Mystic River Watershed Sensor Action Challenge Application

A. Nutrient Issue

The Mystic River watershed contains multiple rivers, lakes, and ponds that are impaired by excessive levels of phosphorus. The Mystic River Watershed Association (MyRWA)--in collaboration with the US Environmental Protection Agency (USEPA), USGS, and other partners--is currently developing a Total Maximum Daily Load (TMDL) Alternative for phosphorus. Three years of sampling and modeling will be completed in 2018, and the project will lead to the creation of a long-term plan for reducing nutrient inputs from watershed sources.

We propose to track progress on nutrient reductions with the deployment of two Systea WIZ probes in the Mystic River watershed. The WIZ nutrient sensor probe is designed and built by Systea, S.p.A. and was a first-prize winner in the Alliance for Coastal Technologies Nutrient Sensor Challenge in 2016. For this study, the two probes will be installed at two different well-established monitoring locations in the Mystic River, each collecting Total Phosphorus (TP) and orthophosphate (PO4) concentrations in the River.

The probes are a cost-effective solution to the challenge of tracking water quality over multiple years and can provide higher resolution Total Phosphorus datasets than what is currently being collected. Data provided by the WIZ probes, coupled with real time continuous flow data from USGS flow gages at the probe locations, will allow researchers to more accurately estimate Total Phosphorus loads exported from the Mystic River Watershed than ever before. These estimates of watershed phosphorus export will be tracked annually to determine whether the trends indicate nutrient reductions. The phosphorus export data will be used by municipalities, state government officials, and federal officials to assess TMDL compliance and drive future future phosphorus reduction strategies for the Mystic River Watershed.

During the first year, data from the WIZ probes will be compared to and quality controlled by data being collected from a flow-weighted composite autosampler and bi-weekly grab samples. Upon verification of the WIZ probe's applicability in the Mystic River, the probes will run independently at the sites. Data collected by the probes will be stored in a PostgreSQL database and made available to the public real-time through telemetry and display on a Mystic data/map web interface (currently in development). A project page will display the most recent measurements, data summaries of storm events, and modeled annual loads of Total Phosphorus exported from the watershed. These summaries will inform land use based decisions within the watershed as well as provide confidence to stakeholders that phosphorus reduction strategy implementation is making a discernable difference in the Mystic River.

B. Team

Lead: Project lead is the **Mystic River Watershed Association**, **Patrick Herron, PhD, Executive Director.** 20 Academy Street, Suite 306, Arlington, MA 02476.

Members:

Mystic River Watershed Association (MyRWA)-Staff of MyRWA will be responsible for deploying and maintaining the sensors in the field and for associated water quality monitoring. Patrick Herron, Ph.D., executive director, has directed MyRWA's science programs for 9 years. Andrew Hrycyna, watershed scientist since 2014, is responsible for field work and data management. MyRWA's science projects include a 15-year baseline program; stormwater outfall monitoring; a bacteria prediction flagging project; and sediment sampling to support a public health risk assessment.

MyRWA has recent and extensive experience in watershed-scale nutrient monitoring. A phosphorus loading study will complete its third year of data collection in 2017. The study was designed to develop a TMDL for phosphorus and executed in collaboration with USEPA, Massachusetts Department of Environmental Protection (MassDEP), and USGS. Activities have included three years of bi-weekly sampling from 12 sites throughout the watershed, plus two years of continuous flow-weighted autosampler monitoring at three locations. All sampling has been done in accordance with a Quality Assurance Project Plan (QAPP) and Sampling Analysis Plan (SAP) approved by USEPA.

A Technical Advisory Committee (TAC) for this phosphorus project was assembled in 2016, funded in part by USEPA. The EPA-led TAC includes federal, state, and professional partners with expertise in nutrient and hydrologic modeling. The committee is currently engaged in using data from this project to model nutrient loading in the watershed in order to inform federal and state regulatory decision-making.

Walker Environmental Research LLC- The web-based data management and communication platform will be designed by Jeff Walker, Ph.D., of Walker Environmental Research, LLC, in collaboration with EPA and others. Walker has extensive experience in hydrologic modeling, and environmental data analysis, management, and visualisation. Walker is a member of our TMDL Technical Advisory committee and will also be a leader in the data analytics aspect of the project.

