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EPA Nutrient Sensor Action Challenge – Stage 1 / 9-20-17

"OPENING UP THE "BLACK-BOX" OF WASTEWATER TREATMENT PROCESSES, MONITORING, AND ANALYTICS"

A. Nutrient Issue:
Describe the nutrient-related topic or need that will be addressed by the addition of data and information from continuous nutrient sensors. Describe how data from continuous sensors will be incorporated into your monitoring operations. Explain how nutrient sensors will enable improved decision-making for nutrient reduction.

The addition of data and continuous nutrient sensors will help us successfully implement our all-in-one advanced monitoring platform and data analytics to:

1) Save costs and reduce environmental impacts by **preventing** wastewater treatment plant (WWTP) operational failures that can arise from unanticipated and deleterious increases in nutrient levels.

2) Save costs by helping to **reduce** key WWTP operational expenditures resulting from ever increasing utilization of resources including energy and chemicals.

In addition, since 2012, our work has been awarded/sponsored by various leading stakeholders including: the New York State Energy Research and Development Authority (NYSERDA) /PowerBridgeNY, National Science Foundation (NSF), and Cleantech Open. These awards prioritize: 1) advanced monitoring and data analytics for water/wastewater treatment; 2) the customer discovery process. Therefore, we continue our collaborations with some of the most prominent and sizeable members of the international water/wastewater ecosystem including: large municipalities/WWTPs who are responsible for over 90% of expenditures on water infrastructure; technology providers; design build contractors; and environmental engineering/consulting firms. As such, our advanced monitoring and analytics also address some key customer concerns:

- Need for more sophisticated monitoring and analytics that can actually tell how effectively WWTP processes are working.
- Minimize/reduce costly *in-situ* monitoring sensors and tech, and simultaneously produce more quality, actionable data.
- More data is not necessarily better. Too many sensors feeding automated real-time information does not necessarily mean certain data can be analyzed faster nor that corrective actions can be implemented faster.
- Plant "engineers" and plant "operators" not talking to each other. Monitoring and analytics has to be simple enough so that both plant operators and plant engineers can agree on, trust the data, and then react accordingly.

- Simplify data management and parse only actionable data.

Presently, industry standard monitoring and analytics may comprise of a single sample from a single location (influent and effluent) for standard aqueous chemical parameters, e.g., ammonia, or nitrate concentrations. However, even with various combinations of laboratory analytics and sophisticated (cost prohibitive) aqueous *in-situ* sensors, this approach is geared toward meeting regulatory requirements but is severely limited in actually improving operational efficiencies. But as our Principal Investigator (PI) has consistently shown, WWTP processes and reactors are not homogenous. As a consequence, this predicament also results in *sparse (or lack of) data* available for process control, one of the biggest limitations toward the full characterization of WWTP reactors including biological nitrogen removal reactors. Without crucial data starting with greater quantities of samples monitored and analyzed, we cannot understand what is actually happening during the treatment processes. Over the course of 15+ years, our PI has resolved numerous WWTP problems that were direct results of this passive approach. A typical case study might include undesirable elevated levels of certain chemical constituents in the effluent but where we might not know where along the multitude of WWTP reactors the problems may have occurred. In such cases, a WWTP has to expend additional time and expenses to first identify the problems and then "fix" the problems. During this time, a WWTP may have to shut down and incur enormous fines. Moreover, it's no surprise that this approach is conducive to a "black-box" of water treatment processes.

In the US, WWTP operations consume nearly 4-6% of the total national annual electricity demand. As EPA water quality standards become more stringent, this energy footprint could at least double in the near future. With the need for water supply at an all-time high and rising, and fewer WWTPs being constructed to handle the flows, new technologies/solutions capable of optimizing (increase capacity and improve energy efficiency) current plants are a must. If not, major US WWTP municipalities could see their wastewater treatment operating costs increase significantly.

Sparse data available for process control is also one of the biggest limitations deterring more widespread implementation of emergent, transformative WWTP solutions such as anaerobic ammonia oxidation (anammox) and other new technologies that have already shown potential for significant impacts such as: energy savings greater than 60% and chemical cost savings up to 100%. Without the advanced means to properly monitor, analyze, and evaluate the effectiveness of these solutions, we will not be able to realize the true benefits.

