OAK RIDGE National Laboratory

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

4.2.2.44 Spatially resolved measurements of environmental sustainability indicators for bioenergy

March 4-8, 2019
Analysis and Sustainability

Natalie Griffiths
Oak Ridge National Laboratory

ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Goal Statement

Project outcome:

- Advance the understanding of the environmental sustainability of bioenergy production systems by quantifying environmental indicators at high spatial resolution using state-of-the-art water quality sensors coupled with unmanned surface vehicles (USVs).

Project goals:

1. Enhance understanding of environmental sustainability indicators for bioenergy through the development and testing of a novel USV-water quality (nitrate) sensor platform.
2. Quantify spatial variability in nitrate concentrations in a bioenergy feedstock production landscape using a USV-nitrate sensor platform.

Relevance:

- Using novel, state-of-the-art methods to improve understanding of spatial variation in environmental sustainability indicators.
- Could be used by land managers to collect spatially resolved environmental indicator (water quality) data in a less time- and labor-intensive manner than traditional techniques.

Quad Chart Overview

Timeline:

- Project start date: FY19
- Project end date: FY21
- Percent complete: 2%

Objective:

- Enhance understanding of environmental sustainability indicators for bioenergy using sensor-based UAVs and USVs.

End of Project Goal:

- Quantify environmental sustainability indicators at high spatial resolution using state-of-the-art water quality sensors coupled with unmanned surface vehicles (USVs) to better assess water quality responses in a bioenergy feedstock production landscape.

Barriers addressed:

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

	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY19-21)
DOE Funded	0K	0K	1020K*

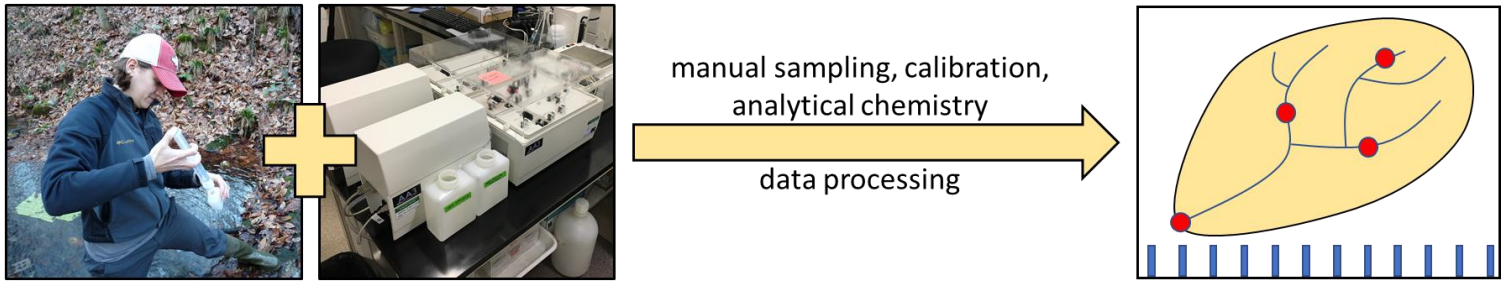
*FY19 funding arrived 11/29/18

1 - Project Overview

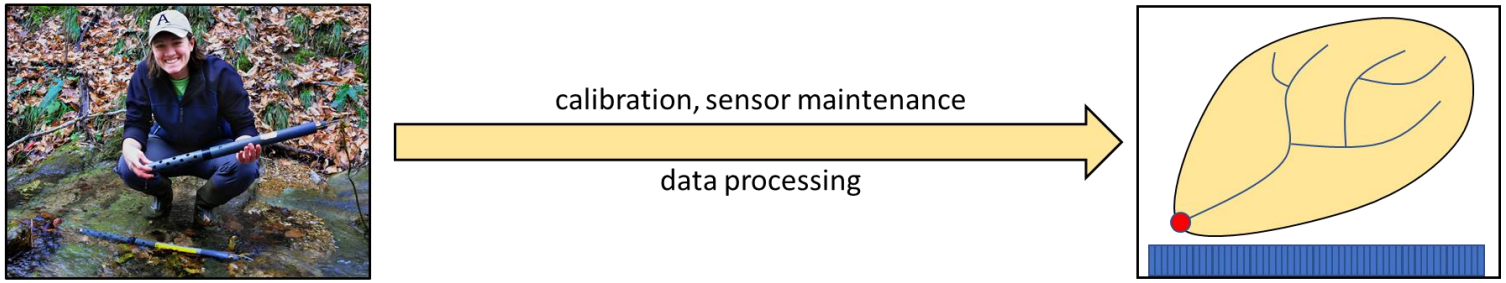
- Measurement of environmental sustainability indicators is an important goal of BETO.
- Many sustainability measurements are collected manually in the field and analyzed in the laboratory, and can be time and labor intensive and limited in spatial and temporal resolution.
- Difficult to sample water quality indicators during high-flow events, which are the predominant time for nutrient losses to downstream ecosystems.

