DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

Spatially resolved measurements of water quality indicators within in a bioenergy landscape

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Data, Modeling, & Analysis Platform

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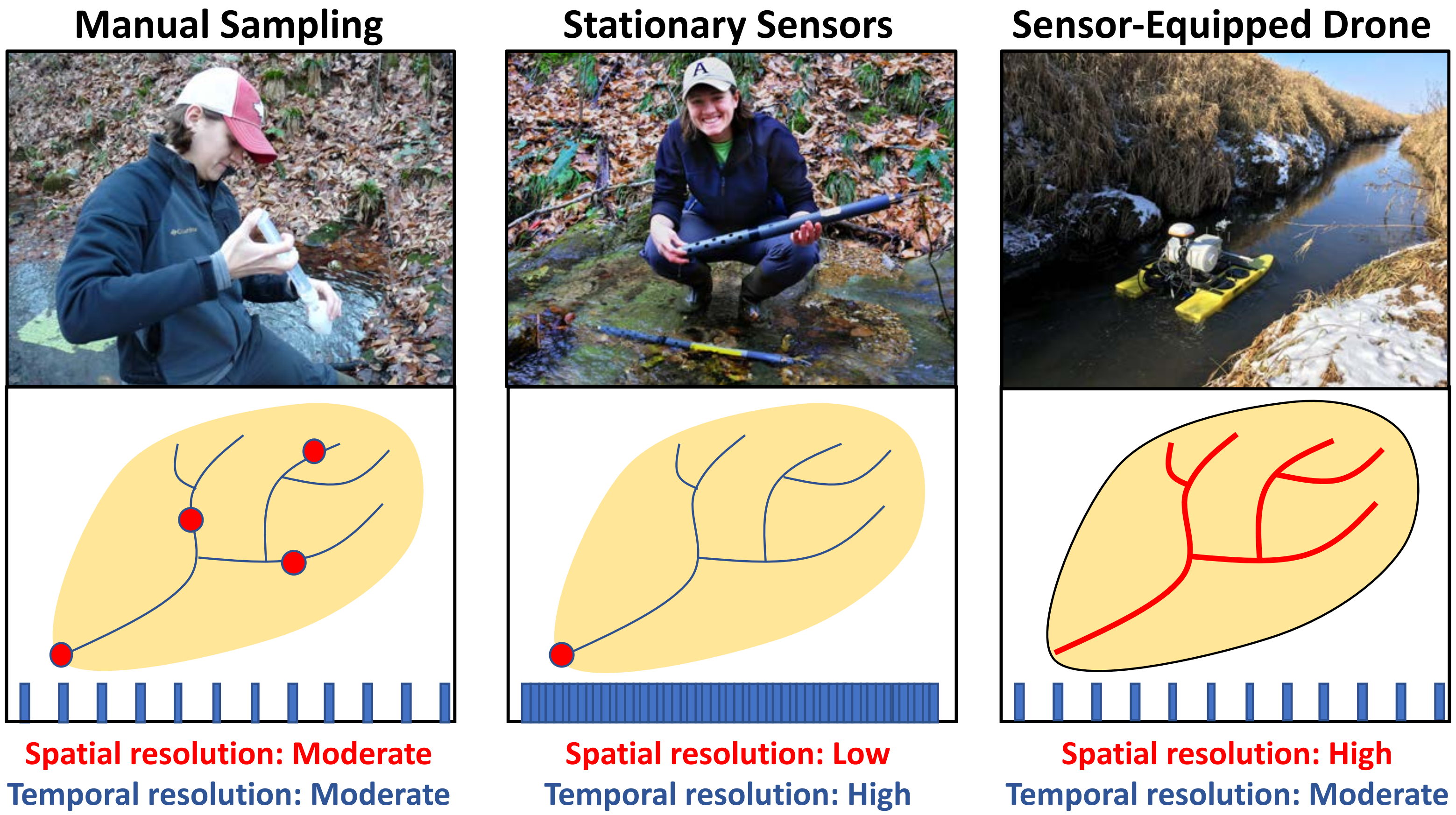
Project Overview

- Evaluating the environmental effects of bioenergy production using robust tools and comprehensive methods is an important goal of BETO.
- Collection of environmental data can be **time and labor intensive** and **limited in spatial and temporal resolution**.
- Sensors have facilitated collection of environmental data but are often deployed in fixed locations.
- **Coupling sensors with drones** can advance understanding of environmental indicators and how these parameters vary spatially.



Project Overview

Enhance understanding of water quality indicators for bioenergy through the development and testing of a novel unmanned surface vehicle (USV)-water quality sensor platform.

Why water quality?

- Impaired water quality negatively affects human health, aquatic biodiversity, recreation.
- **Potential improvement** with bioenergy feedstock production especially in agriculturally dominant areas with degraded water quality.

Why a USV-sensor system?

- Water quality **highly spatially variable** in small streams.
- Longitudinal profilers **limited** to large water bodies and **rarely measure** agriculturally relevant pollutants (i.e., nitrate concentration).
- Can identify point-source inputs & changes with land use/management, evaluate spatial extent of inputs, identify where mitigation may be beneficial.
- Potential to be a **low-cost, efficient, and accurate** method for water quality evaluation.

Project Overview

Goals:

1. **Advance understanding of water quality indicators** for bioenergy through the development and testing of a novel drone-water quality sensor platform (‘**AquaBOT**’); focus on spatial mapping of relevant water quality parameters (nitrate) in small streams.
2. Quantify **spatial variability in water quality** in streams draining an agricultural-bioenergy landscape.

Project history (began FY19):

- FY19: AquaBOT development and testing at ORNL.
- FY20-21: Field deployment in streams in Iowa; data analysis and dissemination.

Multiple risks identified and mitigation strategies developed:

- AquaBOT system will be too costly and will collect data in a less-efficient manner.
- Site accessibility will limit mapping across a watershed.
- COVID-19 will limit ability to carryout fieldwork.

1 – Management

- Team has expertise in water quality, unmanned vehicles, geospatial analysis, and sensor systems.
- Fieldwork in collaboration with Drake University. Labwork and data analysis led by ORNL.
- Linkages with BETO's Antares Landscape Design project (sites, saturated buffers).
- Frequent project meetings to discuss progress (weekly to monthly).
- Quarterly reporting and update calls with BETO technology manager. Quarterly and annual milestones to monitor progress.
- Identify risks annually and develop mitigation plans. COVID-19 impeded fieldwork progress; shifted resources for additional local technical support.

2 – Approach

Tasks:

1. **Design the AquaBOT** using state-of-the-art and commercial, off-the-shelf technologies. Test operation and measurement accuracy in the laboratory and field.
2. Evaluate the **cost, efficiency, and knowledge gained** from using the AquaBOT compared to traditional water quality measurement approaches.
3. **Examine spatiotemporal variation** in water quality in streams and rivers in an agricultural-bioenergy landscape using the AquaBOT, including evaluating the efficacy of saturated buffers at reducing nutrient inputs to streams.
4. **Disseminate findings** to relevant audiences through presentations and publications.

Challenges:

– Designing a system small enough to access small streams but large enough to carry the sensor payload.

– Carrying out robust testing and data collection under varying environmental conditions (e.g., drought) and during the COVID-19 pandemic.

2 – Approach

Go/No-Go (achieved in FY20):

- The USV-sensor platform must **advance understanding** of spatial variation in water quality **by measuring water quality at a higher spatial resolution, more efficiently, and at a lower cost** than achievable through traditional water quality sampling methods.

Metrics to identify progress:

- Quantify measurement accuracy and operational capacity of the AquaBOT via comprehensive field and laboratory testing.
- Analyze the cost and measurement efficiency of the AquaBOT versus traditional sampling approaches through field tests and data analysis.
- Disseminate findings to relevant audiences in a timely manner (via peer-review publications, presentations, BioenergyKDF).

Relevance to BETO goals:

- Developing and testing a **state-of-the-art drone-sensor system** to **improve quantification** of environmental effects of bioenergy feedstock production supports BETO's strategic goals.

