valuable materials – including phosphorus, ammonia, metals, chemicals, proteins and water – sometimes generating enough revenue to fully offset the costs of implementation. Also, in some cases there is no additional cost for removing a second nutrient beyond the target nutrient. For example, the Hampton Roads Sanitation District (HRSD) operates a struvite (magnesium ammonium phosphate) precipitation and recovery process that provides multiple benefits. It eliminates problematic struvite blockages by harvesting the chemical before it can cause problems; it reduces nutrient pollution in receiving waters; and it creates a useful fertilizer product rich in phosphorus, nitrogen and magnesium. Other facilities (e.g., the Chicago Metropolitan Water Reclamation District) are in the process of implementing and operationalizing this and other techniques for struvite recovery.

An example of a promising experimental technology is urine separation. Since urine comprises a very small percentage of the volume of liquid in total WRRF loads, but is densely packed with nitrogen and other nutrients, the development and implementation of strategies to treat urine separately could have a positive impact on the efficiency of nutrient removal and recovery. If urine can be captured and treated separately it greatly reduces the volume of waste that would be subject to the more expensive treatment. Some facilities, including the HRSD, are experimenting with methods for urine source separation, including urine-diverting toilets that separate urine from the main system to a holding tank that can be picked up periodically by a sanitation service. The system uses little or no water or energy, can be incorporated into any standard building and costs less to build and operate than a central sewer. However, any wide-scale implementation of this technology will require significant societal shifts, and under present conditions in most systems, urine collection is impractical.

CASE STUDIES

Case studies can help to illustrate how the different challenges being faced by facilities across the country depend on the characteristics of each facility. The cases below demonstrate the two ends of the spectrum of technological sophistication and show the significant potential for activities at advanced facilities to positively impact the operations and nutrient management practices of others. These cases were presented at the October 2013 meeting by Jeanette Brown (Case 1) and Charles Bott (Case 2).

CASE 1 Modification for Nutrient Removal and Cost Savings

The Long Island Sound Total Maximum Daily Load is currently being reevaluated. This has prompted the New England Interstate Water Pollution Control Commission to deploy U.S. Environmental Protection Agency funding for a study of the feasibility of low-cost retrofits to 29 treatment plants in Vermont, New Hampshire and Massachusetts, to enable nitrogen removal without any major capital investments. Twenty-four of these plants are candidates for low-cost nitrogen removal, and the plant operators have expressed interest in learning about these new processes. The retrofits could include:

- process control changes;
- cyclic aeration;
- the addition of mixed liquor recycle pumps and piping; and
- the creation of an anoxic zone.

These plants present a good example of operations that stand to substantially benefit from guidance offered by the Nutrient Management Roadmap.

CASE 2 A Highly Regulated and Pioneering Facility

The Hampton Roads Sanitation District at the mouth of the Chesapeake Bay is comprised of nine large plants with a combined capacity of 250 million gallons per day, regulated by a bubble permit of 6 million pounds per year of total nitrogen. The plants operated by the HRSD are pushing the limits of nutrient removal and recovery, exploring:

- mainstream and centrate deammonification;
- struvite avoidance and recovery;
- the use of supplemental carbon for denitrification; and
- the impacts of bio-phosphorus on dewatering, among many other practices.

The HRSD is an example of a highly regulated utility that could benefit from an exploration of innovative regulatory mechanisms, and whose practices will provide leadership for the development of the Nutrient Management Roadmap.

Some WRRFs, like the nine plants included in the HRSD, are developing and piloting cutting-edge nutrient removal and recovery technologies. Others with flow volumes below design capacity, including many WRRFs in the small and mid-sized cities of New England, are prime candidates to implement relatively simple and low-cost nitrogen-removal technologies. Of the 29 plants Ms. Brown surveyed that discharge effluent into the Connecticut River (see Case 1 on p. 10), 24 could incorporate low-cost improvements to remove excess nitrogen. Those WRRFs applying innovative technological solutions are paving the way for other WRRFs to implement successful solutions, which could become more advanced over time.