Common techniques for measuring water quality:

Manual sampling and analysis: moderate spatial and temporal resolution



Sensor deployment: low spatial resolution, high temporal resolution

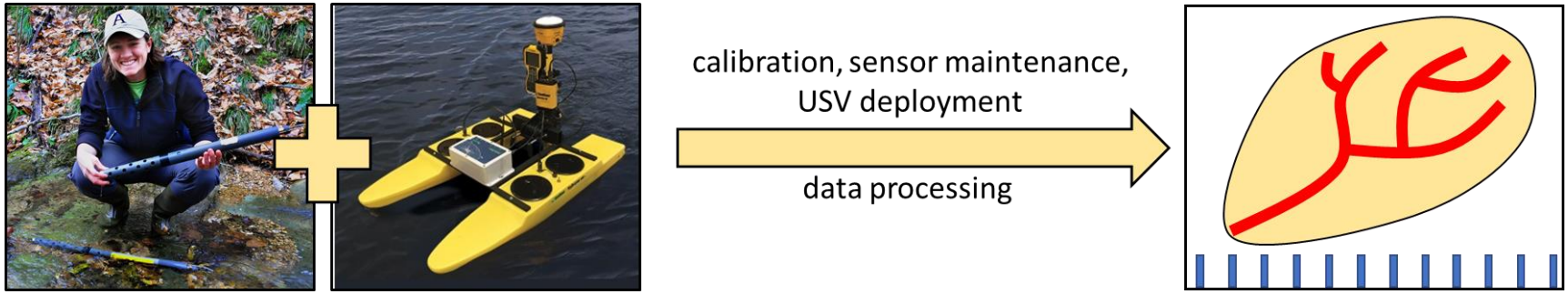


1 - Project Overview

- Coupling commercial, off-the-shelf sensors with UAVs or USVs can allow for the measurement of environmental indicators at high spatial resolution and moderate temporal resolution.

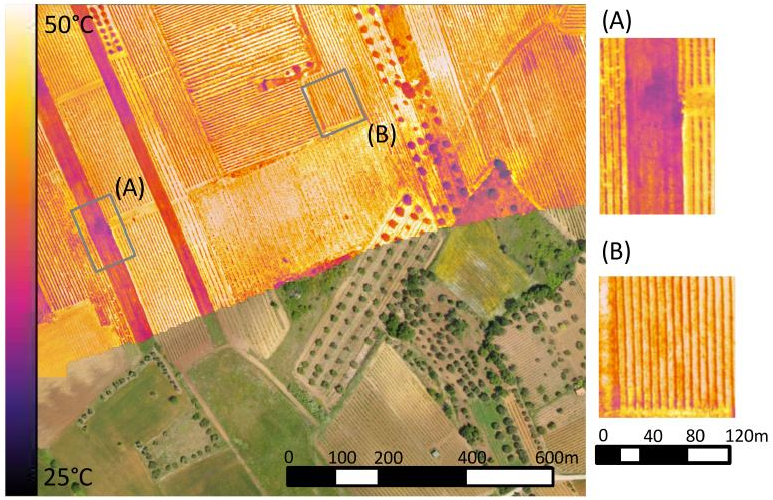
Novel platform for water quality measurements:

Sensor deployment on USV: high spatial resolution, moderate temporal resolution

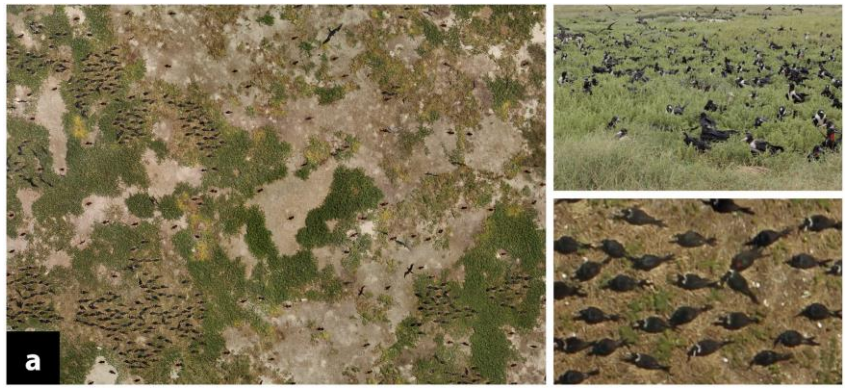


- Can enable sampling during episodic (storm, high flow) events.

1 - Project Overview



From Manfreda et al. 2018



From Hodgson et al. 2016

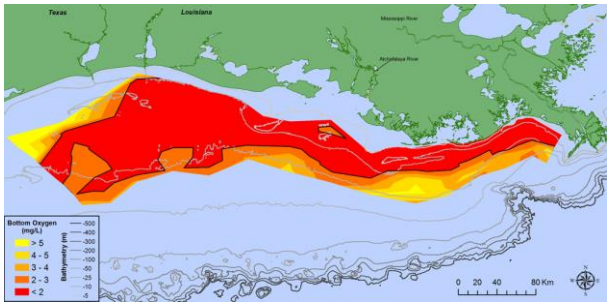
- UAV-sensor systems are being used for precision agriculture and forestry, and are beginning to be used for ecological studies.
- Therefore, a key project goal is to:

Enhance understanding of environmental sustainability indicators for bioenergy through the development and testing of a novel USV-water quality (nitrate) sensor platform.

1 - Project Overview

- BETO-sponsored Antares project is evaluating the productivity, profitability, & environmental responses of multiple bioenergy feedstocks in two fuelsheds in Iowa.

- Important to understand potential for water quality improvement from bioenergy feedstock production given the disproportionate contribution of Iowa to the Mississippi River Basin nitrate load, the Iowa Nutrient Reduction Strategy, and the negative effects of eutrophication on downstream ecosystems.



- Therefore, a key project goal is to:

Quantify spatial variability in nitrate concentrations in a bioenergy feedstock production landscape using a USV-nitrate sensor platform.

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Images from gulfhypoxia.net

2 - Approach (Management)

Natalie Griffiths, ORNL. Water quality, bioenergy systems.

Marissa Morales Rodriguez, ORNL. UAV, sensor systems.

Chris DeRolph, ORNL. Geospatial analysis, aquatic ecology.

Peter Levi, Drake U. Stream ecology and biogeochemistry.

- Team includes excellent technical expertise on UAVs, instrumentation, and analytical analysis.
- In-person project meetings at ORNL. As project progresses, will hold quarterly meetings to discuss project progress (fieldwork, data analysis).
- Collaboration with the Antares project. PI Griffiths participates in monthly Antares project calls; presented USV research plans on Nov 2018 call.
- Quarterly reporting and update calls with BETO technology manager.
- Quarterly and annual milestones to monitor progress.

2 - Approach (Technical)

- Develop a USV-water quality platform using state-of-the-art and commercial, off-the-shelf technologies. Test operation, measurement accuracy in the laboratory and field.
- Deploy the USV-water quality platform seasonally and during storm events to better understand the water quality responses to conservation practices within a bioenergy landscape.
- Broaden the project impact beyond water quality by conducting a literature review of the current state of UAV and USV-compatible sensors for measuring environmental sustainability indicators for bioenergy.

