WERF Nutrient Challenge investigates limits of nutrient removal technologies

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ABSTRACT

The WERF Nutrient Challenge is a multi-year collaborative research initiative established in 2007 to develop and provide current information about wastewater treatment nutrients (specifically nitrogen and phosphorus in wastewater), their characteristics, and bioavailability in aquatic environments to help regulators make informed decisions. The Nutrient Challenge will also provide data on nutrient removal so that treatment facilities can select sustainable, cost-effective methods and technologies to meet permit limits. To meet these goals, the Nutrient Challenge has teamed with a wide array of utilities, agencies, consultants, universities and other researchers and practitioners to collaborate on projects that advance these goals. The Nutrient Challenge is focusing on a different approach to collaborating and leveraging resources (financial and intellectual) on research projects by targeting existing projects and research that correspond with its goals and funding those aspects that the Nutrient Challenge identified as a priority. Because the Nutrient Challenge is focused on collaboration, outreach is an absolutely necessary component of its effectiveness. Through workshops, webinars, a web portal and online compendium, published papers, and conference lectures, the Nutrient Challenge is both presenting important new information, and soliciting new partnerships.

Key words | limit of technology, nitrogen removal, phosphorus removal, regulatory impacts

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INTRODUCTION

Nutrient removal is one of the most pressing water quality challenges currently facing utilities–not just in North America, but all over the world. The implementation of the United States Environmental Protection Agency (EPA)'s national nutrient criteria strategy, which requires states to adopt numeric nutrient standards, will likely require many utilities to achieve effluent nitrogen and phosphorus concentrations at or below our current technical capabilities.

Through the Nutrient Removal Challenge, the Water Environment Research Foundation (WERF) intends to further develop the science and technologies needed to address the pressing needs of regulators and dischargers facing increasingly stringent nutrient limits. The Nutrient Challenge is documenting the practices associated with a wide range of issues, such as nutrient characterization and bioavailability in aquatic environments; the selection of sustainable, cost-effective processes to meet nutrient limits in wastewater treatment facilities; and the demonstration of new nutrient removal technologies and practices, as well as improvements to existing ones.

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This paper outlines the approach taken by the Nutrient Challenge, the projects completed and initiatives under way. It also identifies opportunities for others to collaborate with the Challenge.

BACKGROUND

The Nutrient Challenge initiated its work in early 2007 following initial work by Bott *et al.* (2007) with an invitation to others to collaborate in the efforts. WERF is committed to helping agencies navigate the challenges in nutrient removal. Over thirty wastewater treatment agencies, universities, consultants, and research organizations nationwide and abroad are already collaborating with WERF on this challenge. The challenge has an excellent team of volunteer peer reviewers and stakeholders helping guide research and activities, and a core team led of industry experts that elected to work together.

The goals of the program are to:

- Develop and share credible scientific information about nutrients and their bioavailability to help regulators make informed decisions.
- Better understand existing mechanisms of nutrient removal and best available technologies so that treatment plants can become more efficient and effective, enabling them to cost-effectively meet permit limits.

The expected outcomes of the work are to:

- Provide information to help agencies meet receiving water body requirements and other wastewater treatment goals (e.g., climate change, sustainability, costeffectiveness, reliability).
- Provide data on nutrient removal so that treatment facilities can select sustainable, cost-effective methods and technologies to meet permit limits.
- Inform regulatory decision making by addressing regulatory concerns, utility constraints, and limits of technology and other constraints to improving performance.
- Help practitioners comply with requirements for increasingly high levels of nitrogen and phosphorus removal, while improving plant performance.
- Develop and demonstrate new technologies, as well as improvements to existing ones. One of the goals of this challenge is to reduce capital and operating and maintenance costs for nutrient removal at wastewater treatment facilities by at least 10 percent.

The work needs to be a collaborative effort. These efforts do not exist in a vacuum–many researchers, practitioners, and regulators are working on different aspects of the nutrient removal program. In an attempt to avoid reinventing the wheel, the project team moved ahead with a goal to engage other researchers to complete the needed research. This is a paradigm shift from traditional research funding, where a sponsor sets the course and funds research to solve specific problems. While the Challenge team identifies the research needs and some specific priorities to pursue, a strong emphasis is placed on the work of others and opportunities to collaborate with ongoing research to address the knowledge gaps.

APPROACH

While the goals of the challenge are vast, the available funds are limited and collaborative projects are chosen on the perceived urgency and benefit to the industry as a whole. These topics are determined and prioritized by our Core team (as well as WERF staff, volunteers, and subscribers), who coordinate the research, and also provide the documentation and outreach efforts needed for successful implementation and maximum benefit of the identified projects.