Reflecting all of the above, our advanced monitoring and analytics are more proactive and robust, an approach that can open the "black-box", and "prevent" problems from occurring in the first place as opposed to the passive "fix" approach that attempts to solve problems *after* they have occurred. As such, *strategically incorporating greater quantities of continuous sensors can enable us to improve the decision-making processes for nutrient reduction.*

In mitigating *sparse data* our work has shown that not only must chemical parameters be measured, in tandem, our proven and proprietary microbial/bacterial analysis must be performed. Moreover, a considerable *quantity* of samples must be monitored and analyzed as well including within the actual WWTP reactors (vs. just influent and effluent) to achieve stable operations of advanced biological processes aimed at improved water quality. Eventually, our approach will facilitate advanced monitoring and analytics with a high degree of resolution in three-dimensional space and time. With this knowledge, spatial or temporal non-idealities will be identified and addressed through appropriate process control measures. The ability to generate this novel and actionable data, and to continuously monitor reactor performance is our differentiator approach. We can now lead to truly understanding and characterizing WWTP processes, facilitate advanced data analytics for up-synthesizing the data to knowledge, and help WWTPs to drive improvements in operational efficiencies and understand how to save costs.

As one of the considerations for this Nutrient Sensor Action Challenge imply, new sensors have to be *cost effective*. Otherwise, it can be rather difficult to achieve intensive *in-situ* characterization of the WWTP bioprocesses in a cost-effective and reliable fashion. For instance, while an array of current costly *in-situ* sensors could result in a lot of data being gathered, installing and maintaining such a profusion of sensors in a single WWTP would be cost-prohibitive. Additionally, the maintenance requirements of existing sensors would result in substantially increased labor costs. Therefore, it is imperative that we incorporate *new, cost effective sensors.*

Ultimately, we also believe that proper advanced monitoring and analytic combinations of chemical, our proven microbial/bacterial, and large quantities of data from multiple locations within a WWTP system can allow us to "predict impending process upsets" and thereby, be proactive in knowing what the final effluent might look like before actual completion of the treatment processes. Over time, we also believe that our data generated during the treatment processes but prior to effluent data, will tell us what the minimal number of monitored and analyzed data is required for full WWTP reactor characterization. Many WWTP industry participants mention terms such as "Real-time", "Automated", and "Big Data". However, we've learned through our customer discovery process that many participants do not in actuality understand how to utilize the information. Our proactive approach to data management will help us to not only minimize the number of sensors required but also to focus on parsing only actionable data that plant operators and engineers can react upon to "prevent" problems from occurring and to save costs.

B. Team:
Identify the team that will be working on the challenge.

Lead: Provide the name and contact information for the team lead. The team lead serves as the primary point of contact and may participate on only one Nutrient Sensors Action Challenge team.

Members: Describe team member and roles and responsibilities. The number of team members is not limited. Teams should include expertise in:

– Water quality monitoring, Data Management / Information technology, Communication, Data Analytics
– Continuous Nutrient Sensors (Click here for a list of participants from the 2014 Nutrient Sensor Challenge)

- **Lead/Co-Investigator/Contact:** Young Lee / younglee180@gmail.com; 617.549.9817
  - 15+ years: Senior Civil/Environmental Engineer and Finance
  - Operational leadership for large-scale infrastructure projects with a global top 5 firm.
  - Operational leadership for water/environmental projects with a global top 10 firm.
  - Development and deployment of water and energy related technologies.

- CTO/CFO for hydrokinetic energy venture.
- Awards: NYSERDA/PowerBridgeNY, Cleantech Open

- **Co-Lead/Principal Investigator:** Dr. Kartik Chandran, Ph.D.
  - 15+ years: Environmental Engineer.
  - Professor, Dept. of Earth and Environmental Engineering, Columbia University
  - Established first ever biological wastewater treatment and nutrient removal program at Columbia University.
  - Novel models for resource recovery.
  - Interface of environmental molecular and microbiology, biotechnology, and engineering.
  - Energy and resource efficient treatment of nitrogen containing wastewater streams, and development of sustainable approaches to sanitation.
  - 2015 MacArthur "Genius" Fellowship awardee.
  - Additional Awards: NSF I-Corps, NYSERDA/PowerBridgeNY, Cleantech Open

