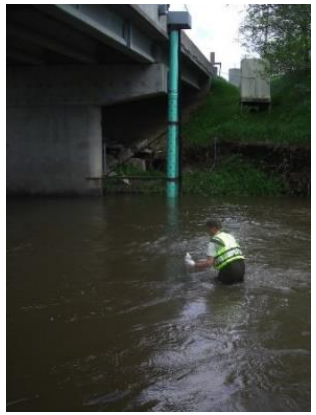
Progress, Applications, and Challenges of Integrating Water Quality Data with Remote Sensing for Inland and Coastal Waters

Sarah Stackpoole
US Geological Survey, Water Mission Area

NASA Water Quality and Remote Sensing Workshop
Greenbelt, MD, September 27th, 2017

Nationally Consistent Discrete and Continuous Water Quality Samples

Discrete Water Quality Sampling and Analysis

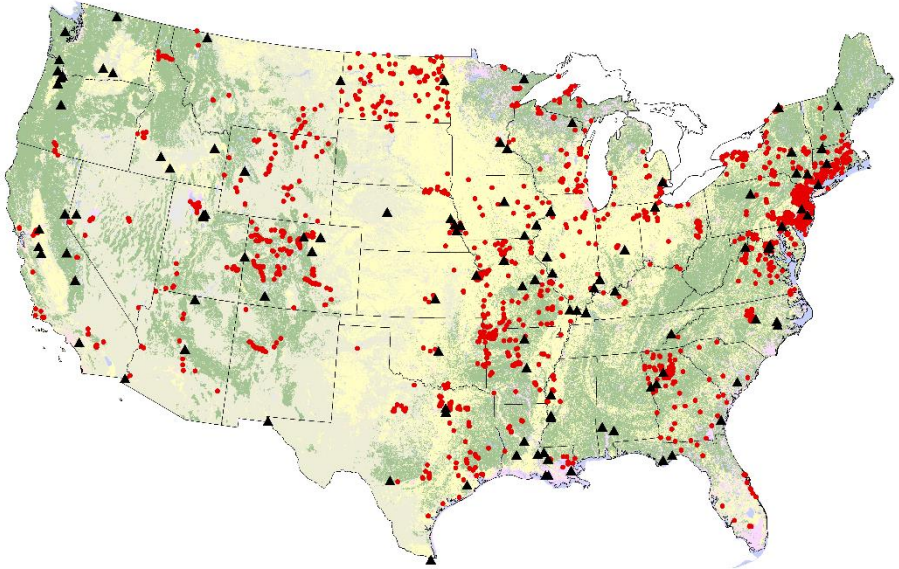


USGS, Laura Hibbard

USGS, Mark Nilles

▲ National Water Quality Network Nitrate Sites, n=116

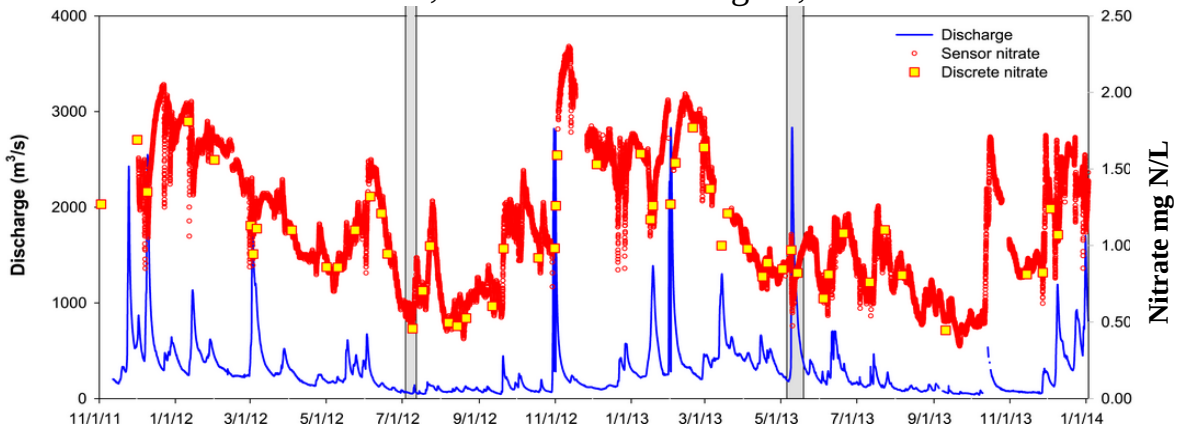
● Additional discrete nitrate sites, n=1,809



