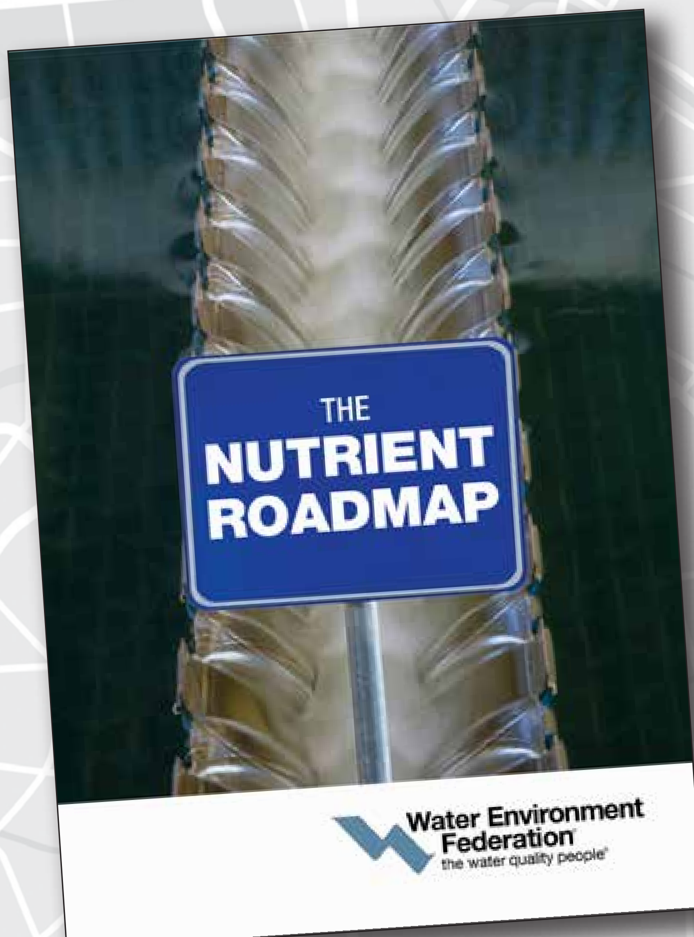
The Nutrient Roadmap

P R I M E R

A preview for smarter nutrient management



Nutrient Roadmap Primer

Preface

In October 2013, the Water Environment Federation (WEF), Environmental Defense Fund (EDF), and The Johnson Foundation at Wingspread sponsored a 1.5-day meeting in Airlie, Virginia – the "Airlie meeting." At the meeting, participants discussed next steps for developing a roadmap to implement a nutrient management vision, primarily for nitrogen and phosphorus.

The Airlie meeting brought together 28 diverse representatives from water utilities, regulatory agencies, academia, consultants, associations, and nongovernmental organizations. These attendees built on results from a February 2013 meeting sponsored by the same three organizations at which a draft aspirational goal was developed.

This aspirational goal, or 25-year challenge, is informing the development of the Nutrient Roadmap, which will serve a short-term need for achieving smarter nutrient removal and recovery at water resource recovery facilities (WRRF). The wastewater "utility of the future" is shifting toward recovering marketable resources rather than just treating wastewater. The Nutrient Roadmap, like the Energy Roadmap before it, is helping the sector actualize the term WRRF in place of wastewater treatment plant. As such, the Nutrient Roadmap also will help WRRFs consider opportunities for reducing energy and greenhouse gas emissions, enhancing public engagement, exploring regulatory opportunities, expanding resource recovery facility operator capabilities, and benchmarking current resource recovery facility performance. Smarter nutrient management includes a cost-effectiveness component to help identify activities that optimize reductions on a unit-cost basis.

The development of the Nutrient Roadmap will progress in two phases. This report represents the first phase, the development of matrices for the major topics and subtopics identified by the Airlie meeting participants. A larger group of subject-matter experts will further develop the matrices into a longer guidance document to be published in 2015. The publication will be supplemented with case studies and additional resources. The Nutrient Roadmap also will inform future research, training, and advocacy programs to support the movement toward smarter nutrient management in WRRFs.

"The next generation of wastewater treatment has zero net 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 emission reduction, and energy neutrality in the treatment of wastewater."

Missions Align

WEF's mission is to "provide bold leadership, champion innovation, connect water professionals, and leverage knowledge to support clean and safe water worldwide." Two of WEF's three critical objectives are to drive innovation in the water sector and enrich the expertise of global water professionals. The development of the Nutrient Roadmap supports WEF's mission and those objectives for the specific topic of nutrient management via point source discharges from WRRFs.

EDF's mission is to "preserve the natural systems on which all life depends. Guided by science and economics, EDF finds practical and lasting solutions to the most serious environmental problems." Among these problems is the rapid increase in reactive nitrogen in the environment resulting from the advent of industrial nitrogen fixation – largely for fertilizer production – along with fossil fuel combustion. EDF has set a goal of cutting nitrogen pollution in half over the coming decades. EDF is engaged in a large effort to help farmers become more efficient in their use of nitrogen fertilizers. The organization also is helping to reduce fossil fuel combustion through increased energy efficiency and increased use of renewable energy. Finally, through the project with WEF and The Johnson Foundation at Wingspread, EDF also is working to decrease nutrient pollution from wastewater treatment.

The Johnson Foundation at Wingspread's mission is to "be a catalyst for positive and lasting change leading to healthier environments and communities." Its Charting New Waters multi-year program engages a network of organizations dedicated to catalyzing new solutions to U.S. water challenges. The ultimate goal is to identify elements of a new paradigm for water infrastructure and the steps needed to transition. This document is a significant step in assisting the shift toward smarter nutrient management.

