Nutrient Sensor Action Challenge

Action Plan for Monitoring the Effects of Storms and Conowingo Dam Inputs on Nutrients in the Upper Chesapeake Bay

University of Maryland Center for Environmental Science
& Maryland Department of Natural Resources

A. Nutrient Issue

The Chesapeake Bay estuary has a long history of degraded water quality (e.g., Kemp et al. 2005) associated with elevated inputs of nitrogen (N), phosphorus (P), and sediments from its large watershed that spans six states and the District of Columbia. Following a series of multi-state agreements to restore the Chesapeake Bay, a total daily maximum load (TMDL) was established for Chesapeake Bay in 2010 that aimed for nutrient reduction targets to be achieved by 2025. As the midpoint of the TMDL restoration period (2017) has approached, initial evidence for progress in the restoration has begun to accumulate, including expanded coverage of submerged aquatic vegetation in low salinity waters (Orth et al. 2017) and reduced summer anoxia in the Bay's mainstem (Testa et al. 2017). Several other case studies have highlighted clear improvements in water quality associated with localized reductions in nutrient inputs, primarily from wastewater treatment plants (e.g., Boynton et al. 2014). Indeed, it appears that reaching the TMDL-based restoration targets is now an achievable goal.

At the same time, recent research has shown that despite long-term declines in *dissolved inorganic* N and P loading from the Susquehanna River to Chesapeake Bay, the inputs of *particulate* N and P have been increasing (Zhang et al. 2015). The elevated particulate nutrient inputs are associated with the infilling of the reservoir behind the Conowingo Dam, which has reached a state of "dynamic equilibrium" where net sediment trapping has effectively ceased (Zhang et al. 2016). The Conowingo Reservoir is the last of the three lower Susquehanna River reservoirs to fill with sediments, ending decades of sediment and particulate nutrient sequestration behind the dams that limited their delivery to Chesapeake Bay via its largest nutrient and freshwater source (the Susquehanna River). Although the potentially negative consequences for water quality of this "new" nutrient source to Chesapeake Bay are of concern in their own right, the bigger problem stems from the fact that the 2010 TMDL did not account for additional nutrient inputs associated with infilling of the Conowingo Reservoir. Monitoring and modeling results indicated that P concentrations in the upper reaches of the estuary near the Susquehanna River have increased over time coincident with the elevated particulate inputs, suggesting that the estuary is responding to elevated loads associated with reservoir infill. Clearly, the infilling of the lower Susquehanna River reservoirs presents a problem for controlling nutrient inputs to Chesapeake Bay, potentially leading to new or adjusted nutrient removal efforts within the reservoir or in upstream communities.

Almost as soon as the infilling of the reservoir had been documented, questions were raised regarding the fate and reactivity of the newly elevated particulate N and P loads to Chesapeake Bay. Phytoplankton growth is fueled by the availability of dissolved inorganic nutrients, so any particulate inputs associated with reservoir infill would have to be remineralized to dissolved

Cowan JL, Boynton WR. 1996. Sediment-water oxygen and nutrient exchanges along the longitudinal axis of Chesapeake Bay: Seasonal patterns, controlling factors and ecological significance. Estuaries 19: 562-580.
Linker LC et al. 2016. Influence of Reservoir Infill on Coastal Deep Water Hypoxia. Journal of environmental quality 45: 887-893.
Palinkas CM et al.. 2014. Sediment deposition from tropical storms in the upper Chesapeake Bay: field observations and model simulations. Continental Shelf Research 86: 6-16.
Sanford LP et al. 2001. Reconsidering the physics of the Chesapeake Bay estuarine turbidity maximum. Estuaries 24: 655-669.
Testa JM, Kemp WM. 2014. Spatial and temporal patterns in winter-spring oxygen depletion in Chesapeake Bay bottom waters. Estuaries and Coasts 37: 1432-1448.

forms before they could stimulate additional phytoplankton growth in the estuary, supporting eutrophication and associated reductions in water clarity and bottom water oxygen – the two variables that drive TMDL restoration targets. The upper Chesapeake Bay also includes a sedimentological phenomenon called the Estuarine Turbidity Maximum (ETM; Sanford et al. 2001), which effectively traps sediments and particulate material in the low-salinity regions of Chesapeake Bay, which is well upstream of the hypoxic region. Even if these sediments were transported downstream, the reactivity of terrestrially-based or river-scoured particulate nutrients is likely much less than organic material newly produced in the estuary that normally fuels hypoxia. Finally, assuming that the new particulate inputs sink to sediments relatively rapidly in the region at or above the ETM, comprehensive measurements of sediment-water nutrient releases plainly indicate that both N and P are effectively retained in sediments or removed via denitrification or burial in this region (Cowan and Boynton 1996). Clearly, there is much left to understand regarding the fate and dynamics of nutrients entering Chesapeake Bay, including additional particulate nutrients resulting from reservoir infill.

