Continuous Water-Quality Monitoring: deployment techniques and applications

December 2nd, 2020

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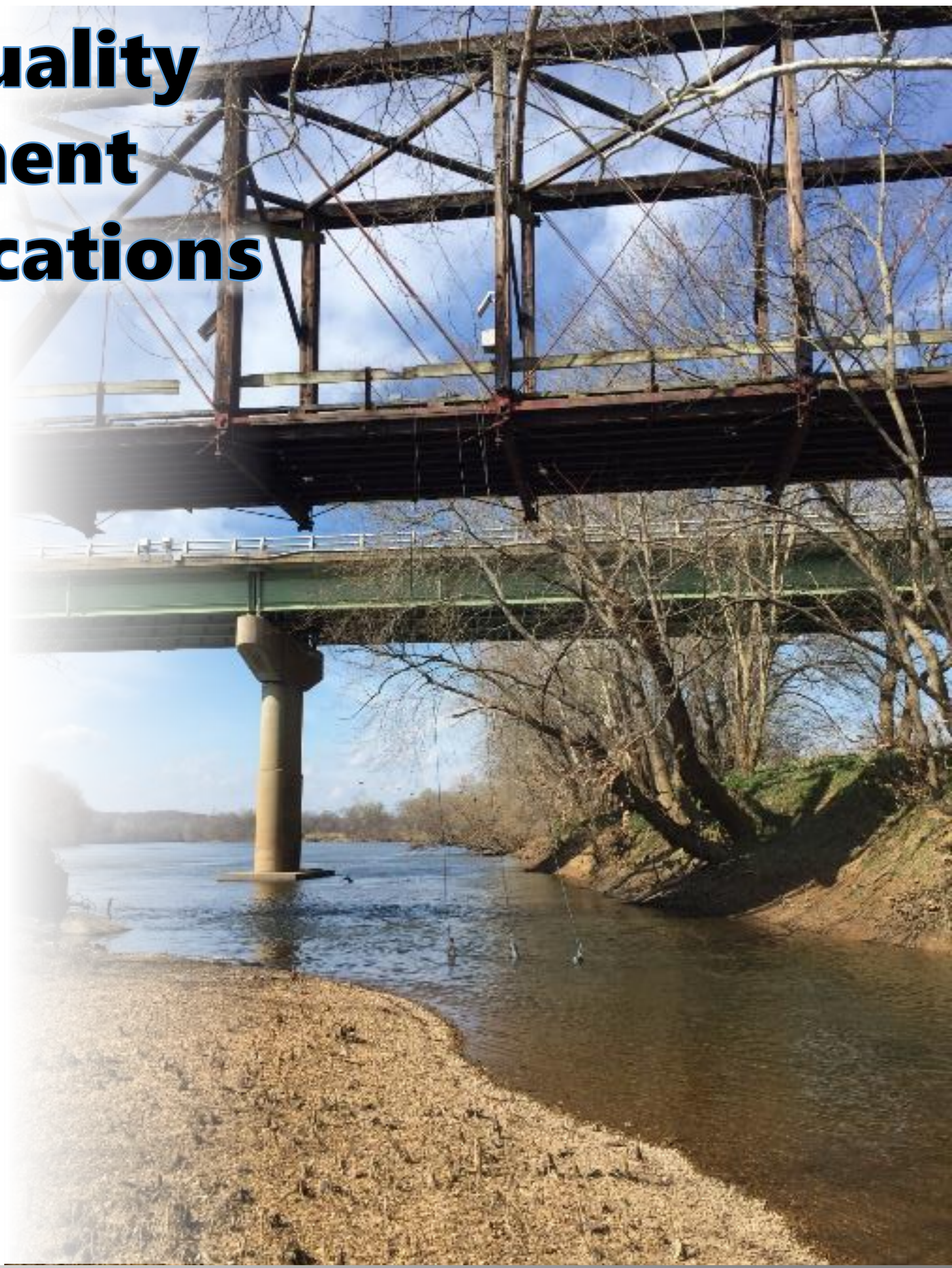
Continuous Water-Quality Monitoring: deployment techniques and applications



What, How, and Why: Continuous Water-Quality Monitoring

Characteristics of an Effective Deployment

Data Transmission, Storage, and Visualization

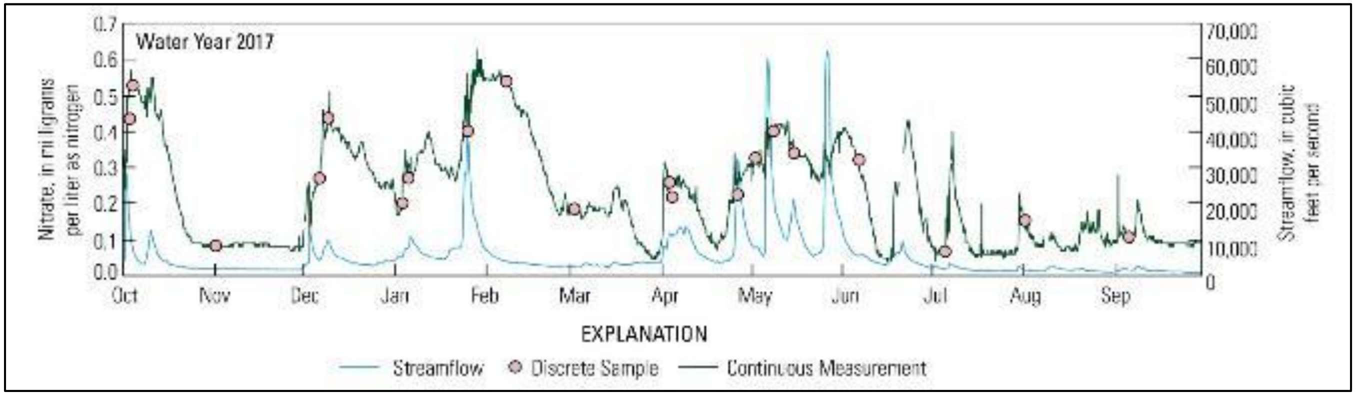
Analysis Techniques

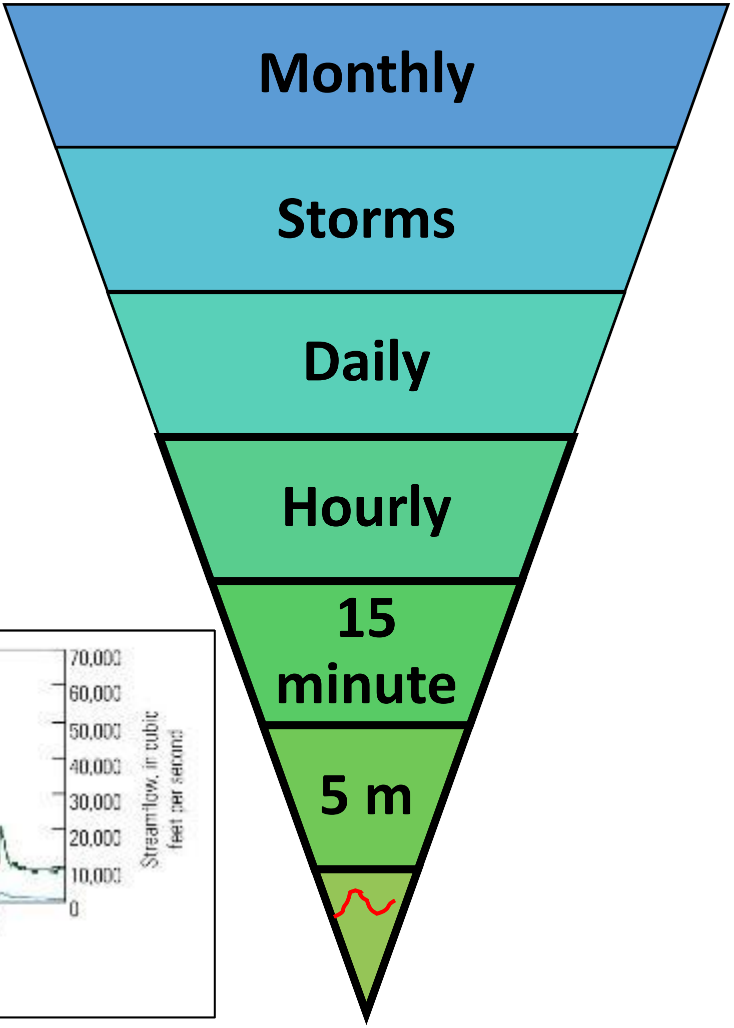
What, How, and Why: Continuous Water-Quality Monitoring

Continuous water-quality monitors are devices that provide frequent, near real-time measurements of water-quality constituents

Traditional water-quality measurements are made by submitting stream samples for lab analysis. This requires physically visiting a location, collecting a sample, and waiting for analytical results

Continuous water-quality monitors are used because water quality can change frequently over time, necessitating frequent, repeated measurements to adequately characterize variations in quality




Monthly

Storms

Daily

Hourly

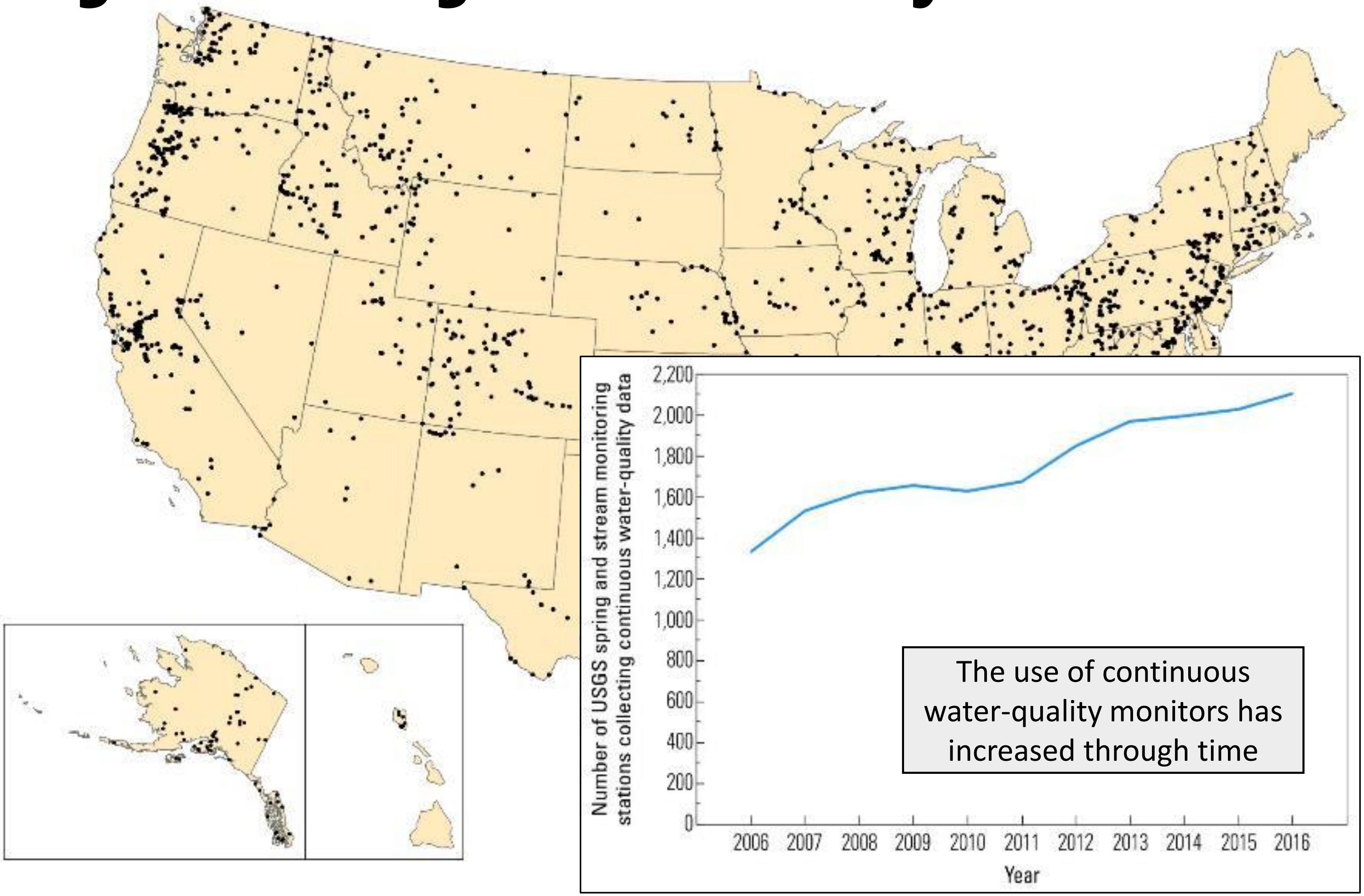
15 minute

5 m

USGS
science for a changing world

James River at Cartersville, VA (USGS 02035000). Data available online: https://waterdata.usgs.gov/usa/nwis/uv?02035000