3 – Impact

Impact on State of Technology:

- **Adoption** of this technology by **monitoring** and **research communities**.
- Use AquaBOT to collect high spatial resolution water quality data in a less time- and labor-intensive manner than traditional techniques and help **identify where bioenergy plantings, conservation practices,** or other management strategies could be **implemented to improve water quality**.
- **Application** of the AquaBOT is **wide-ranging** and may also be used for water quality monitoring at the federal, state, and local level, water quality monitoring at wastewater treatment plants, and for high spatial resolution data collection by the scientific research community.

3 – Impact

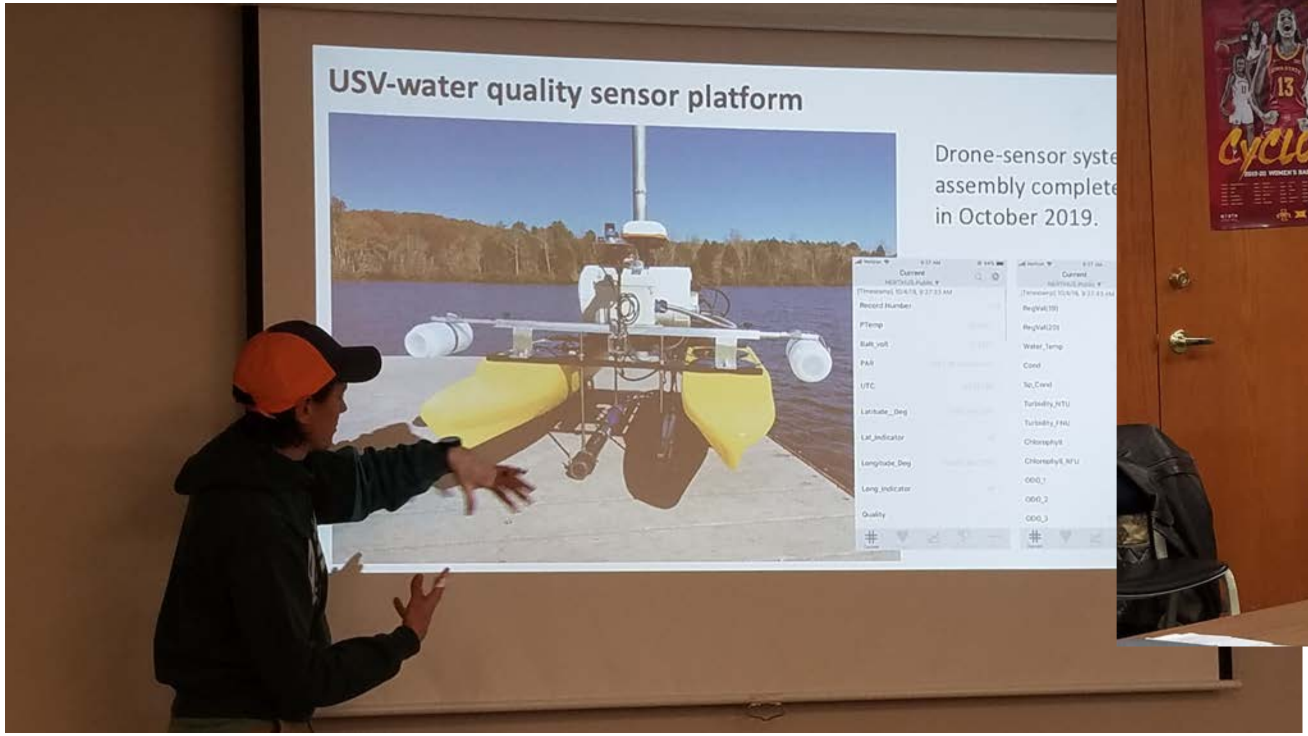
Impact on State of Technology:

- **Discover new water quality patterns and responses** that would not have been found using traditional sampling techniques.
- Improve understanding on the **efficacy** of **saturated buffers** as a land management practice for improving water quality.
- The AquaBOT approach will be **increasingly relevant** as **advances in sensor and drone technologies continue**.

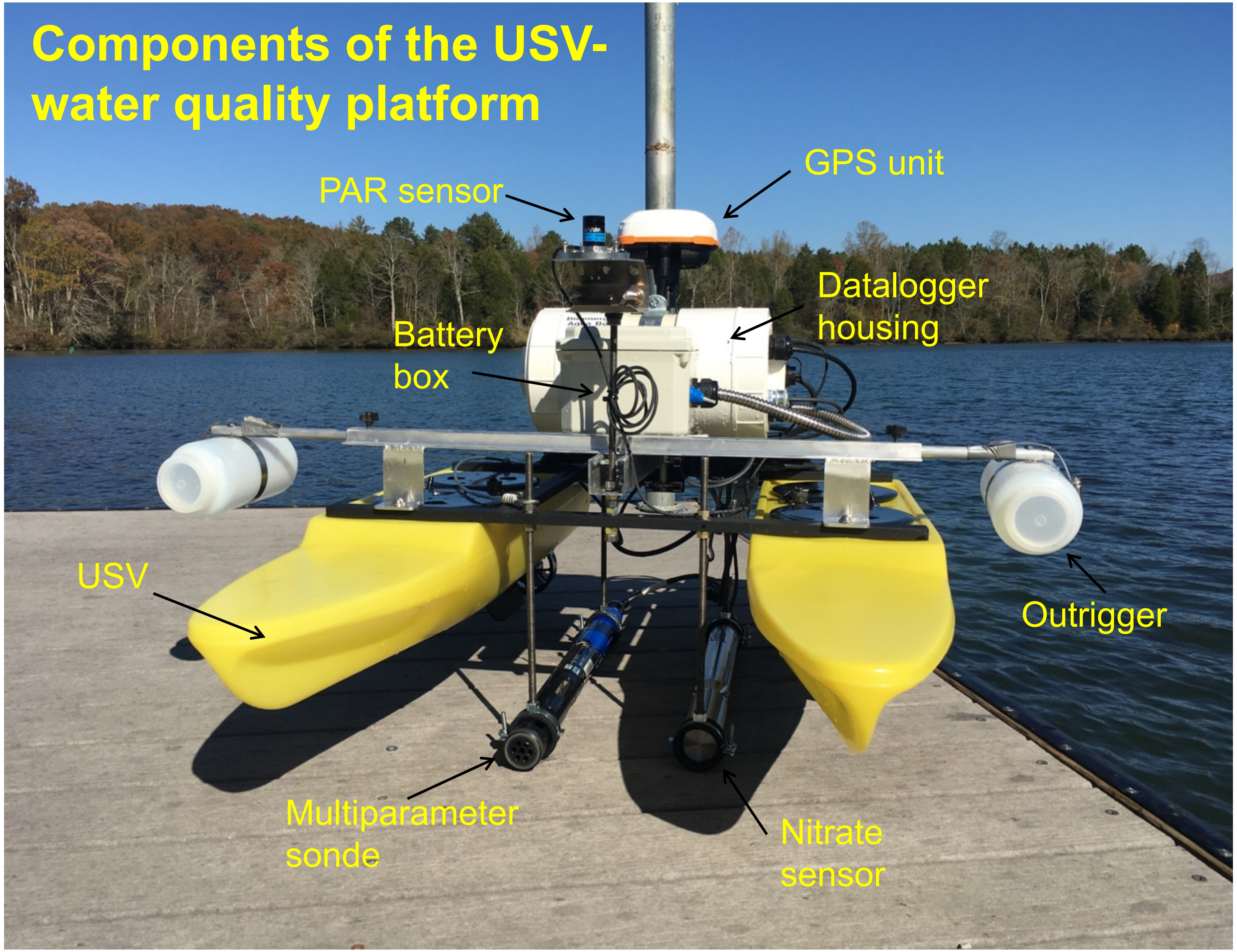
3 – Impact

Dissemination of Results:

- Presented to Southfork Watershed Alliance, multiple scientific societies.
- Drafted manuscript describing the design of the AquaBOT and results from test runs.
- Future manuscript submissions will target environmental monitoring and bioenergy journals.
- Share data via BioenergyKDF.