US Environmental Protection Agency- Partners at the US Environmental Protection Agency (USEPA) Region 1 will provide laboratory and field data collection support as needed. USEPA Region 1 will also provide one (1) WIZ probe for use in this project. In addition, USEPA Region 1 staff will serve on the Technical Advisory Committee for the project and provide input on project design and implementation so that the data collected during this project can be used by regulatory decision makers at the state and federal levels.

United States Geological Survey (USGS)- Richard Verdi, Chief of Hydrologic Surveillance at the USGS Massachusetts/Rhode Island Water Science Center, project contact. USGS will support the acquisition and interpretation of flow gage data from the two USGS flow gages operating at the locations of the sensors during the course of the

project. Our team has worked closely with USGS in executing flow-weighted composite sampling with autosamplers for the past three years.

IBM -Exciting preliminary conversations with researchers at IBM (see letter of support, Appendix 1) have explored possible future collaboration with IBM on this project. IBM has recently acquired the Weather Company (Weather Channel), and so has access to high-accuracy weather forecasting data that could inform sampling plans using the sensor--increasing the frequency of sampling during storm events, for instance, when we know phosphorus inputs are especially high. In addition to supplying weather data, IBM may be able to provide cloud data storage and services and enhanced data visualization capabilities on the project website.

Systea S.p.A.- Preliminary conversations with Systea S.p.A. revealed substantial interest in partnering on this project to test the applicability of the WIZ probe in the Mystic River system in conjunction with autosamplers. If selected for round two on the Nutrient Sensor Action Challenge a formal partnership with Systea will be pursued to ensure proper deployment of the WIZ probes.

C. Current Monitoring

MyRWA is completing a third year of phosphorus and chlorophyll sampling in the Mystic River and its principal tributaries and lakes. We have three years of bi-weekly Total Phosphorus measurements at 12 sites and bi-weekly Chlorophyll-a data at sites in 6 receiving water bodies (60 surveys of the twelve sites over 3 years, measuring TP and Chlorophyll-a, as well Dissolved Oxygen, Specific Conductance, Temperature, and Turbidity) (see Figure 1, below). In addition, MyRWA has 15 years of monthly baseline nutrient data from 10 sites, and the ability to access and analyze data sets from the Massachusetts Water Resources Authority, which has collected 20+ years of nutrient data in the watershed.

Three USGS flow gages--including one installed specifically for the current phosphorus modeling project--contribute flow information on the Mystic River, and the Aberjona River and Alewife Brook (two of the Mystic River's largest tributaries). In order to capture the nutrient inputs from storms in this urbanized watershed, we have deployed three ISCO autosamplers at each of these flow gages, taking continuous, flow-weighted composite samples of Total Phosphorus. These give us high-confidence estimates of phosphorus loads that account for contributions of wet-weather (during and immediately following precipitation) loading, which is disproportionately high in urban watersheds like the Mystic. We have two years of autosampler data from three locations.

The sensor challenge comes at precisely the right time for our organization to put an in-situ nutrient sensor to innovative use. Our already-acquired data and our relationships with partners will allow us to:

- compare data acquired from the sensors with vetted, quality-controlled data from a recent research project in order to calibrate the sensor and test its performance in the field;
- use sensor data to monitor nutrient reductions over time;

- work with our governmental partners, including USEPA, to serve as a showcase watershed for application of continuous monitoring addressing the problem of documenting progress in nutrient reductions in a way that supports public decision-making.

D. Sensors and monitoring

MyRWA will deploy sensors at two sites within the watershed with long -term nutrient concentration datasets. These sites include ABR028 located on the Aberjona River in Winchester, MA and ALB006, located on Alewife Brook in Arlington, MA (see Figure 1). The MyRWA Baseline Science Program has been tracking conditions at these sites for 15 years on a monthly basis. Both sites have USGS flow gages, supplying real-time and historical flow information for each stream. Both sites are locations where MyRWA has been running autosamplers, electronically coupled to the flow gages collecting flow-weighted composite data for two seasons.