Continuous water-quality monitors are being used throughout the country



The use of continuous water-quality monitors has increased through time

Continuous water-quality parameters include water temperature, specific conductance, pH, dissolved oxygen, or turbidity. Data retrieved from NWIS on 12/27/2017

http://phoenix.cr.usgs.gov/gb/2016/greenbook.html

A large and growing list of constituents can be monitored in the field

Water temperature
Specific conductance
pH/ORP
Dissolved Oxygen
Turbidity
Total Algae
fDOM
Ammonium

YSI 6-series

YSI EXO

Hydrolab HL4

Insitu Aqua TROLL

Eureka Manta+

Nitrate

Satlantic SUNA

TriOS NICO

OTT ecoN

Phosphate

Seabird HydroCycle

Oil, optical brighteners, tryptophan

Turner C3 Submersible Fluorometer

…and others

Each instrument has unique deployment requirements and measurement limitations that should be carefully considered before being selected

Multiple sensors can provide laboratory-grade real-time nitrate measurements

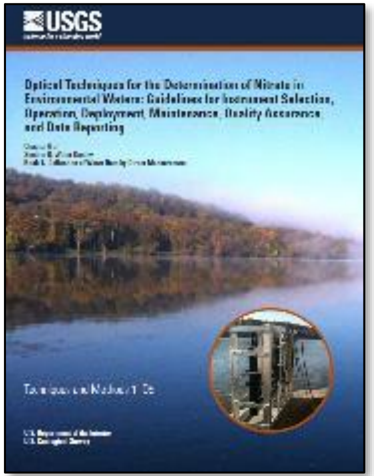
Satlantic SUNA

TriOS NICO

OTT ecoN

Stand-alone instruments infer nitrate concentrations by measuring the absorbance of light at specified wavelengths.

The TriOS NICO and OTT ecoN were recently brought to market at around ~10K, about half the cost of the Satlantic SUNA.



Optical Techniques for the Determination of Nitrate in Environmental Waters: Guidelines for Instrument Selection, Operation, Deployment, Maintenance, Quality Assurance, and Data Reporting

Pellerin and others, 2013

Stand-alone instruments perform similarly, but their strengths and weaknesses should be reviewed to determine what's best for each monitoring situation.

Even more recently, YSI released a nitrate sensor, the NitraLED, that can be integrated into the EXO platform.

We haven't yet used with the NitraLED, but its cost (~$6-8K) and EXO integration make it an intriguing option.

These instruments greatly improve our understanding of nitrate and, with paired discrete sampling, total nitrogen!

Phosphorus can be measured with continuous instrumentation… …but not without challenges

Seabird HydroCycle

GreenEyes NuLAB

Currently-available instruments measure dissolved phosphorus using wet chemistry techniques.

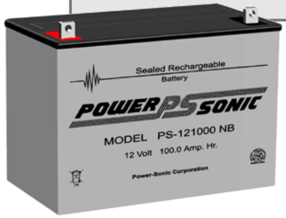
Such instruments produce a waste product that should be stored on site and not released into the stream.

Our HydroCycle field test struggled to maintain high-quality data throughout a deployment because of challenges pumping water through sediment-clogged filters.

Characteristics of an Effective Deployment

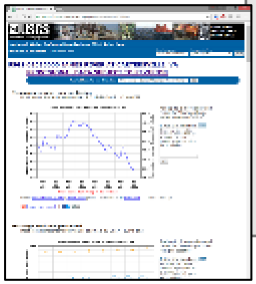
Effective deployments prevent a loss of data by meeting the power, data collection, and data relay requirements of all instruments

POWER
Most instruments are powered using a 30-watt solar panel and a 30- to 100-amp hr battery



A loss or failure of power, data collection, or data relay results in a potential loss of data

DATA COLLECTION
Most instruments are hardwired into the stream and send measurements to a datalogger



DATA RELAY
Measurements are transmitted to the internet to allow data access in near real-time

Effective deployments prevent a loss of data by minimizing the frequency and severity of instrument fouling

Deployed instruments can be fouled by sediment, debris, or organic material and need to be cleaned during routine service visits

Service visits also address the calibration drift of deployed instruments through adjustments to known standards

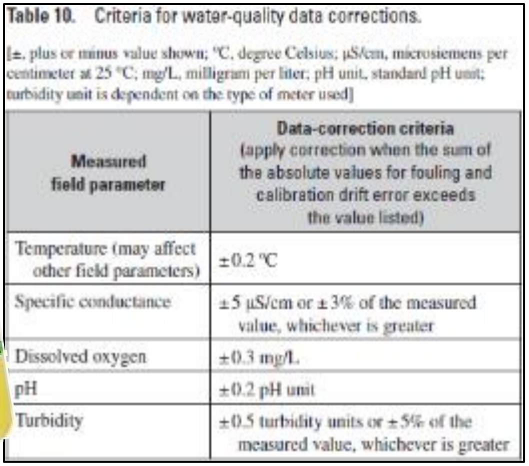


Table 10. Criteria for water-quality data corrections.

[±, plus or minus value shown; °C, degree Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligram per liter; pH unit, standard pH unit; turbidity unit is dependent on the type of meter used]

Measured field parameter	**Data-correction criteria** (apply correction when the sum of the absolute values for fouling and calibration drift error exceeds the value listed)
Temperature (may affect other field parameters)	±0.2 °C
Specific conductance	±5 µS/cm or ±3% of the measured value, whichever is greater
Dissolved oxygen	±0.3 mg/L
pH	±0.2 pH unit
Turbidity	±0.5 turbidity units or ±5% of the measured value, whichever is greater

Guidelines for operating continuous water-quality monitors, including servicing procedures are outlined in Wagner and others, 2006 (TM1-D3)

Fouling or calibration drift that exceeds established criteria require measured data to be deleted

Effective deployments minimize the frequency of fouling by selecting deployment locations that…

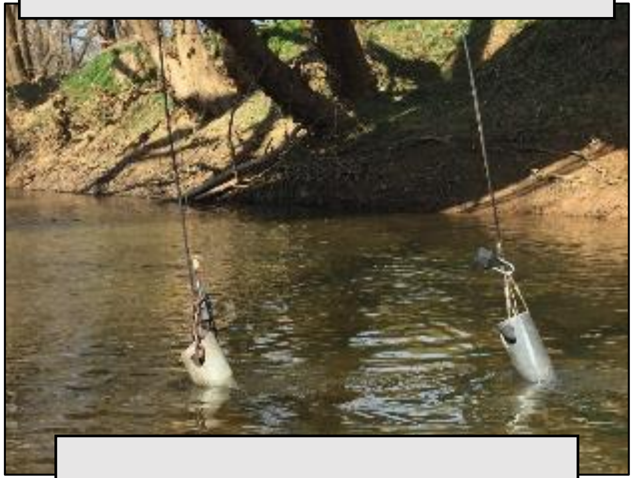
Place the instruments in flowing water

Flowing water flushes sediment and other debris off deployed instruments

Place the instruments away from streambanks

Sediment is often deposited on top of instruments deployed near the bank

Place the instruments away from the bottom of the stream

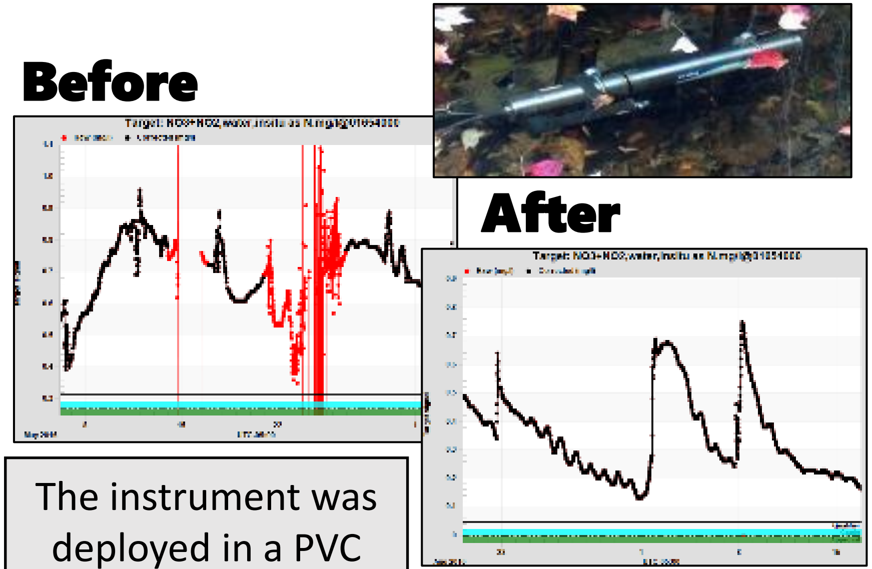


Sediment tends to accumulate on instruments that sit on the streambed

Sometimes the best deployment location isn’t immediately adjacent to the existing streamgage and requires separate power, data collection, and data relay sources

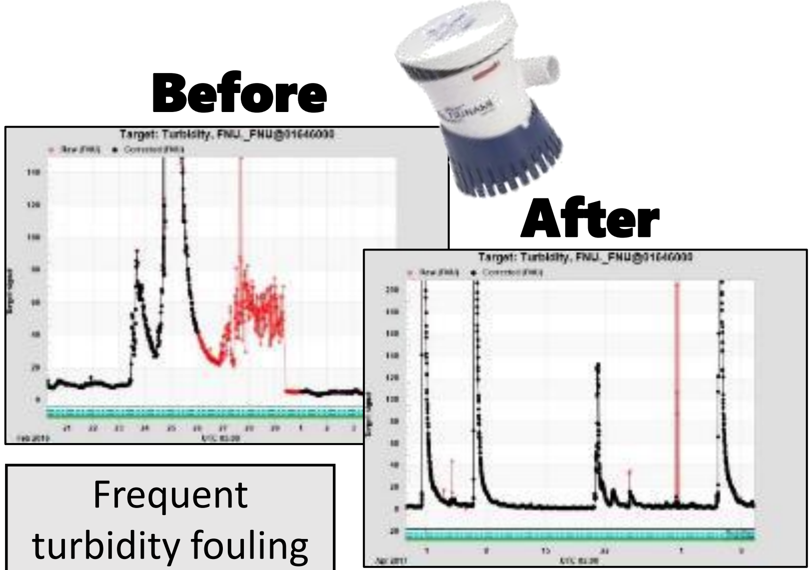
Time spent on site reconnaissance results in less data loss and site maintenance over the life of the deployment

Effective deployments are refined through time to reduce instrument fouling



The instrument was deployed in a PVC tube, which trapped sediment and fouled the nitrate data