Part of the Solution

Nutrients – commonly nitrogen and phosphorus – are found in agricultural and home fertilizers and also are generated by livestock, industrial, and municipal systems. Specific sources include confined animal feeding operations, row crop farming, industrial pre-treatment facilities, septic systems, municipal and industrial stormwater, and WRRFs. According to the U.S. Environmental Protection Agency (EPA), more than 100,000 miles of rivers and streams, close to 2.5 million acres of lakes and ponds, and more than 800 square miles of bays and estuaries are affected by nitrogen and phosphorus pollution.

In excess, nutrients can be harmful water pollutants. Excess nutrients can lead to algal blooms, which cost the tourism industry some $1 billion annually, according to the EPA. Algae also can result in hypoxic zones and can turn to harmful algal blooms (HAB), which produce toxins. HABs received national attention in summer 2014 after a cyanobacteria bloom in Lake Erie caused Toledo, Ohio, to issue notices to nearly half a million people not to drink, cook, or bathe with city water.

This image, taken in 2011, shows one of Lake Erie's worst algae blooms in decades. Image by NASA

However, WRRFs also are part of the solution. With advanced biological and chemical methods, facilities already can achieve significant nutrient reductions. This roadmap lays out a strategy for facilities to achieve zero net impacts from nutrient discharges by 2040. WRRFs also can reclaim nutrients. Biosolids are one such supply of nitrogen and phosphorus. Fertilizers can be energy-intensive to manufacture, and the supply of some nutrients, such as phosphorus, is limited. Recovery not only prevents nutrients from entering waterbodies as point source discharges but provides a supply of these essential resources.

Treatment Technologies

A number of treatment technologies are available for both mainstream and sidestream treatment for nitrogen and phosphorus. The details of these can be found in WEF manuals of practice 8, 11, and 34 or *Design of Municipal Wastewater Treatment Plants, Operation of Municipal Wastewater Treatment Plants,* and *Nutrient Removal,* respectively. Below is a chart of some of the most common nutrient removal and recovery technologies.

- ● Strong Positive Impact
- ⇧ Positive
- ⇩ Negative
- ● Strong Negative Impact

	Nitrogen Removal	Phosphorus Removal	Energy Usage	Supplemental Carbon Requirements	Dewatering	Biogas Production
MAINSTREAM TREATMENT TECHNOLOGIES						
Conventional Nitrification-Denitrification *(e.g., Modified Luszack Ettinger, Bardenpho, etc.)*	Strong Positive Impact	Negative		Strong Negative Impact		Negative
Nitritation-Denitritation = "Nitrite Shunt"	Strong Positive Impact	Negative	Positive	Negative		Positive
Partial Nitritation-Anammox = "Deammonification"	Strong Positive Impact	Positive / Negative	Strong Positive Impact	Positive		Strong Positive Impact
Chemical Phosphorus Removal *(e.g. iron (Fe) & aluminum (Al) addition)*	Negative	Strong Positive Impact			Positive	Positive
Biological Phosphorus Removal *(e.g. Virginia Initiative Plant, University of Cape Town, and Anaerobic/Oxic processes)*	Negative	Strong Positive Impact		Negative	Strong Negative Impact *	Negative
SIDESTREAM TREATMENT TECHNOLOGIES						
Sidestream Deammonification			Positive	Positive		
Struvite Precipitation & Recovery		Strong Positive Impact		Positive	Negative	

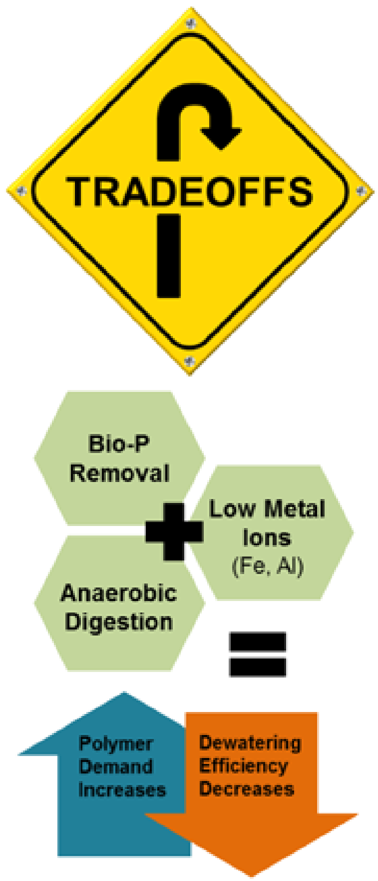
* *The negative relationship between biological phosphorus removal and dewatering is affected by the presence of anaerobic digestion and low metal ions. See the graphic on page 6 for more information.*

Introduction to Nutrient Removal

WRRFs can achieve very low nutrient discharges through a variety of processes, primarily biological nutrient removal (BNR), physical separation, and chemical methods. However, economic and environmental trade-offs exist, such as greenhouse gas production in the form of nitrous oxide (N2O) and increased energy demands due to aeration in BNR. Nutrient removal techniques also can affect biogas production and dewatering.

Most technologies capable of removing both nitrogen and phosphorus utilize BNR, which relies on bacteria to transform nutrients present in wastewater. Select species of bacteria can accumulate phosphorus, others can transform nitrogen, and a few can do both. Achieving significant reductions in both nitrogen and phosphorus requires careful design, analysis, and process control to optimize the environment of nutrient-removing organisms. The uptake of nutrients and growth of microorganisms could be inhibited by a limiting nutrient, available carbon, or other factors, including oxygen levels. The selection of a BNR process should be based on influent flow and loadings, such as biological oxygen demand, nutrient concentrations, and other constituents as well as target effluent requirements.