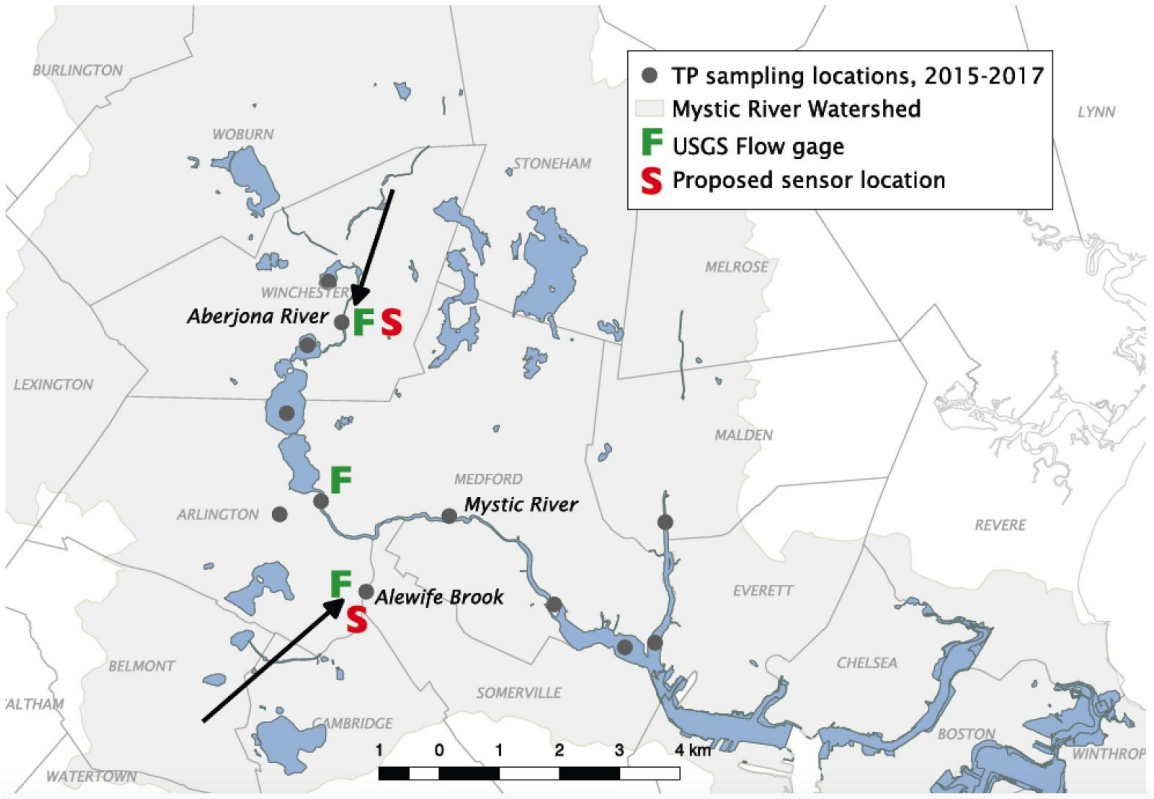

Figure 1. Map showing locations of bi-weekly grab sampling from 3-year TMDL study, USGS flow gage locations, and proposed sensor locations.

EPA staff will be trained this fall in deployment and maintenance of the Systea WIZ sensors by the manufacturer. A structure for mounting a battery, solar panel, and data logger will be mounted on a dock or on a bank. EPA will develop a field sheet to track

maintenance and performance of the instrument. The project team will collect samples at different expected concentrations (in dry weather in during the first hours after a storm, for instance) to evaluate the instrument performance. The instrument will take measurements every hour continuously and be operated from a battery which is charged with a solar panel. In addition, the WIZ probe will be mounted adjacent to other water quality sondes to acquire data on additional water quality parameters such as Dissolved Oxygen, Conductivity, Temperature, and pH. The system will allow remote uploading of data by cellular network.

Sampling frequency will be increased during periods of expected high loading, triggered by forecast precipitation or by measured flow. Hundreds of samples can be acquired in the field before the device needs reagents replenished. Auto-calibration is performed using concentrated standard solutions, contained in the device's reagents container.