Figure 1: Map of sediment plume associated with Hurricane Irene and Tropical Storm Lee in Sept 2011. (photo courtesy of NASA). Station locations of three proposed sensors, including the Susquehanna River (upper), Patapsco River mouth (middle), and Goose's Reef (lower).

The final wrinkle in the story regarding the complications of reservoir infill for the Chesapeake Bay TMDL is that large flow events may now scour ever-larger masses of sediments and associated nutrients from the reservoir floor and deliver them to the estuary. In late summer of 2011, the passing of two tropical storms over the mid-Atlantic region (Irene in late August, Lee in mid-September) resulted in historic Susquehanna River discharges and a massive scour event from the lower river reservoirs (Zhang et al. 2015). Iconic photos of the associated sediment plume (Fig. 1) gave the impression that the storm would catastrophically alter water quality in Chesapeake Bay, but subsequent estimates of new sediment deposition associated with the event indicated that the upper Bay north of the hypoxic zone was the only region that experienced above-average deposition (Palinkas et al. 2014). Subsequent model simulations of past scour events did indicate negative water quality consequences (e.g., reduced bottom-water O_2 levels) that would impact the TMDL, but the overall magnitude of these responses was small (Linker et al. 2016). Analyses of the onset of hypoxia in 2012 did suggest some potential carry-over of the Irene-Lee event to the following spring (Testa and Kemp 2014), but the impact was again small and was complicated by other factors. Although valuable monitoring programs are in place to help investigate *both* storm events and long-term change associated with infill, the downstream effects of these loading changes are unclear, in large part because we don't know how fast the estuarine response is, how long the storm signal lasts, and if there are delayed impacts of the storm loads (months-year). Understanding these responses – and their implication for TMDL allocations associated with reservoir infill - require more temporally and spatially-resolved nutrient measurements, especially for the biologically available dissolved forms of N and P.

Cowan JL, Boynton WR. 1996. Sediment-water oxygen and nutrient exchanges along the longitudinal axis of Chesapeake Bay: Seasonal patterns, controlling factors and ecological significance. Estuaries 19: 562-580.
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One of the challenges faced in answering the questions posed above is the temporally variable characteristic of large nutrient and sediment inputs from the Susquehanna River. It is likely that many of these inputs happen during large storms not typically captured in the existing bi-monthly monitoring program including 20+ stations along the main axis of Chesapeake Bay (www.eyesonthebay.net). Although the questions of interest for the Chesapeake Bay TMDL and Conowingo involves particulate nutrient inputs, *the ultimate impact of additional particulate loading will be realized through dissolved forms that are regenerated once in the estuary*. The delivery of these dissolved forms to locations where new phytoplankton production can occur is the true measure of TMDL impact, and the ability to make frequent dissolved N and P measurements would greatly inform our understanding of the biogeochemistry in this region and the role of particulate inputs, regeneration of inorganic N and P, and the degree to which dissolved N and P make their way from the Conowingo Reservoir and along the main axis of the Chesapeake Bay. Fortunately, substantial infrastructure exists through the current activities of several state and federal agencies tasked with monitoring and managing Chesapeake Bay. For non-tidal water sources entering and leaving the Conowingo Dam, the USGS collects data on discharge and has already invested in one sensor to measure nitrate (Satlantic SUNA). NOAA and the Maryland Department of Natural Resources (MD DNR) maintain a network of buoys along the main axis of Chesapeake Bay measuring atmospheric conditions (wind speed, direction), physical conditions of the water (current velocity, salinity, temperature), and at a few places, biogeochemical measurements (chlorophyll-a, dissolved O_2, https://buoybay.noaa.gov/). We propose to integrate state-of-the-art sensors to measure nitrate and phosphate on a subset of the buoys to quantify variability in these nutrients in relation to phytoplankton production, changes in the availability of these nutrients during storm events and to monitor new inputs of nutrients derived from downstream advection or vertical mixing. We have been able to track storm-induced mixing events during past research related to the passing of more recent tropical storms (Fig. 2), but we lacked continuous nutrient data that would have illustrated the magnitude and duration of nutrient transport to surface waters. While we did invest much cost and effort to organize cruises to make a snapshot of nutrient measurements, the data were too poorly resolved in time to draw any firm conclusions regarding the storm's impact on Chesapeake Bay.