Some nutrient removal systems rely on two separate processes for nitrogen and phosphorus. In some cases BNR is used to remove the majority of nitrogen and phosphorus, and then chemical methods are used to further reduce phosphorus concentrations. Mainstream nutrient treatment takes place within the typical process flow. However, sidestream treatment refers to liquid resulting from biosolids processing that is intercepted with the additional goal of removing nutrients from a concentrated stream. Like mainstream nutrient treatment processes, sidestream treatment also can vary from biological to physical and chemical removal methods.



This figure shows in more detail how the dewatering process is negatively affected by biological phosphorus removal (bio-P). During anaerobic digestion, flow from the bio-P process can decrease the efficiency of dewatering and require additional polymer as a coagulant, particularly when there are fewer metal ions, such as iron (Fe) and aluminum (Al).

Nitrogen Removal

Nitrogen can be removed from wastewater through physiochemical methods, such as air-stripping at high pH, but it is more cost efficient to use BNR. Conventionally, this method utilizes the natural nitrogen cycle, which relies on ammonia oxidizing bacteria (AOB) to transform ammonia into nitrites (NO_2^-) after which nitrite oxidizing bacteria (NOB) form nitrates (NO_3^-) – a process called nitrification. Other species of bacteria can transform these compounds into nitrogen gas (N_2) – a process called denitrification. Biological nitrogen removal requires anaerobic, anoxic, and aerobic conditions in the proper sequence as both nitrification reactions require aerobic conditions while denitrification requires anaerobic conditions. Though optimal conditions differ for nitrification and denitrification, both can be carried out simultaneously in the same unit if anaerobic zones exist. Most processes combine nitrification and denitrification, either in one basin or as two separate stages, and can be broken down into two categories based on whether bacteria are suspended within the waste stream or fixed to a film or filter. As denitrification occurs, nitrogen gas is produced and released safely into the atmosphere, where nitrogen gas is more abundant than oxygen.

When performing biological nitrogen removal, it is important that the activated sludge has enough available carbon, which bacteria use to build new cells. The nitrogen removal rate also dependents on the amount of time sludge spends in the reactor (solids retention time), the reactor temperature, dissolved oxygen, pH, and inhibitory compounds.

Phosphorus Removal

Unlike nitrogen, phosphorus cannot be removed from wastewater as a gas. Instead, it must be removed in particulate form through chemical, biological, hybrid chemical–biological processes, or nano processes. Nano methods involve membranes and include reverse osmosis, nanofiltration and electrodialysis reversal. Chemical methods (chem-P) typically involve metal ions, such as alum or ferric chloride. These compounds bind with the phosphorus and cause it to precipitate. It can then be removed by sedimentation and filtration. Chemical methods are influenced by a number of factors including the phosphorus species, choice of chemical, chemical to phosphorus ratio, the location and number of feed points, mixing, and pH.

Biological phosphorus removal (bio-P) is a two-step process. First, phosphorus is converted to a soluble form, and secondly, it is assimilated by phosphorus accumulating organisms (PAOs). Many biological nitrogen removal processes can be modified to remove phosphorus as well. Similar to biological nitrogen removal, bio-P also requires the proper sequence of anaerobic, anoxic, and aerobic conditions. Additionally, as with biological nitrogen removal, oxygen levels, solids retention time, and temperature play an important role in bio-P. The ability of PAOs to uptake phosphorus is highly dependent on the availability of volatile fatty acids, which serve as a carbon source for the bacteria. Further, nitrates in return streams can negatively affect bio-P – an important factor to consider in combined nutrient removal systems.

Definitions

Nitrification-Denitrification: A biological nitrogen removal process where ammonia is oxidized to nitrate through biological nitrification. The process of denitrification follows where nitrate is reduced to nitrogen gas.