Core team

The WERF Nutrient Challenge Core team is led by HDR, with AECOM (formerly Metcalf & Eddy), CH2M-Hill, the University of Washington, and other universities and collaborators also supplying input and guidance. Together, the Core team deliberates on the agenda and focus of the Nutrient Challenge for the future year. This is done by soliciting input regarding the perceived needs in Nutrient research from members of various utilities, universities, consultants, and research organizations at workshops and conferences. The team also receives unsolicited proposal from potential collaborators, typically as an opportunity to collaborate with ongoing work and leverage existing or potential funding sources. These proposals are evaluated to determine their match with current priorities. If a match

exists, the proposal is considered for support based on available resources and the opportunity for enhancing ongoing work. Once these topics are gathered, the Core team identifies those topics that appear to be the most focused and fundamental, can be leveraged with ongoing projects, and which benefit all sides of the industry. Figure 1 presents the flow diagram for project development process.

Compendium

The LOT Compendium serves, in large part, as the guide for the Nutrient Challenge. The LOT Compendium discusses regulatory and technological nutrient removal issues, identifying what we know about nutrient removal and the current state of nutrient removal technology. The LOT Compendium also addresses the knowledge gaps and research needs to achieve nutrient removal to very low levels

The LOT Compendium exists on the WERF Nutrient Challenge web portal as a "living" document. As new advancements in technology or research are made, the LOT Compendium is updated to reflect those changes, bridging the gap from research and regulation to technology and practice. This constant updating is possible due to the format of the Compendium, which is presented as a series of concise questions and answers that are interlinked.

The LOT Compendium is written by a group of industry experts on various nutrient removal issues. For each issue, a leader is selected to guide the assembly of the document, beginning with what we do know and moving toward what we do not know and need to know. Once a draft is developed, the Core team reviews the LOT Compendium for both quality assurance purposes and to confirm that the larger goals of the Nutrient Challenge are being furthered by the document. The document is submitted to external reviewers for comment before posting to the website.

Currently, the following LOT Compendium knowledge areas (Clark *et al.* 2008; Neethling *et al.* 2008*a*,*b*;