E. Data

1. Solution Architecture

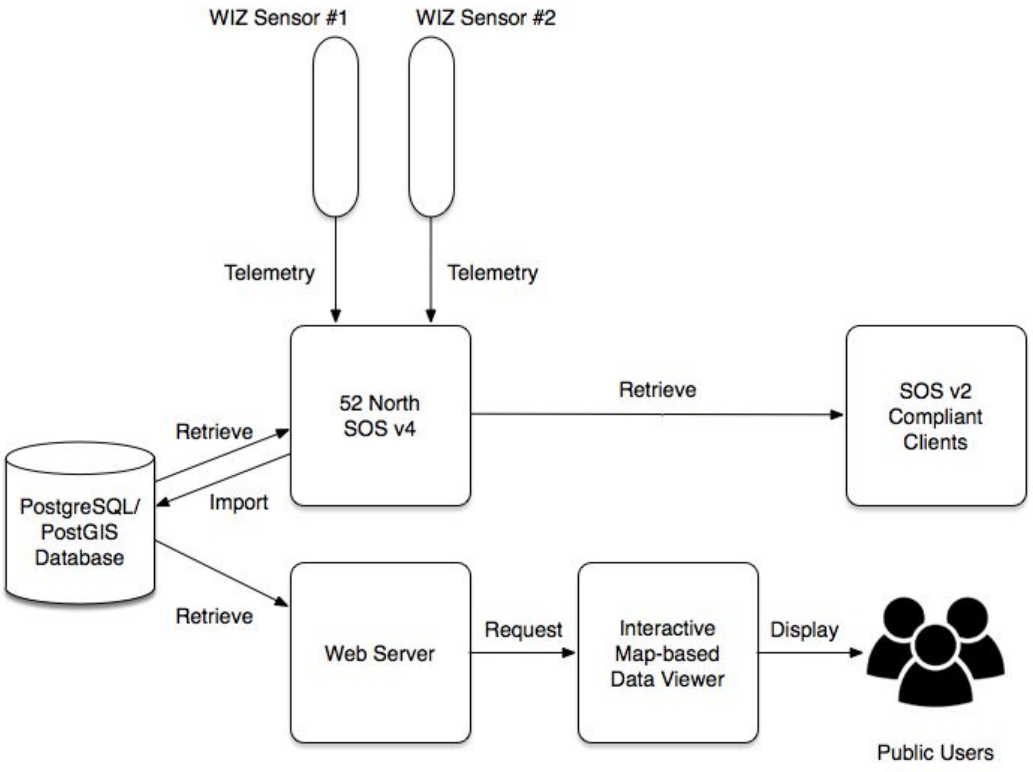

Figure 2. Data architecture for Mystic watershed sensor project.

The data system will use cloud-based infrastructure to transfer, store, manage, and retrieve the sensor data. The two sensors will be equipped with a telemetry system to transmit data in real-time from the monitoring sites to a cloud-based computing instance

running the 52 North Sensor Observation Service v4 open-source software platform (http://52north.org/communities/sensorweb/sos/). The 52 North software will store this data in a PostgreSQL database (https://www.postgresql.org/) with the PostGIS extension (http://postgis.net/), which together will serve as a powerful open-source geospatial relational database. The 52 North software will also provide web-based access to the sensor data for any Sensor Observation Service (SOS)-compliant client. The data will also be available to public end users through an interactive map-based data viewer described below.

2. QA/QC

The Total Phosphorus and Orthophosphate concentrations measured by the WIZ sensors will be compared to biweekly grab samples collected at the same locations as part of MyRWA's existing water quality sampling programs. For each period between grab sample collection, the sensor data will be considered of acceptable quality of the measurements at both the start and end of the period are within 30% of the grab sample measurements (standard drawn from EPA-approved QAPP). Furthermore, each sensor will undergo standard calibration using procedures and frequencies as recommended by the manufacturer (Systea).