4 – Progress and Outcomes



AquaBOT design & assembly:

- Designed using commercially available, off-the-shelf products.
- Optimized to operate in small streams (116 cm length, 73 cm width, 58 lbs with full payload).
- Key challenge to overcome was the integration of sensors into one datalogging program; needed to facilitate data retrieval and analysis.
- AquaBOT assembly completed in October 2019 (delayed due to sensor delivery delays).

4 – Progress and Outcomes

AquaBOT testing:

- Payload, maneuverability, and communication testing at ORNL and in the Clinch River.



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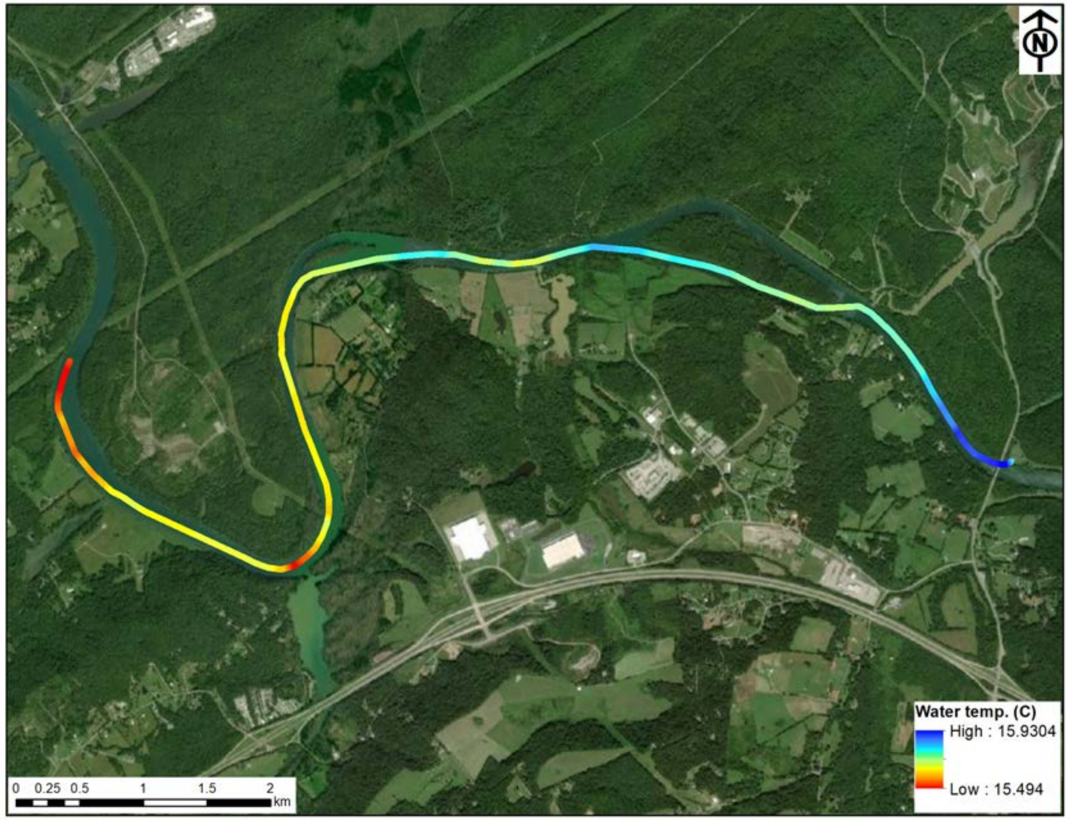
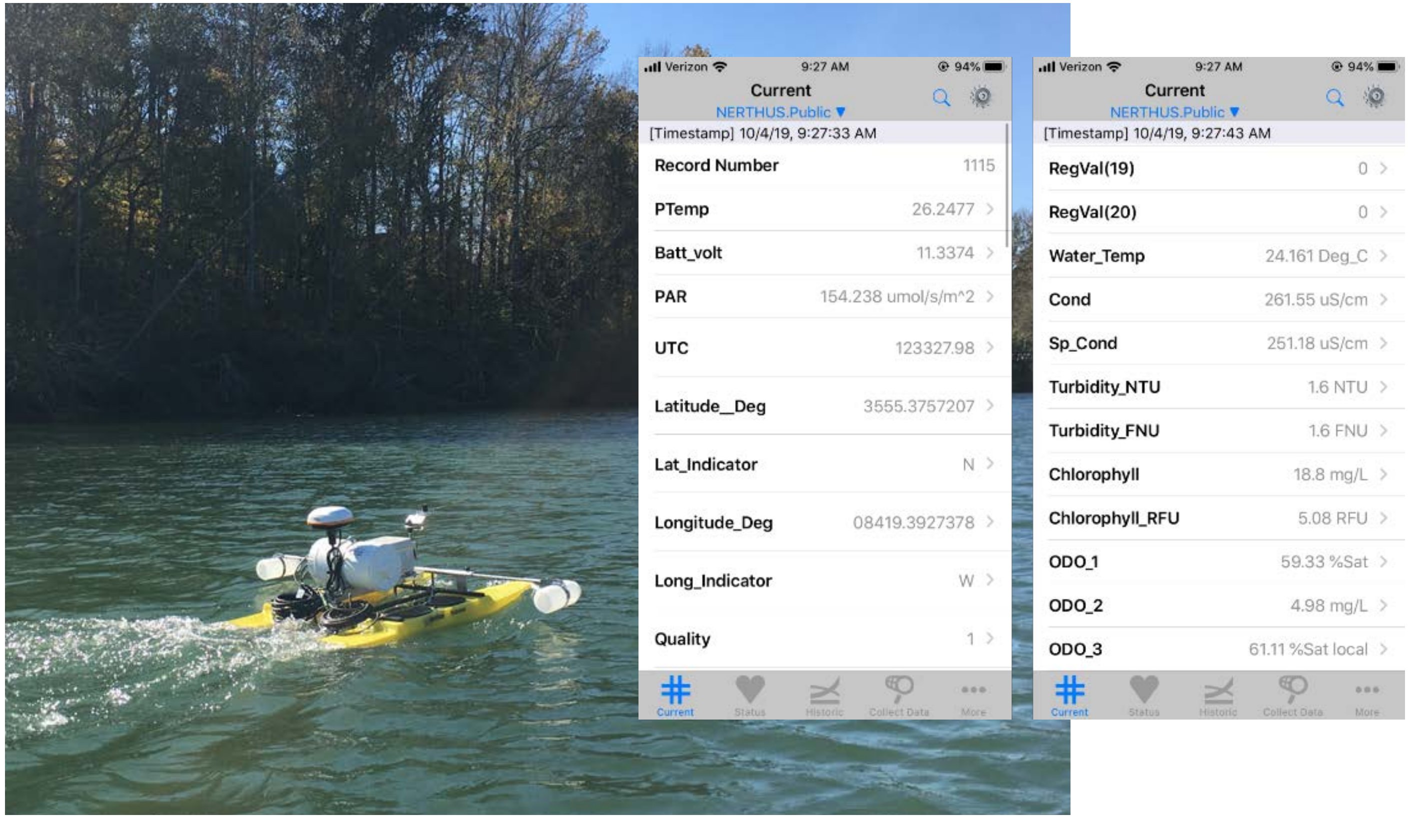