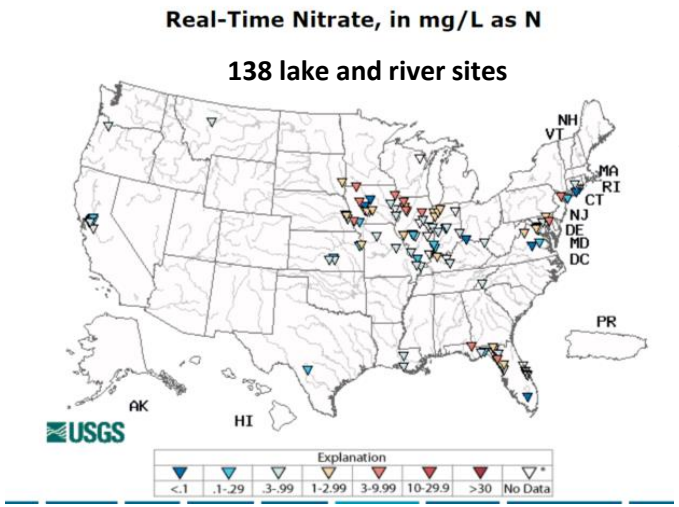
USGS, Casey Lee

Continuous water-quality data show changing environmental conditions that may be missed with discrete samples

Potomac River, Little Falls Washington, DC



From Pellerin et al. (2016)



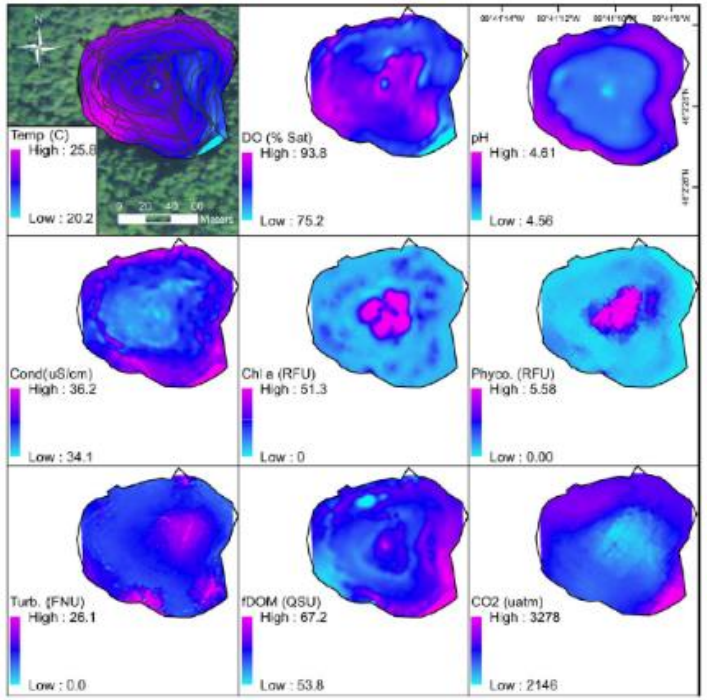
https://waterwatch.usgs.gov/wqwatch/

USGS, Jennifer Graham

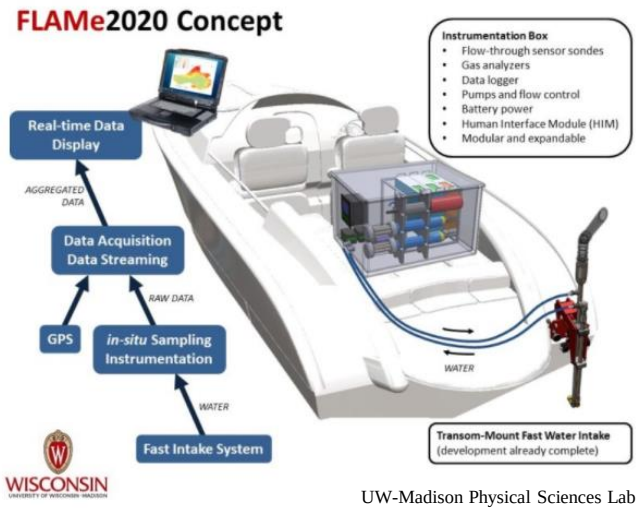
USGS science for a changing world

Water Quality Data - Mobile Sensors

Fast Limnology Automated Measurement (FLAMe): Sensor technology + a mobile sampling platform shows changing environmental conditions that may be missed with either discrete or fixed-continuous sensors