3. Data Sharing

The sensor data will be made available to the general public through both web services and an interactive web application. The web services will provide functionality and data formats in compliance with the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) v2 standard (http://www.opengeospatial.org/standards/sos). The web services application will be powered by the 52 North SOS v4 open-source software platform (http://52north.org/communities/sensorweb/sos/), which allow us to upload, manage, and retrieve sensor data using SOS-compliant interfaces. In addition to the web services that will provide data access to any SOS-compliant client application, the data will be displayed using an interactive map-based data viewer, which is currently under development by MyRWA. This web-based data viewer will allow public users to view and download real-time sensor data collected at each monitoring location, and to compare these measurements to other environmental variables such as streamflow and rainfall to better understand the wet-weather dynamics causing nutrient impairments in the Mystic River watershed. Lastly, the viewer will also provide data views highlighting long-term trends in phosphorus concentrations based on both the sensor data and other grab sampling data being collected as part of existing monitoring programs.

4. Metadata*:* Metadata will be associated with all measurements and include elements specifying the sensor, georeferenced location, and description of the analytes being measured. The sensor itself will be described using unique identifying attributes such as the make and model, serial number, etc. The location metadata will specify the geographic coordinates where measurements are collected. Lastly, the analyte metadata will use the USGS parameter codes (https://help.waterdata.usgs.gov/parameter_cd?group_cd=NUT) as a basis for characterizing each of the two nutrient species (TP and ortho-phosphate). Metadata will

be available through the web services API, and provided in human-readable format on the interactive web-based interface. Calculated phosphorus export rates will be available for download as Phosphorus Load Export (PLE) at timeframes selected by the user and will include an explanation of PLE calculation using real time TP concentrations and river flow data.

F. Analytics and Interpretation

Long-term monitoring of phosphorus in streams faces the challenge that infrequent sampling events (monthly, bi-weekly) can miss important loading inputs that occur on short-time scales at non-regular intervals, especially driven by storm events (Pellerin et al, 2016). The WIZ remote nutrient sensor promises to overcome these challenges by allowing a frequency of sampling during periods of high loading (especially storms) that would not be practical using traditional sampling methods (Copetti et al, 2017).

By deploying a Systea WIZ nutrient sensor armed with Total phosphorus (TP) and orthophosphate (PO4) sensors at the Aberjona and Alewife sites, we seek to answer two related research questions:

- *How do phosphorus load estimates from grab sample and autosampler sampling projects currently underway compare with those generated from in-situ sensors?* Using flow data, we will be able to generate load estimates from the high-frequency concentration data acquired by the sensors. We will then be able to compare the load estimates from continuous sensor data with estimates emerging from our conventional TMDL sampling, including autosamplers. By comparing these two data sets, this project can serve as a critical real-world field test of the reliability, accuracy, and feasibility of in-situ continuous nutrient sensing.

- *Can we use the sensor data to document nutrient load reductions over time?*

To investigate the data delivered by the remote sensor with respect to these research questions, we will conduct the following analyses:

1) Differences between field probe results and field-collected laboratory-analysed discrete sample results (expected result) will be evaluated as Relative Percent Difference to assess the WIZ probe's precision. Statistical analyses will be performed using the latest version of the R statistical programming language (http://www.r-project.org/). This data analysis will indicate whether probe measurements are reliable and precise relative to traditional and validated standards of measure, acceptable thresholds for Relative Percent Difference will be +/- 30% of the expected result.

2) An analysis of WIZ probe's efficiency and accuracy will be conducted by comparing the distributions of measured concentrations between the probe and lab datasets using quantiles, means, medians and asymmetry metrics of the distributions. The study will use the Shapiro-Wilk test and linear regressions to determine normality and correlation between datasets. This data analysis will

indicate whether the accuracy of the probe measurements are consistent over the full range of observed concentrations, and whether there are any differences in accuracy among higher or lower concentration magnitudes.

3) Analysis and compilation of storm event concentrations using a linked precipitation and flow dataset such that any precipitation-triggered storm event with a rising and falling limb and discharge 20% above base flow is considered. This analysis will yield a stronger understanding of the role that episodic precipitation events have in driving phosphorus dynamics.

