A. The Nutrient Issue

The coastal waters of Louisiana continue to undergo long-term change as coastal lands disappear and deep waters on the continental shelf are impacted by excess nutrient runoff on an annual basis. A multi-billion dollar Coastal Master Plan for Louisiana (CPRA 2017) is attempting to stave off continued and future land loss by implementing a series of engineered restoration strategies, many of which involve marsh creation, shoreline protection, hydrologic restoration, and sediment diversions. Previous work at LUMCON's DeFelice Marine Center and in nearby areas of Terrebonne Bay has shown that annual above- and below-ground primary production of the dominant salt marsh vegetation, *Spartina alterniflora*, is higher in years and locations with higher growing season dissolved inorganic nitrogen concentrations (Hill and Roberts 2017). Our ability to assess the extent to which changes in the coastal wetland ecosystems will result in changing nutrient fluxes to the coastal seas and how changing hydrology and nutrient availability interact with wetland plant growth requires more time- and spatially-rich datasets on nutrients in those waters.

One of the other pressing issues in the northern Gulf of Mexico is the sustained presence of bottom-water hypoxia, or the "Dead Zone," annually each summer. The areal extent of the Dead Zone in summer 2017 was the highest it has been since measurements began in the 1980s (NOAA 2017), and there are significant questions related to the effects of Hurricane Harvey and either disruption or exacerbation of bottom-water hypoxia as we move into fall. Previous studies have shown that models for Dead Zone extent are improved by including nitrate data from continuous sensors in the Mississippi River basin (Pellerin et al. 2014). Deployment of such technology in the coastal waters that are connected to and influence nitrate flux to the continental shelf will allow scientists, modelers, and managers further test the use of this technology in predicting the dynamics of this important ecological and economic disturbance to the region.

B. Team

The team consists of researchers, technologists, and educators working in the south Louisiana region. Specifically, the team is comprised of:

Lead: Brian Roberts, Ph.D., Associate Director of Science and Associate Professor, Louisiana Universities Marine Consortium (LUMCON). Dr. Roberts is a biogeochemist and ecologist whose research investigates how ecosystems transform and retain nutrients and energy. Dr. Roberts oversees scientific activities of the resident faculty and their research teams at the DeFelice Marine Center in Cocodrie as well as the research and education activities of non-resident researchers and educators at LUMCON's facilities. He also serves on LUMCON's environmental monitoring committee that oversees the monitoring stations as well as and other measurement and monitoring activities.

Team Members: Beth Stauffer, Ph.D., Assistant Professor, Dept. of Biology, University of Louisiana at Lafayette. Dr. Stauffer is an expert in phytoplankton ecology and biological oceanography. Her research focuses on better understanding the factors controlling phytoplankton biomass and community structure in dynamic coastal environments and how changing communities affect marine and coastal food webs. Dr. Stauffer is also coordinating an

effort to purchase and deploy additional nutrient sensors in the Gulf of Mexico, a project which will be leveraged to purchase a second sensor for use with the LUMCON colleagues in this action plan.

Brian Miles, Ph.D., Senior Consultant, CGI Technologies and Solutions, Inc., Lafayette, Louisiana. Brian is trained as a software engineer and physical geographer. His research has focused on hydrology, energy policy, and land use and transportation modeling. His current work focuses on developing open source, standards-based data management systems for Internet of Things (IoT) solutions, including air quality and water monitoring.

Murt Conover, LUMCON Associate Director of Education and Outreach. Ms. Conover has been a marine educator at LUMCON since 2002 and now oversees all education and outreach programs and activities that take place at or utilize LUMCON facilities and staff. She will lead the coordination of education and outreach activities associated with the proposed plan.

Susan Testroet-Bergeron, Barataria-Terrebonne National Estuary Program (BTNEP). Ms Testroet-Bergeron serves as the director of the BTNEP. She worked in the wetlands community performing education and outreach for over 15 years prior to becoming director. She is a former classroom teacher, former BTNEP formal education coordinator and worked with the Louisiana Coastal Wetlands Planning, Protection, and Restoration's (CWPPRA) Public Outreach Committee. She and her BTNEP staff will help facilitate the management and outreach components of the proposed plan.

We have discussed with Systea, Inc. (Luca Sanfilippo and colleagues) the possibility of using the Wiz probe - the N and P winner in the Nutrient Sensor Challenge - for this effort. The current price for the NO_3 Wiz probe is 7,000 Euro (estimated $8,394 USD), not including any additional accessories. This cost is within the scope of the proposed action plan.