#	Task Description	Start Date
1	Design and test the USV-water quality measurement platform.	FY19
2	Evaluate the efficacy of saturated buffers at reducing nutrient concentrations using a USV-water quality measurement platform.	FY20
3	Create and analyze spatial maps of water quality within a bioenergy landscape using a USV-water quality measurement platform.	FY20

2 - Approach (Technical)

Go/No-Go (end of FY19):

- The USV-sensor platform must advance understanding of spatial variation in water quality by measuring nitrate concentrations at a higher spatial resolution than achievable through traditional water quality sampling methods.
- A Go decision requires that the USV-sensor platform collects nitrate concentration data along longitudinal stream transects (i.e., 500-m stream length) at a faster rate and a lower cost than traditional methods.

2 - Approach (Technical)

Success Factors:

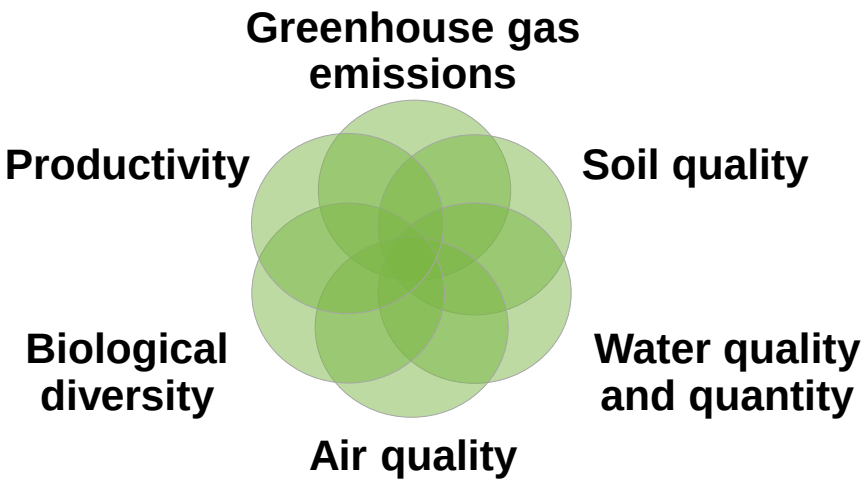
- Comprehensive field and laboratory testing of the USV-sensor platform to fully understand measurement accuracy, operational capacity, etc.
- Collect high-quality data in a cost-effective, and less time- and labor-intensive manner.
- Rapidly address issues that arise in the field and lab.
- Share results with relevant audiences (via presentations, BioenergyKDF, peer-review journals).

Challenges:

- USV-sensor platform may be too large to be deployable in small, headwater streams or during low-flow conditions.
  - *Solution: change sampling frequency to more intensively sample high-flow events and increase spatial coverage of larger streams.*
- Complete watershed maps of water quality will be difficult to complete due to large areas to cover, site access issues.
  - *Solution: focus sampling on the most relevant locations within the watersheds (e.g., bioenergy crop plantings, conservation practices).*

3 - Technical Accomplishments

- USV and nitrate sensors purchased. Will begin assembling platform in early 2019.
- Presented USV project plan for Antares project team during a monthly meeting. Discussed field sites and potential USV deployment locations with USDA Antares project collaborators.
- Began literature review on the current state of sensor-based UAVs and USVs for measuring environmental sustainability indicators for bioenergy (i.e., the 19 metrics outlined in McBride et al. 2011).



4 - Relevance

Project goal:

- Advance the science of water quality monitoring for bioenergy sustainability by quantifying water quality indicators at high spatial resolution through the development and testing of a state-of-the-art technique that couples USVs to sensor technologies.

Importance:

- More comprehensively quantify indicators (spatial variation) and thus advance understanding of environmental sustainability of bioenergy systems using novel, cost-effective, and less time- and labor-intensive measurement techniques.