Other examples of innovative nutrient removal and recovery practices include the following:

- Watershed-based bubble permits in the HRSD in Virginia, the Long Island Sound watershed, and the lower St. Johns River Basin in Florida
- Pollutant-trading programs between point and nonpoint sources of pollution and between nonpoint sources in the Neuse and Tar-Pamlico Basins in North Carolina
- Adaptive management of phosphorus in Cumberland, Wisconsin
- A collaboratively developed permit on the Spokane River

Watershed Management

Smart nutrient management involves assessing the impact of an individual facility in the context of the overall health of its surrounding watershed. Some existing permitting models reflect an integrated, watershed-scale approach to nutrient management, although these are not widely used in the regulation of wastewater treatment facilities. One such example is the watershed-scale "bubble permit," which takes a step in the right direction by providing an aggregate limit for a set of plants, rather than setting mass-load or waste-load allocations for each plant individually. Another example is the nutrient program, in which point or nonpoint source nutrient trading reductions provide credits that can then traded or sold to regulated entities that need to reduce nutrient outflows but are constrained from doing so because of technology limitations, cost or other factors at their own facilities.

Watershed-scale approaches could allow a level of flexibility and facilitate inter-facility and even cross-sectoral collaboration that is not encouraged by more-common permitting practices. A more integrated, place-based approach could also balance the broader environmental benefits of nutrient management (e.g., positive impacts beyond cleaner water) with economic considerations on a community or regional scale.

Improved data collection at the watershed scale is needed to measure and evaluate the effectiveness of these approaches, as are sub-watershed models. To be effective, water-quality management at the watershed scale requires gathering temporal information in order to cultivate a detailed understanding of the impacts of outflows on receiving streams. Nutrient management practices for any given wastewater facility will vary from watershed to watershed, depending in part on the relative nutrient load of other emitting bodies in that watershed.

It's also important to note that nitrogen can be emitted directly or indirectly to the atmosphere, where its effects are felt beyond any given watershed. Also, long-distance transport in waterways can result in impacts beyond areas traditionally considered a watershed, as in the Mississippi River.

Carbon Management

Managing carbon as a component of an overall nutrient management strategy is important, and can both reduce the overall greenhouse gas footprint of a plant's operations and optimize its nutrient management processes. Strategies for extracting and redirecting the carbon in incoming wastewater streams can benefit different stages of nutrient removal and recovery, depending on the sophistication of the plant. For example, carbon from wastewater can be used in the denitrification process at some plants, while other plants can redirect unnecessary carbon to digesters to generate energy. Filtering carbon to specific levels can also facilitate the operation of a nitrite shunt or facilitate deammonification, among other processes. Identifying mechanisms to manage and harness carbon in waste streams and effluent in location-specific ways is a crucial part of developing cost-efficient and comprehensive nutrient management strategies for WRRFs.

Better Data for Better Management Decisions

Facilities' ability to generate smarter, more viable solutions for nutrient management and to track progress over time is undermined by a surprising lack of a centralized database on the nutrient load going into U.S. waterways from wastewater treatment plants. Prompted by discussions during the first of our two meetings, Don Pryor of Brown University, working with a data team of participants from the Wingspread meeting, surveyed the available data on nutrient removal in the United States. Out of 14,780 treatment plants he evaluated, the majority of facilities did not report to any national database the amount of total nitrogen or total phosphorus in their effluent (see tables at right).

This work, complemented by discussion at the second meeting, revealed that nutrient-removal facilities tend to report their nutrient loads only if their operating permit includes a specific numeric limit for a particular nutrient. It also showed inconsistency in reporting and monitoring techniques.