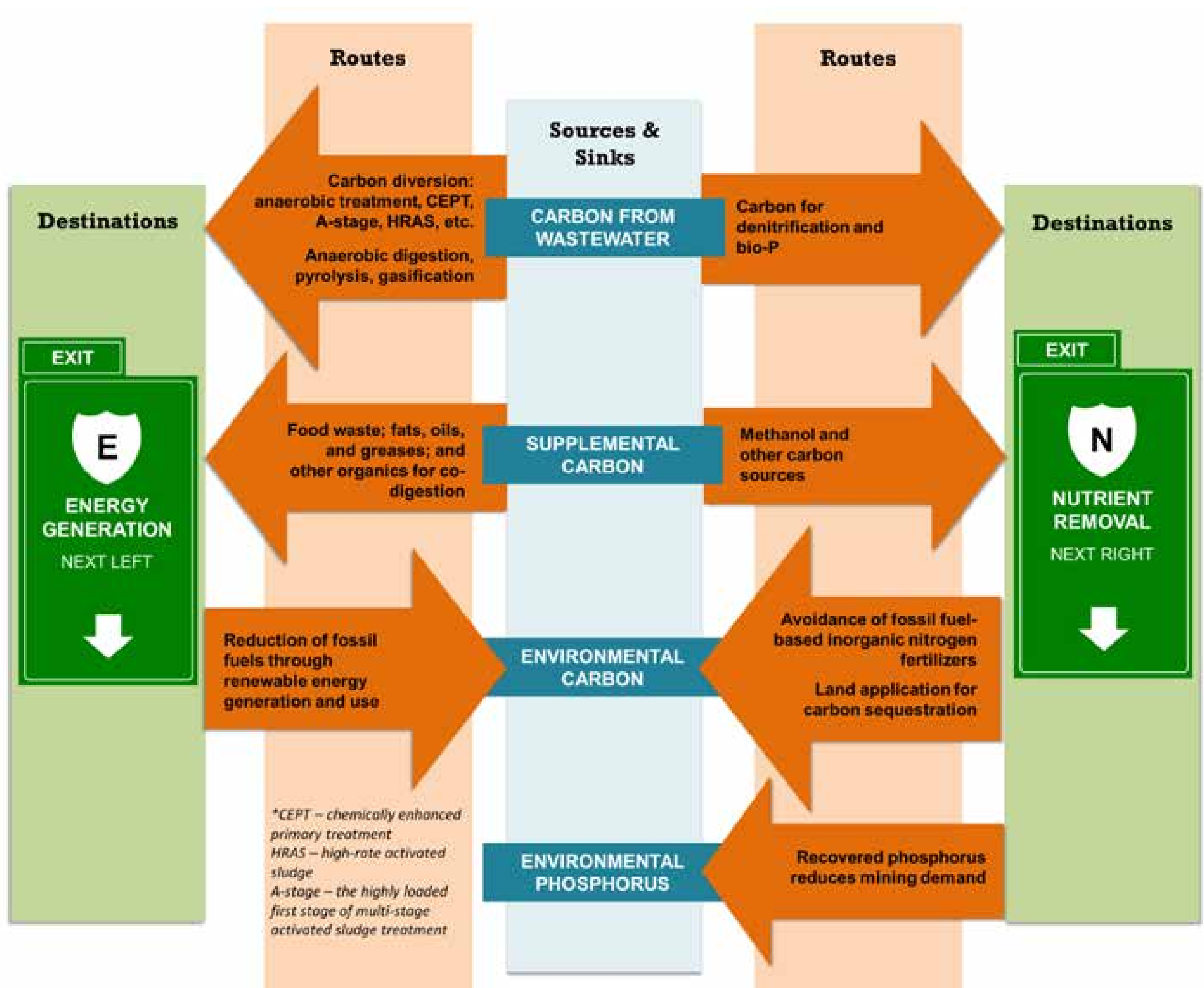
Nitritation-Denitritation: Another biological nitrogen removal process. Here ammonia is oxidized to nitrite and then biologically reduced to nitrogen gas. The term nitrite shunt is often used to describe this process.

Partial Nitritation-Anammox: Often referred to as “deammonification,” it is a two-step process that includes partial nitration. Aerobic ammonia oxidation to nitrite occurs in the first phase then nitrogen gas is produced by anaerobic ammonia oxidation. Anammox refers to anaerobic ammonia oxidation, a biological process carried out by specialized bacteria in which ammonia is oxidized using nitrite as an electron acceptor under anaerobic conditions.

Struvite Precipitation and Recovery: By this method, both phosphorus and ammonium can be simultaneously recovered and used as a fertilizer.

Interrelationships

In upgrading facilities for better nutrient management, WRRFs must make decisions about the amount of carbon used for nutrient recovery and removal and carbon used for energy generation. The following graphic gives a high-level overview of the interrelationships to consider when planning for nutrient management. The WRRF exemplified here must remove nutrients but also wants to generate energy. “Energy Generation” and “Nutrient Removal” are destinations or goals in the roadmap allegory. There are various “routes” WRRFs can take to reach these two outcomes using various carbon sources. Carbon can come from wastewater and other supplemental sources to achieve nutrient removal and energy generation goals. The WRRF also should consider new products – energy and fertilizer – that are generated as a result of nutrient removal and energy generation.



Products of Resource Recovery

Nutrient management begins with nutrient removal to meet permit requirements. However, "utilities of the future" are using the removal process to produce marketable products. It should be noted that there are other products that can be recovered that are not nutrient related, such as metals, heat, water, and more, which may bring financial rewards and benefits to help offset costs for the WRRF. Below are some nutrient-based resources that can be recovered.

- **Solid fertilizer from biosolids**
  - Land application of biosolids recycles nitrogen, phosphorus, carbon and other macronutrients.
  - Soil blends and composts are potential phosphorus recovery products.
  - Incinerator ash can be a source of phosphorus for recovery.
- **Solid fertilizer from the treatment process**
  - Struvite provides high quality fertilizer from some sidestream systems.
- **Water reuse**
  - Irrigation with reclaimed water can have some nitrogen and phosphorus benefits.
- **Chemical recovery**
  - Structural materials can be obtained from carbonates and phosphorus compounds.
  - Proteins and other chemicals, such as ammonia, can be recovered.
  - Solids can be stored for future mining.

Greenlighting Nutrient Recovery

Phosphorus is a finite resource, with some estimating that demand will outpace supply within the next century. For this and other reasons, interest in recovering nutrients from wastewater has increased over the last decade. The "utility of the future" is shifting toward recovering nutrients and other marketable resources, including energy, electricity, and vehicle fuels. However, the maturity of nutrient recovery technologies varies and each has its advantages and disadvantages.

EPA estimates that the approximately 16,000 WRRFs in the U.S. generate about 7 million tons of biosolids. About 60% of these biosolids are beneficially applied to agricultural land, with only 1% of crops actually fertilized with biosolids. However, generating solid fertilizer from biosolids is the most common method of nutrient recovery from wastewater treatment.