4 - Relevance

Contribution to BETO goals:

- BETO is *"committed to developing and applying scientific approaches to quantify bioenergy sustainability"*. The *"science-based quantification of the sustainability of advanced bioenergy"* is an important goal of BETO's Sustainability program (BETO MYP 2016).
- By collecting spatially resolved data on a key environmental indicator in a bioenergy production landscape using a newly developed, state-of-the-art tool, this project:
  - Contributes to BETO MYP Sustainability performance goals: *"By 2022, validate landscape design approaches that…maintain ecosystem and social benefits..."*
  - Is key to BETO meeting milestones in the Strategic Plan: *"By 2023, demonstrate a suite of analytical methods for quantifying environmental benefits..."*
  - Aligns with the BETO MYP Sustainability strategic goal: *"to understand and promote the positive environmental, economic, and social effects and reduce the potential negative impacts of bioenergy production activities"*.

4 - Relevance

Relevance to bioenergy industry:

- Critical to quantify the environmental sustainability of bioenergy production in a cost-effective and comprehensive manner, including better understanding spatial variability of indicators.
- Novel sensor platforms could be used by land managers to collect high spatial resolution environmental indicator (water quality) data that is less time and labor intensive than traditional techniques.
- USV-sensor platform can be used to advance understanding of spatial variability in water quality during storm events, which are disproportionally important but traditionally difficult to sample.

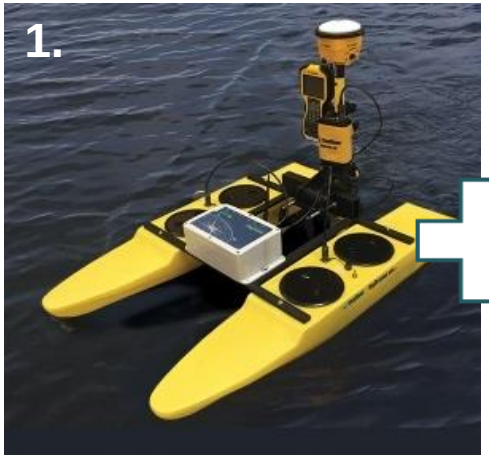
Broader relevance:

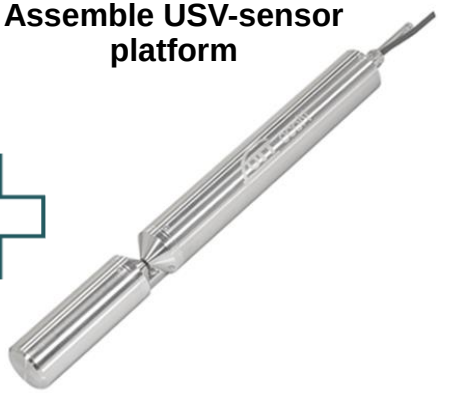
- Application of a USV-sensor system is wide ranging and may also be used for water quality monitoring at federal, state, and local levels.

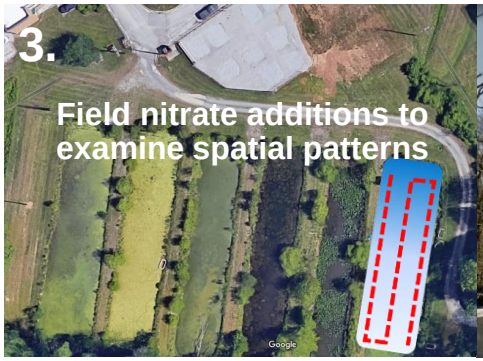
5 - Future Work

FY19: Design & test the USV-water quality platform **(Task 1)**.

1. March 2019: Assemble USV, including sensor mounting. Will explore option to attach additional water quality sensors; data can be used to help interpret spatial patterns of nitrate.
2. June 2019: Laboratory testing of nitrate sensors. Assess accuracy of nitrate sensors compared to traditional grab samples.
3. Sept. 2019: Field testing of USV-water quality platform. Compare nitrate concentrations to grab samples. Test maneuverability (determine stream width and depth needed for operation), measurement frequency, operation distance.







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Images from seafloorsystems.com, ott.com, Google maps

5 - Future Work

FY19: Literature review and cost-benefit analysis **(Task 1)**.