4) Application of an error-corrected regression model to interpolate concentration values to match the 15-minute time-steps of USGS flow monitoring. Common goodness-of-fit statistics such as the root mean square error (RMSE) and coefficient of determination will be used to evaluate the regression equations.

G. Communication and Use

Our project will feature a real-time cloud-based data portal for dissemination of flow data, Total Phosphorus data, weather data and all other water quality data collected as part of this project. This publicly accessible portal will allow to be used by multiple decision makers at the federal (USEPA), state (MassDEP), and municipal levels.

Municipalities. EPA regulations will impose requirements on municipalities to reduce phosphorus inputs to the Mystic River to comply with TMDL targets. Municipalities throughout the Mystic River Watershed will be implementing green infrastructure practices and other phosphorus control practices in order to decrease the loading of phosphorus to the Mystic River and bring the river into compliance with the future TMDL. Municipal leaders will be able to utilize phosphorus loading information and modeling available on the web portal to assess watershed wide progress in meeting the TMDL targets and plan and budget for additional practices when the data indicates the River is not in compliance with necessary TMDL reductions.

Likewise, the data portal will tell the municipalities when the TMDL targets have been reached and additional phosphorus control efforts and expensive retrofits of the urban environment are no longer necessary.

Federal and state. At the federal and state levels the web portal will allow officials to assess the health of the Mystic River, to analyze trends in phosphorus exports from the Mystic River Watershed, and assess if adequate progress is being made toward the achievement of TMDL targets. This information will invaluable to regulators who seek to identify whether additional regulatory drivers or TMDL amendments are needed in the future.

It is imperative that once a TMDL is developed for the Mystic River that Total Phosphorus exports continue to be monitored in a cost-effective manner in the decades to come so resources are expended on phosphorus reduction technologies in the watershed

in in the most prudent manner possible. Without a low-cost solution to the long-term monitoring problem like the one outlined for this project it will be impossible to tell if resources are being spent in the wisest way possible to meet TMDL targets.

Public. Finally, the data generated by this project will create a uniquely powerful educational tool. By allowing citizens to see high-resolution data that illustrates the mechanisms and patterns of nutrient pollution, the project will help galvanize citizen support and advocacy for changes in municipal practices and investment in needed infrastructure.

References

Copetti, D., Valsecchi, L. , Capodaglio, A.G. & Tartari, G. (2017). Direct measurement of nutrient concentrations in freshwaters with a miniaturized analytical probe: evaluation and validation. *Environ Monit Assess*, 189:144. DOI 10.1007/s10661-017-5847-0

Pellerin, B.A., Stauffer, B.A. , Young, D.A., Sullivan, D.J., Bricker, S.B., Walbridge, M.R. Clyde, G.A., and Shaw, D.M. (2016). Emerging Tools for Continuous Nutrient Monitoring Networks: Sensors Advancing Science and Water Resources Protection. *Journal of the American Water Resources Association (JAWRA)* 52(4):993–1008. DOI: 10.1111/1752-1688.12386

Appendix 1. Letter of support.

IBM
International Business Machines
One Roger Street
Cambridge, MA 02412

September 19, 2017

Patrick Herron
Executive Director
Mystic River Watershed Association
20 Academy Street, Suite 306
Arlington, MA 02476

Dear Mr. Herron,

IBM appreciated the opportunity to learn about the Mystic River Watershed Association's leadership efforts to manage and reduce nutrient loading and your research project proposing design of a real-time monitoring solution using the SYSTEA WIZ nutrient sensor armed with total phosphorus (TP) and orthophosphate (PO4) sensors to answer three related research questions that will benefit from long-term watershed management.

I am writing you to confirm IBM's interest in becoming a potential project partner in this exciting project. Some potential ways we can offer support include providing the research team access to precision meteorological data and forecasting capabilities from The Weather Company, IBM Watson IoT cloud storage and devices management tools, supercomputing power from World Community Grid, and/or contributions by global subject matter experts from our global IBM Water and Environmental management team.

Best wishes on your project proposal. If you have any questions about our proposal, please do not hesitate to contact me at 508-713-1012.

Sincerely,

Michael E. Sullivan
Global Solutions Leader, IBM Water and Environment