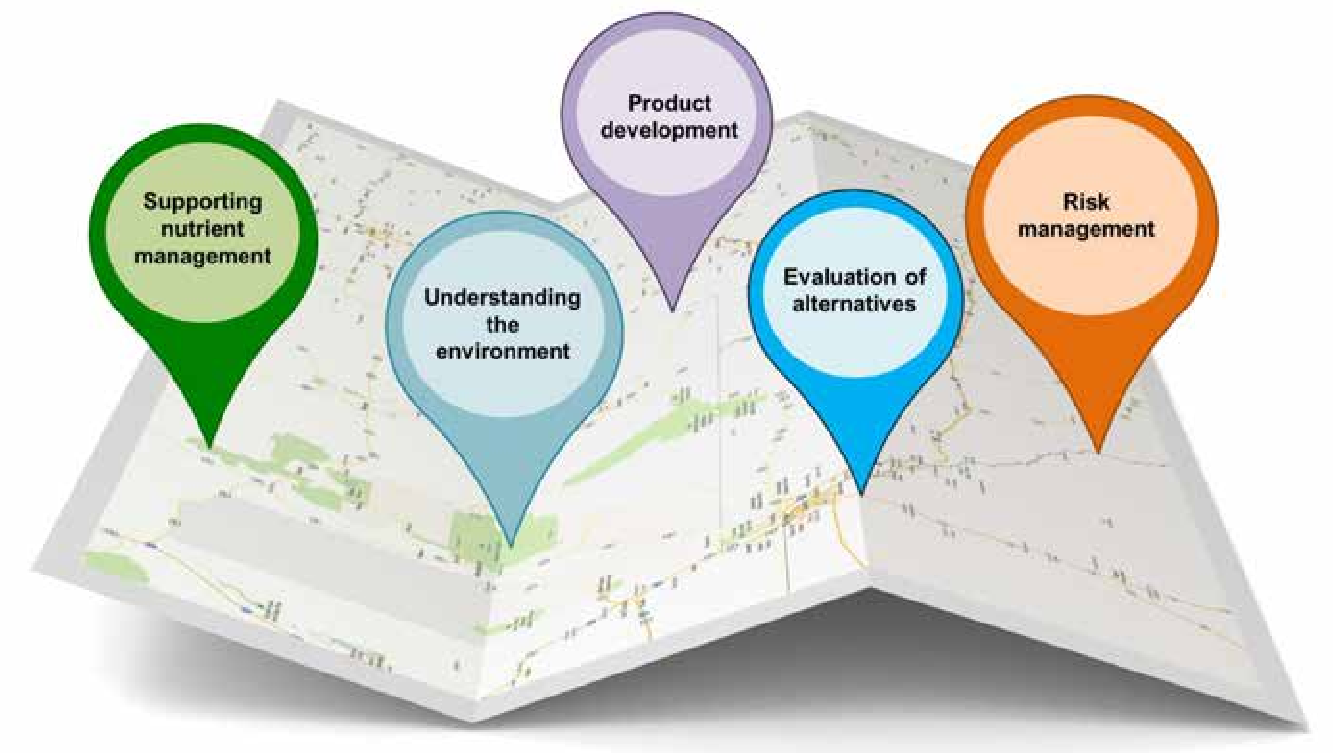
Currently some WRRFs are having success with struvite recovery, which allows for the precipitation and recovery of both nitrogen and phosphorus. Other methods of phosphate precipitation also are becoming more common. Sidestream treatment of sludge and sludge liquor, where the nutrients are more concentrated, is generally the preferable target for nutrient recovery.

SuperMatrices

The matrices are broken into five topics:

- **S**upporting nutrient management
- **U**nderstanding the environment
- **P**roduct development
- **E**valuation of alternatives
- **R**isk management

The matrices provide a high-level overview of the roadmap to net-zero nutrient discharges. Under each topic, objectives are outlined following three phases, from planning to implementation to evaluation and improvement.



Want more information about the Nutrient Roadmap and matrices?

Contact Barry Liner at the Water Environment Federation
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TOPIC 1: SUPPORTING NUTRIENT MANAGEMENT

	PLAN	PREPARE & IMPLEMENT	EVALUATE & IMPROVE

Nutrient Vision	*Develop Vision*
	• Evaluate goals and current drivers
	  • Regulatory requirements
	  • Watershed water quality and total maximum daily loads
	  • Effects of nutrient management beyond the watershed (long distance aquatic connections, atmospheric)
	• Establish aspirational goals and sub-goals
	  • Nitrogen and phosphorus recovery
	  • Energy and water recovery
	• Become climate-ready
	  • Reduce direct and indirect emissions
		Communicate Internally
		• Determine level of treatment required to meet goals
		• WRRF leadership/managers link the nutrient management vision to staff performance plans
		• WRRF leadership/managers incorporate nutrient goals and key performance indicators into strategic plan
			Communicate Externally
			• WRRF shares nutrient vision with external stakeholders and the sector
			• Plans are in place to embrace external market changes
			• Review performance against goals
			• Reassess long-term goals

Staff Development and Alignment	*Set Training Plan* • Staff performance plans include related training and professional development to support WRRF's vision for nutrient management • WRRF fulfills training needs for all relevant positions: management, engineering, and operations	*Train and Support Staff* • WRRF staff are trained in operations • WRRF staff maintain/increase knowledge of emerging technologies through information sharing events	*Empower Staff* • WRRF leadership/managers establish incentives for nutrient results • WRRF leadership/managers empower staff to make changes toward nutrient goals • WRRFs mentor and guide other local and regional utilities to advance nutrient goals