C. Current Monitoring

LUMCON currently operates two continuous environmental monitoring stations and has received funding to establish a third before the end of 2017 (Figure 1). The longest established station (since 2000) is located on the bayou adjacent to the main grounds of the DeFelice Marine Center in Cocodrie, LA and is surrounded by salt marsh ("LUMCON Weather Station"; 29.25502°N, -90.666357W). LUMCON also operates a second station located on a hardened platform in Terrebonne Bay ("Terrebone Bay Station";

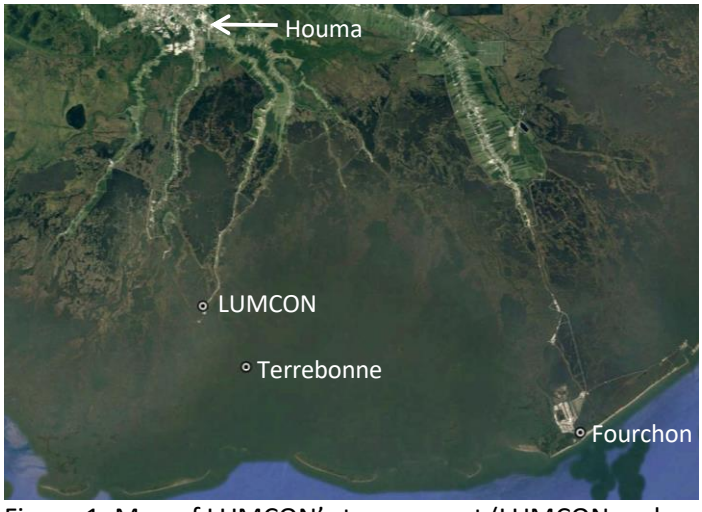

Figure 1: Map of LUMCON's two current (LUMCON and Terrebonne) and one planned (Fourchon) environmental monitoring stations.

29.1867°N, -90.608°W). A third station is being constructed at LUMCON's field camp located in Port Fourchon, LA ("Fourchon"; 29.1138°N, -90.1846°W). Currently, these stations measure: wind speed, air temperature, water temperature, water depth, salinity, and light intensity (as photosynthetically active radiation, PAR). All of the sensors are connected to a data logger (Campbell CR1000) through voltage channels for the meteorological sensors and a RS232 serial data connection for the hydrographic sensors. The data logger is connected via RS232 serial to a cellular modem that has a Verizon 4G LTE data plan and this is visible to the internet through Verizon's system. The LoggerNet Server at LUMCON dials into the cell modem's IP address and "polls" the CR1000 for data every 15 minutes. The LoggerNet Server at LUMCON adds this data to a .dat file which can be accessed by LUMCON personnel over LUMCON's network and updates the LoggerNet Realtime display, which is hosted on the server.

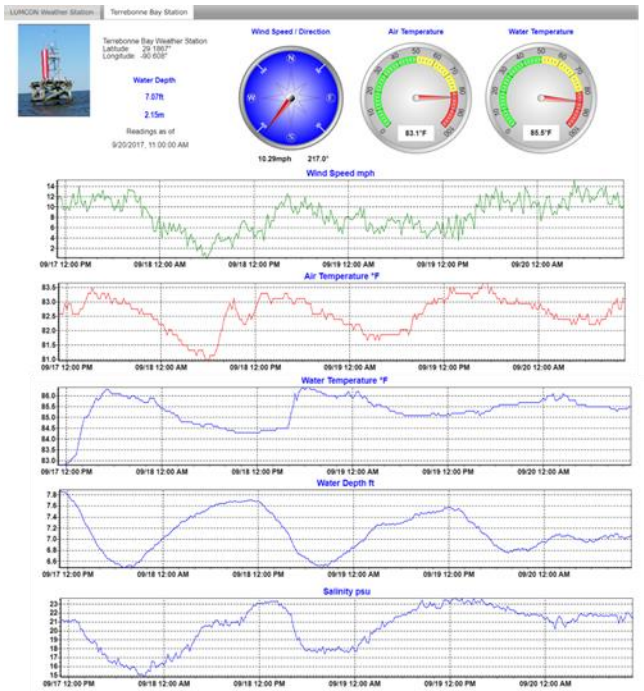

Figure 2: Data from the LUMCON Station as it is currently made available via the LUMCON environmental monitoring website, http://weatherstations.lumcon.edu/index.html

Data is made publicly available on the LUMCON website, http://weatherstations.lumcon.edu/index.html. An example screenshot of data output from the LUMCON monitoring station is depicted in Figure 2. The raw data, however, is not currently accessible to the public. Anyone interested in data is directed via the website to email monitoring@lumcon.edu to request data, and a staff member then sends them the requested dataset via email attachment. This unavailability of archived data following QA/QC is a significant challenge for the effective reuse of the data for a variety of users, and is a main component we seek to address with this action plan.