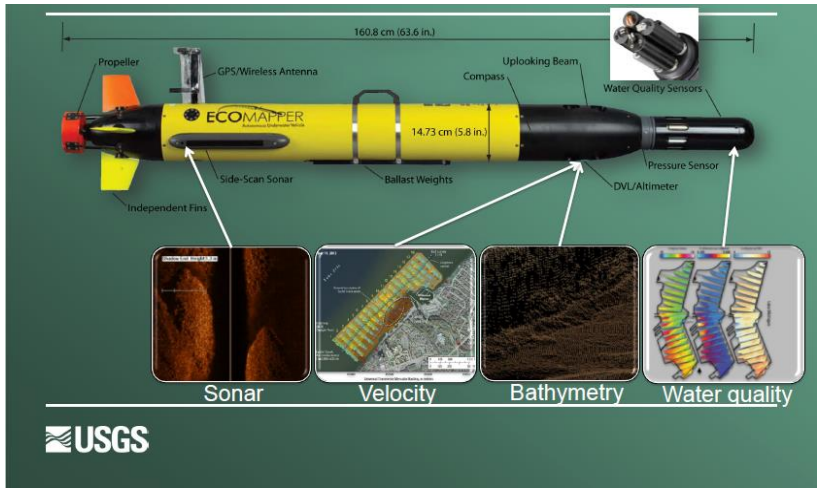
FLAMe technology applied to a lake in Northern WI, Trout Bog (0.01 km^2) to answer the question: *How well does a sampling location (center) represent the lake as a whole?*



UW-Madison Physical Sciences Lab

- FLAMe has a Multiparameter Sonde + Optical Nitrate Sensor + Portable Greenhouse Gas Analyzer
- Flow-through water-quality sampling system
- Works at low (0 to 10 km hr^{-1}) and high speeds (10 to > 45 km hr^{-1})
- Useful to identifying transition zones in aquatic systems and potential identification of terrestrial - aquatic linkages

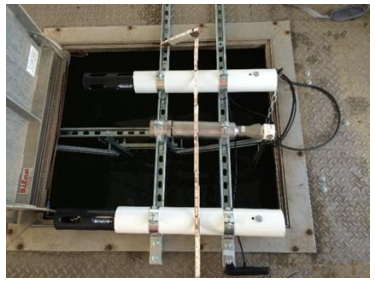
From Crawford et al. (2014)



Another example of a mobile sampling platform for water quality - Autonomous Underwater Vehicle, P. Ryan Jackson

Additional configurations of sensor technology + mobile platforms

B. Bergamaschi & B. Downing, California Water Science Center, Fichot et al. (2015)



G. Foster & J. Graham, Kansas Water Science Center, Foster et al. (2015)

USGS
science for a changing world

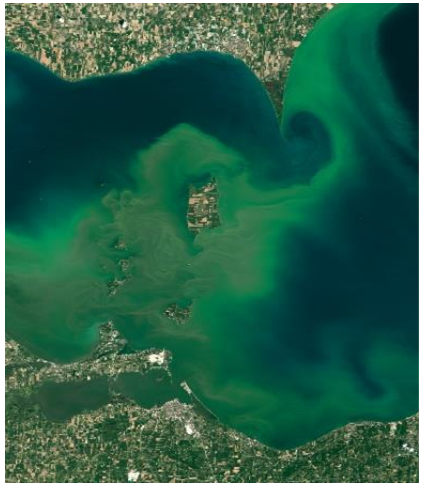
Integrating Water Quality & Remote Sensing

Discrete

Continuous

Mobile Sensors

Ground-Level Signal



Remote sensing signal

Identify anomalous water quality issues and/or expand spatial coverage for routine monitoring