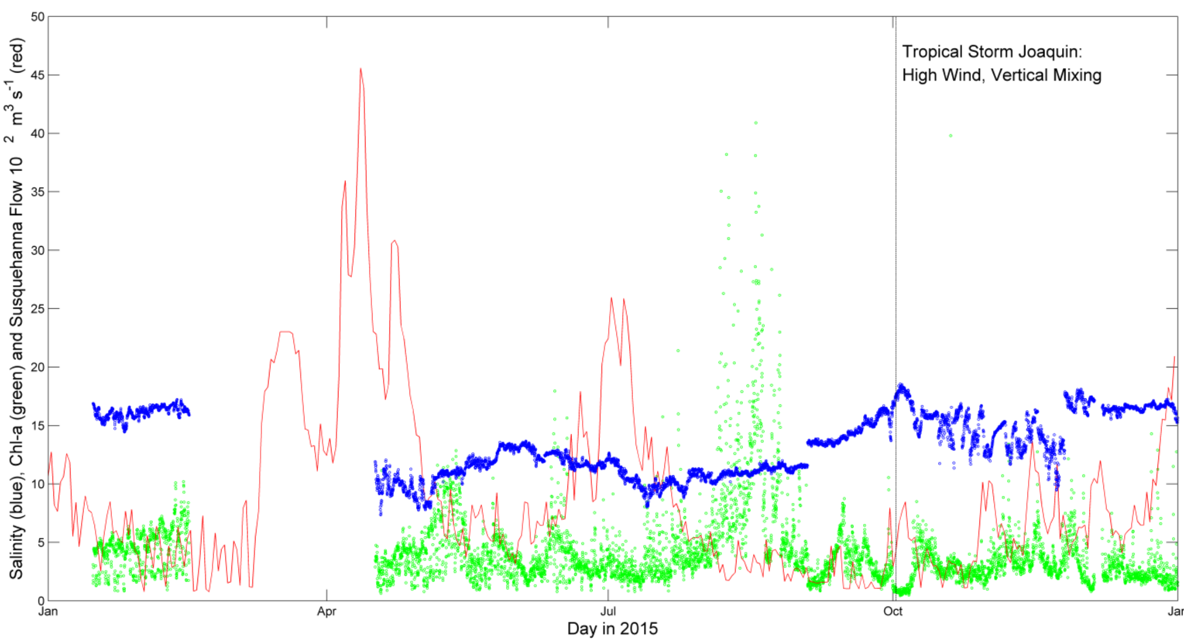

Figure 2: Time-series of continuously measured river flow at the Susquehanna River (red lines) and surface water salinity (blue) and chlorophyll-a (green) measured at the Goose's Reef buoy during 2015. The passage of Tropical Storm Joaquin is highlighted in October, where strong winds mixed high salinity, low chlorophyll-a water from deep waters into the surface layer. The event lasted only a few days. Note chl-a values are divided by 2.

These questions are the current focus of intense decision making as private interests controlling the Conowingo Dam and stakeholders (local, county, state, federal) in the watershed subject to the Chesapeake Bay TMDL attempt to determine a course for management actions. Addressing the additional nutrient loads from the lower Susquehanna River now that the Conowingo has reached "dynamic equilibrium” is one of Maryland's and the Chesapeake Bay Program's (hereafter CBP) highest priorities. To that end, a suite of nutrient and sediment reduction strategies, including dredging options, are being developed to address the increased load. The nutrient sensor action plan proposed here would provide much needed insight into the temporal variability of nitrate and phosphate in the source water from the Susquehanna as well as two sensors installed in the Upper Chesapeake Bay. Because the Chesapeake Bay TMDL is derived from model simulations of the estuary in response to nutrient inputs, these new nutrient measurements help validate these model simulations. Secondly, data to evaluate how elevated particulate nutrient inputs derived from Conowingo Reservoir may affect phytoplankton production and associated oxygen depletion have yet to be collected. The missing link is certainly the connection to dynamics of inorganic nutrients remineralized from the particulates. Extended deployments of nutrient sensors in combination with physical, atmospheric, and biogeochemical measurements will provide the high temporal variability to establish these links and to determine if the particulate inputs are of great concern. Finally, the spatial extent and temporal duration of the Chesapeake’s response to large storm events that include both dissolved inorganic nutrient loads and scour of reservoir sediments have yet to be adequately quantified, which will aid in numerical model simulations of scour events.

