

# Advanced water quality monitoring: The state of the technology and what's next

Beth A. Stauffer, Ph.D.

Assistant Professor

Department of Biology

University of Louisiana at Lafayette

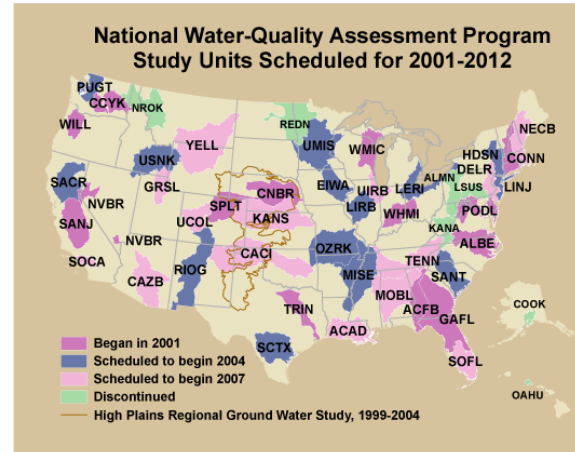
[stauffer@louisiana.edu](mailto:stauffer@louisiana.edu)



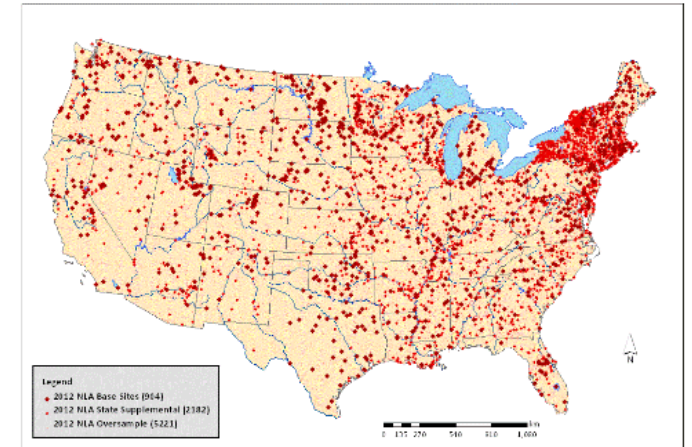
# How do we monitor water quality?

The “we”:

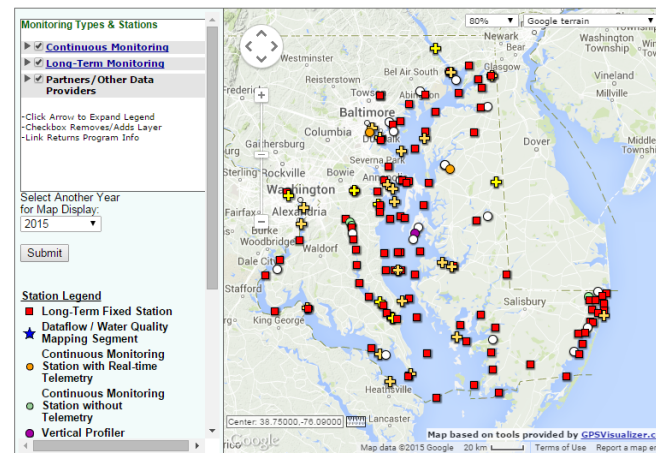
- Federal agencies
- Interstate commissions
- State agencies
- Counties, cities, parishes
- Non-profits
- Academics
- Citizens
- Industry
- Private/public sector utilities



USGS - NAWQA (2001-2012)  
<http://water.usgs.gov/nawqa/>



EPA - National Lakes Assessment (2012)  
[http://water.epa.gov/type/lakes/lakessurvey\\_index](http://water.epa.gov/type/lakes/lakessurvey_index)



Maryland DNR - Eyes on the Bay  
<http://mddnr.chesapeakebay.net/eyesonthebay>



Hudson Riverkeeper  
<http://www.riverkeeper.org/>

# How do we monitor water quality?

## Discrete Sampling



Space



Time

# How do we monitor water quality?

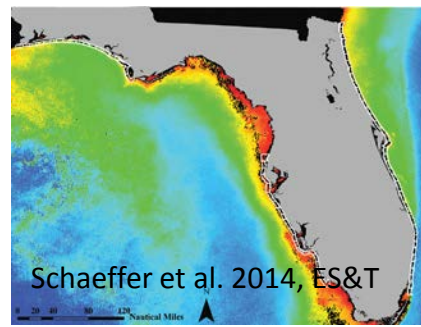
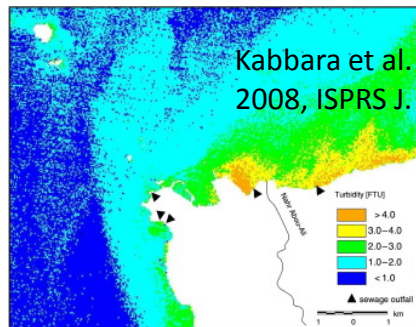
## Discrete Sampling