D. Sensors and monitoring

Nutrient sensors will be deployed as part of the existing monitoring stations that LUMCON operates and maintains. With two full-time staff maintaining these stations, LUMCON is well positioned to deploy and maintain the sensors, and to work with the broader team to incorporate them into new data telemetry and hosting systems (see below). At least two sensors will be deployed as part of this project. The second sensor will be leveraged as part of an EPA- and NOAA-funded Gulf of Mexico nutrient sensor pilot project which team member Stauffer is coordinating with partners across the region, including LUMCON.

E. Data

1. Solution Architecture:

The architecture of the proposed solution is depicted in Figure 3. Nutrient data from the sensor platform will be delivered to the Data Gateway via cellular or low-power radio telemetry. The gateway will be responsible for transmitting nutrient data to the cloud-based CGI Kinota™ data management applications programming interface (API). This API is responsible for storing the data into PostGIS, a version of the open source PostgreSQL database with advanced geospatial indexing and querying capabilities, for later retrieval. The API makes real-time data available via MQTT (Message Queue Telemetry Transport). The MQTT interface allows for real-time analytics, such as QA/QC procedures, to be automatically applied in real-time. QA/QC'd data are stored in the database as distinct data streams separate from the raw data. Once the raw or QA/QC'd data are stored, users or third-party applications can retrieve the data using the Kinota API. This API is also used to serve data via the web-based LUMCON sensor dashboard. All data transmitted to and from the Kinota-API are encrypted, and users are authenticated via JavaScript Web Tokens, ensuring that only authorized users may make changes to the data stored in the system.

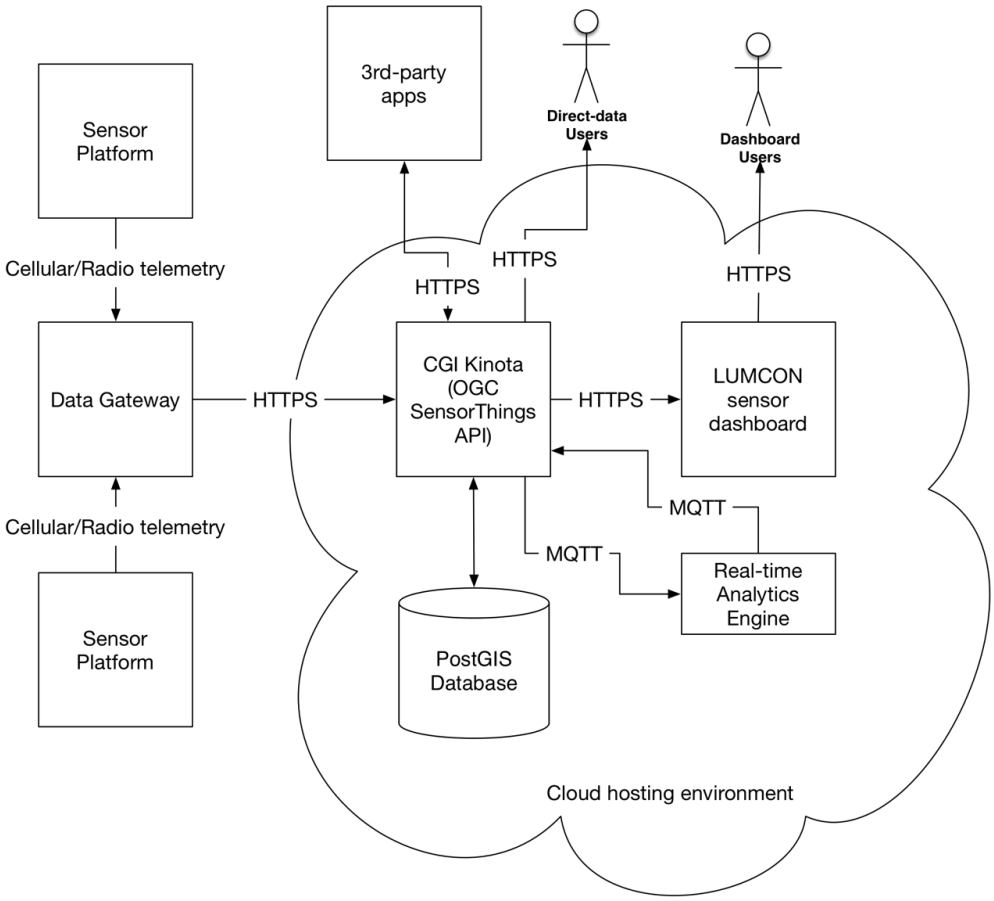

Figure 3. Architecture of proposed solution.