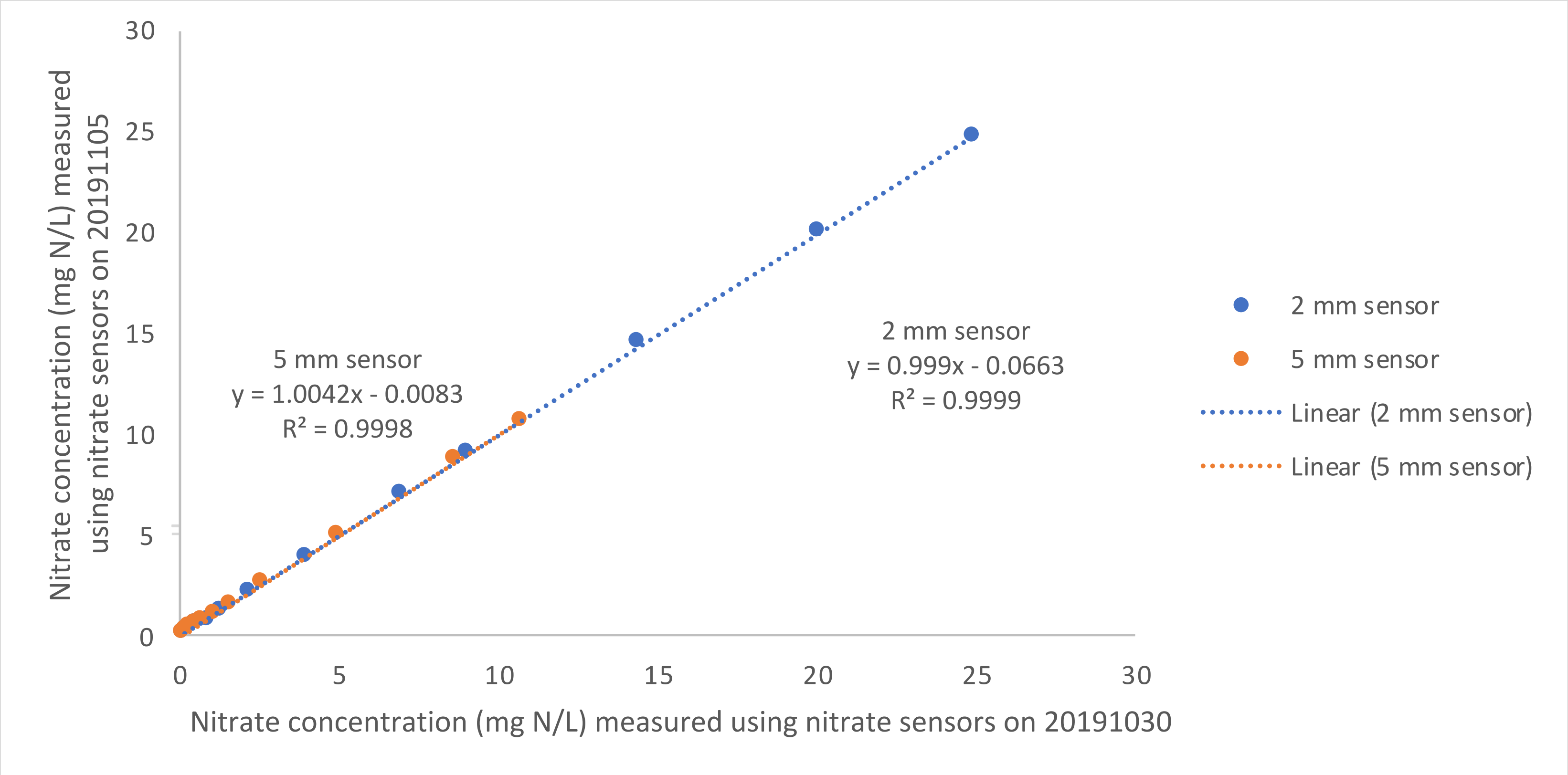


- 8.1 km reach measured in 2 h 23 min (121 measurements).
- Data logged every minute; datalogger with WiFi to allow data to be observed in real time.

4 – Progress and Outcomes

AquaBOT testing:

- Tested accuracy and precision of nitrate sensors in the the laboratory.
  - 2 mm nitrate sensor measurement range: 0.25 to 30 mg N/L
  - 5 mm nitrate sensor measurement range: 0.1 to 12 mg N/L
- Nitrate sensors accurately measured nitrate concentrations, provided repeatable results, and measured concentrations across the ranges reported by the manufacturer.



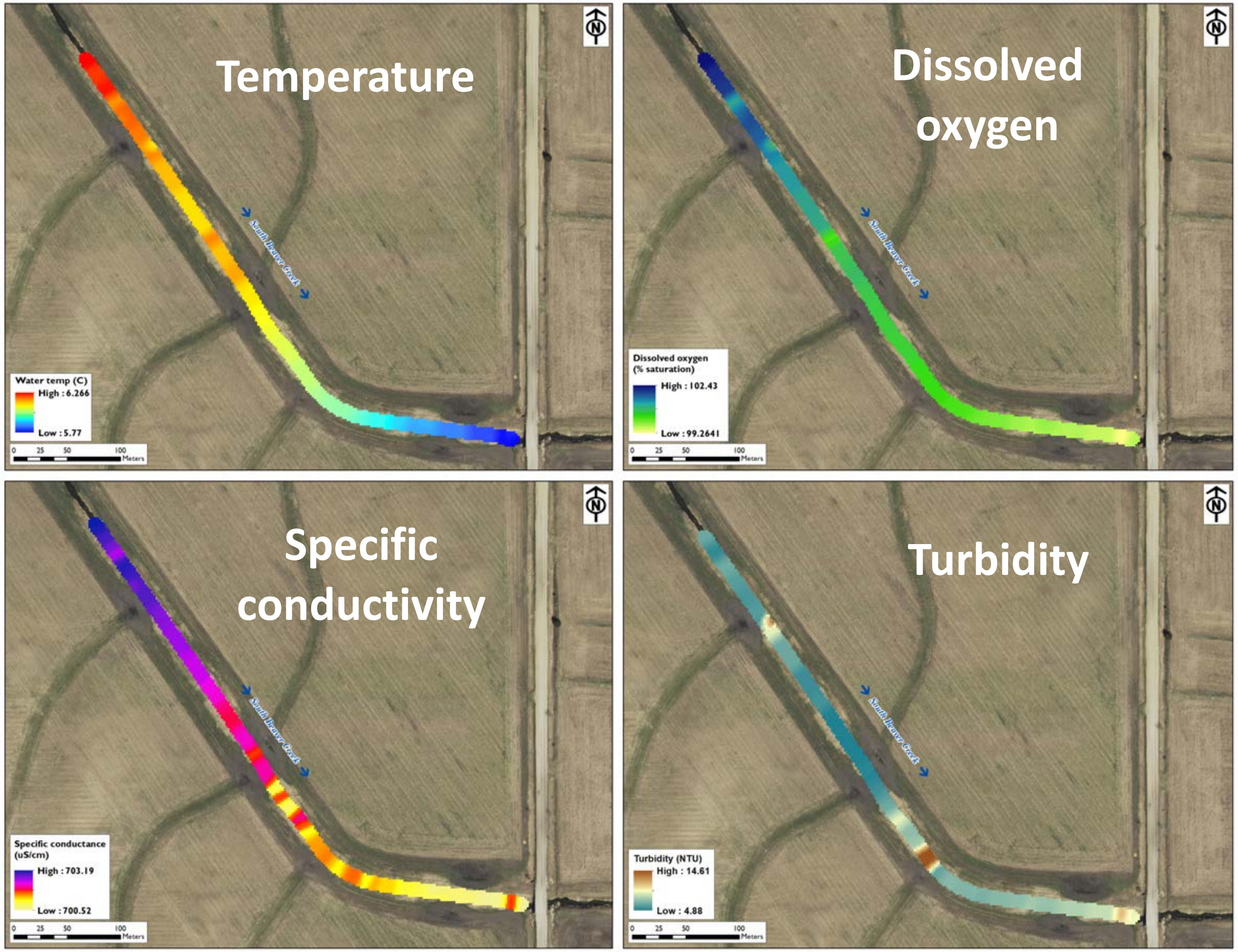
- Testing revealed the need to modify our analytical methods for measuring high nitrate concentrations on the spectrophotometer in the laboratory.