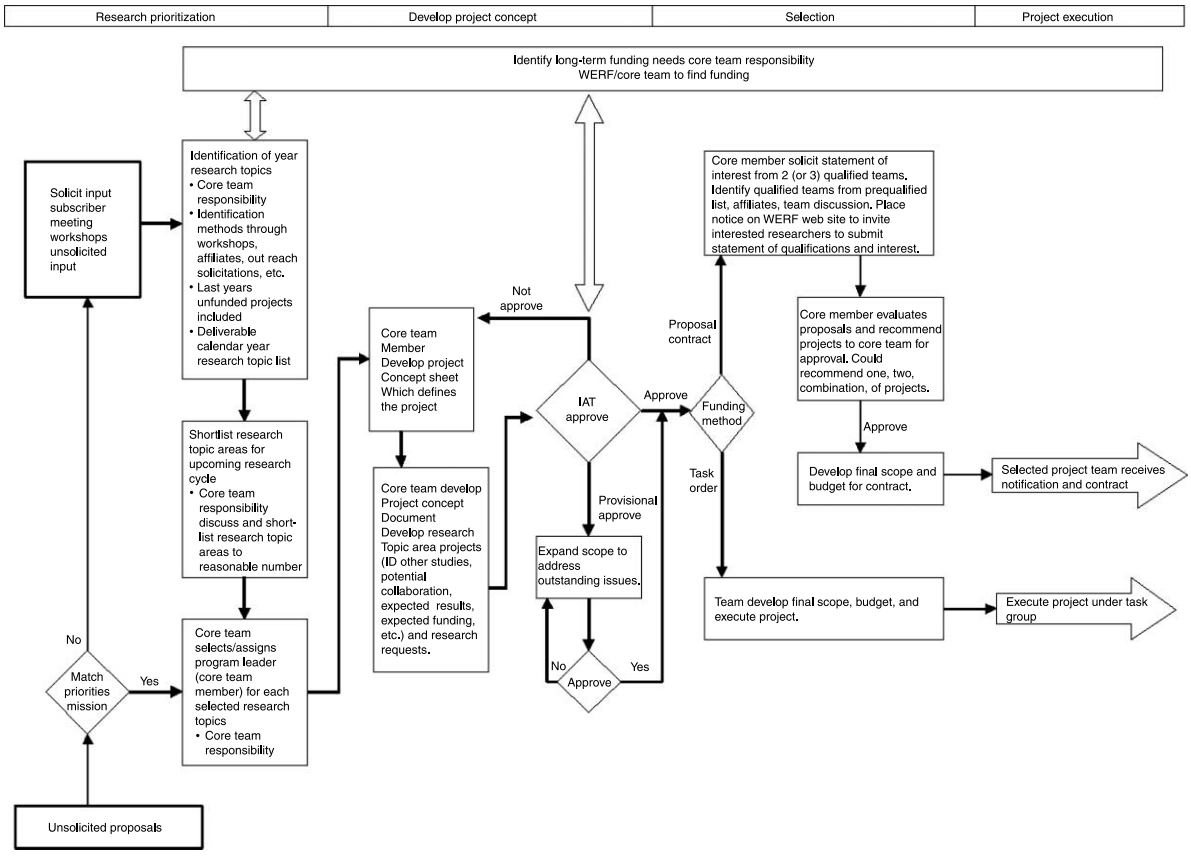

Figure 1 | Research project development.

Sandino *et al.* 2008; Stensel *et al.* 2008; Tsuchihashi *et al.* 2008; Eleuterio & Neethling 2009) have been finalized and posted:

- Regulatory Issues for Low-level N and P
- Dissolved Organic Nitrogen (DON)
- Carbon Augmentation for Nitrogen Removal
- Operations and Control
- Low P Measurement Methods
- Tertiary Phosphorus Removal
- Sidestream Treatment for Nitrogen Removal

Current and future knowledge areas being developed as part of the LOT Compendium include BNR processes for low N and P, greenhouse gas emissions from nutrient facilities, process control with online instrumentation, nitrification inhibition, and achieving low effluent ammonia concentrations.

Outreach and collaboration

A key requirement of the Nutrient Challenge is the outreach effort to engage regulators, utilities, researchers, consultants, other stakeholders, and, ultimately, the public. The Nutrient Challenge's needs from these stakeholders vary from soliciting their input and involvement to training and knowledge sharing.

Because many of these stakeholders are involved in existing projects or research, the Nutrient Challenge is able to piggyback on these ongoing efforts and leverage its investment. In cases where the Nutrient Challenge is collaborating on an on-going project or research effort, the bulk of the funding comes from a third-party, often the party that initiated the research for their specific objectives (for example, a pilot study to evaluate the performance of a technology). In these cases, the Nutrient Challenge can collaborate and sponsor the additional effort in order to research the identified research topics. Table 1 presents some current projects that illustrate these collaborative efforts.

Other aspects of outreach include presentations at various conferences, the facilitation of workshops on key research topics, published articles, and instructive webcasts. The common (e.g. WEF/WERF 2008) objectives of all of these other outreach activities are to identify the current state of the industry's collective knowledge of nutrient removal issues and develop protocols or standards to approach these issues.

KEY FOCUS AREAS AND FUTURE EFFORTS

Figure 2 shows some of the factors and issues that need to be considered when developing a plan to achieve sustainable nutrient control. In order to address these issues, six focal areas have been identified: regulatory, nitrogen, phosphorus, design and modeling, operation and maintenance, and outreach.

Regulatory issues

Regulatory requirements are the main driver to implement nutrient control. Regulatory agencies set the limits and targets for nutrient control. In doing so, the environmental impact of nutrients is determined through modeling to determine the TMDL (total maximum daily loading) allocated to a discharger. The EPA has established criteria for total phosphorus and total nitrogen for ecoregions for rivers and streams, lakes and reservoirs, and wetlands. The concept of ecological regions, or ecoregions, is the grouping of areas of similar climate, hydrology, geology, physiography, soils, land use, vegetation, and wildlife. The ecoregional criteria are a starting point for states to develop local criteria for dischargers.

Nitrogen and phosphorus limits under ecoregional criteria are very low and effluent limits often below the performance of the treatment plants. This raises many questions that falls into the regulatory area, such as: How low can current technology reduce nitrogen an phosphorus? What is the limit of technology? Which technologies are included: biological, membrane, RO? What is the cost for implementing new technology? How reliable are the technologies? How variable is the effluent technology? What are the broader environmental impacts of setting standards below currently achievable limits? Does the carbon footprint increase and by how much? Over what time frame should the permit limit apply–monthly, daily, annually? Is all nitrogen and phosphorus available for algal growth? How should non-point sources be handled?