Algal Blooms, Harmful & Beneficial

Guy Foster and Jennifer Graham

Wildlife Habitat

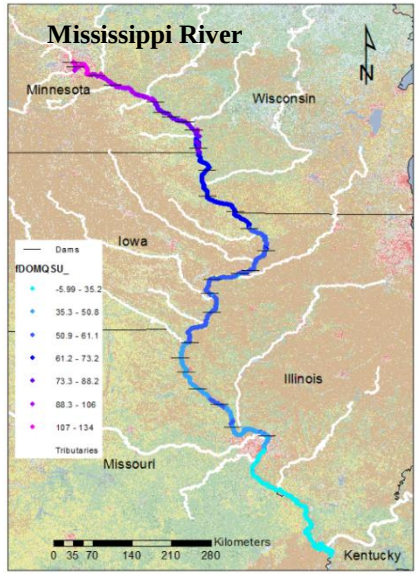
Brent Knights, USGS, Upper Midwest Environmental Science Center

Drinking water supply

California Department of Water Resources

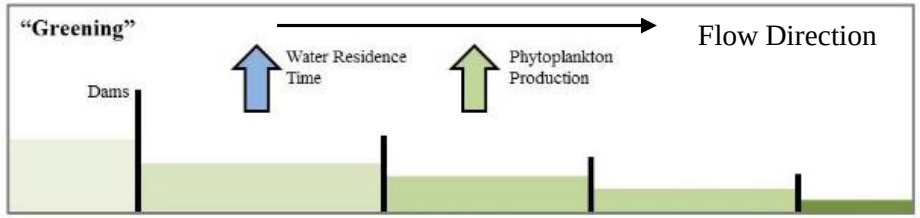
Integrating Water Quality (WQ) & Remote Sensing – Applications

Anomalous WQ Issue: Identify changes to ecosystem state in large rivers to assess the quality of essential habitat to support both recreational and commercial fishing.