The PVC tube was removed, improving the nitrate record

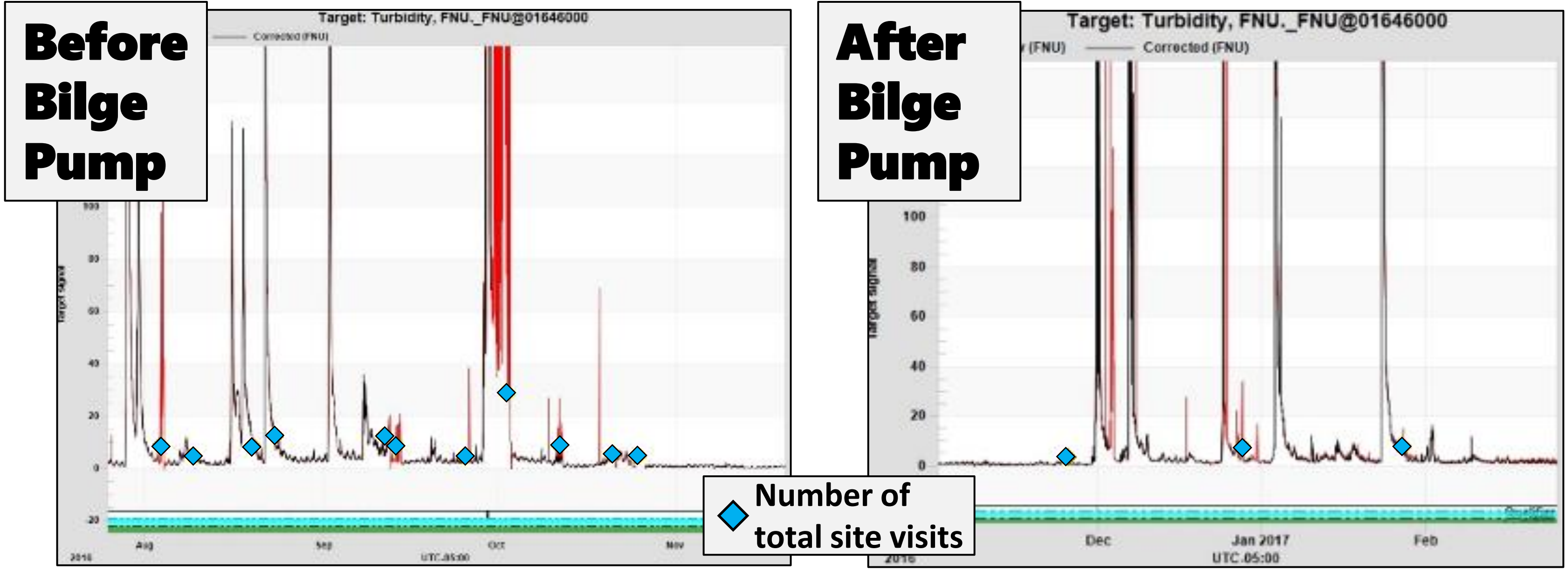


Frequent turbidity fouling was caused by sediment accumulation

A bilge pump was installed to clean the probes, improving the turbidity record

Across the Virginia continuous water-quality monitoring locations, less than 10% of all data are missing or have been deleted as a result of equipment failure or fouling

Effective deployments that minimize instrument fouling reduce the number of necessary site visits



Before Bilge Pump

After Bilge Pump

◆ Number of total site visits

Technicians needed to visit this site once every other week to clean the sonde before a bilge pump was installed

There have been few unscheduled visits to address fouling at this site after the bilge pump was installed

Scheduled visits will always be necessary to properly maintain instrumentation, but unscheduled visits to address fouling should be minimized

An unscheduled site visit is required less than once a month at most Virginia continuous water-quality monitoring stations

Effective deployments minimize data loss, site visits, and…

Collect data from a location that accurately represents stream conditions

Allow personnel to safely and easily access the instruments

Keep instruments safe from debris and vandalism

Enable data collection during all flow conditions

Satisfy partner needs

What's it take to do this well??

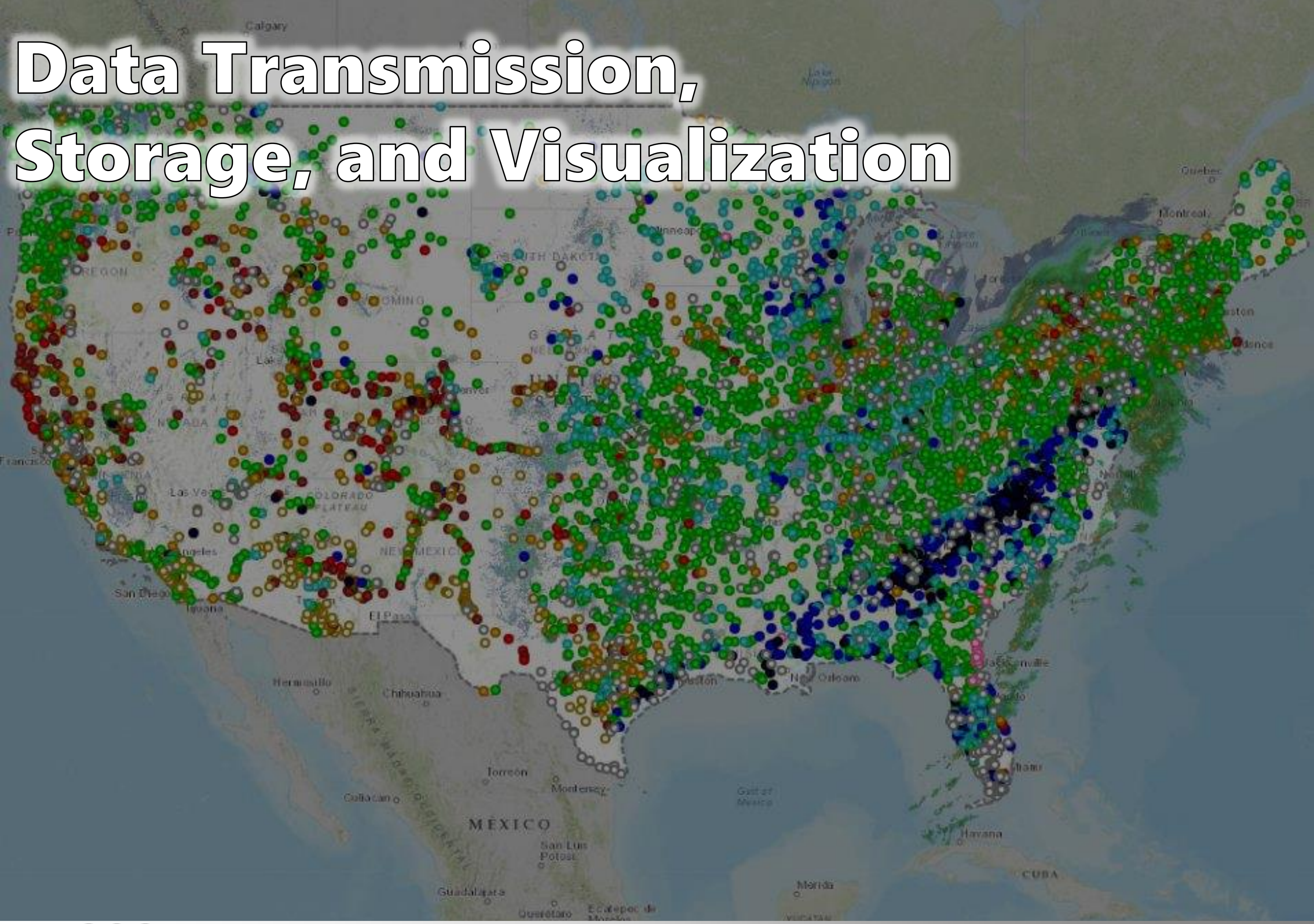
The right instruments. From power to logging to measurement: the right tools differ by site and situation.

Flexible personnel. Deployments are never perfect; unplanned field work is expected. Personnel need to actively monitor conditions and respond to problems quickly.

Experience. It takes a trained eye to review continuous data and decide when changes are needed.

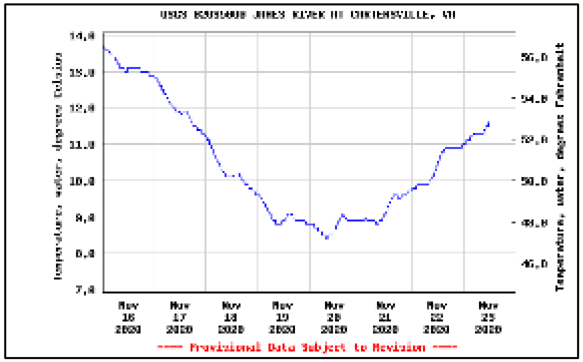
Commitment. The proper investment of time and resources will return high-quality data.

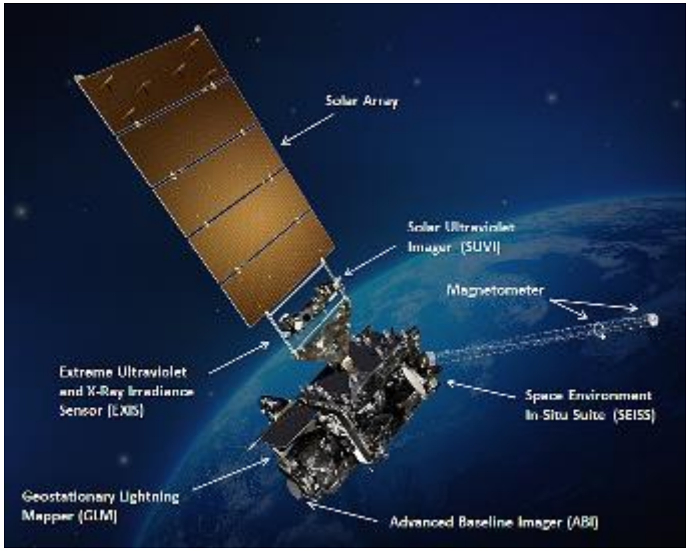
Data Transmission, Storage, and Visualization



Data transmission intervals should meet project needs

USGS data is traditionally transmitted from monitoring stations once an hour. Continuous data is subsequently refreshed every hour on the internet.





5-minute data transmissions can be made at sites when project needs demand accurate data, fast.

Water-quality is measured and transmitted every 5-minutes at a Roanoke River monitoring station upstream of the City of Salem drinking water intakes.

These data provide real-time alerts that inform water treatment operations and were recently used when 2,000 tons of coal were spilled in the river following a train derailment.

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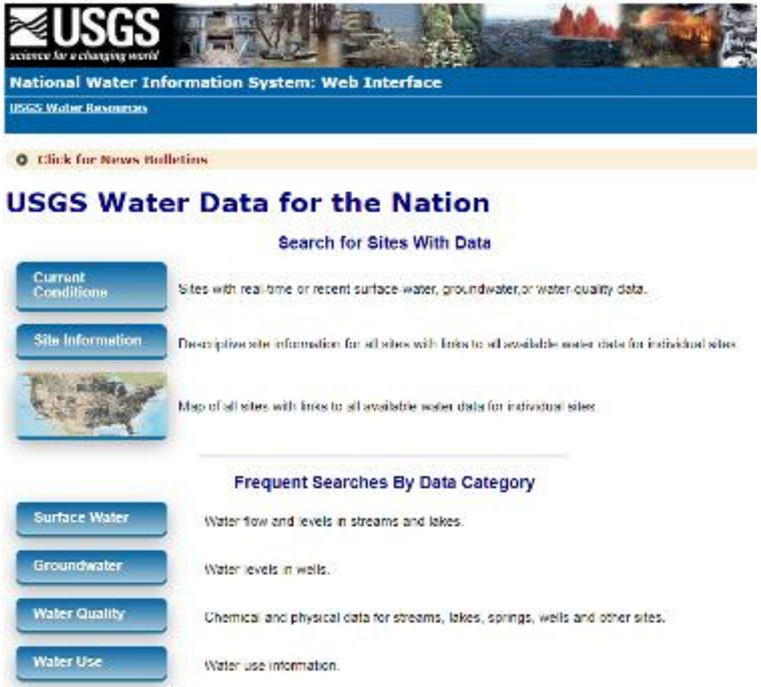
science for a changing world

Data storage should be robust, descriptive, and stable

USGS water-resource data are stored in the National Water Information System (NWIS), a publicly accessible, online database.

NWIS serves current and historical data collected from approximately 1.5 million sites throughout the country.