## Continuous Monitoring



## Remote Sensing



Space

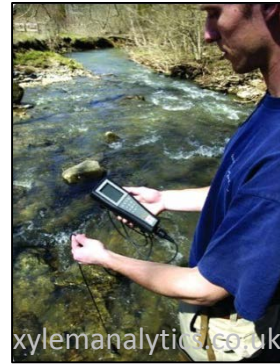


Time



# How do we monitor water quality?

## Discrete Sampling



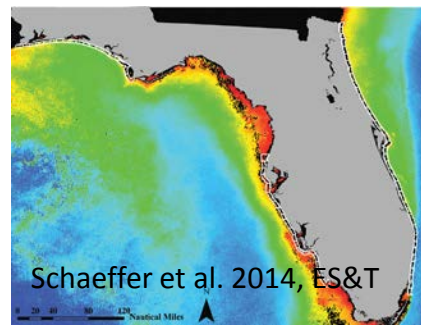
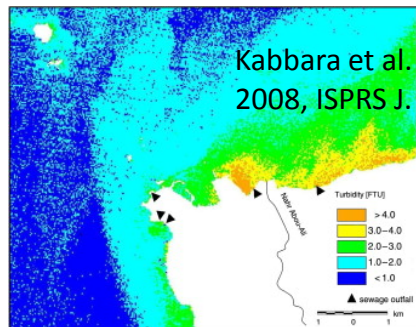
## New Capabilities



## Continuous Monitoring



## Remote Sensing



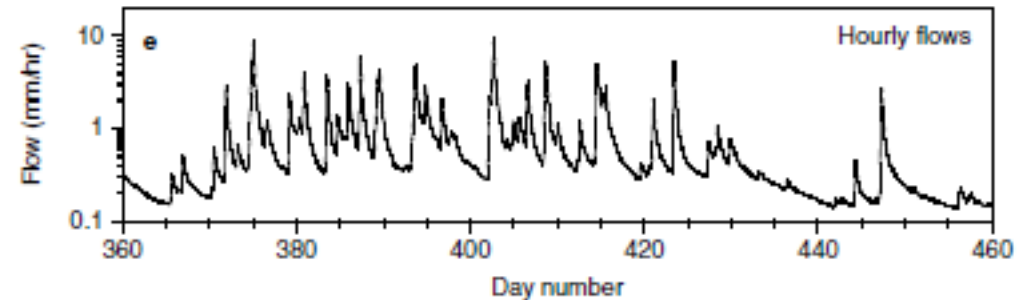
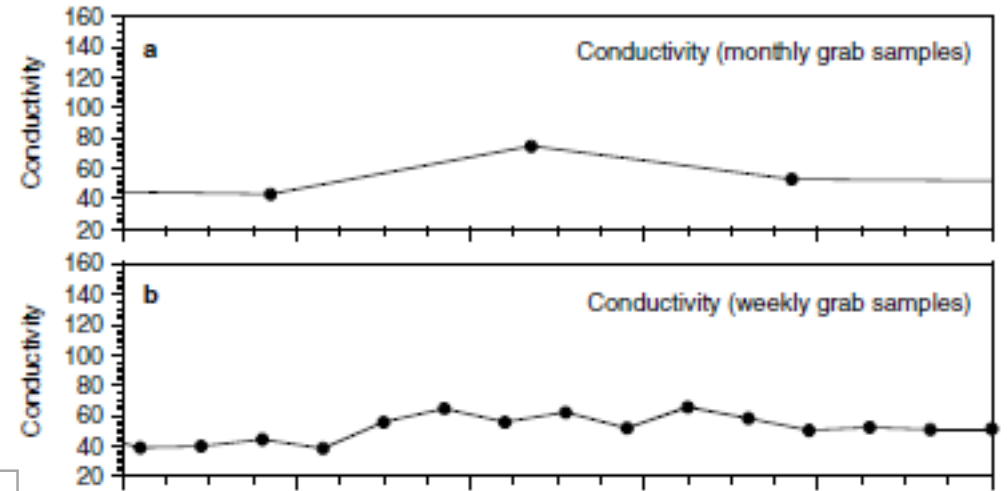
Space