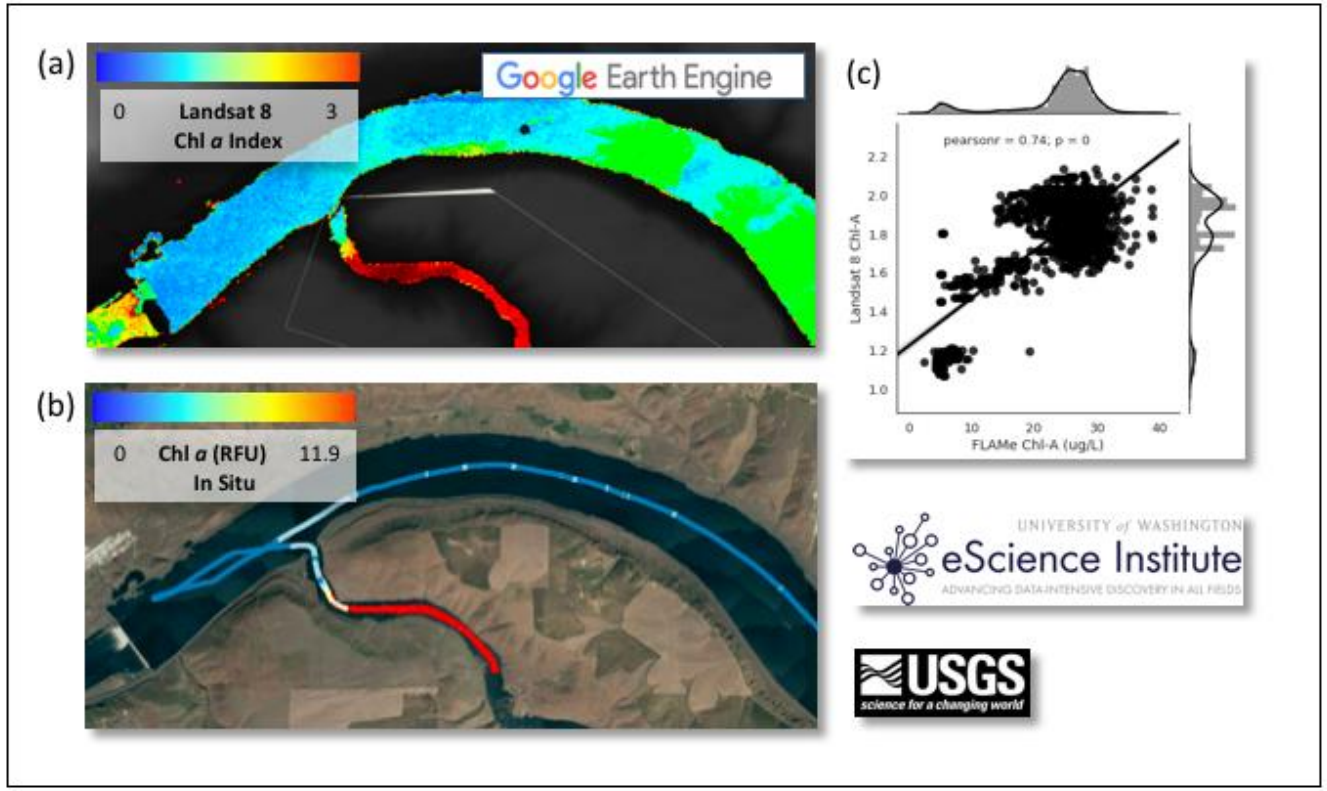


WQ Results: Map showing 1300 km of UMR fluorescent dissolved organic matter (fDOM) values, quinine sulfate units (QSU) using FLAMe mobile sensor platform. Navigational infrastructure and nutrient enrichment caused changes in water quality, including increased phytoplankton production.

From Crawford et al. (2016)



Potential Link to Remote Sensing: Use remote sensing imagery (Landsat 8 or Sentinel 2) to determine variability in timing of onset and/or duration of eutrophic state.



(a) Satellite-retrieved chlorophyll-a estimated in the Google Earth Engine platform using the ratio of reflectance in the blue and green bands of the Landsat 8 OLI sensor.
(b) *In situ* chlorophyll-a underway transect measurements taken in July 2016 using the FLAMe platform.
(c) Scatterplot showing the relationship between the in situ and satellite remote sensing measurements for the John Day river. From Kuhn et al. (2017)

Integrating Water Quality & Remote Sensing – Applications

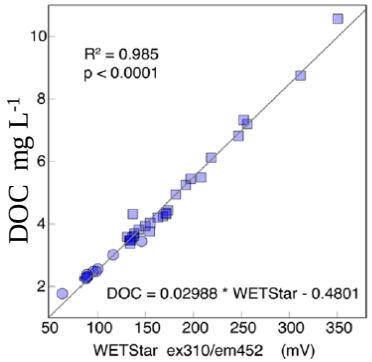
Routine WQ Issue: Monitoring of point and nonpoint source pollution in the San Francisco Bay-Delta Estuary, a key water supply for a major urban area.

Remote Sensing: Hyperspectral imaging with airborne portable remote imaging spectrometer (PRISM).

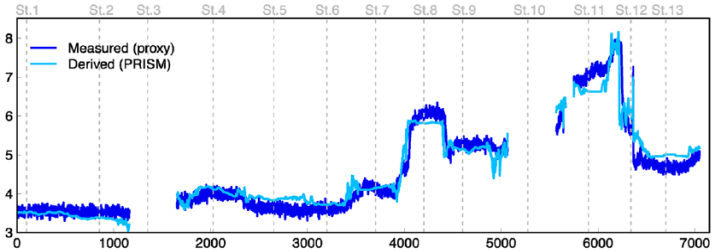
Methods: Link measurement of in situ organic matter optical properties with remote sensing data to develop maps of a surrogate water quality parameter of interest, methylmercury.