Image from ott.com

4 – Progress and Outcomes

AquaBOT testing:

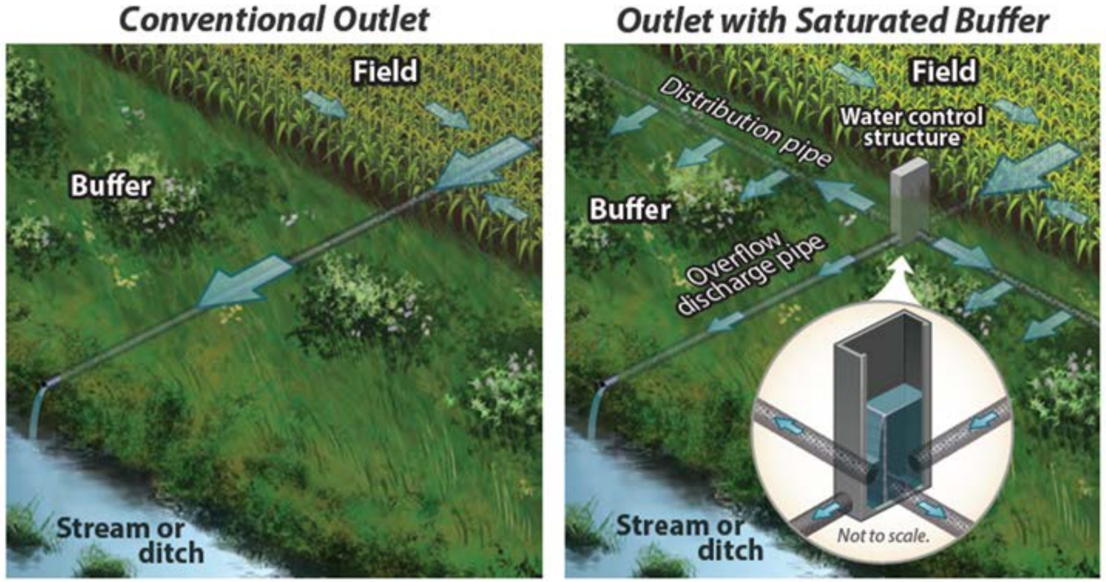
- Water quality measurements in three small, agriculturally influenced streams in Iowa.
- All measured water quality parameters varied along the stream/river lengths.
- Some longitudinal patterns reflected temporal changes (e.g., warmer temperatures with increased solar irradiance).
- Temporal variation imprinting on spatial patterns of water quality is a challenge for all longitudinal measurement approaches to address.



4 – Progress and Outcomes

Evaluation of spatiotemporal variation in water quality:

- Primary field site – 2.1 km reach of Alleman Creek, Iowa
  - 94% agricultural land use
  - 26 tile drain inputs
- Site of multiple saturated buffer installations (planned for spring/summer 2021).
  - **Potential win-win for bioenergy:** feedstock production and reduced nutrient export.



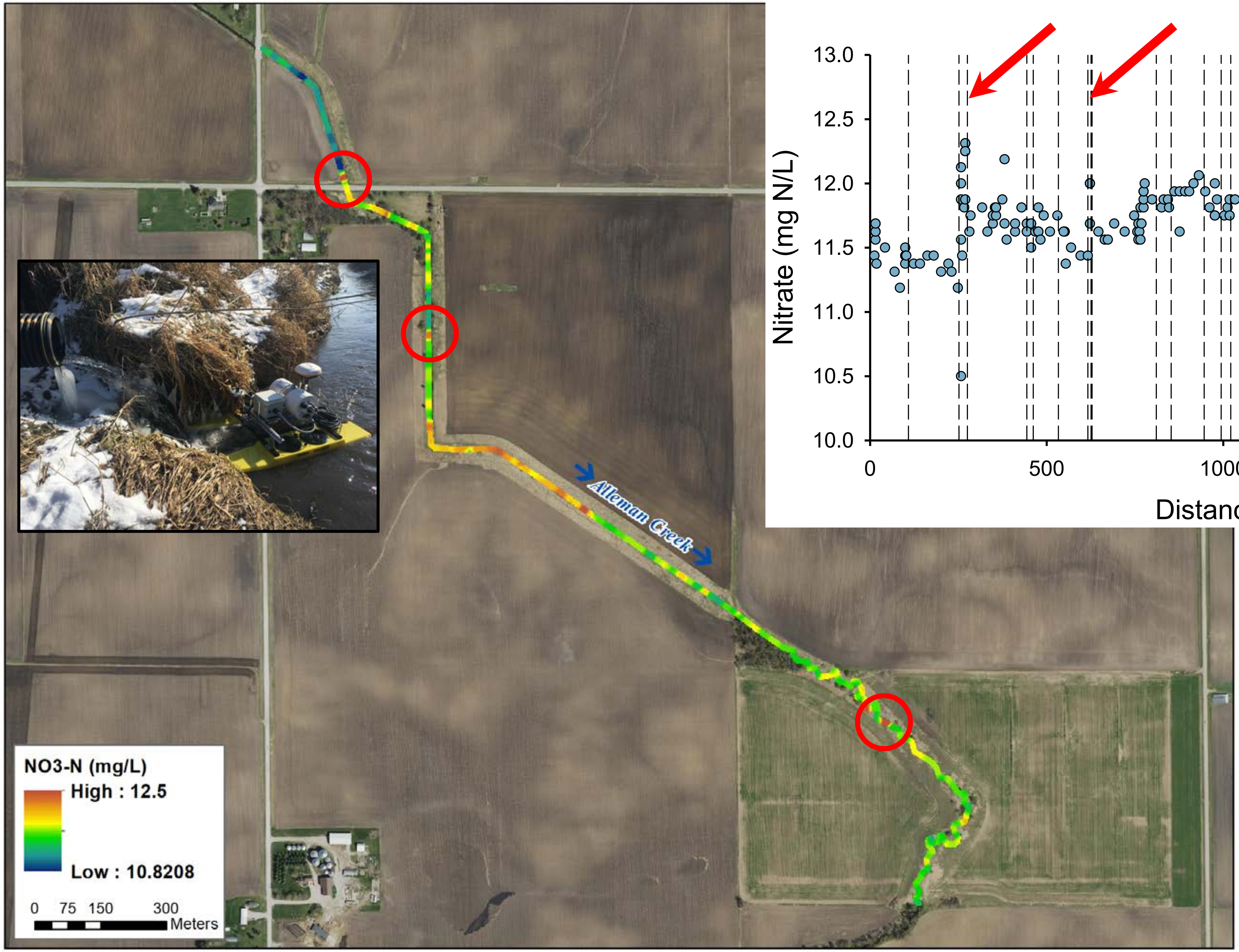
Tile/buffer image from: https://www.ars.usda.gov/midwest-area/ames/nlae/news/what-are-saturated-buffers/