- **Other Team Members:** 5-10 Ph.D., level students at Columbia University that in combination possess expertise in water quality monitoring, data Management / information technology, communication, and data analytics

- **Continuous Nutrient Sensors:** We are currently developing our own advanced monitoring/sensor platform that complements our proven and proprietary advanced data analytics (already validated around the globe). However, for this *"Nutrient Sensor Action Challenge"***,** we are developing a plan that can collaborate with existing sensors including those from the *2014 "Nutrient Sensor Challenge"*. Thus, upon determining complimentary fit, we would have to establish logistics with the corresponding teams.

C. Current Monitoring:
Describe current water quality monitoring efforts, locations and assets including links to any relevant websites, data or publications.

Clients/partners that have collaborated/continue to collaborate with our PI include some of the most prominent and sizeable members of the international water ecosystem.

Municipalities/WWTPs: NY City Department of Environmental Protection (DEP), DC Water, Hampton Roads Sanitation District, East Bay Municipal Utility District, MWRDGC-Chicago, and Denver Metropolitan Wastewater Reclamation District. DEP and DC Water have also collaborated on full scale implementation of the transformative anammox solution.

Technology providers, design build contractors, and environmental engineering/consulting firms who provide services to both public and private sectors: CH2M, AECOM, Black and Veatch, Suez, Veolia, and Hazen and Sawyer.

For 100+ articles related to our PI's work, the following links are provided. Please let us know if there are troubles accessing.

http://apps.webofknowledge.com/Search.do?product=WOS&SID=3DWme8cNMPTssSOanI4&search_mode=GeneralSearch&prID=e94e5eb6-42ca-492c-bdd9-894c4b199564

https://scholar.google.com/citations?user=vZsZnFEAAAAJ&hl=en&oi=ao

D. Sensors and monitoring:

Please provide plans for sensor deployment that includes placement of sensors, power considerations, sensor maintenance, telemetry, calibration, sampling regime etc. Teams must plan on deploying 2 or more low-cost (less than $15k each) continuous nutrient sensors.

****Note: We are currently developing our own advanced monitoring/sensor platform that complements our proven and proprietary advanced data analytics (already validated around the globe). Some platform features that we are targeting include:**

- Measuring close to real time (10 second delay)
- Increased measured chemical parameters within one platform
- Proprietary algorithms that can establish relationships between different chemical parameters
- Accuracy within plus/minus 3%; 95% precision confidence
- Efficient data management via proprietary algorithms, ethernet/power communications, remote web browser interface, and Modbus/TCP Ethernet for connectivity to all controls
- First maintenance no sooner than 2 years; 5-10 year life of system (greater than 10 with care)
- Estimated cost less than $5,000

However, for this *"Nutrient Sensor Action Challenge"***,** we are developing a plan that can collaborate with existing sensors including those from the *2014 "Nutrient Sensor Challenge".* Thus, upon determining complimentary fit, we would have to establish logistics with the corresponding teams.

We anticipate that individual sensor manufacturers will have their own requirements including that for power, maintenance, and calibration. We will work with these manufacturers to ensure optimum performance.

Whether we use our own monitoring/sensor designs and/or others', we will begin with a hazard resistant containment box as per numerous manufacturers' recommendations. The mobile box will be placed along the sides of WWTP reactors, and can be moved to relocate sensors and/or to comply with WWTP needs. Placed in the box will be a small laptop computer with connectivity to the chosen sensor, corresponding power supplies for sensor and laptop, a multiple outlet surge protector, and any spare parts. The containment box will have a port (or ports depending on what is most efficient) to allow for industrial grade extension cord(s) and any sensor wiring entry/exit. Electric power will be provided to components via an industrial grade, outdoor use approved cord that can easily be connected to an outlet within the property. Based on conversations with several WWTPs, this power can be provided with minimal challenges. Our proposed continuous power source addresses another key concern, namely, batteries that may have to be replaced. If necessary, all of the components will be secured via manufacturers' recommendations, e.g., integrated fastening mechanisms to deter movement. All of the components will be covered in insulating and protective material. The containment box will include a watertight locking mechanism (with a key if necessary). This basic containment structure inclusive of all internal components is estimated to cost less than $1,500.