Table 1 | Current collaborative projects

Collaborators	Topic	Comment	Primary funding by
Debbie Bronk, Margie Mulholland, Nancy Love	Bioavailability of EON in freshwater to saltwater	Research project to evaluate fate of dissolved organic nitrogen in the environment. Part of coordinated research into characteristic and fate of dissolved organic nitrogen	National Science Foundation
Kartik Chandran	Methylotrophic denitrification	Research project into the kinetics of denitrification using methanol as external carbon source. Determine kinetics and growth requirements	DCWASA; Columbia; National Fish and Wildlife Foundation
JB Neethling, Lazaro Eleuterio	Low phosphorus analysis	Evaluating the reliability of current analytical methods to measure phosphorus at low concentrations (<10 ug/L)	Spokane County; Coeur D'alene; Las Vegas
Jacek Makinia, Krishna Pagilla, Kimberly Jones	Fate of DON in WWTP *(Three separate studies)*	Studies that investigate the fate of organic nitrogen during full scale treatment	Polish ministry science & education; DCWASA; Hazen & Sawyer; HDR inc
Imre Takacs, Scott Smith, Sudhir Murthy	Phosphorus chemistry and removal *(several studies)*	Collaborative work on ferric-phosphorus chemistry, kinetics, and limits of removal	DCWASA; envirosim; canada dept of interior
Various utilities, consultants, regulators, academics	Workshop: biodegradability and bioavailability of effluent organic nitrogen	Workshop discussed technology based biodegradability and water quality based bioavailable models to identify current knowledge and research needs	DCWASA; WERF; participants
Various utilities, consultants, regulators, academics	WERF workshop: external carbon sources for denitrification	Workshop on experiences on external carbon usage for denitrification and alternative carbon sources available	Scientific and technical advisory committee (Chesapeake); WERF; participants
Nutrient Challenge core team and others	Municipal nutrient removal technologies document	Challenge core team review EPA technology document	USEPA
Various utilities, consultants, academics	WEFTEC 2008 & 2009: LOT treatment performance reliability	Discussion of high performance plants, reliability and variability of performance to reach limits of technology	22 plants, utilities & consultants
Various utilities, consultants, academics	LOT compendium chapters	Documentation of current knowledge, knowledge gaps, and research needs	Volunteer contributions from authors/reviewers

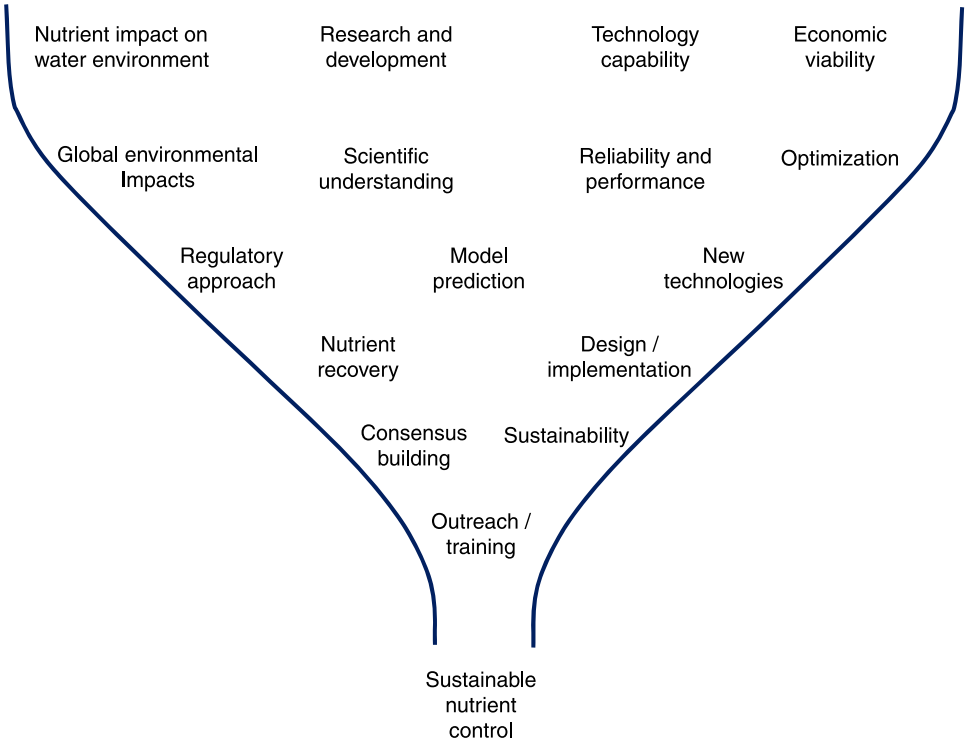

Figure 2 | Issues and concerns to be addressed on the road to sustainable nutrient control.