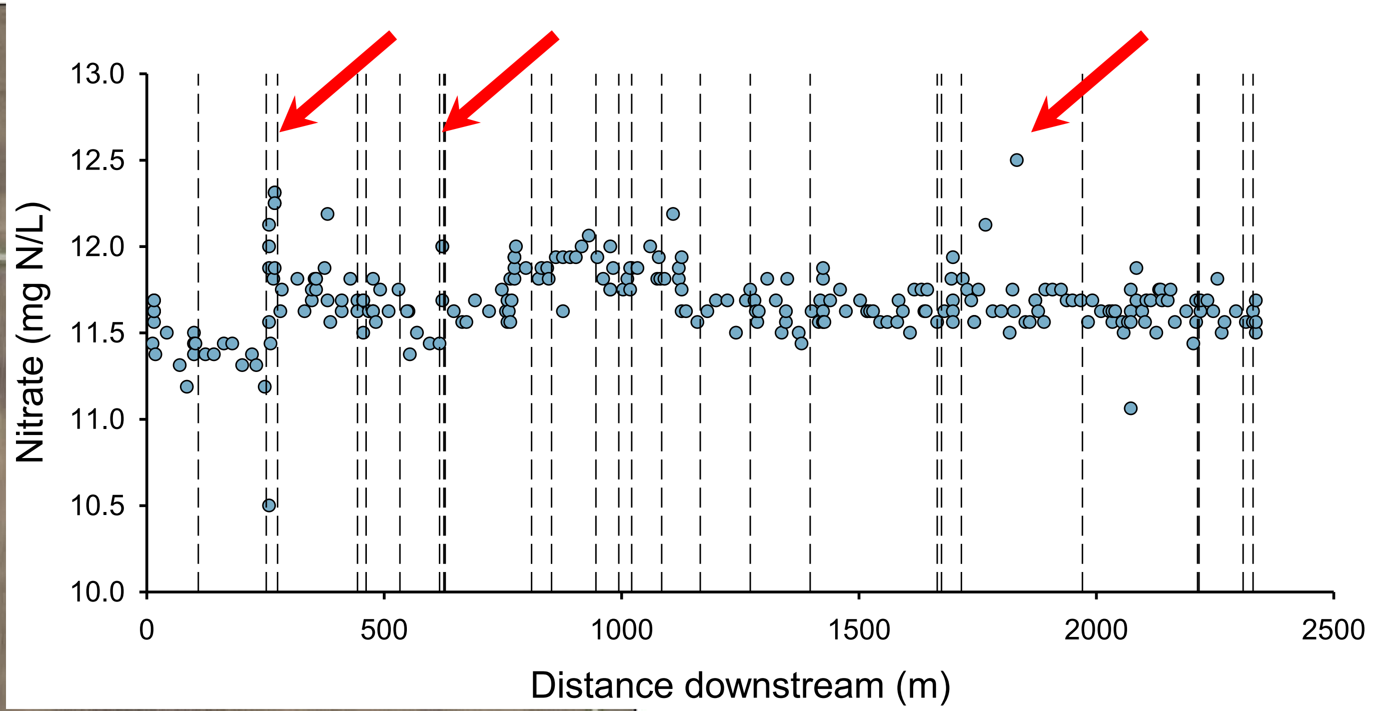
4 – Progress and Outcomes

Evaluation of spatiotemporal variation in water quality:

- Three AquaBOT runs of Alleman Creek in June 2020.
  - Deployments delayed to June due to COVID-19.
  - In July, stream level decreased below AquaBOT operation (< 1 ft) and dried up in places; fieldwork shifted to grab sampling.

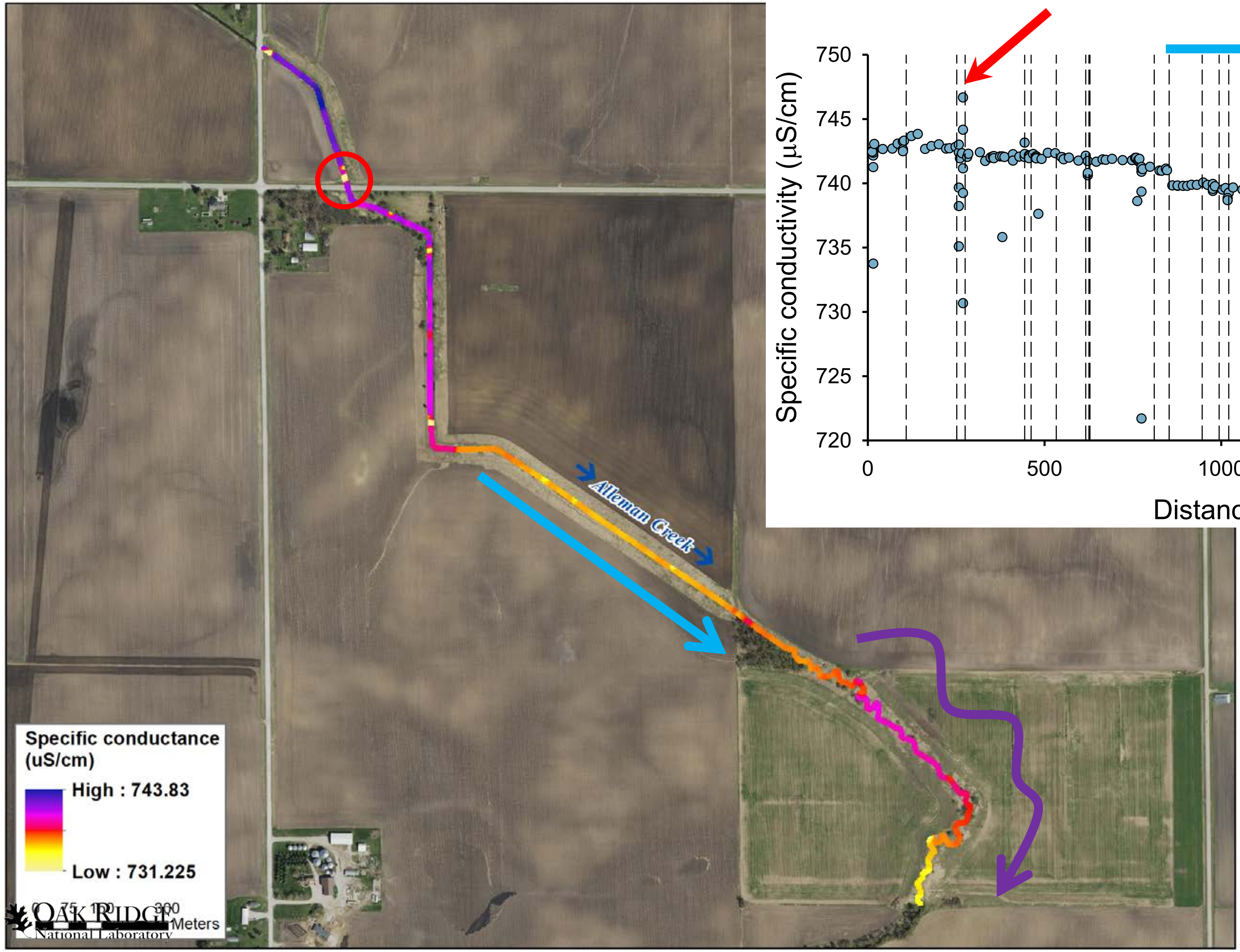
4 – Progress and Outcomes

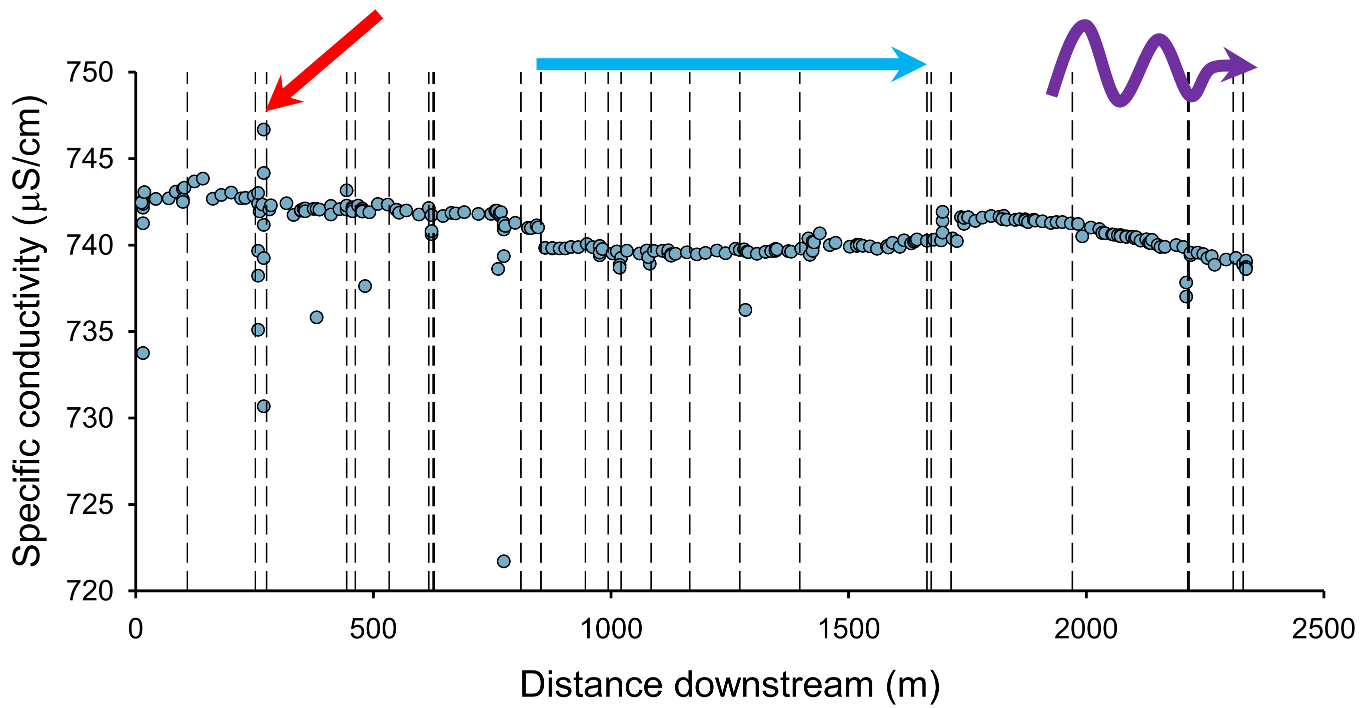




- Hotspots of nitrate downstream of tile drains in some but not all instances.