Financial Viability	*Identify Funding Options*
	• Identify economic incentives and costs for nutrient removal and/or recovery
	• Identify size of WRRF where recovery is cost-effective (Am I big enough or too big?)
	• Develop financial strategy to support nutrient projects
	• Consider alternate financing methods
	  • Private vs public finance and operations
	  • Alternative project delivery (design-build-operate, build-own-operate-transfer, etc.)
	  • Sale of greenhouse gas credits for N2O-emission reduction and renewable energy generation
		Budget for Success
		• Use lifecycle analysis for project decision-making
		• Nutrient management/recovery is considered on all capital project designs, in operating budget decisions, and standard operating practices
			Invest in the Future
			• WRRF's recovered resource revenues generate sufficient funding to invest in other priorities and reduce upward pressure on rates

TOPIC 2: UNDERSTANDING THE ENVIRONMENT

	PLAN	PREPARE & IMPLEMENT	EVALUATE & IMPROVE

Data and Characterization	Collect Information
	• Parameter monitoring for decision-making (nitrogen species, carbon, greenhouse gas emissions, etc.), potentially includes:
	  • Upstream
	    • Collection system
	    • Industrial dischargers
	  • At facility
	    • Influent
	    • In-facility
	    • Effluent
	  • Environment
	    • Receiving body
	• WRRF considers frequency of sampling
		Analyze Data
		• Process information to understand options, examples include:
		  • Carbon to nitrogen ratio
		  • Carbon to phosphorus ratio
		• Assess current facility performance for nutrient removal
		• Understand current removal of nitrogen species (incidental/intentional)
		• Assess receiving-water impacts/needs
		  • Water quality degradation because of nutrient discharges
		  • Understand greenhouse gas emissions
			Proactively Use Data
			• Use data to improve:
			  • Facility operations
			  • Trading programs
			  • Source control
			  • Next design upgrade

Modeling	Select Model
	• Ensure that data gathered is useful for modeling efforts
		Modeling for Design
		• Use water quality modeling to identify/quantify receiving water response to nutrients
		  • How do nutrient effluent concentrations change and affect receiving waters?
		  • Decision making support for appropriate technology for various performance levels
		• Model the treatment process to understand its constraints and opportunities
		  • Redundancy in design
		• Determine whether nitrogen removal technology will require major capital investment
		• Understand effects on greenhouse gas emissions
			Modeling for Operations
			• Utilize molecular tools
			• Use modeling in decision-making
			  • Determine carbon tradeoffs with nitrogen removal
			  • Nitrogen removal requires more supplemental carbon if using bio-P
			  • Max denitrifying PAOs
			• Develop digester phosphorus precipitation models focusing on critical chemistry
			• Understand settling characteristics –must not compromise settleability or dewaterability
			• Model to understand diffusion and mass transfer to facilitate control schemes
			• Implement online control
			• Control N2O

TOPIC 3: PRODUCT DEVELOPMENT

	PLAN	PREPARE & IMPLEMENT	EVALUATE & IMPROVE

Marketing	*Data Collection*
	• Collect data to understand the market
	  • Identify stakeholders and customers in the market for nutrients and other recovered resources
	  • Assess competition for product
	  • Track economic projections on future supply of phosphorus to keep up with current thinking about potential shortages of mined phosphorus
	  • Use market-driven standards (ex. U.S. Department of Agriculture partnership for phosphorus products)
	  • Evaluate potential for greenhouse gas reduction credits
		Develop Marketing Strategy
		• Create a value-cost proposition
		  • Identify value of recovered resource
		  • Evaluate recovery costs
		• Develop marketing, sales, and branding strategy
		• Communicate benefits and advantages of nutrient recovery
			Sell Recovered Resources
			• Brand and sell nutrients and other recovered resources
			• Sell greenhouse gas offset credits

Product Production and Control	*Product Development* • Develop a quality assurance program and process for products	*Product Production* • Produce product for market	
Public Communications	*Identify Stakeholder Values* • Identify values of community and utility board of trustees • Shift cultural mindset from “meeting the permit” to recovering resources • Identify environmental incentives for nutrient recovery	*Public Outreach* • Develop public understanding of the new purpose of a WRRF • Conduct public relations for nutrient recovery	*Share Experience* • Share best practices with other utilities and the sector

TOPIC 4: EVALUATION OF ALTERNATIVES

	PLAN	PREPARE & IMPLEMENT	EVALUATE & IMPROVE
General Evaluation	*Identify Treatment Levels* • Determine level of treatment available • Determine level of treatment required or desired • Define operational/process changes required to recover nutrients	*Identify Opportunities* • Identify additional opportunities requiring more time or capital to implement, and develop a plan to finance/implement • Assess liquid vs. solid recovery (water reuse vs. land application/struvite recovery) • Ensure biosolids nutrients are considered a resource	*Evaluate Nutrient Recovery* • Identify research and development needs to drive innovations • Evaluate how simultaneous nitrification and denitrification can lower carbon requirements • Evaluate whole facility nutrient recovery • Identify water quality trading and greenhouse gas offset credit opportunities

Nitrogen Removal Evaluation	*Identify Low-Cost Options*
	• Determine whether the facility currently has capacity (tankage, blowers, etc.) for nitrification and denitrification
	• Evaluate the energy cost of various technologies and sustainable nitrogen removal for various effluent concentrations
	• Evaluate opportunities for high-nitrogen sidestreams
		Optimize Facility
		• Reuse existing tankage to get immediate nitrogen removal to ~10-15 mg/L at low cost
		• Consider N2O emissions from nitrification and denitrification when designing the system
			Evaluate Long-Term Improvements
			• Study impact of low dissolved oxygen and ammonia-based aeration control on:
			    • PAO uptake of phosphorus
			    • Competition between PAOs and glycogen-accumulating organisms (GAOs)
			    • Increases in N2O emissions