B. Team

Lead:

Lora Harris, Ph.D., Associate Professor, University of Maryland Center for Environmental Science, *expertise in Data Analysis, Communication, Water Quality*

Members:

Jeremy Testa, Ph.D., Assistant Professor, University of Maryland Center for Environmental Science, *expertise in Water Quality Monitoring, Sensor Deployment, and Data Analysis*

Mark Trice, Program Chief, Water Quality Informatics, Resource Assessment Service, Maryland Depatrment of Natural History, *expertise in Data Management/Information Technology, Water Quality Monitoring, Communication*

Luca Sanfilippo, Project Coordinator, Marketing Manager, SYSTEA SpA, *expertise in Nutrient Sensor Technology*

Lora Harris (UMCES) will lead this effort, coordinating team members and periodic meetings, insuring that partner agencies are looped into monitoring efforts, and leading efforts to analyze and communicate results to managers. UMCES has a long history of collaboration with Maryland DNR, beginning decades ago in the implementation of an annual contract (The “Ecosystem Processes Component”) that has enabled timely analysis in support of a variety of science-related management questions. These have ranged from suggestions for design options of the Maryland portion of the Chesapeake Bay Water Quality Monitoring Program, analytical exercises to evaluate continuous monitoring station data to document long term trends, and current activities to construct nutrient budgets for the Upper Chesapeake Bay that are relevant to the questions outlined in this proposal. Currently led by team member Jeremy Testa in collaboration with Harris, these activities include periodic meetings with Maryland DNR and a close working relationship with team member Mark Trice (MD DNR) and others in the DNR Resource Assessment Service. Harris and Testa have also collaborated on a monitoring program for the Calvert County Board of County Commissioners that just ended its 30th summer of sampling and have extensive experience in implementation of water quality monitoring programs. Work by Harris and Testa at UMCES frequently involves collection and analysis of near-continuous data, providing our team with a solid background in leveraging this information for greater insight into relevant estuarine research questions, frequently in support of policy or management concerns.

Because the Maryland portion of the Chesapeake Bay's continuous monitoring program management is so central to the success of this effort, it is key that the lead scientists at MD DNR serve in this role. The expertise housed in the MD DNR Resource Assessment Service team will be applied here to coordinate installation and maintenance of the nutrient sensors, as well as incorporation of the data collected into currently operational data management plans. Existing communication platforms (Eyes on the Bay) described below will also be coordinated through MD DNR. Drs. Harris and Testa provide academic research support for this effort to insure that data collected are interpreted and applied to the management question focused on in this action plan; determining the role of storms and seasonal cycles on dissolved inorganic nutrient availability in the Upper Chesapeake Bay. They will coordinate with MD DNR to align monitoring plans with research needs, and will process datasets once collected. Sanfilippo is an expert in nutrient sensor technology for SYSTEA SpA, one of the companies selected for final verification testing in the original Nutrient Sensor Challenge. Sanfilippo will advise our team on installation considerations and the use and maintenance of the two SYSTEA SpA sensors.

C. Current Monitoring

MD DNR, as part of the EPA Chesapeake Bay Program, has intensively monitored Chesapeake Bay and tributary water quality since 1985 and the Maryland Coastal Bays since 1999 at long-term fixed sites. Water quality profiles, chlorophyll, nutrients, sediment, water clarity and other parameters are collected to assess water quality criteria, improve management and modeling efforts, guide and track restoration activities, explain episodic events and educate the public.