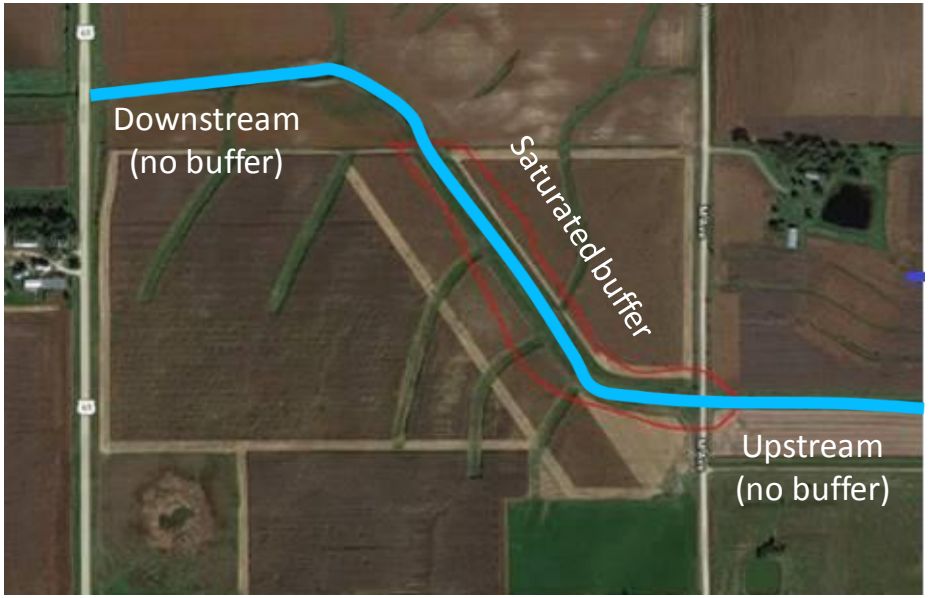
1. **Literature Review (by Sept. 2019):**
   - Complete a literature review summarizing the current state of UAV and USV-compatible sensors for measuring environmental sustainability indicators for bioenergy.
   - Review will be broadly applicable for use of UAVs/USVs for environmental monitoring, but will focus on UAV-sensor systems that can measure the 19 environmental sustainability indicators for bioenergy outlined by McBride et al. (2011).
2. **Cost-Benefit Analysis (by Sept. 2019):**
   - Based on knowledge gained by developing and testing the USV-sensor system, we will complete a cost-benefit analysis of a USV-water quality sensor platform compared to traditional water quality sampling and analysis methods.

FY19: Go/No-Go. USV-sensor platform must advance understanding of spatial variation in water quality by measuring nitrate concentrations at a higher spatial resolution than via traditional sampling methods.

5 - Future Work

FY20/21: Examine the effect of saturated buffers on water quality in the Antares landscape, seasonally and on an event basis (spring freshet), using the USV-water quality platform **(Task 2)**.

- Saturated buffers can have a dual benefit: 1) reduced N and sediment loading to adjacent waterways; 2) N can serve as a fertilizer for buffer grasses, which can then be harvested for bioenergy.
- Deploy USV-sensor system upstream, within, and downstream of the buffers to examine, at high spatial resolution, the efficacy of buffers at reducing nitrate inputs.
- Seasonal measurements for 2 y, and higher-frequency sampling during the spring freshet period, when nitrate fluxes are highest.
- Discharge measurements to calculate nitrate fluxes.
- Field sampling will be led by Peter Levi (Drake U).