The WERF Nutrient Challenge is working to address these questions. The ultimate success will hinge on reaching a consensus among key stakeholders, including researchers, regulators, operators, and environmental groups on how to apply the results from the research to create a sustainable, long term nutrient control strategy.

Nitrogen

Nitrogen and phosphorus control issues are similar, even though the details are different. Four general areas need to be addressed for nitrogen issues:

- Analytical methods to measure the biodegradable (within a treatment plant) and bioavailable (available for algal growth in natural water) fraction of dissolved organic nitrogen. No standard method for measuring these compounds is currently available.
- Process fundamentals for nitrogen removal and transformation and understanding the science and engineering of nitrogen removal. This include topics such as increasing biodegradability of nitrogen, inhibition of nitrifiers, effective use of external carbon sources, greenhouse gas emissions, growth kinetics (especially in cold weather), etc.
- Technology development and performance addresses issues related to the implementation and cost effectiveness of existing and new treatment processes. It relates to engineering to develop and apply technology, the reliability of a technology, methods to improve efficiency, design challenges to achieve low nitrogen limits (phosphorus needs, DO, etc.).
- Operation and control of nitrogen removal processes. This address online process control, operator training, nitrogen recovery, alternative external carbon sources, life cycle costs, greenhouse gas emissions, etc.

Phosphorus

Four general areas need to be addressed for phosphorus issues:

- Analytical methods to measure the fundamental phosphorus species (reactive and nonreactive phosphorus) below 20 ug/L in effluent. Similar to nitrogen,

determine the biodegradable (within a treatment plant) and bioavailable (available for algal growth in natural water) fraction of dissolved nonreactive phosphorus. No standard method for measuring these compounds is currently available.

- Process fundamentals for phosphorus removal and transformation and understanding the science and engineering of chemical and biological phosphorus removal. This includes topics such as increasing biodegradability of phosphorus, improving reliability of biological phosphorus removal, effective use of external or internal carbon sources for biological phosphorus removal, chemistry of ferric, alum, and ferrous phosphorus removal, etc.
- Technology development and performance addresses issues related to the implementation and cost effectiveness of existing and new treatment processes. It relates to engineering to apply technology, the reliability of a technology, methods to improve efficiency, design challenges to achieve low phosphorus limits (optimizing chemical phosphorus removal, reliability of biological phosphorus removal, particle removal, phosphorus speciation, etc.).
- Operation and control of phosphorus removal processes. This address online process control, operator training, phosphorus recovery, life cycle costs, etc.

Design and modeling

Modeling is a central part of both scientific research and engineering application. Every new idea (for example, biodegradable organic nitrogen and phosphorus) requires that treatment and water quality models be updated to reflect the new knowledge. In addition, models are used for the design and optimization of treatment processes to meet permit limits.

Design and modeling covers six areas:

- Fundamental model development is part of each research project. For example, a project on denitrification kinetics using alternative external carbon sources requires that the biological model be modified to address new findings, chemical phosphorus reactions must be added to models, including greenhouse gas emissions, etc.
- Model application to assess the ability of the model to accurately predict performance under very low (near nutrient deficient) limits. Assessing simultaneous nitrogen and phosphorus removal.
- Design at limits of technology. This is the application of process models in designing facilities to meet local requirements for temperature, wet weather, seasonal performance, etc.
- Model uncertainty addresses both the uncertainty in knowing the true model parameters for a given design and designing for variability in influent and environmental conditions.
- Nutrient recovery and side stream treatment.

Operation and maintenance (O&M) requirements

Operators are looking for tools to help them manage and control large, complex, processes under highly variable loadings and environmental conditions. Increasing complexity in the treatment processes also necessitates that both operators and designers understand the operability and reliability of the process control and maintenance issues. In summary, operators need clear directions in three areas:

- Understanding the fundamental processes and factors affecting process performance. These topics include handling peak flows, reducing recycle loads, strategies for seasonal operation (wet/dry weather, hot and cold temperature).
- Tools to assist in control strategies, including biological process control, online instrumentation, process control strategies, and chemical dose control.
- Information sharing is of high importance to operators. Learning from other operators, sharing standard operating procedures, troubleshooting commonly encountered problems, corrective actions, etc.