2. QA/QC:

Real-time QA/QC procedures (e.g. filtering outliers) will be performed in the QA/QC engine depicted in Figure 3. These procedures will allow for near-real-time hosting of data using the architecture described, as well as provision of archived data that have had at least preliminary QA/QC filtering via an automated web request. Longer-term QA/QC procedures will compare sensor-generated nutrient concentrations (primarily NO_3) with standard analytical methods run by Team Lead Roberts in his LUMCON biogeochemistry lab by collecting water samples water that will be filtered through 0.2µm Whatman Puradisc sterile, PES membrane filters and analyzed for NO_2^- and $NO_3^- + NO_2^-$ by azo dye colorimetry (without and with Cu-Cd reduction, respectively), using a Lachat Instruments QuikChem® FIA+ 8000 Series Automated Ion Analyzer with NO_3^- concentrations being determined by difference.

3. Data Sharing:

CGI Kinota (https://github.com/kinota/) is an open source implementation of the OGC SensorThings API Part 1: Sensing standard. The Open Geospatial Consortium (OGC) is the leading international standards body for geospatial data standards. The SensorThings API (STA; http://ogc-iot.github.io/ogc-iot-api/) is a recent standard for representing and transmitting data from Internet Of Things (IoT) devices. Part of the OGC Sensor Web Enablement (SWE) suite of standards (which includes Sensor Observation Service, Sensor Provisioning Service, etc.), STA provides a robust, domain-agnostic data model for representing IoT data, as well as a convenient, human-readible JSON-based data serialization format, and powerful data querying capabilities. STA was designed to be user-friendly for developers to learn and adopt, and to make it easy for data to be shared among users and third-party applications.

4. Metadata:

Metadata for sensor data will be stored in the Kinota-based SensorThings API; NOAA/IOOS metadata standards will be adapted for use within the SensorThings data model, which is similar to the Sensor Observation Service (SOS) data model upon which NOAA/IOOS metadata standards have been implemented.

F. Analytics and Interpretation

Kinota's real-time data analytics capabilities will be used to perform automated QA/QC on raw sensor data. Other real-time analyses (e.g. production or derived products such as temporal aggregation and computation of summary statistics) are possible using the same analytics framework. Raw, QA/QC'd, or other derived datasets are stored by Kinota and made available for other analyses via the SensorThings API. The simple JSON format of the SensorThings API make it easy to integrate with analysis tools such as R, Python, MATLAB, etc. Further, the SensorThings API provides robust querying capabilities, which makes advanced analyses easier in such tools. These relatively simple queries can interrogate data that are spatially distant or return data from within certain date ranges and parameters. For example, queries can be created that return datasets whose last known locations are at a certain distance from a set point.

Additionally, queries can be that return data that have observations of a feature of interest and from a certain time period. These advanced querying capabilities can also be used by visualization tools such as the LUMCON sensor dashboard.

G. Communication and Use

We envision several uses of the data to support research, management, and outreach. Additional uses for the nutrient data are likely to emerge, especially as they become integrated with the LUMCON data which has many users. Anticipated uses are described below:

- Research: LUMCON environmental data has a rich history of supporting scientific research, student training, and environmental management since LUMCON began collecting and making data available in 2000. This has included data being incorporated into 28 peer-reviewed journal articles or book chapters, 7 reports or other publications (including multiple reports by the National Hurricane Center documenting the impacts of tropical events), 8 Masters theses, and 6 PhD dissertations. The addition of continuous nutrient data to this longterm data environmental data record is likely to increase the utilization of data generated by the environmental monitoring program for scientific research and water quality monitoring efforts. Scientists studying nutrient loading, wetland dynamics and restoration, wetland and estuarine nutrient cycling, and phytoplankton bloom dynamics will have time-dense nutrient data available from two unique but complimentary locations in the Terrebonne Bay region (one near the marsh edge and one reflecting conditions within the Bay itself). These data will provide more accurate and better resolved nutrient dynamics, thus allowing scientists to better understand how nutrient delivery to coastal waters is influencing many important processes.
    - The Roberts lab has already published several papers including two in 2017 that have utilized the data provided by the current monitoring stations. In one of these studies, Hill and Roberts (2017) demonstrated that variations in annual above-and below-ground production of *Spartina alterniflora* is strongly influenced by growing season salinity and nutrient (primarily nitrate) availability at a given marsh location. However, one of the limitations of this original 3 year study is that the nutrient characterization was based on limited discrete sampling events of nutrient concentrations. We are now completing year 5 of this ongoing project and it would greatly benefit from continuous measurements of nutrients to better constrain our models for salt marsh plant productivity.
    - Students in Dr. Stauffer's lab, for example, will be conducting experiments over the next year assessing the effects of changing phytoplankton communities in Terrebone Bay on oyster feeding rates and top-down control. These data would directly benefit these studies on commercially- and ecologically-important estuarine organisms.