Phosphorus Removal Evaluation	*Evaluate Short-Term Improvements*
	• Modifying existing facilities to get low-hanging fruit
	    • Phosphorus to ~1 mg/L at no/low cost
	    • Switch off mixers for low-tech phosphorus removal
	    • More carbon for fermentation of mixed liquor
	• Recognize emerging information to minimize cost of chem-P
	    • Good mixing at the point of application
	    • Ferric/Magnesium addition
		Optimize Facility
		• Recognize phosphorus-removal techniques vary for meeting different objectives, such as developing a product vs. minimizing negative impacts on receiving waterbodies
			Observe Regulatory Landscape
			• Assess phosphorus limitations on land application of biosolids in areas with phosphorus saturated soils
			• Based on Natural Resources Conservation Service code 590, land application may not be applicable for phosphorus recovery/reuse, depending on local conditions

Carbon	*Identify Low-Cost Options*
	• Determine if facility can denitrify simply and at low cost (excess capacity, sufficient carbon), and what effluent concentrations/mass could be achieved
		Investigate Potential Problems
		• Explore supplemental carbon issues
		    • Procurement policy and pricing
		    • Demonstration and testing
		    • Waste products	

TOPIC 5: RISK MANAGEMENT

	PLAN	PREPARE & IMPLEMENT	EVALUATE & IMPROVE

Regulatory Risk Management	*Identify and Prioritize Risks*
	• Evaluate legal/regulatory implications of voluntary action
	• Identify early technology adoption risks
	  • State-of-the-art technology vs. new technology (anammox, demon, etc.)
		Mitigate Risks
		• Develop strategy for risk mitigation and/or sharing
		  • "Creating the Space for Innovation"
		  • "Safe Harbor"
			Leverage Innovation
			• Organization successfully tries to implement innovative projects and is adaptable to emerging opportunities

Upstream Management	*Understand Upstream*
	• Reduce inflow and infiltration
	• Evaluate water efficiency and conservation
	• Evaluate water efficiency and conservation
	• Separate combined systems
	• Pretreat to minimize nitrification inhibition
	• Identify sewer scalping and stream separation opportunities
	• Integrate resource management – include outside wastes and broaden markets
		Create Balanced Framework
		• Pretreatment policy
		  • Charge for Total Kjeldahl Nitrogen (TKN), total phosphorus, and low alkalinity
		  • Reward for readily biodegradable chemical oxygen demand and high alkalinity
		• Put a water efficiency program in place
		• Decentralize infrastructure to optimize recovery
		  • Treatment (sewer scalping)
		• Stream separation
			Balance Source Control with Resource Recovery
			• Seek partnerships for animal waste and other waste streams
			• Implement sewer scalping and urine diversion
			• Recover proteins, and remove nitrogen and phosphorus before treatment (industrial waste)
			• Separate ecological sanitation streams

Innovation	*Reward Innovation*
	• Reduce risk through collaborative research and information sharing
	• Have WRRF leadership/managers recognize and reward innovative approaches
	• Characterize discharge impacts by conducting research on how receiving waters react to different effluent concentrations
		Improve Models
		• Develop better modeling tools
		  • Multiple populations of AOB and NOB
		  • Kinetics for anammox bacteria (AMX)
		  • Bioaugmentation speed
		  • Biofilms and granules
		• Develop better stoichiometry and kinetics for chem-P models
		• Improve simulation models for GAOs and the benefit to bio-P from internal carbon fermentation
		• Model the digester for sidestream returns
			Pilot Test
			• Test model recommendations
			• Obtain patents to protect the WRRF and water sector

Infrastructure Risk Management	*Plan for the Future* • Identify unit operations/basins for use in future iterations of nutrient reduction • Leave space in the facility hydraulic profile to accommodate future processes	*Mitigate Risks* • Evaluate future reduction targets • Design for current requirements with an eye toward future requirements	*Evaluate Options* • Assess resource recovery versus treatment/reduction

Airlie Meeting Participants

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Appendix: References

Online Resources

"Phosphorus in Biosolids: How to Protect Water Quality While Advancing Biosolids Use," WEF, May 2014. Web: http://bit.ly/PBiosolids

"Enabling the Future: Advancing Resource Recovery from Biosolids," WEF, 2013. Web: http://bit.ly/EnablingtheFuture

"The Road Toward Smarter Nutrient Management in Municipal Water Treatment," The Johnson Foundation at Wingspread, March 2014. Web: http://bit.ly/smarternutrient

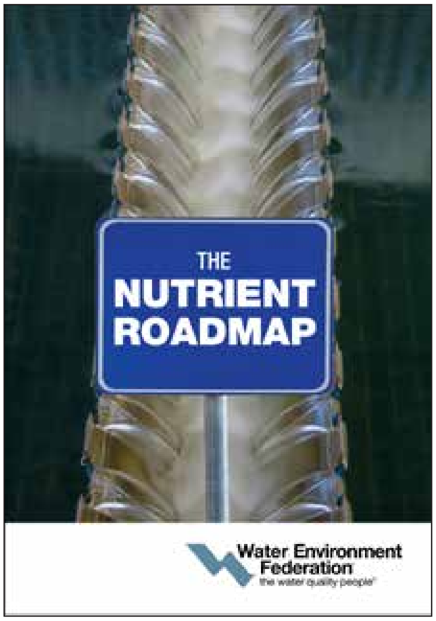
Books

Design of Municipal Wastewater Treatment Plants (MOP 8), WEF, 2009.

Operation of Water Resource Recovery Facilities (MOP 11), WEF, 2017.

Nutrient Removal (MOP 34), WEF, 2010.