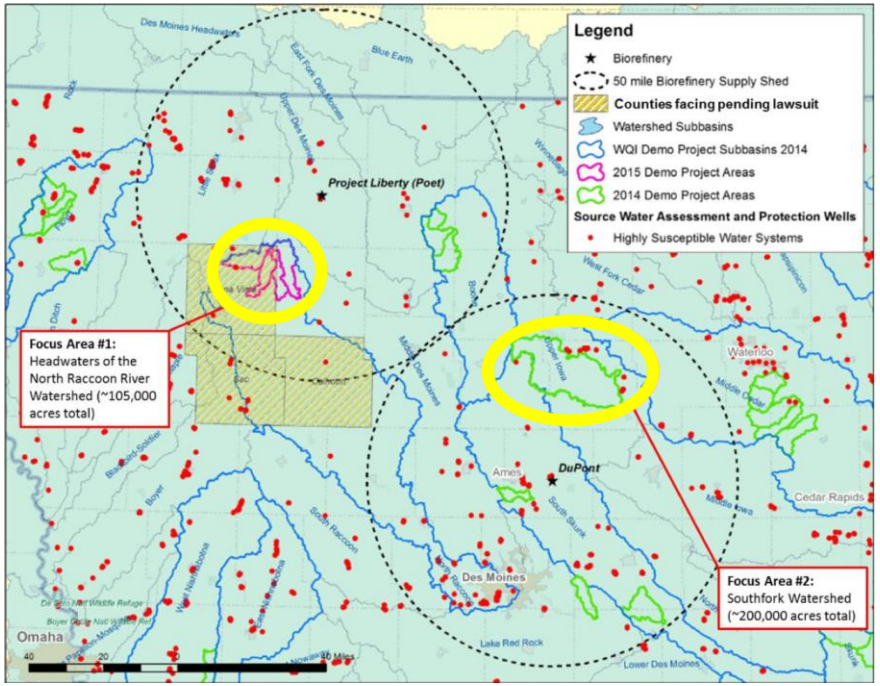
Saturated buffers installed as part of the Antares project.

Image from Kevin Comer and Bill Belden

5 - Future Work

FY20/21: Examine spatial patterning of water quality within the Antares focus watersheds on a seasonal and event (spring freshet) basis **(Task 3)**.

- Deploy the USV-sensor system in North Raccoon River and Southfork Watersheds to produce spatial maps of water quality.
- Focus spatial measurements on areas with bioenergy feedstock plantings and conservation practice installations, as well as areas where nitrate concentrations are expected to be most spatially variable (tile drains, tributary confluences).
- Same sampling frequency as in **Task 2** and sampling led by Peter Levi (Drake U).
- Spatial analyses will be used to examine drivers (e.g., crops, conservation practices) of nitrate concentrations.



North Raccoon and Southfork Watersheds are the focus of the Antares Project.

Image from Kevin Comer and Bill Belden

5 - Future Work

#	FY19 Milestones	Due date	% Completed as of Jan 2019
1	Design field-deployable USV-nitrate sensor platform.	12/31/2018	75%
2	Assemble USV-nitrate sensor platform, including mounting the sensor to the USV.	3/31/2019	0%
3	Test USV-nitrate sensor platform in the Aquatic Ecology Lab mesocosms.	6/30/2018	0%
4	Test USV-nitrate sensor platform in the field. Complete a cost-benefit analysis of a USV-water quality sensor platform compared to traditional water quality sampling methods. Complete a literature review summarizing the current state of UAV and USV-compatible sensors for measuring environmental sustainability indicators for bioenergy.	9/30/2018	5%

Summary

1. **Overview:**
   - Novel tools have the potential to collect high-quality data needed to quantify environmental sustainability of bioenergy systems.
   - Project will advance understanding and provide valuable, spatially resolved environmental sustainability indicator data for bioenergy using novel sensor-based UAVs and USVs.

2. **Approach:**
   - Develop and test a USV-water quality sensor platform in the laboratory and field.
   - Complete a comprehensive literature review on the state of the science on UAV/USV-sensor systems for measuring environmental sustainability indicators for bioenergy.
   - Deploy the USV-water quality platform in the Antares landscape to: 1) understand the role of saturated buffers on stream nitrate dynamics; 2) examine spatial patterning of water quality within the Antares watersheds.

Summary

3. **Technical Accomplishments:**
   - Project has just begun. USV and sensors purchased. Literature review started.

4. **Relevance:**
   - Need to advance understanding of environmental sustainability of bioenergy systems using cost-effective, and less time- and labor-intensive measurement techniques. Sensor-based UAVs/USVs are novel tools that could be used by land managers.
   - Addresses key BETO milestones and goals focused on quantifying and understanding environmental sustainability.

5. **Future Work:**
   - FY19: Complete 1) assembly and testing of USV-sensor platform; 2) literature review; 3) cost-benefit analysis.
   - FY20/21: Deploy USV-sensor platform in the Antares landscape (saturated buffers, larger watersheds) to examine spatial patterning in nitrate concentrations.

Additional Slides

Presentations

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, Wisconsin, February 2019.