- Management: Researchers, modelers, and managers will all benefit from greater availability of robust nutrient data, particularly nitrate since elevated concentrations cause significant problems with water quality and eutrophication both in coastal and estuarine regions and in the near shore shelf waters. For example, scientists and managers working to improve

predictions of the Gulf of Mexico dead zone use nitrate loads coming out of the Mississippi River to inform models on hypoxia (low oxygen availability) development, extent, and maintenance. Continuous nitrogen data will assist managers in understanding the temporal aspects of nutrient delivery that have not previously been investigated.

- Studies have shown that using more time-dense nutrient concentration data can help improve models of nitrogen delivery via the Mississippi River (e.g. Pellerin et al. 2014). Continuous data in the nearshore and coastal waters of Louisiana would directly benefit these efforts to better constrain timescales and mechanics of nutrient loading and its effects.
- A major component of the proposed action plan involves a coordination of efforts between these enhanced monitoring stations with nutrient sensors and the Barataria-Terrebonne National Estuary Program (BTNEP). BTNEP works to protect and preserve the culture and land located between the Mississippi and Atchafalaya Rivers in Southeast Louisiana. It is one of 28 National Estuary Programs throughout the United States and its territories. Congress established the National Estuary Program (NEP) through section 320 of the Clean Water Act in 1987. The Barataria-Terrebonne estuarine complex became a National Estuary in 1990. BTNEP was established in recognition of the national significance of this estuary system. BTNEP is about to release its updated Comprehensive Conservation and Management Plan which targets eutrophication as a priority problem within the Barataria-Terrebonne National Estuary. They have developed several action plans to address this problem that would greatly benefit from the addition of nutrient sensors at two (and hopefully 3 in the longer term) environmental monitoring stations within the Barataria and Terrebonne estuaries.

- Outreach & Education: LUMCON plays a unique role in fulfilling its mission "to increase society's awareness of the environmental, economic and cultural value of Louisiana's coastal and marine environments by conducting research and education programs." LUMCON has a well-established and very successful student based water quality monitoring program called Bayouside Classroom (https://bayousideclassroom.lumcon.edu/). For over 20 years, LUMCON has built strong connections with many local, state, and national partners bringing water quality monitoring to the forefront of science education in the classroom. By collecting and using data students within the Mississppi River Basin have been asking and answering a diversity of scientific questions about water quality issues. LUMCON's principal partner in the Bayouside Classroom effort has been the Barataria- Terrebonne National Estuary Program. This partnership has resulted in 237 teachers being trained to use Bayouside Classroom which allows over 10,000 students per year to be engaged in water quality monitoring in their science classes. Using Bayouside Classroom, which includes an existing database, with over 100,000 data points, these data will be incorporated into efforts on water quality and nutrient issues for middle to high school classrooms. Beyond the Bayouside Classroom program, LUMCON offers a number of outreach opportunities, including summer courses for K-12 and university students, teacher training workshops, and community events. This means that the boarder impact of this proposed project will also extend to undergraduate

students and research interns and graduate students participating in field-based summer classes and research projects at LUMCON. Through incorporation of these data into the various education and outreach activities, the outputs of this effort will extend to a broad audience interested in the effects of nutrients on coastal life and environments.

Literature Cited

Coastal Protection and Restoration Authority (2017) Louisiana's Comprehensive Master Plan for a Sustainable Coast.

Hill TD, Roberts BJ. (2017) Effects of seasonality and environmental gradients on Spartina alterniflora allometry and primary production. Ecology and Evolution. In press.

NOAA (2017) "Gulf of Mexico 'dead zone' is the largest ever measured." Press Release, 2 August 2017, www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

Pellerin, BA, BA Bergamaschi, RJ Gilliom, CG Crawford, J Saraceno, CP Frederick, BD Downing, JC Murphy (2014) Mississippi River nitrate loads from high frequency sensor measurements and regression-based load estimation. Environ Sci Technol. 48(21):12612-12619