DNR has been collecting continuous real-time and near-time data since 1997. Capabilities were first built through NOAA grants to assess *Pfiesteria* harmful algal bloom outbreaks on the lower Eastern Shore of Maryland. Further capabilities were built through EPA, NOAA, state and partner funding, when continuous water quality monitoring became a standard program in 2003 to assess the attainment of water quality criteria in shallow waters and to enhance and refine Chesapeake Bay model outputs for management purposes. Throughout the program history, DNR has annually deployed and maintained 30 to 50 real-time and near-time monitors. Dissolved oxygen, chlorophyll, turbidity, water temperature, salinity, pH, and in some cases water depth and blue green algal concentrations are collected every 15 minutes. Monitoring normally occurs April through October in conjunction with the submerged aquatic vegetation growing season, but is carried out year round in some locations. DNR has partnered with many organizations to deliver reliable quality assured data, such as, the EPA and NOAA Chesapeake Bay Program offices, NOAA National Estuarine Research Reserve System (NERRS), Maryland Coastal Bays Program, The National Aquarium in Baltimore, The Nature Conservancy, Oyster Recovery Project, National Fish and Wildlife Foundation, The Dominion Foundation, The Port of Baltimore, Maryland Environmental Service and many others. For the past several years, DNR has also maintained the water quality instrumentation for the NOAA Chesapeake Bay Interpretive Buoy System. For the purposes of this proposal, we have garnered support from the NOAA Buoy System to install sensors on two of their systems as outlined in section D.

Since 2003, DNR has maintained the Eyes on the Bay website (www.eyesonthebay.net). The site provides download access and charting for the full historic record of continuous monitoring data, and recent near-time and real-time provisional data. Real-time data are also captured from the Eyes on the Bay database via web services by the IOOS Mid-Atlantic Coastal Ocean Observing System's (MARACOOS) OceansMap (http://oceansmap.maracoos.org/). Long-term fixed station water quality data, as well as continuous monitoring calibration datasets are submitted to the EPA Chesapeake Bay Program's datahub (http://data.chesapeakebay.net/WaterQuality) and are available for download/web services. These data are also submitted to the Maryland Department of Environment where they are made available through the EPA Water Quality eXchange (WQX) (https://www.epa.gov/waterdata/water-quality-data-wqx). Documentation of monitoring program details can be accessed by selecting Quality Assurance Project Plans and metadata in the search criteria at this site: http://eyesonthebay.dnr.maryland.gov/eyesonthebay/stories.cfm.

In summary, DNR has gained a wealth of experience over decades collecting, quality assuring, delivering, and maintaining tens of millions of data records, and has been on the forefront of many new monitoring technologies. In a complementary manner, UMCES scientists have a long track record of leveraging these data into publications and reports that are used for management or as insight into the trends and status of the Chesapeake Bay (Pennino et al. 2016, Testa et al. 2008, Boynton et al. 2009). Affordable continuous nutrient monitoring is at the vanguard of these efforts, and this opportunity is analogous to the emergence of continuous water quality monitoring technology 20 years ago, which developed into a watershed-wide program that informed estuarine research and guided management and restoration efforts.

D. Sensors and Monitoring

Our proposed action plan accounts for three nutrient sensors at locations in the Susquehanna River and tidal Chesapeake Bay. One of these locations is maintained by the United States Geological Survey at station 01579550 Susquehanna River near Darlington, MD. This site is equipped with a YSI-EXO multi-parameter monitor meter including a YSI-6580 integrated temperature and specific conductance sensor, YSI-6561 pH sensor, YSI-6136 turbidity, and YSI-ROX-6150 dissolved oxygen optical sensors. Also deployed, is a SUNA Nitrate monitor meter with internal temperature sensor. Monitor meters are connected to a Campbell Scientific CR1000K data logger (EDL). Data are collected on fixed 15 minute intervals (0 and 15 minute marks) and transmitted every 1 hour via a Sierra Wireless AirLink Raven modem. Because this station is maintained by the USGS, data will be accessed through our collaborators.

New sensors will be deployed on buoys installed by the NOAA Chesapeake Bay Office through their Interpretive Buoy System (CBIBS). We have secured permission for this purpose from NOAA (Dr. Byron Kilbourne personal communication) and feel confident in this approach as MD DNR also contributes to the CBIBS program through maintenance of water quality sensors on the buoys. In this way, visits to nutrient sensor sites and maintenance of the instruments will be integrated as part of their regular monitoring program. The two buoys selected for our nutrient question are located at the mouth of the Patapsco and at Goose's Reef (Fig. 1). These locations are ideal for tracking inputs from the Upper Chesapeake Bay and Susquehanna River into the

Boynton, WR, Testa, JM et al. 2009. An Ecological Assessment of the Corsica River Estuary and Watershed: Scientific Advice for Future Water Quality Management. Final Report to the Maryland Department of Natural Resources. Ref. No. [UMCES]CBL 09-117.
Pennino MJ, Harris LA et al. 2016. Sources and transformations of anthropogenic nitrogen along an urban river-estuarine continuum. Biogeosciences 13: 6211.
Testa JM et al. 2008. Long-term changes in water quality and productivity in the Patuxent River estuary: 1985 to 2003. Estuaries and Coasts 31: 1021-1037.

main stem of the Chesapeake Bay, where phytoplankton productivity and resulting hypoxia are of concern and where storm-induced nutrient inputs to surface waters can be tracked.