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National Water Information System: Web Interface

USGS Water Resources

Click for News Bulletins

USGS Water Data for the Nation

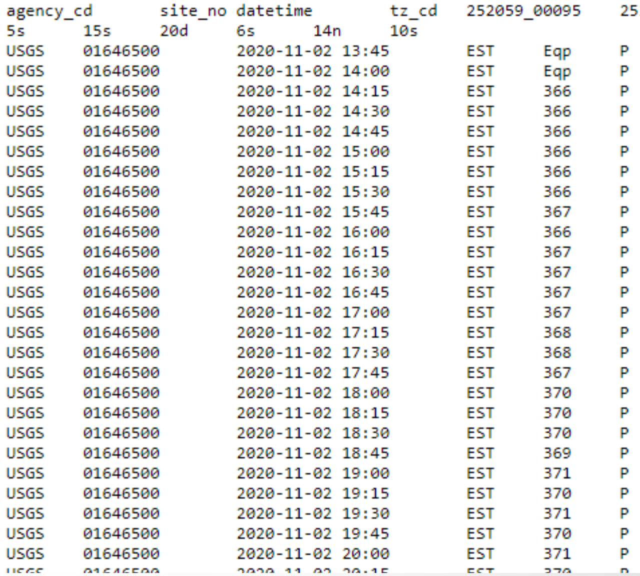
Search for Sites With Data

Current Conditions	Sites with real-time or recent surface-water, groundwater, or water-quality data.
Site Information	Descriptive site information for all sites with links to all available water data for individual sites.
	Map of all sites with links to all available water data for individual sites.

Frequent Searches By Data Category

Surface Water	Water flow and levels in streams and lakes.
Groundwater	Water levels in wells.
Water Quality	Chemical and physical data for streams, lakes, springs, wells and other sites.
Water Use	Water use information.

Continuous water-quality data generates a lot of data! Data measured every 15 minutes produces 96 values a day, about 35,000 measurements per year.



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USGS	01646500	2020-11-02 14:00	EST	Eqp	P
USGS	01646500	2020-11-02 14:15	EST	366	P
USGS	01646500	2020-11-02 14:30	EST	366	P
USGS	01646500	2020-11-02 14:45	EST	366	P
USGS	01646500	2020-11-02 15:00	EST	366	P
USGS	01646500	2020-11-02 15:15	EST	366	P
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USGS	01646500	2020-11-02 16:15	EST	367	P
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USGS	01646500	2020-11-02 18:15	EST	370	P
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USGS	01646500	2020-11-02 18:45	EST	369	P
USGS	01646500	2020-11-02 19:00	EST	371	P
USGS	01646500	2020-11-02 19:15	EST	370	P
USGS	01646500	2020-11-02 19:30	EST	371	P
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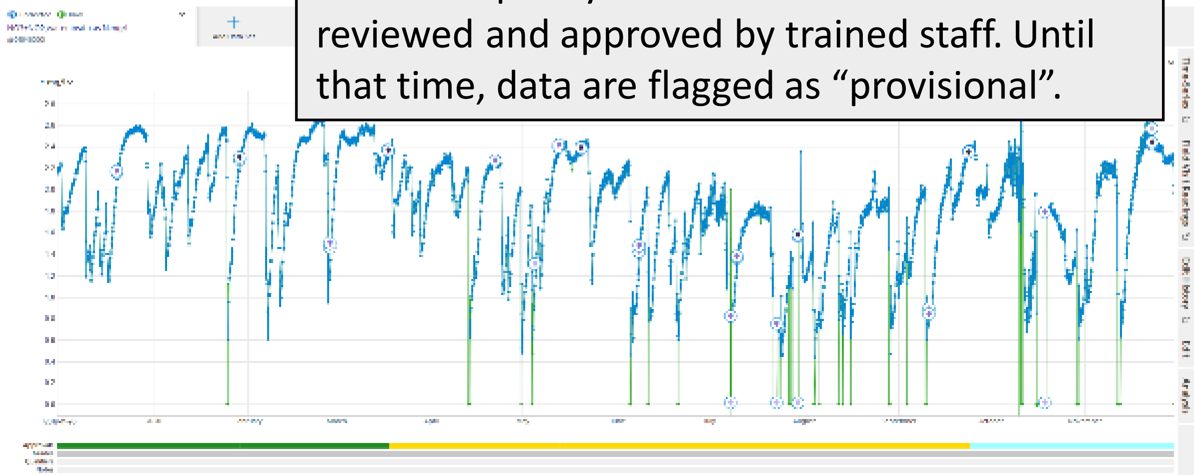
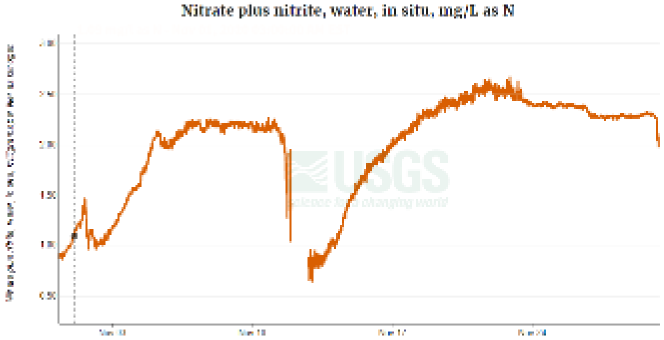


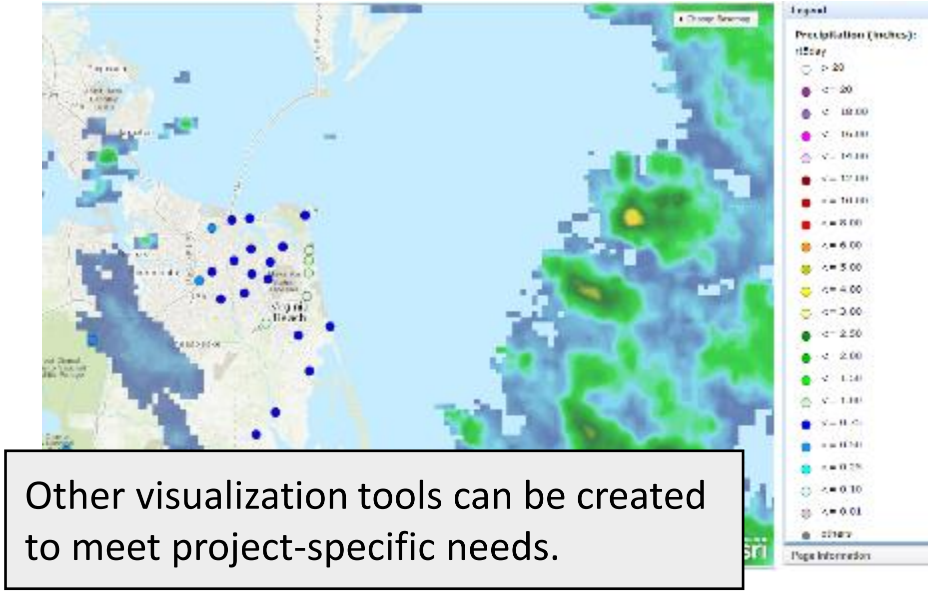
All water-quality data stored in NWIS are reviewed and approved by trained staff. Until that time, data are flagged as “provisional”.

Data visualization tools should communicate key information to maximize investments

NWIS contains visualization tools…

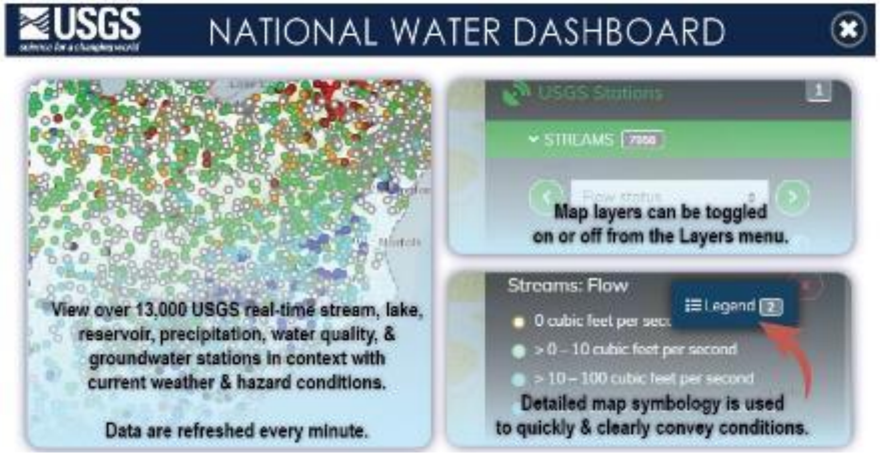
…for individual sites and parameters





Other visualization tools can be created to meet project-specific needs.

…and for multiple sites in an area



View over 13,000 USGS real-time stream, lake, reservoir, precipitation, water quality, & groundwater stations in context with current weather & hazard conditions.

Data are refreshed every minute.

Map layers can be toggled on or off from the Layers menu.

Detailed map symbology is used to quickly & clearly convey conditions.

https://dashboard.waterdata.usgs.gov/app/nwd/?region=lower48

Users can sign up to receive real-time notifications when parameters meet selected criteria at selected sites using the USGS Water Alert system.

From: USGS WaterAlert
Date: Sat, Jan 21, 2017 at 1:32 PM
Subject: WaterAlert ft, PEACHTREE CREEK AT ATLANTA, GA

Gage height of 10.70 ft exceeds subscriber threshold of 10 at 2017-01-21 13:15:00 EST PEACHTREE CREEK AT ATLANTA, GA
Notification interval, no more often than: Daily

For Realtime Data of this station:

For Subscription Help:

How much will it cost?

It Depends…

What constituents will be measured?

What instruments will be used?

How frequently will data be updated online?

How will equipment be housed and secured?

Are there supporting resources in the area?

New site vs existing streamgage?

Some ballpark figures…

Startup costs for building a new site typically range from ~$10K - $15K, excluding instrumentation and labor costs.

- 5-parameter sonde ~$15K
- Nitrate monitor ~$15K – $25K

WT, Sp. Cond., pH, DO, turbidity

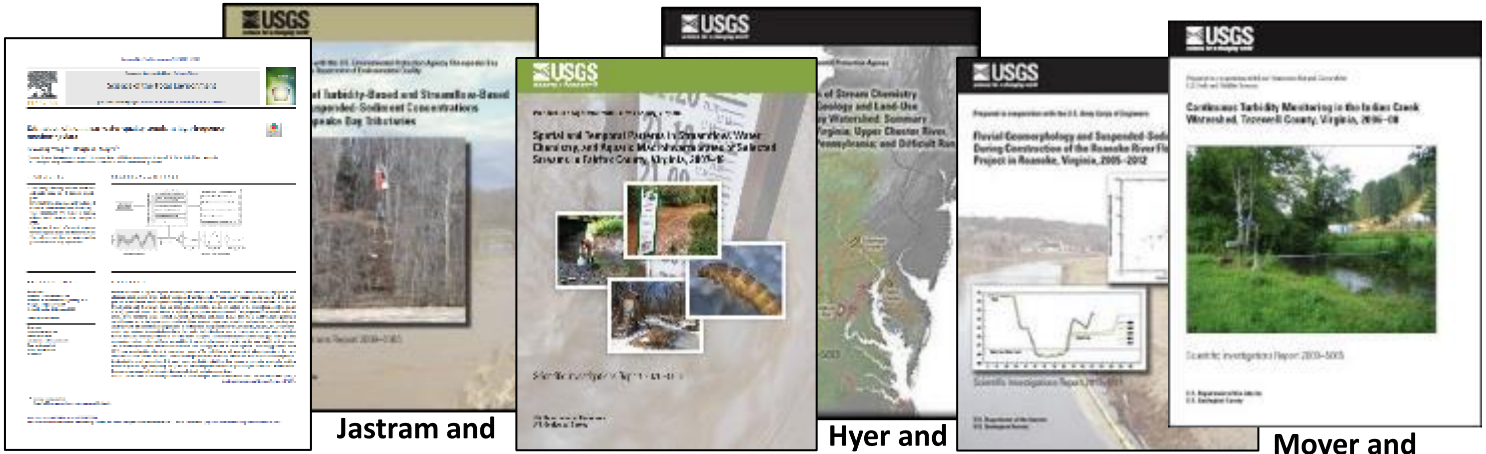
Annual costs to maintain continuous water-quality data ~$25K.

Want to calculate streamflow? Instrumentation costs are ~$5K and annual costs to develop and maintain data are ~$15K.

USGS can offset some of these costs through fund matching programs- each project is unique!