Time

# How do we monitor water quality?

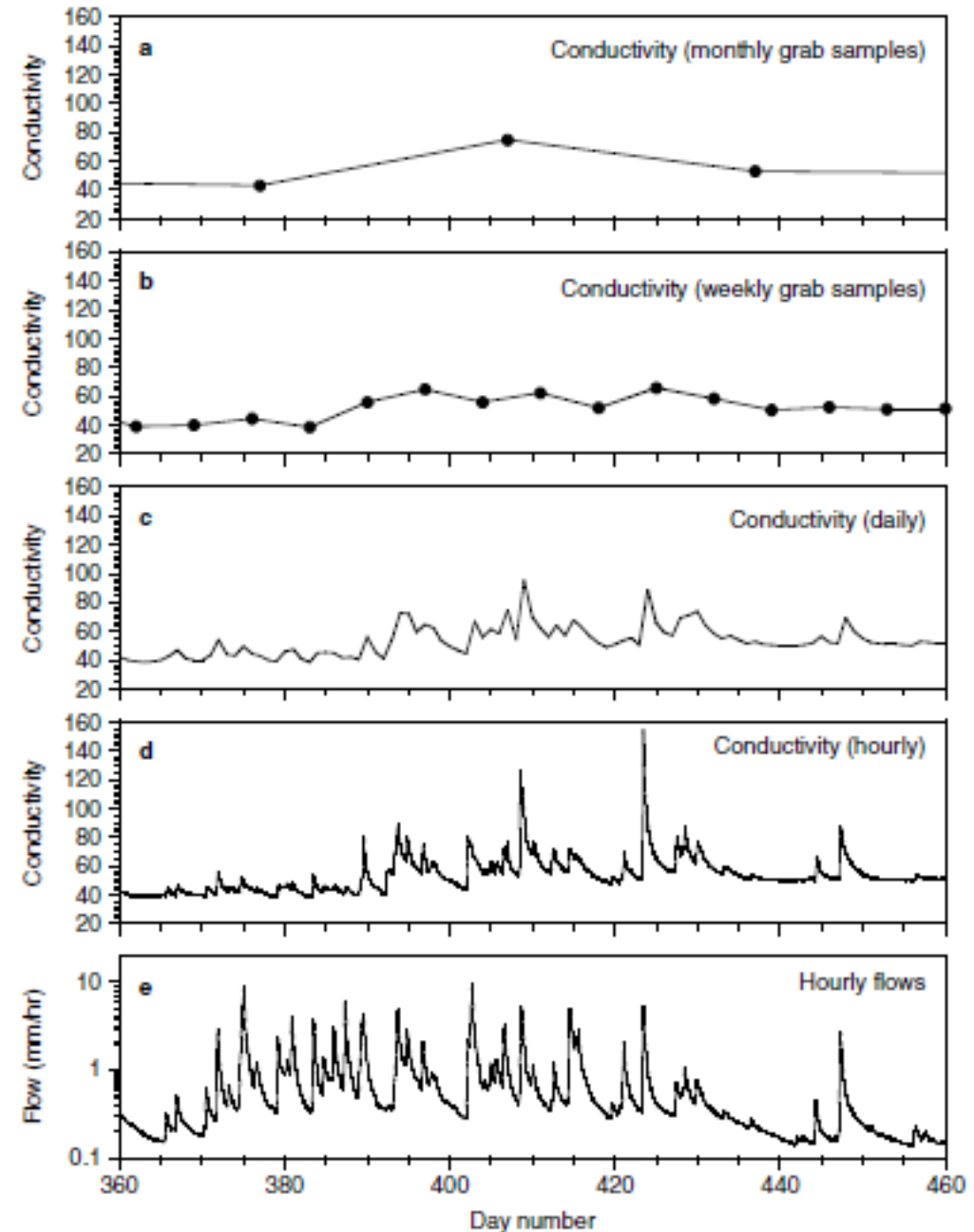
## Discrete Sampling



# How do we monitor water quality?

“...typical weekly or monthly monitoring programmes cannot capture the short-term chemical dynamics that most closely reflect hydrological processes. Thus high-frequency chemical observations will be essential in developing, calibrating, and validating the next generation of catchment models.”