USGS
science for a changing world

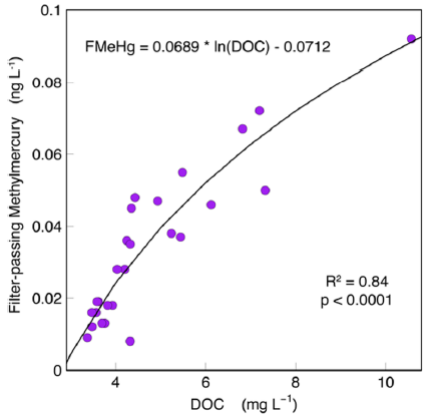
Results:

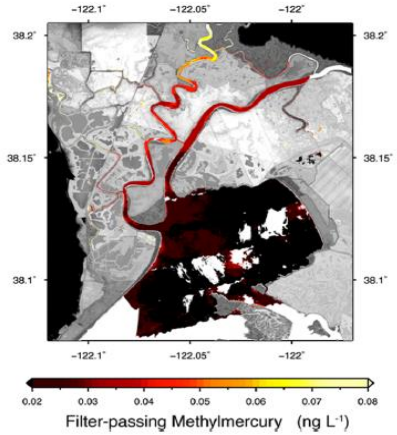


Measured DOC proxy (sensor DOC) has a strong positive relationship with discrete samples of DOC.



Measured DOC proxy (sensor DOC) correlates with derived DOC from remote sensing.

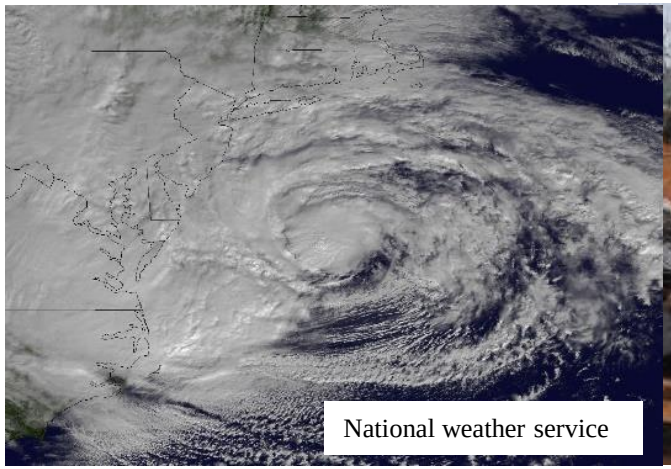




Relationship between DOC concentrations and methylmercury from discrete samples (left). A map of methylmercury was derived from the remotely sensed DOC concentrations (right).

Integrating Water Quality & Remote Sensing – Applications

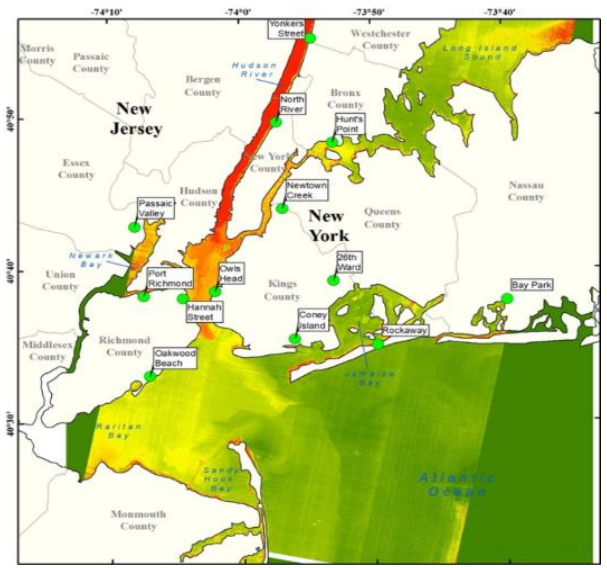
Anomalous WQ Issue: Map wastewater and sediment plumes in New York and New Jersey resulting from infrastructure damage following Hurricane Sandy.


National weather service

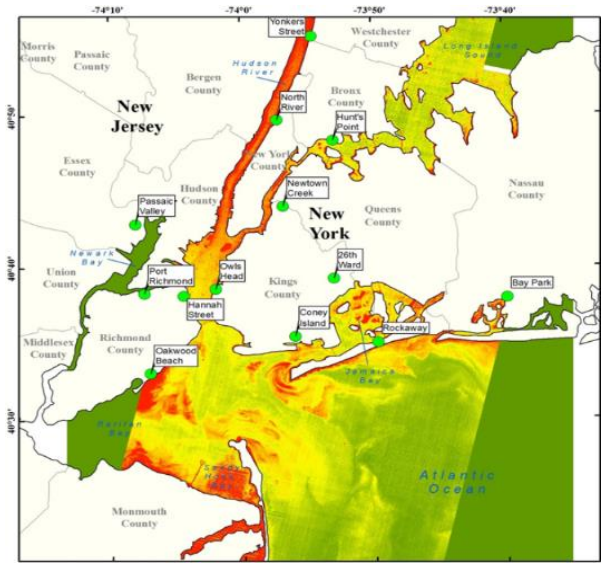

USGS, Cheryl Hapke

Remote Sensing: Landsat and USGS Earth Resources Observation and Science Center (EROS) surface reflectance data product (for atmospheric correction).