Analysis Techniques

Continuous water-quality data are used to enhance understanding of stream conditions and transport processes



Yang and Moyer, 2020

Jastram and others, 2009

Porter and others, 2020

Hyer and others, 2016

Jastram and others, 2015

Moyer and Hyer, 2009

To improve load estimates by developing surrogate regression models

To better characterize water-quality dynamics and temporal variability in a watershed

To measure impacts from anthropogenic activities on an ecosystem

Maximizing the scientific output and value of continuous water-quality monitors begins with an effective deployment

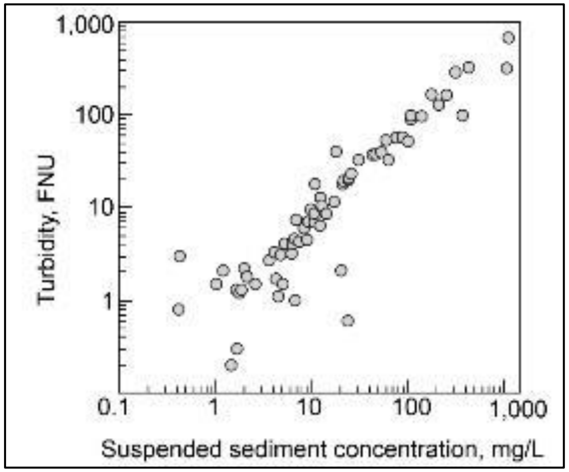
Continuous water-quality data can be used to generate real-time estimates of many infrequently measured constituents

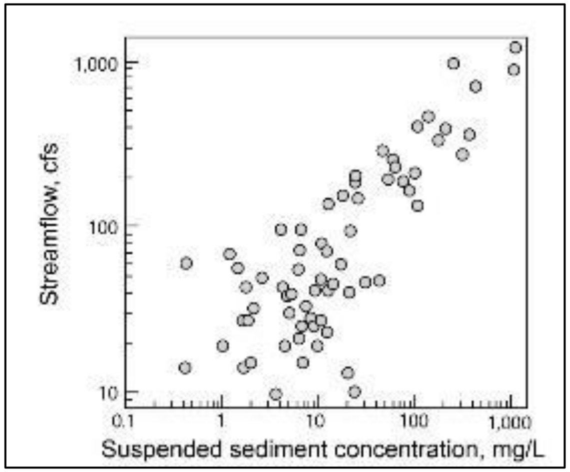
When is it likely that bacteria concentrations exceed set criteria?

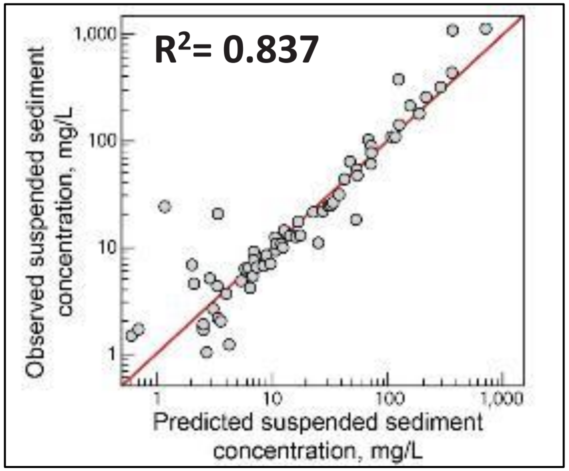
What is the total nitrogen and total phosphorus load in a river?

What is the sediment load delivered downstream during the largest storms?

These questions can be addressed by developing regression models that take advantage of the relations between continuous and discrete data







$$\ln(SSC) = 0.886 + 0.135*\ln(Q) + 0.817*\ln(TB)$$

Data from Smith Creek nr New Market, VA (USGS 01632900).
Load model published in Hyer and others, 2016.

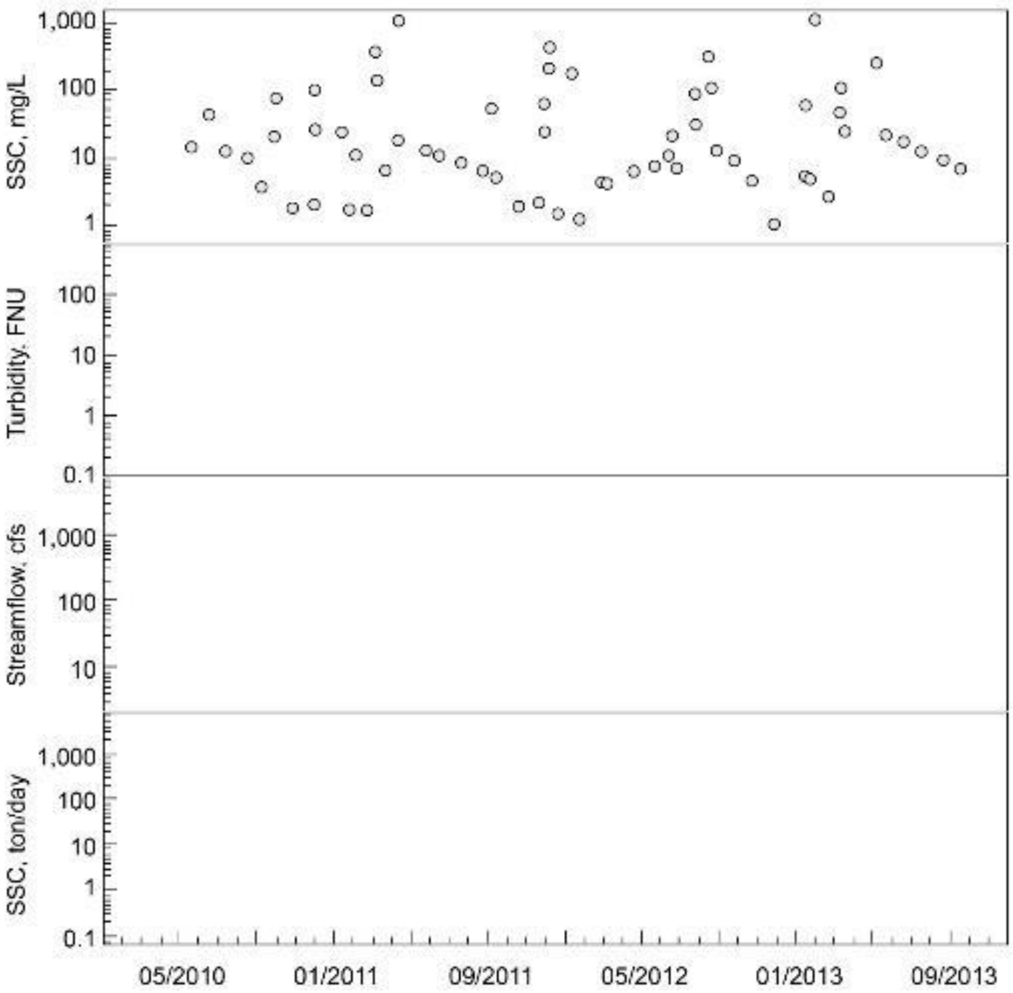
Continuous water-quality data can be used to generate real-time estimates of many infrequently measured constituents

SSC data were collected during monthly and storm-flow events

Turbidity and **streamflow** were measured every 15 minutes

A regression model was used to estimate **daily SSC concentrations**

Regression was used to compute **daily SSC loads** (concentration * flow)



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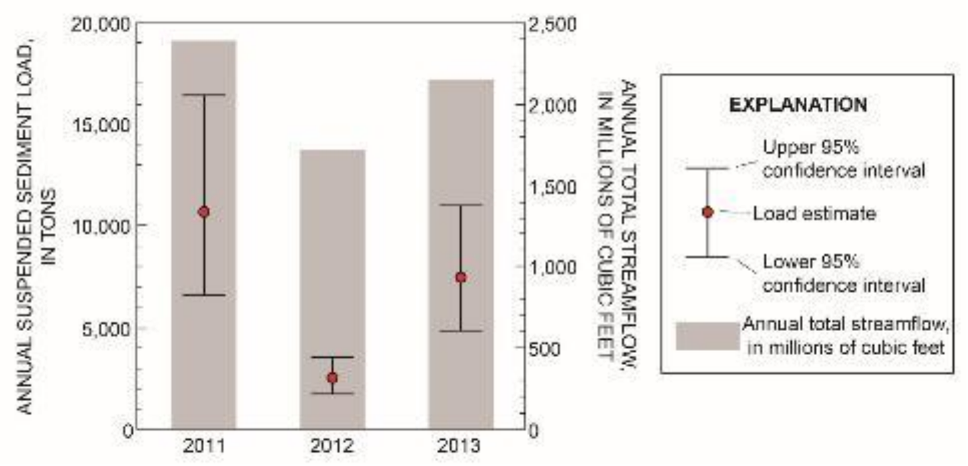
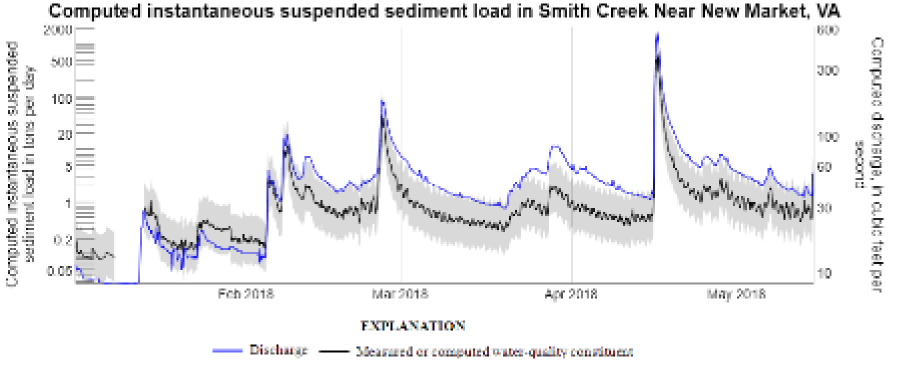


USGS

Guidelines and Procedures for Computing Time-Series Suspended-Sediment Concentrations and Loads from In-Stream Turbidity-Sensor and Streamflow Data

Techniques for computing suspended sediment loads from surrogate data were published by Rasmussen and others, 2009.

Once established, regression models can provide real-time estimates that can be used for management decisions.



Continuous water-quality data has been used to estimate occurrences of nutrients, metals, major ions, bacteria, cyanobacteria, cyanotoxins, optical properties, and more!

Real-time computations are available online: **https://nrtwq.usgs.gov**

Data from Smith Creek nr New Market, VA (USGS 01632900).
Load model published in Hyer and others, 2016.

Continuous water-quality data can be used to compute trends over time

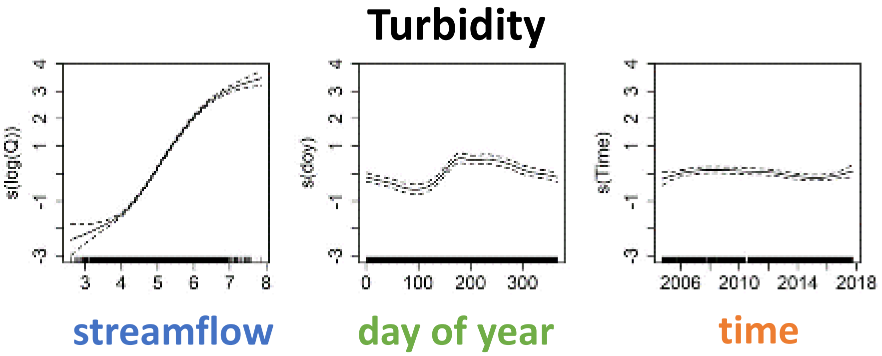
Science of the Total Environment

Estimation of nonlinear water-quality trends in high-frequency monitoring data

The need to develop a trend computation method using continuous water-quality data increased as record lengths increased throughout the country.