With the basic containment box in mind, we can then coordinate with an appropriate sensor provider and customize configurations to suit their needs. Based on our monitoring and analytics plans, we can build framing apparatuses to hold the *in-situ* sensors in locations of our choosing. Prior to commencing with sampling, monitoring, and analytics, we will predetermine the initial number of sensors to be deployed and the various locations within a reactor that we believe will help us completely characterize the reactor. In conjunction, we will develop a scheme, e.g., daily, to collect samples for microbial/bacterial analytics at the identical locations to the nutrient sensors. The actual number or nutrient sensors will be predetermined based on the capacity of the reactors but we initially anticipate between 5 – 10. A single containment structure may be able to accommodate connections to 2 sensors. Thus, we initially anticipate deploying up to 5 containment boxes.

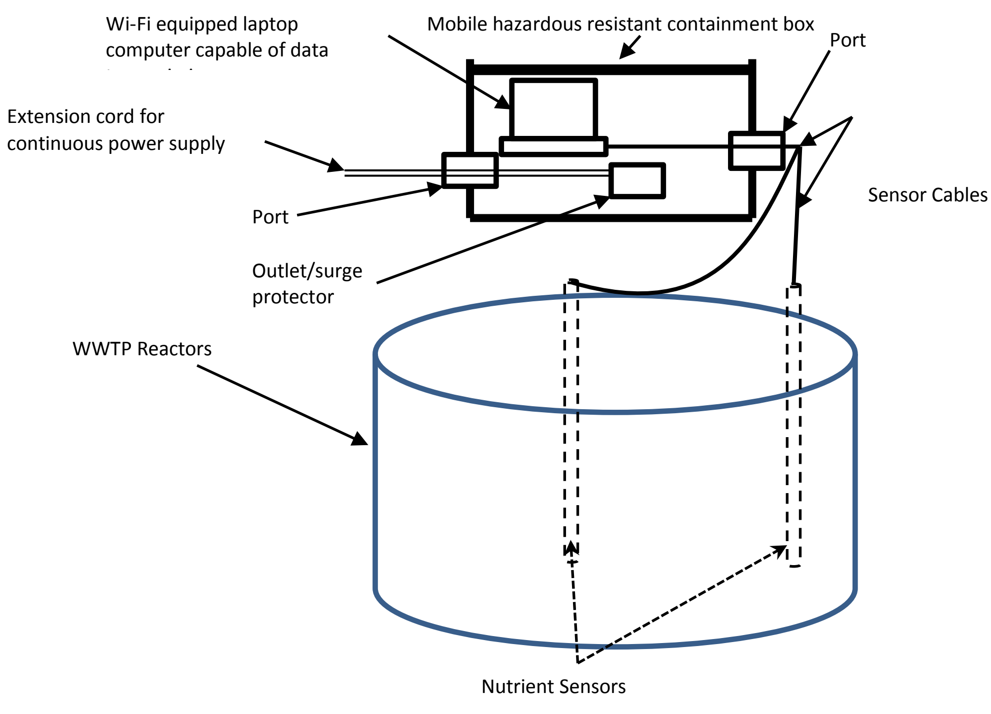
Nutrient sensor data will get uploaded to laptop computers for data management. The data can be accessed at any time via the secured containment box with a key. Algorithms that we will develop will enable data to be automatically transmitted to a designated server or cloud, and then disseminated to interested parties including WWTP personnel and Columbia University. We have readily available resources with respect to algorithms that can enable/enhance interconnection via the internet of devices to send and receive data (“internet of things” - IoT).

Over time, we will build a database that correlates chemical and our proprietary microbial/bacterial parameters. We will establish a “grid” system whereby we can determine the minimal quantity of sampling, monitoring, and analytics data points that will still allow us to completely characterize a given WWTP reactor. As mentioned previously in Section A, this in turn will enable to us to achieve the proactive approach to advanced monitoring and data analytics, and address customer discovery concerns including those related to actionable data, minimizing costly tech, and simplified data that both engineers and operators can work with.