Team member Sanfilipo represents our expertise in the nutrient sensor technology. Sensors developed by his company will be used for the buoy installation as cost effective solutions (~$10-12 k each) that also have been tested and evaluated for installation in tidal waters. The proposed WIZ in-situ probe will sequentially measure nitrate (NO3) and orthophosphate (PO4) parameters, according to the following analytical methods:

- **PO4:** the orthophosphate present in the sample reacts with molybdate in an acid medium to form phosphomolybdate and then with ascorbic acid to form molybdenum blue, which is measured spectrophotometrically at 880 nm. The antymonium catalyzes the reaction.
- **NO3:** this method is based on the reduction of NOx sample by Vanadium chloride in acid solution. The sample is first enriched by Griess reagent (SAA+NED) and then by VCl3: the reason is that a small fraction of NO2 is lost to NO (but not NO3) if VCl3 is added at first. Then the complex is trapped in a heating bath at about 60°C to convert all NOx species present in the sample to NO2. The pink colored compound is moved in the flow cell measured spectrophotometrically at 525 nm.

Measurement results will be directly provided in concentration units, with a maximum measurement frequency of 30 minutes. All measured values will be stored with date, time and sample optical density (O.D.). The same data will be remotely available to a database server through GPRS/3G FTP communication; proper software procedures will insure remote diagnostics of the sensor and generation of text messages alarms to the operators, in case of sensor failures or data threshold overlaps. The WIZ probe is composed of the analytical unit and the reagents canister; accessories will include stainless steel mooring frame, a second reagents canister, submergible 12 Vdc + RS-232 serial cable, data-logger, autonomous power and 0.1 microns tangential filtration system with autocleaning capability. Calibration samples for NO3 and PO4 will be collected biweekly-monthly, filtered immediately and frozen, and analyzed at the Chesapeake Biological Laboratory’s Nutrient Analytical Services Laboratory (http://nasl.cbl.umces.edu).

While recommendations are provided for field maintenance every two months, MD DNR maintenance schedules occur more frequently (once per month or sooner if fouling or equipment issues arise) and will be followed for the purposes of this study. Liquid reagents and the other required solutions will be periodically prepared at UMCES according to standard procedures supplied by the manufacturer. Reagents and DI replacement, liquid waste disposal, hydraulics priming and calibration time on field will require approximately one hour. Nutrient sensor sampling will occur every 30 minutes during a deployment that will take place over a one year time period. The meteorological data available along with other critical water quality sensors on the two buoys will greatly enhance the interpretive capacity of these new data (see Section C).

E. Data

1. Solution Architecture:

MD DNR’s continuous monitoring program has evolved through its 20-year history and as such uses a variety of telemetry hardware and software solutions to upload real-time data. Three types of cellular telemetry; YSI, Campbell, and Fondriest are used. Each uses a different method of proprietary software and/or custom script to upload data into a SQL Server database that resides on a DNR database server. Near-time data are uploaded by field staff via a custom webpage. Outputs are discussed in the data sharing section. In the case of this action plan, the nutrient sensors will be added to the existing telemetry architecture using Fondriest systems or NOAA AXYS Watchman 500 telemetry.

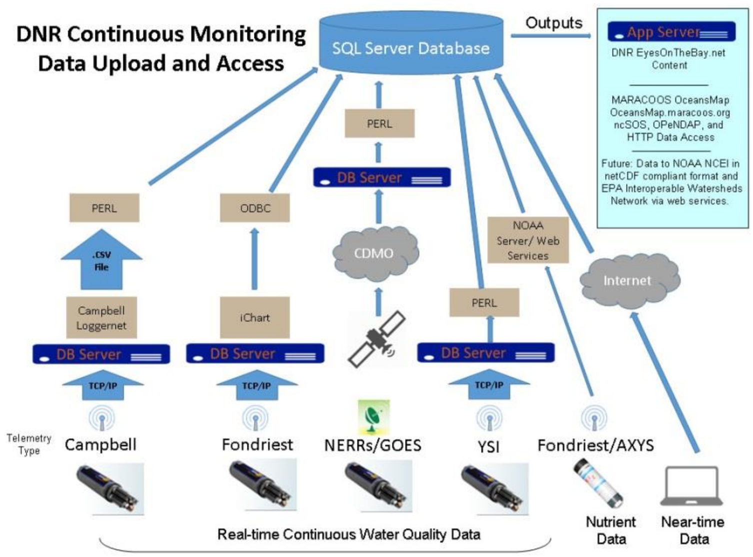

Figure 3: Architecture diagram for Maryland DNR data collection, telemetry and management systems.