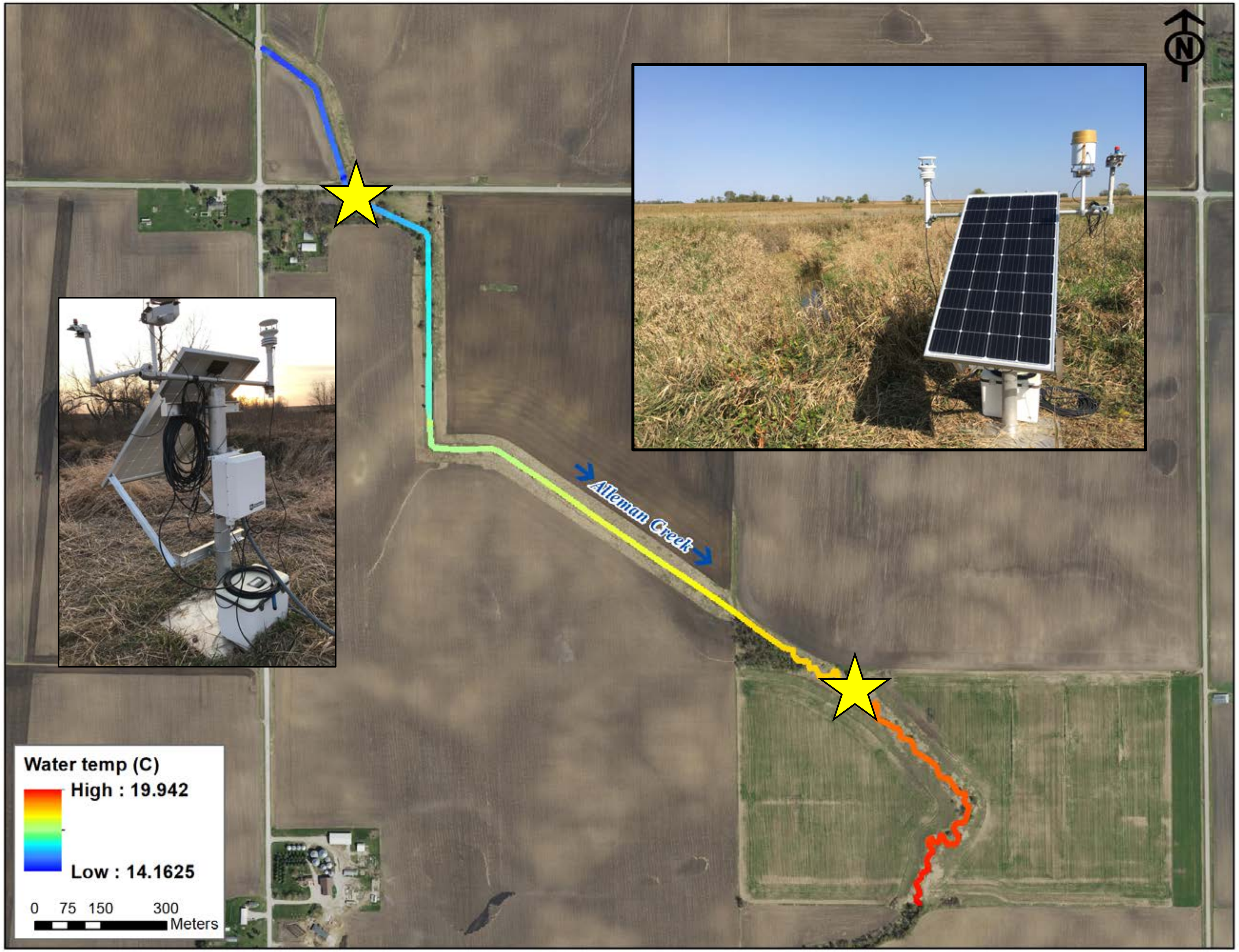
4 – Progress and Outcomes





- Varying specific conductivity due to tile drain inputs and changing geomorphology.

4 – Progress and Outcomes



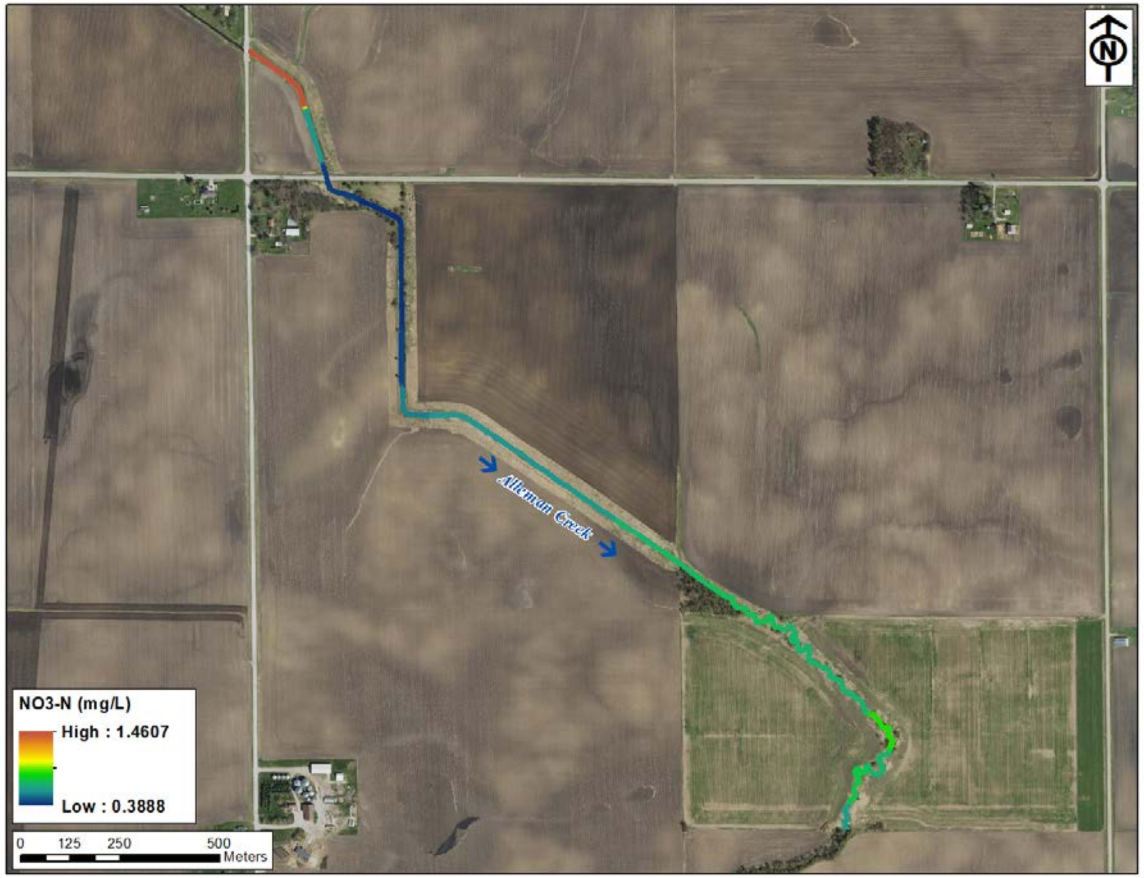
- Two fixed water-quality sensor stations installed at the upstream and downstream reaches in September 2020.
  - Weather station
  - Water level sensor
  - Multiparameter sonde
  - Nitrate sensor
- Will use water quality data measured over time (every 15-min) to better separate out temporal from spatial signals, especially in parameters that vary greatly over time (temperature, dissolved oxygen).