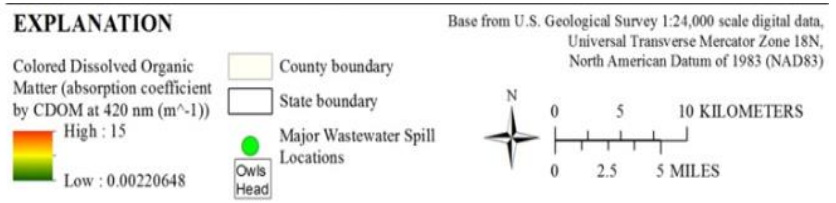
Methods: Used pre-established reflectance band ratios (Kutser et al. 2005) to create maps of relative differences in colored dissolved organic matter (CDOM) absorption before and after a major storm event.



CDOM gradient before the storm 9/12/2011



CDOM gradient after the storm 11/12/2012



Results: Anomalous and potentially hazardous regional-scale water quality conditions were detected using Landsat remote sensing imagery.

From Slonecker et al. (2016)

USGS science for a changing world

Challenges and Needs for Successful Integration of Water Quality & Remote Sensing for Inland Waters

Challenges:

- Temporal mismatch of data: Matching up timing of water quality sampling for inland waters with remote sensing pass is difficult because changes in water quality are highly variable over space and time, e.g. estuaries vary with the tide, rivers change with streamflow, and lakes change with precipitation and wind events.
- Spatial mismatch of data: Many inland waters are too small to be observable with remote sensing technology.

Needs:

- A national program calibrating remote sensing data with ground truth data, including a standardization of terms and methods
  - The link between remote sensing and water quality requires cross-walking between water quality lab methods which focus on absorbance, in situ sensors that are based on fluorescence, and remote sensing that is based on reflectance.
  - The effect of particles on light attenuation needs to be accounted for in field deployable sensors measuring optical properties of water quality.
- A standardized atmospheric correction methodology for application of satellite – derived remote sensing data to water quality data for inland waters
- Surrogate models that relate optically active components of water quality with the constituent of interest as many important attributes of water quality are not detectable with remote sensing, i.e. metal contaminants.
- Good communication between the water quality and remote sensing communities to identify anomalous and potentially hazardous water quality issues and improve the spatial coverage of routine water quality monitoring.

Acknowledgements

Brian Bergamaschi (USGS, California Water Science Center)

David Butman and Catherine Kuhn (University of Washington - Seattle)

John Crawford, Jack Eggleston, Brian Pellerin, Gary Rowe, Ted Stets, and Dick Smith (USGS, Water Mission Area)

Jennifer Graham, Guy Foster, Casey Lee, Keith Loftin (USGS, Kansas Water Science Center)

Jennifer Rover (USGS, Earth Resources Observation and Science Center)

John Dwyer, Jonathan Smith, and Zhuoting Wu (USGS, Land Resources Mission Area)

Terry Slonecker (USGS, Eastern Region Geographic Sciences Center)

Emily Stanley and Luke Loken (University of Wisconsin - Madison)