2. QA/QC:

DNR creates detailed annual Quality Assurance Project Plans (QAPPs) for each monitoring project type for submission as a deliverable to the EPA Chesapeake Bay Program. QAPPs consist of detailed information on: project description; methods and performance measures; field measurements and sampling; laboratory analysis; data management; verification and documentation; project quality assurance/quality controls; data analysis and reporting; and project organization and responsibilities. QAPPs are available by selecting the QAPP publication type at: http://eyesonthebay.dnr.maryland.gov/eyesonthebay/stories.cfm.

Data collected for the Nutrient Sensor Action Challenge would adhere to the same rigorous QA/QC protocols outlined in the DNR QAPPs. Sensor operation would adhere to the manufacturer's pre- and post-calibration, deployment and maintenance recommendations. Continuous data undergo a three step data QAQC process. Data are initially run through a QAQC macro that flags data that fail various criteria and produces data visualization outputs of data for review by field biologists. After manual review by field biologists who deploy and maintain the sensors, data are additionally quality assured by data analysts for additional criteria. Suspect data are flagged with various error codes and/or comments within the data, which are also summarized within project metadata. Any calibration data or water column profiles collected onsite are additionally submitted through the EPA Chesapeake Bay Program's (CBP) Quality Assurance Tool which runs additional data checks and comparisons to historical data ranges. Continuous data are ultimately submitted bi-annually to the CBP data manager who provides an additional review and acceptance of data. Continuous data are made available through www.eyesonthebay.net. Data are extensively used within the Chesapeake Bay research, modeling and management community. If analysis for these purposes detects additional data abnormalities, data are updated and are documented within QAPPs and/or metadata.

2. Data Sharing:

DNR makes all of its provisional real-/near-time and final QAQC'ed data available via its Eyes on the Bay website (http://eyesonthebay.dnr.maryland.gov/contmon/ContMon.cfm). DNR additionally is working with other partners to capture and display data (https://buoybay.noaa.gov/). DNR real-time continuous data is displayed on the Mid-Atlantic Coastal Ocean Observing System's OceansMap (http://oceansmap.maracoos.org/). DNR has worked RPS Group to create a service that makes continuous data available via text files, and conversion into net CDF format following community CF 1.6 conventions. Data are served by a THREDDS Data Server providing OPeNDAP, HTTP and ncSOS data access. Additionally, DNR is in the process of working with RPS Group to make all continuous data available to the National Centers for Environmental Information (NCEI) (https://www.ncei.noaa.gov/) in NCEI 2.0/CF 1.6 compliant netCDF format. In another project, DNR is working with EPA and USGS to provide continuous data to the Interoperable Watersheds Network (https://e-enterprisefortheenvironment.net/our-projects/water-quality-projects/iwn/) using 52North open source software to serve data that conform to SOS standards. For this action plan, we anticipate working with MARACOOS to add data to the Chesapeake Bay product, while USGS maintains a separate server for data from the Susquehanna SUNA sensor (https://waterdata.usgs.gov/md/nwis/wys_rpt/?site_no=01579550&agency_cd=USGS).

3. Metadata:

The DNR continuous monitoring program has a long history of creating detailed FGDC compliant annual metadata records that are data deliverables to the EPA Chesapeake Bay Program. The first step of metadata is reported by field biologists who service the instrumentation. Routine events are recorded (deployment dates and details), and any abnormal events or conditions are reported via an internal webpage and stored in a database for inclusion in metadata. Data records are quality assured both by field biologists and data analysts, and assigned error codes or comments if they deviate from the norm. These details are recorded in the data and also cataloged within metadata.