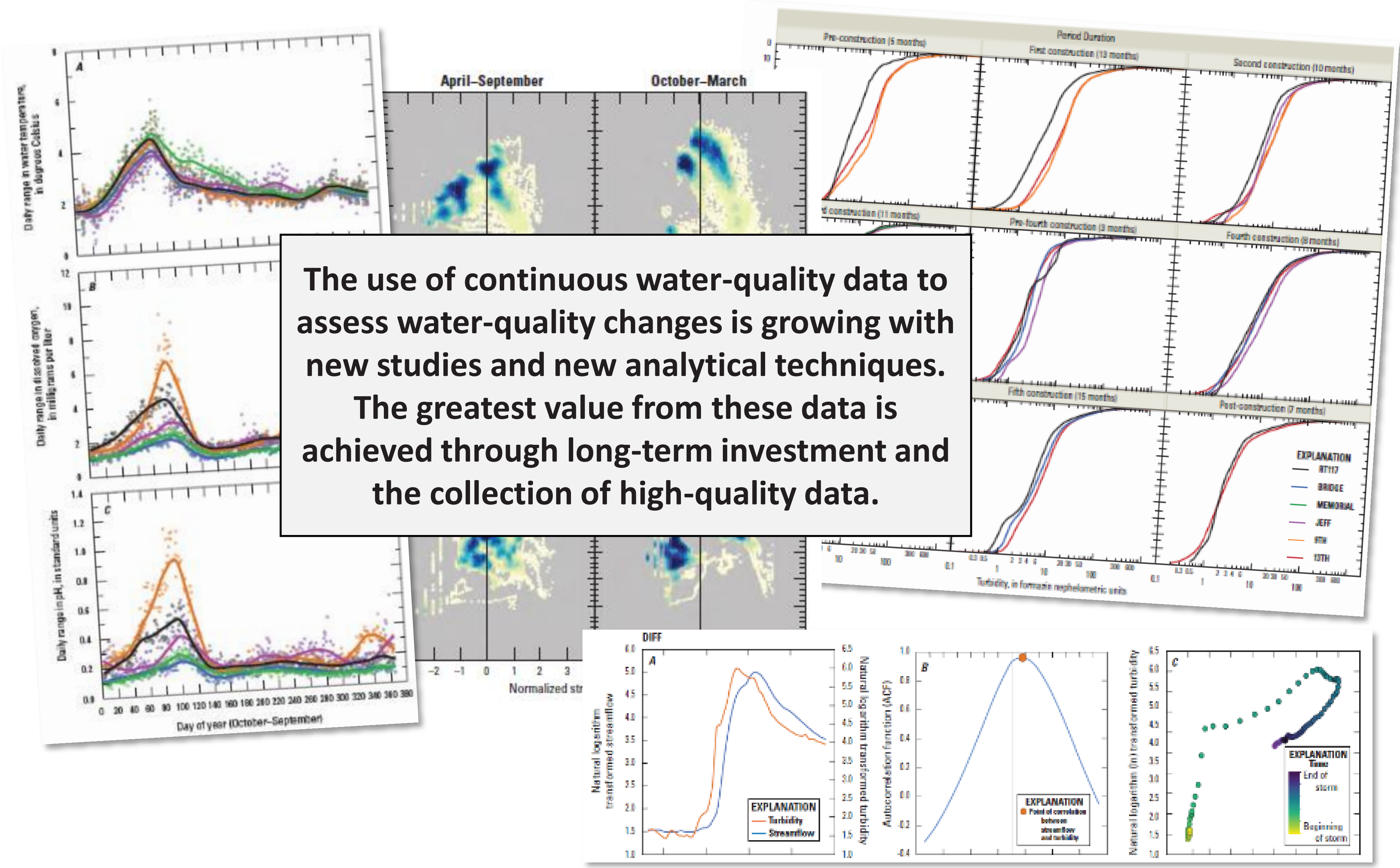
Yang and Moyer published a novel approach for computing trends in such data using a generalized additive modeling framework (GAM)

The approach removes the effects of streamflow and seasonality before assessing changes over time.



Yang and Moyer, 2020

The applications are endless…



The use of continuous water-quality data to assess water-quality changes is growing with new studies and new analytical techniques. The greatest value from these data is achieved through long-term investment and the collection of high-quality data.

Continuous Water-Quality Monitoring: deployment techniques and applications

December 2nd, 2020

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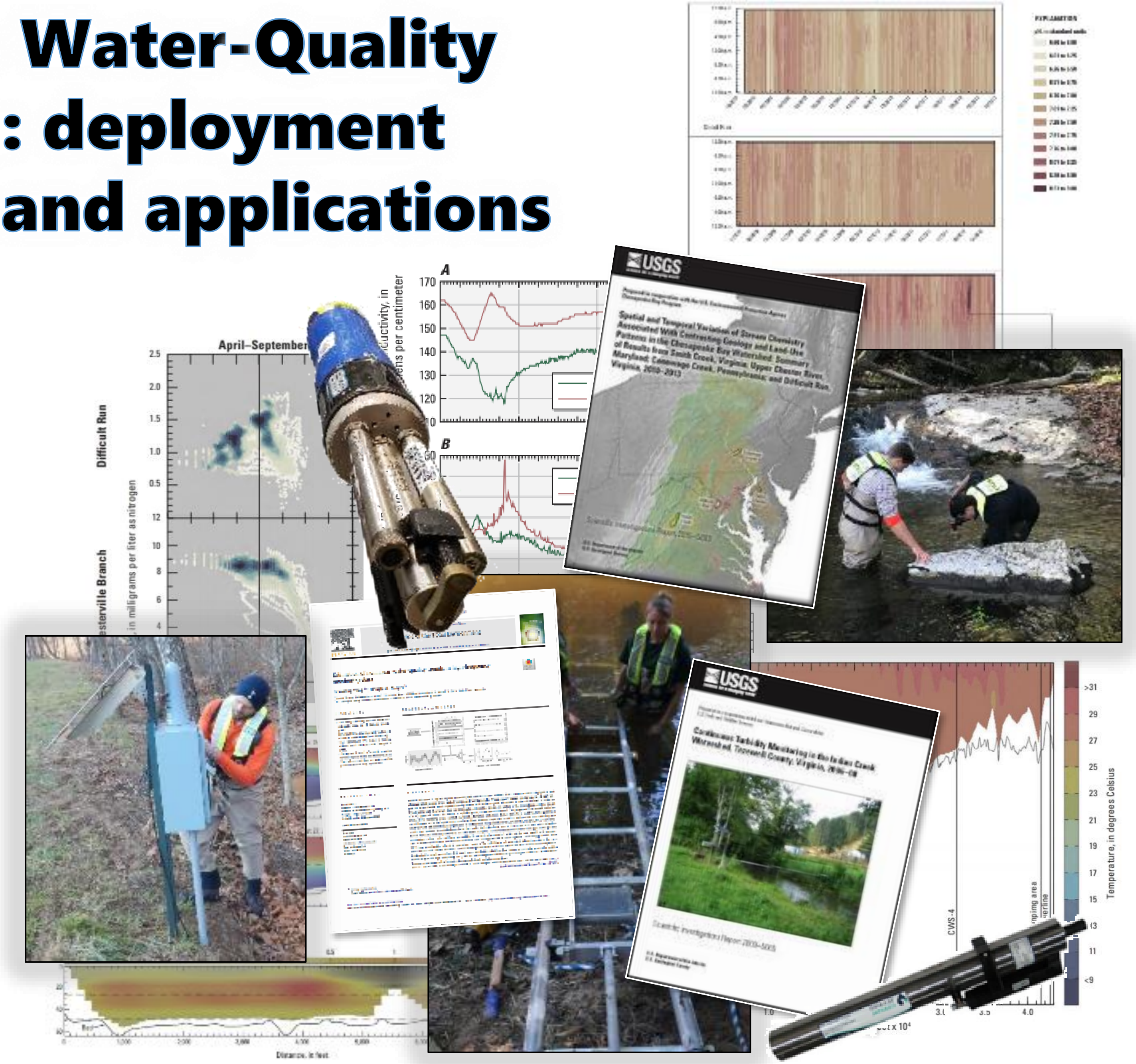

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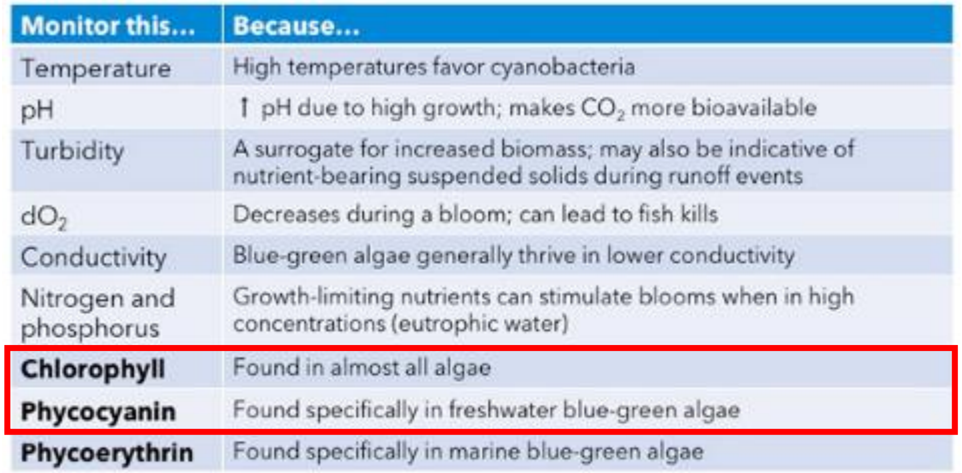
Many continuous parameters can inform the management of harmful algal blooms



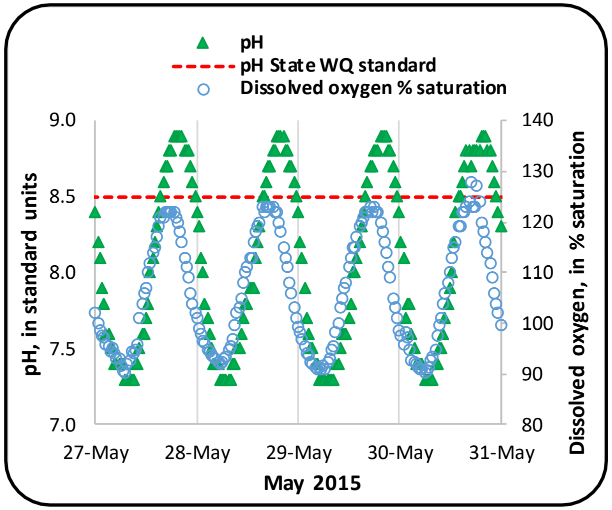
Monitor this…	Because…
Temperature	High temperatures favor cyanobacteria
pH	↑ pH due to high growth; makes CO_2 more bioavailable
Turbidity	A surrogate for increased biomass; may also be indicative of nutrient-bearing suspended solids during runoff events
dO_2	Decreases during a bloom; can lead to fish kills
Conductivity	Blue-green algae generally thrive in lower conductivity
Nitrogen and phosphorus	Growth-limiting nutrients can stimulate blooms when in high concentrations (eutrophic water)
Chlorophyll	Found in almost all algae
Phycocyanin	Found specifically in freshwater blue-green algae
Phycoerythrin	Found specifically in marine blue-green algae

Chlorophyll and phycocyanin measurements are expressed in relative fluorescence units, however, an internal algorithm developed by YSI can also provide a generalized estimate of chlorophyll in ug/L and cyanobacteria density in cells per mL.

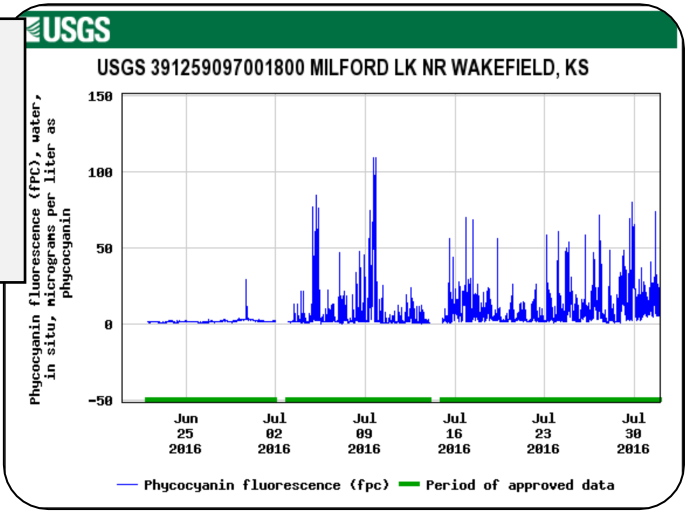
Much is still being learned about this relatively new technology, discrete chlorophyll and cyanobacteria samples should be collected to verify the concentration data produced from this algorithm.