From: Kirchner et al. 2004, Hydrologic Processes





## High temporal resolution of ion fluxes in semi-natural ecosystems – gain of information or waste of resources?

C. ALEWELL<sup>1,\*</sup>, G. LISCHIED<sup>1</sup>, U. HELL<sup>1</sup> and B. MANDERSCHIED<sup>2</sup>  
<sup>1</sup>*BITÖK, University of Bayreuth, Bayreuth, D-95440, Germany;* <sup>2</sup>*ZADI, Information Centre for Genetic Resources (IGR), Bonn, D-53177, Germany;* \*Author for correspondence (e-mail: [christine.alewell@bitoek.uni-bayreuth.de](mailto:christine.alewell@bitoek.uni-bayreuth.de); phone: 49-921-555741; fax: 49-921-555799)

James W. Kirchner<sup>1\*</sup>  
Xiahong Feng<sup>2</sup>  
Colin Neal<sup>3</sup>  
Alice J. Robson<sup>3</sup>

<sup>1</sup> *Department of Earth and Planetary Science, University of California, Berkeley, CA, USA*

<sup>2</sup> *Department of Earth Sciences, Dartmouth College, Hanover, NH, USA*

<sup>3</sup> *Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, UK*

Ecological Indicators 45 (2014) 529–537

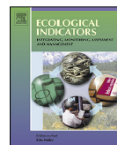


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Ecological Indicators

journal homepage: [www.elsevier.com/locate/ecolind](http://www.elsevier.com/locate/ecolind)



Too much data is never enough: A review of the mismatch between scales of water quality data collection and reporting from recent marine dredging programmes

Laura J. Falkenberg\*, Craig A. Styan

*School of Energy and Resources, UCL Australia, University College London, Torrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia*



HYDROLOGICAL PROCESSES

*Hydrol. Process.* 25, 828–830 (2011)

Published online 1 February 2011 in Wiley Online Library ([wileyonlinelibrary.com](http://wileyonlinelibrary.com)). DOI: 10.1002/hyp.7961

## On the value of long-term, low-frequency water quality sampling: avoiding throwing the baby out with the bathwater

T. P. Burt,<sup>1\*</sup>  
N. J. K. Howden,<sup>2</sup>  
F. Worrall<sup>3</sup> and  
J. J. McDonnell<sup>4</sup>

<sup>1</sup> *Department of Geography, Durham University, Science Laboratories, South Road, Durham DH1 3LE, Durham, UK*

<sup>2</sup> *Department of Civil Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR, UK*

<sup>3</sup> *Department of Earth Sciences, Durham University, Science Laboratories, South Road, Durham DH1 3LE, UK*

<sup>4</sup> *Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, Oregon 97331, USA*

INVITED COMMENTARY



HYDROLOGICAL PROCESSES

*Hydrol. Process.* 18, 1353–1359 (2004)

Published online in Wiley InterScience ([www.interscience.wiley.com](http://www.interscience.wiley.com)). DOI: 10.1002/hyp.5537

## The fine structure of water-quality dynamics: the (high-frequency) wave of the future

HYDROLOGICAL PROCESSES

*Hydrol. Process.* 29, 950–964 (2015)

Published online 7 May 2014 in Wiley Online Library ([wileyonlinelibrary.com](http://wileyonlinelibrary.com)) DOI: 10.1002/hyp.10205

## Using the precision of the mean to estimate suitable sample sizes for monitoring total phosphorus in Australian catchments

Jason S. Lessels\* and Thomas F. A. Bishop

*Department of Environment Sciences, Faculty of Agriculture and Environment, The University of Sydney, Sydney, NSW, Australia*



# Monitoring at appropriate scale



INVITED COMMENTARY

## High temporal resolution of ion fluxes in semi-natural ecosystems – gain of information or waste of resources?

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<sup>1</sup>*BITÖK, University of Bayreuth, Bayreuth, D-95440, Germany;* <sup>2</sup>*ZADI, Information Resources (IGR), Bonn, D-53177, Germany;* \**Author for correspondence:* christine.alewell@bitoek.uni-bayreuth.de; phone: 49-921-555741; fax: 49-921-555742

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Laura J. Falkenberg\*, Craig A. Styan

*School of Energy and Resources, UCL Australia, University College London, Torrrens Building, 220 Victoria Square, Adelaide, SA 5000, Australia*

DATAKLEPTOMANIA

## Long-term, low-frequency water quality monitoring – throwing the baby out with the bathwater

T. P. Burt,<sup>1\*</sup>  
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<sup>4</sup> *Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, Oregon 97331, USA*

## The precision of the mean to estimate suitable sample sizes for monitoring total phosphorus in Australian catchments

“the uncontrolled desire to collect more data”

Hellawell, et al., 1991; Vos et al., 2002

Department of Environmental Sciences, Faculty of Agriculture and Environment, The University of Sydney, Sydney, NSW, Australia