4 – Progress and Outcomes

AquaBOT is a cost- and time-efficient method for measuring water quality

- Surveyed 15 analytical laboratories: estimate ~400 samples could be collected for the cost of one AquaBOT.

AquaBOT:
~4.5-hour deployment; 257 measurements



Manual sampling:
~5-hour sampling event; 24 measurements

4 – Progress and Outcomes

Completed key milestones and developed mitigation strategies due to COVID-19 related challenges:

- Design, assemble, and test the AquaBOT
  → Delayed due to sensor delivery delays but completed.
- Draft manuscript describing the AquaBOT system
  → Completed.
- Initiate fieldwork at saturated buffer site
  → Fieldwork initiated but field season shortened due to COVID-19 and low water levels. Travel restrictions mitigated by shifting resources for additional local technical support.
- Design, assemble, and install fixed sensor stations at saturated buffer site
  → Stations installed; awaiting increased water levels to deploy water sensors.
- Initiate fieldwork at Southfork River site
  → Work currently on hold due to COVID-19. Increasing efforts at the saturated buffer site and exploring multiple options for longer river reach measurements.

4 – Progress and Outcomes

Future Work (FY21 and beyond):

- Planning frequent AquaBOT runs in 2021 once water levels increase; concentrated effort in spring to capture high-nitrate period.
- Collect water quality measurements before, during, and after saturated buffer installation.
- Continue comprehensive assessment of the novel AquaBOT vs traditional measurement approaches.
- Examine longitudinal water quality patterns in larger rivers.
- Expect fieldwork to continue into 2022 due to limited 2020 field season.

4 – Progress and Outcomes

Future Work (FY21 and beyond):

- Sensor-equipped drones have the potential to revolutionize the field of environmental science.
- Our goal is to be a **leader in designing, testing, and validating novel drone-sensor systems** for assessment of environmental effects of bioenergy feedstock production, especially in key focal areas that advance BETO's goals.
- A critical aspect will be drone-sensor technologies that operate at a **lower cost** and at a **similar (or greater) accuracy**, and that **advance knowledge** of environmental responses relative to traditional measurement techniques.
- Future research ideas include:
  - A 'fleet of AquaBOTs' for comprehensive water quality assessment at scales relevant to environmental and water quality models.
  - Coupling aerial and aquatic drone systems for assessing related ecosystem processes across a watershed (e.g., crop productivity & health, nutrient use, water quality).
  - Aerial and aquatic drone systems for mapping spatiotemporal dynamics of algae to inform algal feedstock production.

Summary

- **Coupling sensors with drone technologies** has the potential to greatly advance environmental monitoring.
- We designed, assembled, and tested the AquaBOT – a novel approach for monitoring agriculturally important water quality parameters in small streams.
- AquaBOT revealed **meter-scale variation** in water quality parameters, some of which was related to tile drain inputs. AquaBOT provides much **higher resolution data** than manual sampling for **less effort** and at a **comparable cost**.
- Future work will focus on comparing the AquaBOT approach to traditional measurement methods, evaluating spatiotemporal variation in water quality in streams and rivers, and assessing the efficacy of saturated buffers in retaining nitrate.
- **Application** of the AquaBOT is **wide-ranging** including use by land managers to identify where bioenergy plantings, conservation practices, or other management strategies could be implemented to improve water quality.
- **Supports BETO's goals** of quantification and assessment of environmental effects of bioenergy feedstock production.

Quad Chart Summary

Timeline

- Start date: FY19
- End date: FY21

	FY20	Active Project
DOE Funding	330 K	1020 K

Project Partners

- Drake University (via subcontract)

Barriers Addressed

- At-C: Data availability across the supply chain
- At-E: Quantification of economic, environmental, and other benefits and costs.

Funding Mechanism

- Annual Operating Plan (Merit Reviewed Concept Paper in FY19).

Project Goal

1. Assess the utility of a USV-water quality sensor platform (the 'AquaBOT') as a novel tool to enhance understanding of water quality, which is a key environmental indicator for bioenergy.
2. Better understand spatiotemporal variability in water quality parameters in an agricultural-bioenergy feedstock production landscape using the AquaBOT.

End of Project Milestone

Summarize the advances in water quality monitoring in two draft manuscripts:

1. Manuscript detailing water quality responses to saturated buffers based on AquaBOT data.
2. Manuscript comparing water quality data collected via the AquaBOT to stationary sensor stations.

Additional Slides

Responses to Previous Reviewers' Comments

Comment: I don't remember hearing what the transition plan is; this is one of the few A&S projects that has a clear potential commercial route.

Response: We do not plan to pursue a commercial route at this time as we are coupling a commercial, off-the-shelf USV with commercial, off-the-shelf sensors. Similar approaches (coupling USVs/UAVs with water quality measurement systems) have been described in the literature. However, we are not aware of any studies that have used USVs to measure nitrate concentrations in freshwater, and are also not aware of any studies that have USVs to measure water quality when addressing scientific questions related to bioenergy sustainability. These are the objectives of our study. Most studies on USV/UAVs-water quality sensor system studies that we reviewed in the literature focus on describing the technology, but have few used this technology to address specific research questions.

Comment: In addition to cost and performance assessments indicated in the project plan, I strongly suggest some evaluation of reliability, durability, and maintenance of performance over time, as the long-term performance will significantly affect overall cost to run these sensors.

Response: Thank you for these excellent comments and suggestions. We will incorporate an assessment of reliability, durability, and maintenance in our cost-benefit analysis (FY19 Q4 milestone).

Comment: The title is extremely broad (measurement of sustainability indicators); the project is actually very focused on runoff nitrate.

Response: The title of this project was selected to be broad because we wanted the title to encompass the literature review of the 19 environmental sustainability indicators, thus expanding our scope beyond water quality. We are also interested in expanding these ideas of coupling environmental sensors to UAVs/USVs to measure other bioenergy sustainability indicators in the field if there is a continued interest by BETO and if future funding is available. However, we will discuss the concerns about the title with BETO and determine if it should be changed to be more focused on USVs for water quality research.

Publications and Presentations

Publications:

- Griffiths, N.A., P.S. Levi, J.S. Riggs, C.R. DeRolph, A.M. Fortner, and J.K. Richards. A sensor-equipped unmanned surface vehicle for high resolution mapping of water quality in streams. In preparation for Environmental Science & Technology.

Presentations:

- Griffiths, N.A., P.S. Levi, J.S. Riggs, C.R. DeRolph, A.M. Fortner, and J.K. Richards. A novel unmanned surface vehicle-sensor platform for mapping water quality in streams and rivers in the agricultural Midwest. American Geophysical Union virtual fall meeting. December 2020. Oral presentation.
- Vroman, T., N.A. Griffiths, P.S. Levi, J.S. Riggs, C.R. DeRolph, A.M. Fortner, and J.K. Richards. Using an aquatic drone to map water quality. Soil and Water Conservation Society virtual meeting. July 2020. Oral presentation.
- Griffiths, N.A., P.S. Levi, J.S. Riggs, C.R. DeRolph, A.M. Fortner, and J.K. Richards. Development and testing of an unmanned surface vehicle platform for mapping water quality in streams and rivers. Society for Freshwater Science virtual conference. June 2020. Poster presentation.
- Griffiths, N.A. Advancing aquatic sciences with emerging sensor technologies. EERE Energy Talk, Oak Ridge National Laboratory, Oak Ridge, TN. December 2019. Oral presentation.
- Griffiths, N.A., P.S. Levi, and A. Fortner. Using aquatic drones to map water quality within a bioenergy landscape. Southfork Watershed Alliance meeting, Iowa Falls, IA. November 2019. Oral presentation.
- Griffiths, N.A., and P.S. Levi. Using aquatic drones to map water quality within a bioenergy landscape. Southfork Watershed Alliance meeting, Iowa Falls, IA. May 2019. Oral presentation.
- Levi, P.S., N.A. Griffiths, K. VanDooren, and E.D. Anderson. A drop in the bucket? The role of small-scale restorations on improving downstream water quality. Upper Midwestern Stream Restoration Symposium, La Crosse, WI, February 2019. Oral presentation.