The combined signal from multiple parameters and data sources can help inform HAB occurrences

Diurnal pH or DO signals can indicate algal activity



"Noisy" algal fluorescence can be associated with HABs

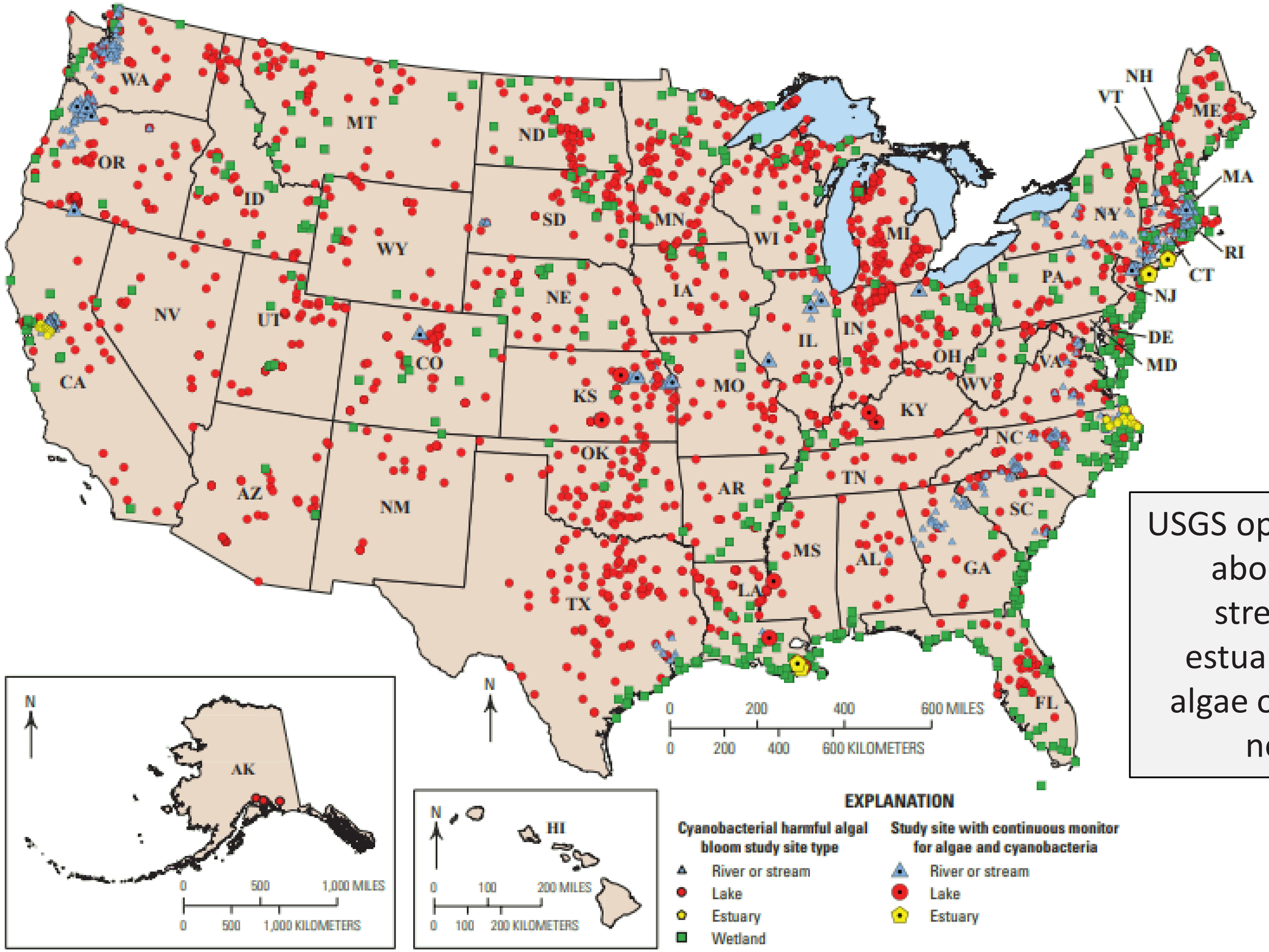


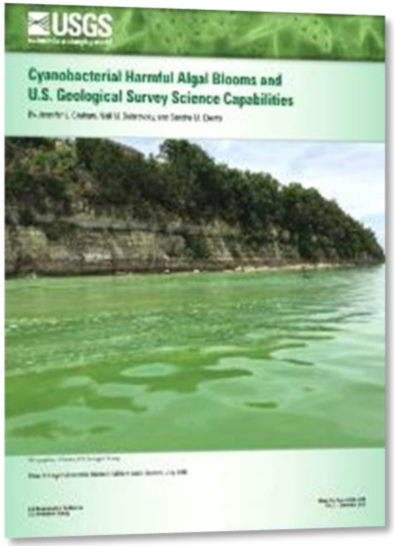
Webcams can be used to visually confirm HABs

July 7, 2016 at 1700

July 7, 2016 at 1800

USGS cyanobacterial harmful algal bloom study sites from mid-1990s through 2016



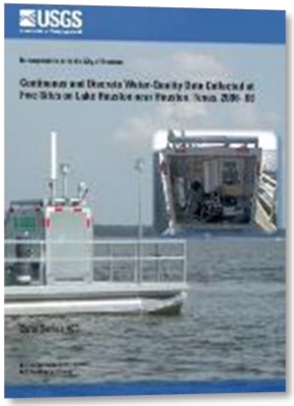

USGS

Cyanobacterial Harmful Algal Blooms and U.S. Geological Survey Science Capabilities

Graham and others, 2016

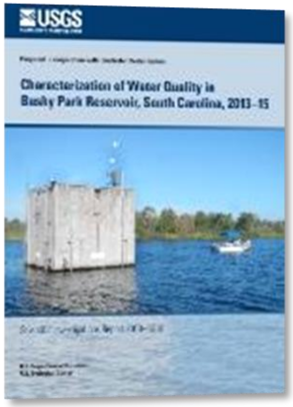
USGS operates a network of about 80 sensors in streams, lakes, and estuaries that measure algae or cyanobacteria in near real-time.

Studies using continuous water-quality data have been performed in drinking water supplies throughout the country…



Beussink and Burnich, 2009

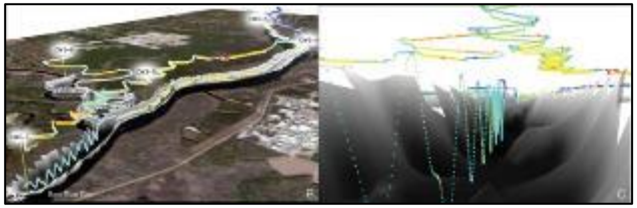
…to characterize the in-lake processes that affect water quality.

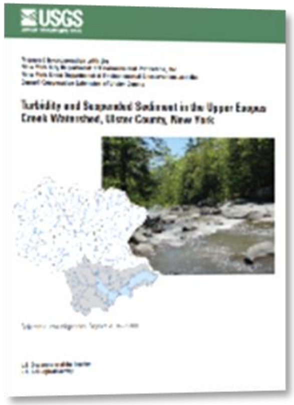


Characterization of Water Quality in Bushy Park Reservoir, South Carolina, 2013–15

Conrads and others, 2018

…to describe the processes that influence the occurrence and abundance of taste-and-odor constituents and cyanobacteria.

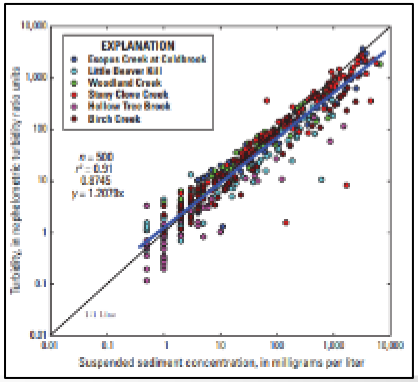


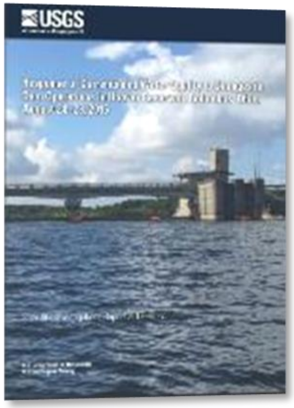


Turbidity and Suspended Sediment in the Upper Esopus Creek Watershed, Ulster County, New York

McHale and Siemion, 2014

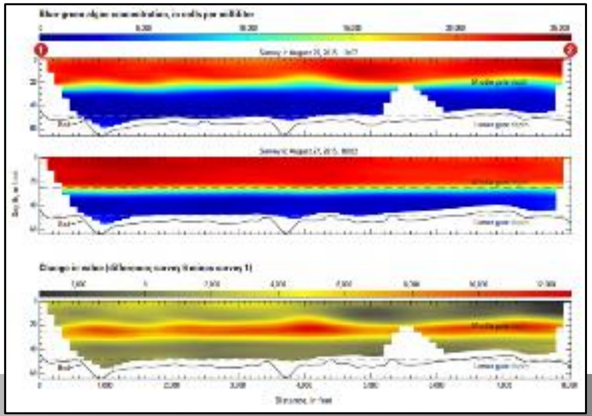
…to identify the temporal and spatial patterns of sediment loads in a water supply system.





Vonins and Jackson, 2017

…to characterize algal responses to different water withdrawal management strategies.



A real-time notification system of changing water-quality conditions that may affect drinking-water treatment: Cheney Reservoir, Kansas

USGS

Occurrence of Cyanobacteria, Microcystin, and Taste-and-Odor Compounds in Cheney Reservoir, Kansas, 2001–16

Scientific Investigations Report 2017–5016

Graham and others, 2017

The Cheney Reservoir is one of the primary drinking-water supplies for the city of Wichita, KS.

Cyanobacterial blooms have been occasionally present in the reservoir since the early 1990s.

The USGS, in partnership with the city of Wichita, has been collecting discrete monthly measurements of cyanobacteria, microcystin, and taste-and-odor compounds since 2001.

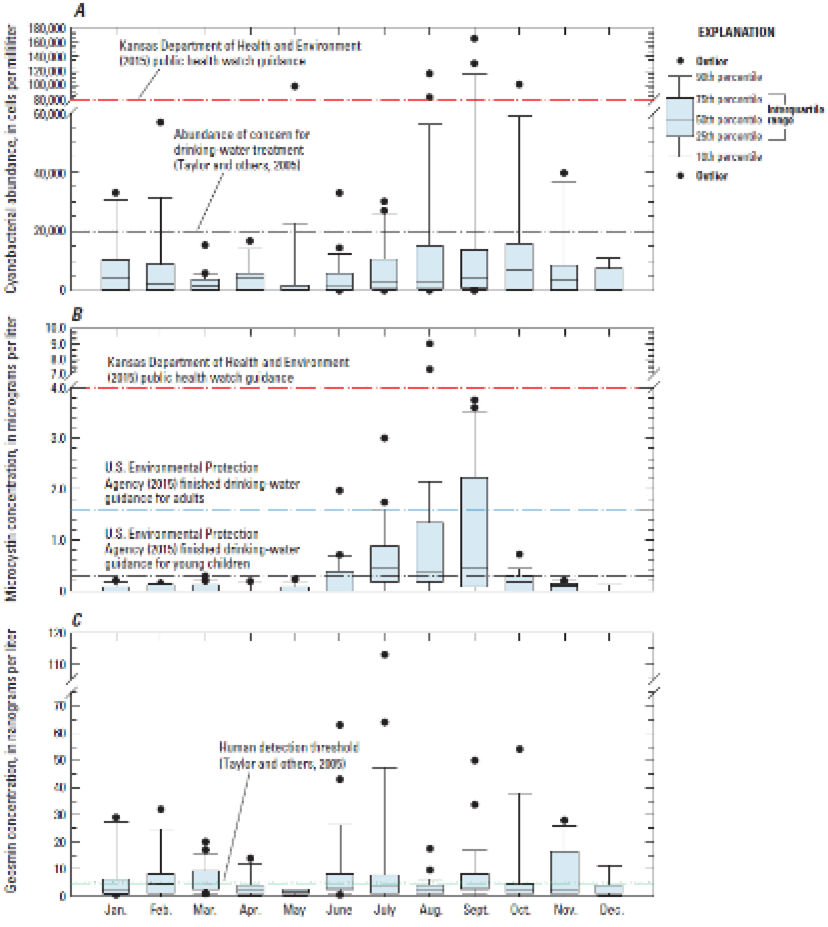


Figure 2. Seasonal patterns in Cheney Reservoir, Kansas, May 2001 through June 2016. *A*, cyanobacterial abundance. *B*, microcystin concentration. *C*, geosmin concentration.