E. Data:

1. Solution Architecture: Provide a diagram which illustrates the overall configuration of the proposed data solution. The diagram should provide information about how data is taken from the sensor and loaded into the data storage and how the data repository will be accessed for judging (e.g. web services)

Figure 1. Diagram of Proposed Data Solution (Not to scale)



2. QA/QC: Describe how quality assurance and data validation will be addressed

We will reference our extensive QA/QA protocols established by our PI at Columbia University. The protocols are rather comprehensive and thus the complete document can be furnished upon request. For this "*Nutrient Sensor Action Challenge",* we will provide an outline of the major sections:

1.1. Data Quality Objectives
- Method Detection Limit (MDL)
- Procedure to calculate MDL
- Precision
- Accuracy
- Representativeness
- Completeness
- Comparability

1.8 Special Training Requirements/Certification
1.9 Documentation and Records
2.3. Sampling Handling and Custody Requirements
2.4. Quality Control Requirements and Corrective Measures
2.5.1. Recovery of Known Additions
2.5.2. Analysis of Externally Supplied Standards
2.5.3. Analysis of Reagent Blanks
2.5.4. Calibration with Standards
2.5.5. Analysis of Split Samples
2.5.6. Analysis of Duplicates
2.6. Performance Audits
2.6.1. Monitoring Lab Analysis
2.6.2. Monitoring Standard Operating Procedures
2.7. Corrective Measures
2.8. Instrument Calibration, Maintenance and Quality Control Checks
2.9. Inspection/Acceptance Requirements for Supplies and Consumables
2.10. Data Management
4.1. Data Validation
4.2. Reconciliation with User Requirements

3. Data Sharing: Teams are required to make the sensor data accessible for judging using web services that follow Open Geospatial Consortium data standards for communicating and sharing continuous monitoring data. (www.opengeospatial.org/standards/sos, www.opengeospatial.org/standards/waterml). Describe any additional plans for sharing data.

We are currently establishing protocols and will follow **Open Geospatial Consortium data standards.**

4. Metadata: Teams are expected to provide metadata that will explain the data content. Describe your metadata approach and identify and describe the naming convention for characterizing the nutrient data. Teams may consider using one of the formats below:

– NOAA/IOOS metadata standards and SOS guidelines: http://ioos.github.io/sos-guidelines/

– NWQMC Water Quality Data Elements: a user's guide: https://www.ioos.noaa.gov/wp-content/uploads/2016/04/national_water_quality_monitoring_council_elements.pdf

We are currently establishing the metadata approach that we plan to use, and will refer to **NOAA/IOOS metadata standards and SOS guidelines.**

F. Analytics and Interpretation:

Describe plans for analyzing the data and if there are specific analytical and statistical tools (e.g. platforms, algorithms, models) that you anticipate using. Please describe how these analytics will provide insight and support use of the data and information.

We will employ long standing and well established proprietary methods developed by our PI which includes chemical and microbial/bacterial analytics. One of our core strengths toward advanced analytics is our PI's expertise in genetics/gene expression. This expertise allows us to truly understand what occurs inside WWTP reactors at both the chemical and bacterial levels. To reiterate just one of the benefits already described previously in Section A, this expertise in turn will be the only means to properly analyze the effectiveness of transformative WWTP solutions such as anaerobic ammonia oxidation (anammox) and other new technologies that have already shown potential for significant impacts such as: energy savings greater than 60% and chemical cost savings up to 100%.

G. Communication and Use:
Describe plans for communicating the information for use by decision-makers. Describe how the data and information will be integrated with existing water quality data to improve decisions about nutrient reduction.

Starting at the WWTP operational levels, nutrient sensor data will get uploaded to laptop computers for data management. Algorithms that we will develop will enable data to be automatically transmitted to a designated server or cloud, and then disseminated to interested parties including WWTP personnel and Columbia University.

In addition, we will conduct extensive laboratory analytics for both chemical and microbial/bacterial utilizing well established proprietary methods developed by our PI. We will work closely with WWTP personnel to evaluate generated data, and to understand and respond to their needs. We also anticipate that moving forward, we will notice repeatable consistent quality differences in the newly generated data when compared to that of existing water quality data. As described previously in Section A, one of our goals is to employ a proactive approach to monitoring and analytics and produce/isolate actionable data that plant operators and engineers can react upon to enact timely WWTP reactor adjustments, "prevent" problems from occurring in the first place, and to ultimately save costs.