USGS science for a changing world

UNIVERSITY of WASHINGTON

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

References

- Crawford, J. T., D. E. Butman, L. C. Loken, P. Stadler, C. Kuhn, and R. G. Striegl. 2017. Spatial variability of CO2 concentrations and biogeochemistry in the Lower Columbia River. Inland Waters:1-11.
- Crawford, J. T., L. C. Loken, N. J. Casson, C. Smith, A. G. Stone, and L. A. Winslow. 2014. High-speed limnology: Using advanced sensors to investigate spatial variability in biogeochemistry and hydrology. Environmental Science & Technology **49**:442-450.
- Crawford, J. T., L. C. Loken, E. H. Stanley, E. G. Stets, M. M. Dornblaser, and R. G. Striegl. 2016. Basin scale controls on CO_2 and CH_4 emissions from the Upper Mississippi River Mississippi River Greenhouse Gases. Geophysical Research Letters **43**:1973-1979.
- Fichot, C. d. G., B. D. Downing, B. A. Bergamaschi, L. Windham-Myers, M. Marvin-DiPasquale, D. R. Thompson, and M. M. Gierach. 2015. High-resolution remote sensing of water quality in the San Francisco Bay–Delta estuary. Environmental Science & Technology **50**:573-583.
- Foster, G. M., J. L. Graham, T. C. Stiles, M. G. Boyer, L. R. King, and K. A. Loftin. 2017. Spatial variability of harmful algal blooms in Milford Lake, Kansas, July and August 2015. 2328-0328, US Geological Survey.

- Crawford, J. T., D. E. Butman, L. C. Loken, P. Stadler, C. Kuhn, and R. G. Striegl. 2017. Spatial variability of CO2 concentrations and biogeochemistry in the Lower Columbia River. Inland Waters:1-11.
- Crawford, J. T., L. C. Loken, N. J. Casson, C. Smith, A. G. Stone, and L. A. Winslow. 2014. High-speed limnology: Using advanced sensors to investigate spatial variability in biogeochemistry and hydrology. Environmental Science & Technology **49**:442-450.
- Crawford, J. T., L. C. Loken, E. H. Stanley, E. G. Stets, M. M. Dornblaser, and R. G. Striegl. 2016. Basin scale controls on CO_2 and CH_4 emissions from the Upper Mississippi River Mississippi River Greenhouse Gases. Geophysical Research Letters **43**:1973-1979.
- Fichot, C. d. G., B. D. Downing, B. A. Bergamaschi, L. Windham-Myers, M. Marvin-DiPasquale, D. R. Thompson, and M. M. Gierach. 2015. High-resolution remote sensing of water quality in the San Francisco Bay–Delta estuary. Environmental Science & Technology **50**:573-583.
- Foster, G. M., J. L. Graham, T. C. Stiles, M. G. Boyer, L. R. King, and K. A. Loftin. 2017. Spatial variability of harmful algal blooms in Milford Lake, Kansas, July and August 2015. 2328-0328, US Geological Survey.

- Kuhn, C, Butman, D., Crawford, JT., Loken, L., Stadler, P., Striegl, R., (2017) “Leveraging spectral-biogeochemical patterns to map carbon chemistry across a large, highly regulated river system.” Association for the Sciences of Limnology and Oceanography; Honolulu, HI. Abstract #29871
- Kutser, T., D. C. Pierson, K. Y. Kallio, A. Reinart, and S. Sobek. 2005. Mapping lake CDOM by satellite remote sensing. Remote Sensing of Environment **94**:535-540.
- Pellerin, B., B. A. Stauffer, D. A. Young, D. J. Sullivan, S. B. Bricker, M. R. Walbridge, G. A. Clyde, and D. M. Shaw. 2016. Emerging tools for continuous nutrient monitoring networks: Sensors advancing science and water resources protection. Journal of the American Water Resources Association **52**:993-1008.
- Slonecker, E. T., D. K. Jones, and B. A. Pellerin. 2016. The new Landsat 8 potential for remote sensing of colored dissolved organic matter (CDOM). Marine Pollution Bulletin **107**:518-527.

- Kutser, T., D. C. Pierson, K. Y. Kallio, A. Reinart, and S. Sobek. 2005. Mapping lake CDOM by satellite remote sensing. Remote Sensing of Environment **94**:535-540.
- Pellerin, B., B. A. Stauffer, D. A. Young, D. J. Sullivan, S. B. Bricker, M. R. Walbridge, G. A. Clyde, and D. M. Shaw. 2016. Emerging tools for continuous nutrient monitoring networks: Sensors advancing science and water resources protection. Journal of the American Water Resources Association **52**:993-1008.
- Slonecker, E. T., D. K. Jones, and B. A. Pellerin. 2016. The new Landsat 8 potential for remote sensing of colored dissolved organic matter (CDOM). Marine Pollution Bulletin **107**:518-527.