A real-time notification system of changing water-quality conditions that may affect drinking-water treatment: Cheney Reservoir, Kansas

Total algal sensors are used to collect hourly chlorophyll and phycocyanin measurements

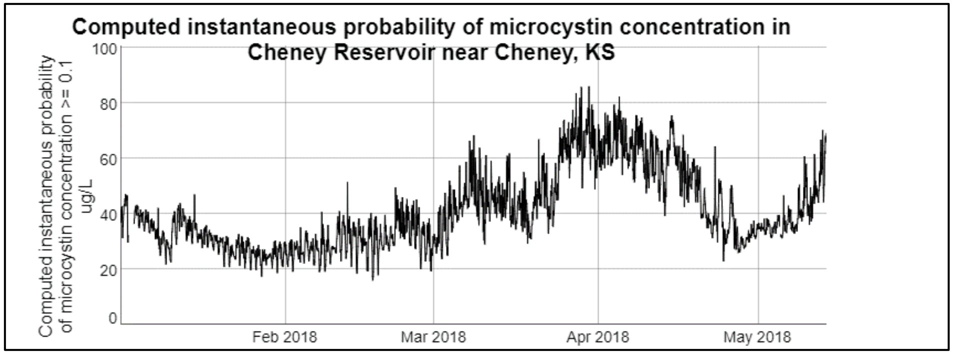
Continuous measurements of total chlorophyll, along with a seasonal term, are used to predict probability of microcystin >=0.1 ug/L

$$PMC = \frac{e^{-0.19 - 1.868 \sin(2\pi D / 365) - 1.109 \cos(2\pi D / 365) + 0.091 TChl}}{1 + e^{-0.19 - 1.868 \sin(2\pi D / 365) - 1.109 \cos(2\pi D / 365) + 0.091 TChl}}$$

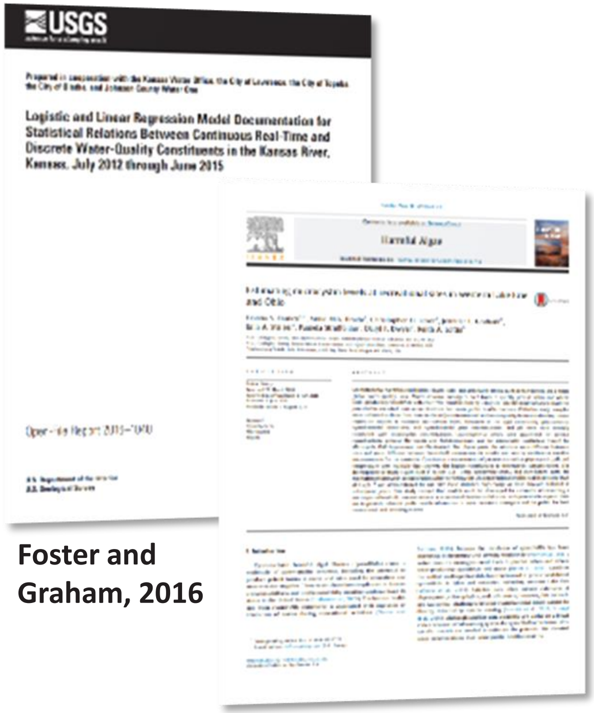
where:

- PMC is computed probability of microcystin >= 0.1 ug/L
- D is day of year, in the range of integers 1 through 365
- TChl is total chlorophyll, in micrograms per liter

These real-time exceedance estimates are available online: www.nrtwq.usgs.gov



Similar studies were performed on two sites on the Kansas River and three lakes in Ohio used for drinking-water supplies.



USGS

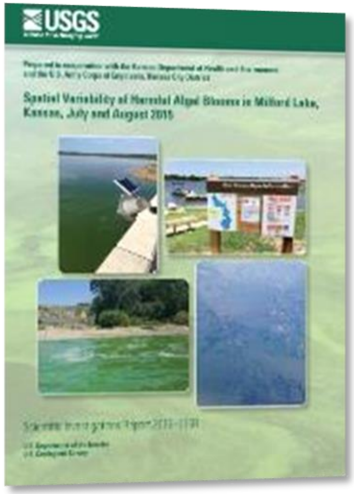
Logistic and Linear Regression Model Documentation for Statistical Relations Between Continuous Real-Time and Discrete Water-Quality Constituents in the Kansas River, Kansas, July 2012 through June 2015

Harmful Algae

Foster and Graham, 2016

Francy and others, 2016

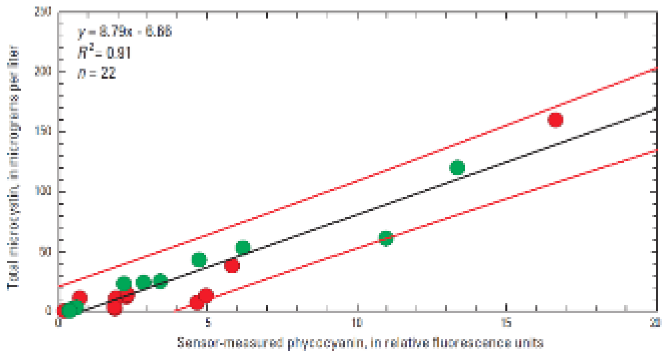
Spatial variability of harmful algal blooms in Milford Lake, Kansas, July and August 2015



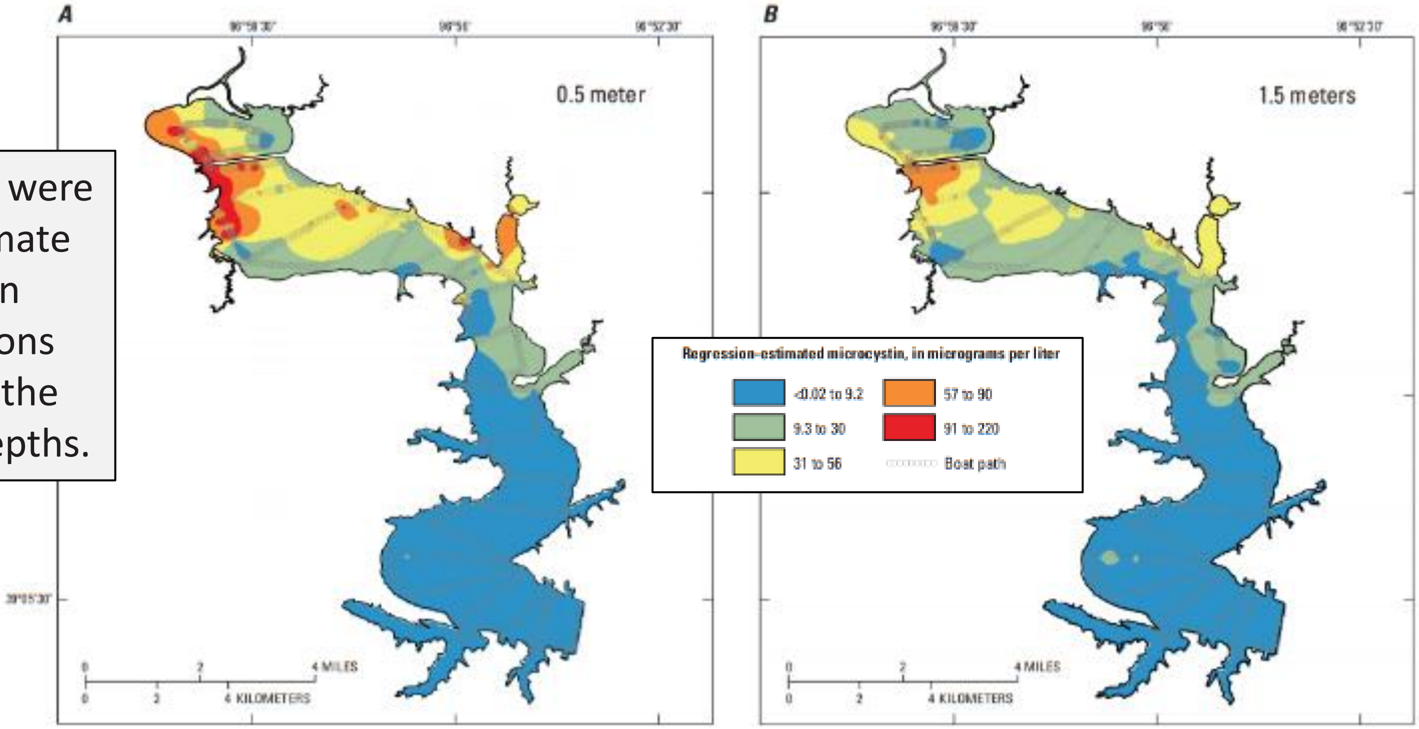
Foster and others, 2017

Continuous chlorophyll and phycocyanin measurements were collected from boat during a spatial survey.

Combined with discrete measurements of cyanotoxin concentrations, these data were used to construct regression models.



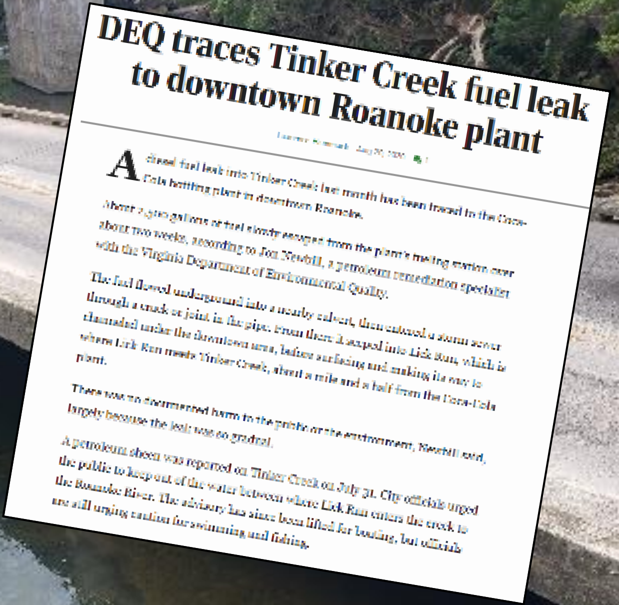
These models were used to estimate cyanotoxin concentrations throughout the lake at two depths.



Fluorometers can be used to detect anthropogenic compounds

Turner C3 Submersible Fluorometer

Fluorometers infer the presence of compounds such as fuels, oils, optical brighteners, and tryptophan by measuring stream fluorescence at specific wavelengths.



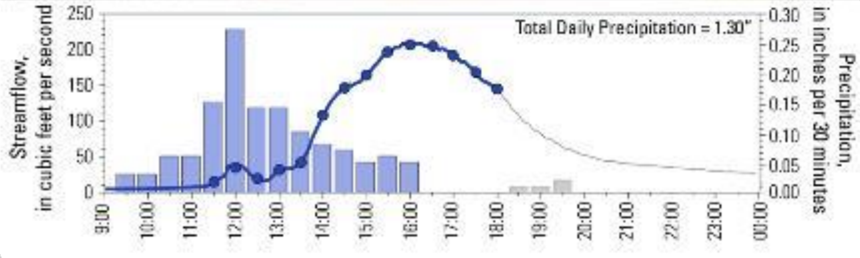
DEQ traces Tinker Creek fuel leak to downtown Roanoke plant

This instrument was used in the City of Roanoke in the summer of 2020 after a fuel leak was detected in local waterways.

Fluorescence readings were highest in waters near a Coca Cola factory, where DEQ later traced the source of the leak.

Imagery is used to estimate streamflow and visualize stream conditions

Imagery can also be used to better communicate the impacts and scope of stormflows.



Large-scale particle image velocimetry (LSPIV) is an emerging technique that uses videos to estimate streamflow through particle tracking.