Metadata records consist of the following informational categories: identification, data quality, spatial data organization, spatial reference, entity and attributes, distribution, and metadata reference. The records are comprised of contact information, project justification, site coordinates, sampling event details, equipment, field procedures, analytical processes, data scheme, completeness, quality assurance methods, and confidence, as well as access protocols.
More than 50 metadata records for various DNR monitoring projects and years are available at http://eyesonthebay.dnr.maryland.gov/eyesonthebay/stories.cfm by searching the metadata publication type. The most recent continuous monitoring metadata for year 2016 is available at http://eyesonthebay.dnr.maryland.gov/eyesonthebay/documents/metadata/MdDNR2016CMonProj.html. Metadata are also submitted to the EPA Chesapeake Bay Program (https://www.chesapeakebay.net/what/downloads/cbp_water_quality_database_1984_present)

F. Analytics and Interpretation

Team members Harris and Testa will lead analytical efforts to include data visualization, statistical analysis, and numerical modeling. Continuous oxygen data will be used to estimate ecosystem primary production and respiration (e.g., Beck et al. 2015), which will be related to nutrient availability (including storm pulses) and chlorophyll-a, as well as used to constrain numerical models. Time-series analysis will be used to understand the periodicity of nutrient time-series that will help discern tidal effects from other external forces. Ongoing efforts to develop nutrient budgets for the Upper Chesapeake Bay via a DNR-UMCES collaboration led by Testa will assimilate these new nutrient time-series to examine how short-term variations in

Beck, M. et al. 2015. Improving estimates of ecosystem metabolism by reducing effects of tidal advection on dissolved oxygen time series. L&O: Methods. 13(12):731-745 nutrients relate to longer-term patters and how large, short-lived storms may impact nutrient budgets. Finally, Testa is currently running a suite of simulations with a coupled hydrodynamic-biogeochemical model (ROMS-RCA) for the entire Chesapeake Bay (e.g., Testa et al. 2014) to examine changes in Susquehanna nutrient inputs on the estuary, will use the new NO3 and PO4 time-series to validate these simulations. The nutrient time-series will also be made available to CBP modelers to aid in validation of their TMDL simulations.

G. Communication and Use:

The new nutrient sensors will be deployed downstream of the Conowingo Dam to measure and track nutrient reduction strategies. This new technology will supplement and complement long-term water quality monitoring efforts above and below the Dam conducted by Maryland DNR and the USGS. New sensor data results will be analyzed and presented to various CBP management committees and workgroups to inform managers on the effectiveness of nutrient reduction strategies. The CBP partnership has an extensive committee structure used to build consensus, develop monitoring and modeling strategies, target restoration activities and track restoration progress (see http://www.chesapeakebay.net/who/how_we_are_organized). The nutrient sensors will provide more temporally and spatially intensive results, with better resolution to assess the impacts of high flow events that have a larger impact on Bay water quality due to potential scouring from behind the Dam. In particular, we anticipate presenting results to the Chesapeake Bay Integrated Trends and Analysis Team (co-chaired by Testa, Harris a member), which is facilitating analysis of long-term nutrient trends in Chesapeake Bay to support the 2017 TMDL midpoint assessment. This collaborative team includes academics, state and federal analysts, and local management agency officials. We will also present these new data to the Water Quality Goal Implementation Team (GIT), where monitoring results are presented to local and state governments throughout the watershed, environmental groups and interested stakeholders to demonstrate progress on restoration activities. This is extremely important as local governments are required to spend hundreds of millions of dollars on protecting and restoring the Bay - potentially more to address Conowingo - and they want to see progress.

In addition to formal channels offered through the Chesapeake Bay Program, MD DNR maintains a robust network of communications and social media outlets that reach a large audience ideal for highlighting the Nutrient Sensor Action Challenge. It is estimated that more than a third of Maryland state residents are exposed to DNR's communications products, as well as residents throughout the District of Columbia and six state Chesapeake Bay watershed. DNR has more than 250,000 social media followers for its flagship accounts, and more than 11,000 for its specialized Eyes on the Bay water quality specific accounts. There is a DNR mobile application with over 60,000 downloads, a monthly newsletter that reaches over 340,000, and a monthly YouTube video newsletter. There are over 4 million annual visitors to http://dnr.maryland.gov and over 40,000 annual visitors to www.eyesonthebay.net specifically for access to water quality data and information. Press releases are shared via the DNR virtual newsroom (http://news.maryland.gov/dnr/) and are disseminated to numerous news agencies, magazines, websites, and the public. DNR will use its extensive communication resources to highlight the mission of the grant as well as the findings that result from its monitoring and research.

Testa JM et al. 2014. Quantifying effects of nutrient loading on dissolved O2 cycling and hypoxia in Ches Bay using a coupled hydrodynamic-biogeochemical model. J Mar Sys 139: 139-158.