Better decision making will be supported by improved assessments, monitoring and reporting, as well as improved access to information from and about wastewater facilities, the populations they serve, the water quality of the watersheds in which these facilities are situated, and factors influencing nutrient removal and recovery. In many cases, much of the data is already collected, but it is not reported in a way that allows it to be aggregated.

In order to measure progress toward nutrient recovery and removal, it is necessary to establish a baseline of current practices across wastewater systems. Significant opportunities exist to harness emerging technologies to facilitate data collection and monitoring. Among these, a voluntary effort to collect and organize existing data into a centralized database might prove to be quite fruitful.

Total Nitrogen, Ammonia and Total Phosphorus Reporting by Plant Size

MGD = millions of gallons per day

Total Nitrogen (mg/l) – percent of plants in each category

	<3	3-5	5-8	8-12	12-20	>20	no data
>1 MGD	4	3	5	5	8	8	67
>10 MGD	5	2	6	8	12	7	61
>100 MGD	0	2	5	6	17	14	58

Ammonia (mg/l) – percent of plants in each category

	<1.5	>1.5	no data
>1 MGD	51	20	30
>10 MGD	45	28	27
>100 MGD	29	50	21

Total Phosphorus (mg/l) – percent of plants in each category

	<1	1-3	>3	no data
>1 MGD	23	16	10	51
>10 MGD	26	18	8	48
>100 MGD	21	15	11	53

In order to make best use of these available technologies, however, plants must do better at recording data, tracking metrics and monitoring progress. A behavioral shift is needed to establish the baseline from which useful data platforms can be built. Gathering data about the state of nutrient removal and sharing the collected information will help facilities to understand their complex challenges, identify their top priorities and identify robust alternatives for addressing both.

Conclusions: Smarter Nutrient Management on the Path Toward the Utility of the Future

Profound changes are taking place in the water utility sector. These changes are being driven in part by bold leadership and a vision for the future in which municipal waste becomes a dependable source for scarce and valuable resources. The perspectives of diverse stakeholders are helping to shape effective solutions for wastewater nutrient management by raising the visibility of pioneering utilities, generating innovative models that others can replicate across geographies and scales, and investigating appropriate regulatory mechanisms that allow for the uncertainty associated with innovation without compromising environmental protections.

The water resources sector faces a broad set of challenges, some of which can be addressed through technical solutions. Other challenges include regulatory measures that limit innovation and a lack of useful data and consistent metrics to measure and track progress. Catalyzing and sustaining cross-sector partnerships is helping to increase collective understanding of nutrient management issues and encourage decision makers at the local, regional and national levels to accelerate action to build the water resources infrastructure of the future.

The development of a nutrient roadmap, under the leadership of WEF and EDF, will provide a helpful tool and guidance for smarter nutrient management for facilities ranging in size, sophistication and the challenges they face. To be successful, the roadmap must be accompanied by a broader set of activities that help to address issues facing the wastewater sector and identify opportunities for collaboration and innovation in the long term. These activities include:

- continuing to identify and make a compelling case for improved data collection and metrics development;
- further exploring opportunities for developing new regulatory incentives and/or minimizing disincentives; and
- identifying and catalyzing pilot projects to test new ideas and mitigate uncertainties associated with innovation.

A key consideration in the continued development of technologies and innovative solutions for nutrient management is the importance of looking beyond the constraints of current conditions in the interest of planning for and moving toward long-term, transformative goals. Practices that were considered impossible 40 years ago are now routine. This set of meetings reinforced the value of a coalition of diverse partners that can provide needed leadership and bold thinking to increase the sustainability and resilience of municipal water systems while breaking down barriers that inhibit cross-sectoral collaboration. Optimal outcomes can be achieved if the water sector, public municipal sector, environmental conservation community and state and federal regulatory agencies continue to work in concert to push beyond the status quo to identify solutions that will help achieve a more transformational future of nutrient management and enhance the full spectrum of activities shaping the utility of the future.

Appendix: Meeting Participants

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