Resources



The Nutrient Roadmap

The Nutrient Roadmap is a first step toward accelerating the transition to smarter nutrient management, facilitating the shift from removal to recovery, and anticipating future requirements to conserve energy and reuse resources. Case studies explore the innovative, cost-effective solutions employed by pioneering wastewater resource recovery facilities.

The Nutrient Roadmap acknowledges that each utility faces unique challenges and provides you with a variety of paths to follow and alternative destinations from which to choose as you embark on the road toward sustainability.

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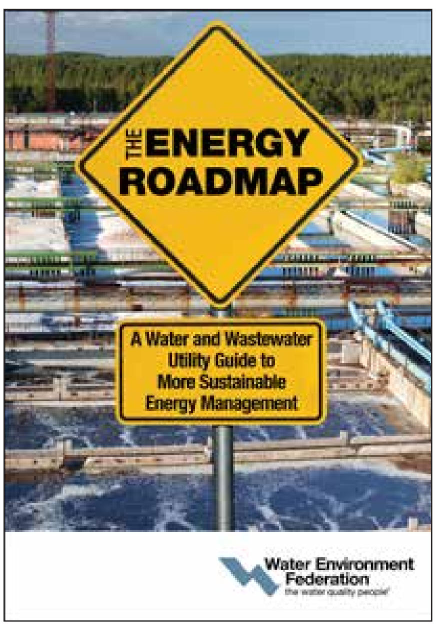

The Energy Roadmap

The Energy Roadmap serves as a guide for utilities of all sizes on the path to sustainable energy management. In it, you will explore innovative approaches to cost-effectively recover and reuse resources to transform "wastes" to valuable products. The book outlines six stops on the path to resource recovery, presenting insights and models for

1. strategic management,
2. creating an organizational culture,
3. effective communication and outreach,
4. demand-side management,
5. energy generation, and
6. innovating for the future.

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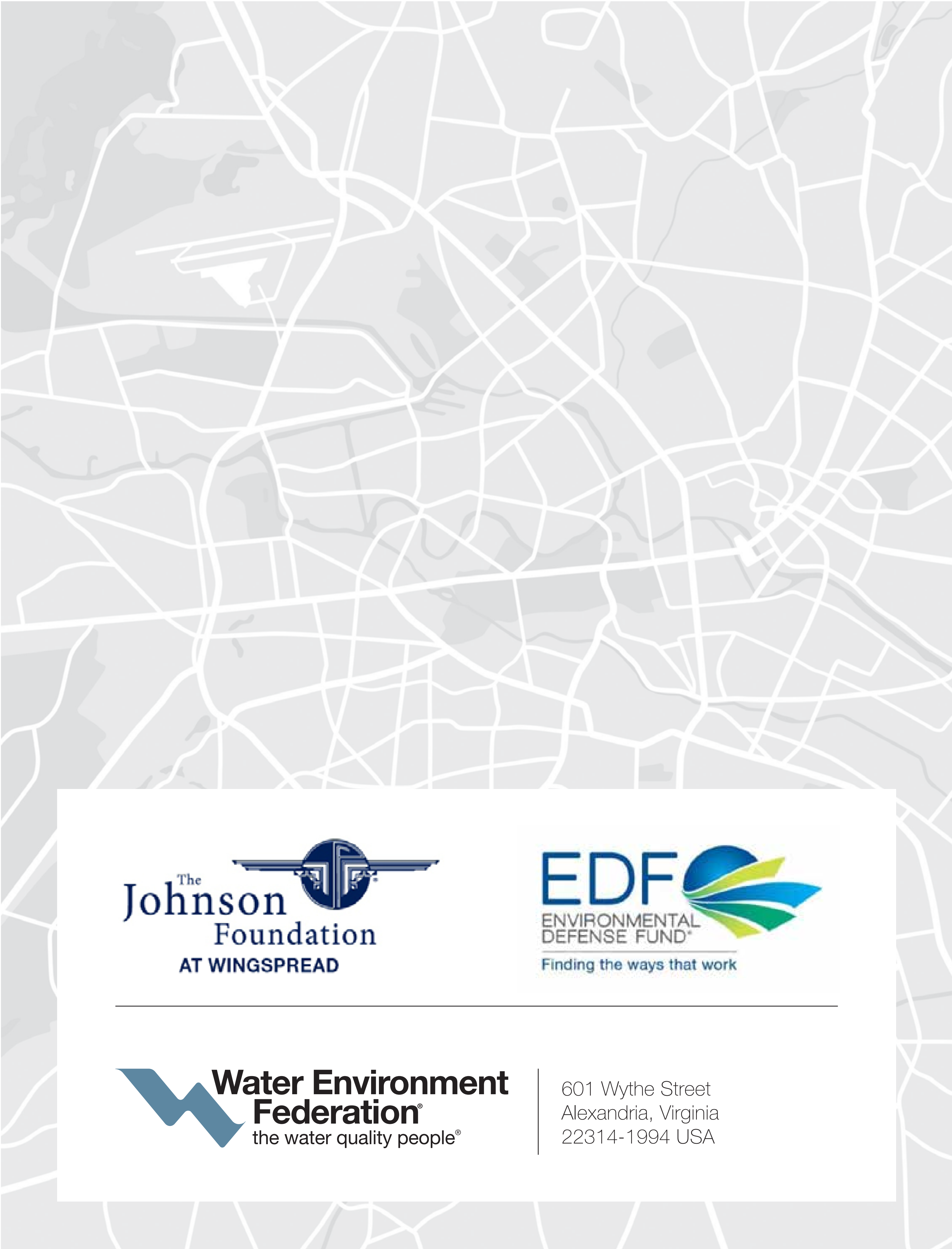

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