Outreach

Reaching out to stakeholders and other is a key for the WERF Nutrient Challenge. Outreach activities attempts to reach a broad audience through news releases, workshops, webinars, papers, and presentations at conferences. The goal of the outreach activity is three-fold:

- Disseminate information collected as part of the nutrient challenge program. These include reports, techniques, protocols, etc.
- Provide a forum to learn from others about their experiences and form affiliations with ongoing work to leverage those opportunities.
- Engage decision makers to reach consensus on key issues. This is particularly critical for regulatory outreach to present research results, discuss the implications of the results, and reach agreement on how to implement the findings to reach a sustainable, long term approach to nutrient control.

Table 2 | High priority projects

Area	Topic
Regulatory	Establish LOT for N and P (LOT workshop II)
Regulatory	Nutrient trading and non-point source control
Regulatory	Regulatory issues and nutrient technology outreach
Regulatory	Sustainability, GHG, carbon footprint
Regulatory	Strategies for achievable and sustainable N & P permits
Nitrogen	External carbon protocol
Nitrogen	Alternative external carbon workshop
Nitrogen	Methylotrophic denitrification kinetics
Nitrogen	rDON workshop on bioavailability/biodegradability methods
Nitrogen	RDON research–measuring inert DON
Nitrogen	Methylotrophic denitrification–phase I & II
Nitrogen	Simultaneous nitrification-denitrification
Nitrogen	Side stream treatment to optimize nitrogen removal and recovery
Phosphorus	Low P measurement
Phosphorus	Phosphorus speciation, availability, and occurrence
Phosphorus	Chemical phosphorus removal with ferric, alum, and ferrous
Phosphorus	Refractory dissolved phosphorus (RDP) removal
Phosphorus	Phosphorus measurement (analytical methods)
Phosphorus	LOT Compendium
Design and modeling	WEFTEC LOT performance workshop
Design and modeling	N and P growth requirements at LOT operation
Design and modeling	Modeling–MEGA–uncertainty in models and parameters
Design and modeling	Side stream treatment for nitrogen control and recovery
Design and modeling	Side stream treatment for phosphorus control and recovery
Design and modeling	Nitrification inhibition–update list of inhibitors
Operations	BNR/ENR process control using online instrumentation
Operations	Alternative substrates for EBPR (including fermenters)
Operations	Information exchange/technology sharing–wikipedia for operators
Operations	Cold/Wet weather impacts
Outreach	WEF nutrient June 2009
Outreach	WEFTEC 2009/2010 Carbon augmentation testing protocol workshop
Outreach	WEFTEC 2009 2nd LOT workshop
Outreach	Carbon augmentation testing protocol webcasts
Outreach	Presentations at different conferences in 2009
Outreach	Regulatory issues outreach program
Outreach	WEF/IWA biofilm conference 2010 carbon testing protocol workshop

Table 3 | Overview of activity/level of effort

	2007	2008	2009	2010	2011
Outreach/tech transfer activities	XXX	XX	X	XXX	XXXXX
Regulatory issues	X	XXX	XXX	XX	XX
Nitrogen research	XX	XXXX	XXXX	XX	XX
Phosphorus research	x	XX	XXXX	XXXX	XX
Design & modeling	x	X	XX	XXXX	XXX
Operations & maintenance	x	XX	X	XXXX	XXX

X = Relative measure of activity/level of effort.

The core team has taken stakeholder input, workshop respondents' feedback, and prioritized the research needs. These topics form the focus of the near-term efforts and potential collaboration opportunities. The priorities are shown in Table 2, organized into the various focus areas.

CONCLUSIONS

Only in its third year, the Nutrient Challenge still faces the bulk of its work. Regulatory requirements are still emerging in many areas and will change as new information becomes available. The Nutrient Challenge seeks to compile and disseminate the information needed to make informed and sustainable decisions to meet these challenges. It is the goal of the Nutrient Challenge to act as a storing house for the combined knowledge necessary to meet future challenges and, hopefully, to leverage that combined knowledge into new and exciting work in the future.

Table 3 presents the level of effort (the number of "X"s in a cell corresponding with level of effort) for each topic area in the Nutrient Challenge by year for the lifetime of the project. While initial efforts focused on nitrogen issues, current projects address phosphorus removal with design and operations becoming more important. As the program matures, outreach and dissemination of knowledge will become more important.

The needs of the industry will best be met through collaborative efforts from all parties involved. This can become a reality only by leveraging other ongoing work, not only in the U.S.A., but all around the world.

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