# How do we monitor *water quality*?

Acrolein	Chloride	Gases, Total	Nutrients (Total Phosphorus, Total Nitrogen, Chlorophyll a and Water Clarity)	Silver
Aesthetic Qualities	Chlorine	Dissolved		Solids Suspended and Turbidity
Aldrin	Chloropyrifos	Guthion		Sulfide-Hydrogen Sulfide
Alkalinity	Chromium (III)	Hardness	Oil and Grease	Tainting Substances
alphaEndosulfan	Chromium (VI)	Heptachlor	Oxygen, Dissolved Freshwater	Temperature
Aluminum	Color	Heptachlor Epoxide	Oxygen, Dissolved Saltwater	Toxaphene
Ammonia	Copper	Iron	Parathion	Tributyltin (TBT)
Arsenic	Cyanide	Lead	Pentachlorophenol	Zinc
Bacteria	Demeton	Malathion	pH	4,4'-DDT
betaEndosulfan	Diazinon	Mercury	Phosphorus Elemental	
Boron	Dieldrin	Methylmercury		
Carbaryl	Endrin	Methoxychlor		
Cadmium	gamma-BHC (Lindane)	Mirex	Polychlorinated Biphenyls (PCBs)	
Chlordane		Nickel	Selenium	
		Nonylphenol		

Recommended Aquatic  
Life Criteria

[http://water.epa.gov/scitech/  
swguidance/standards/criteria](http://water.epa.gov/scitech/swguidance/standards/criteria)

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Chlordane		Nickel		
		Nonylphenol		

Recommended Aquatic  
Life Criteria

[http://water.epa.gov/scitech/  
swguidance/standards/criteria](http://water.epa.gov/scitech/swguidance/standards/criteria)



http://www.act-us.info/database

**ALLIANCE FOR COASTAL TECHNOLOGIES**  
SUPPORTING INNOVATION TO BETTER UNDERSTAND, PREDICT AND MANAGE COASTAL, OCEAN AND GREAT LAKES ENVIRONMENTS

EVALUATIONS reports more  
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TECHNOLOGIES database more

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**ACT TECHNOLOGIES DATABASE**

The ACT Technology Database is a continuously updated catalogue of instrumentation used for coastal and ocean science and observations, designed to help you identify technologies available to meet your specific needs. Search by environmental parameters, sensor types or manufacturers.

- PHYSICAL
- BIOLOGICAL
- CHEMICAL
- PLATFORM
- HARDWARE
- SENSOR TYPE
- MANUFACTURER

https://www.nemi.gov/home

**NEMI**  
National Environmental Methods Index

NEMI is a searchable database that allows scientists and managers to find and compare analytical and field methods for all phases of environmental monitoring.

ABOUT NEMI  
Glossary  
FAQ

WNI's new web NEMI  
Sampling Protocols are now included in NEMI.  
Selected USGS-NAWQA and EPA-NARS ecological sampling methods added Jan. 2014

**GENERAL SEARCH**

Keyword  
Number  
Browse  
Protocols

Search entire NEMI database by keyword:

SEARCH

**FILTERED SEARCH**

Analytes  
Chemical  
Microbiological  
Population/Community  
Toxicity  
Physical  
Statistical  
Regulatory

Search by ANALYTES

Analyte name(s):

OR

Analyte code(s):

Limit by: (optional)

SEARCH

Home About Tech Database Workshops Evaluations The Sensor Contact

**CONDUCTIVITY/SALINITY**

The ACT Technology Database is a continuously updated catalogue of instrumentation used for coastal and ocean science and observations, designed to help you identify technologies available to meet your specific needs. Search by environmental parameters, sensor types or manufacturers.

<p><b>Compact CT</b></p> <p>Conductivity MIL Measurement Co.</p> <p>CONTINUE</p>	<p><b>SC200 Optical Conductivity Sensor</b></p> <p>Conductivity Oceanographic Oceanographic Analytical</p> <p>CONTINUE</p>	<p><b>Conductivity Sensor</b></p> <p>Conductivity MCK Environmental</p> <p>CONTINUE</p>	<p><b>Conductivity Sensor</b></p> <p>Conductivity Sea-Bird Electronics</p> <p>CONTINUE</p>	<p><b>Conductivity Sensor</b></p> <p>Conductivity Oceanographic Analytical</p> <p>CONTINUE</p>
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CONDUCTIVITY

Back to Physical - Tech Database

Modify your search: nitrate sensor  SEARCH

**RESULTS:** Your search for "nitrate sensor" returned: 3 results. [Back to search](#) Page 1 of 1

Method ID	Method Source	Descriptive Method Name	Get Method	Search Ranking
TM1-05 Maintenance and Field	USGS-OWQ	Maintenance and Operation of UV nitrate sensors	<a href="#">Download full method now (PDF file)</a>	41
TM1-05 Instrument Deployment	USGS-OWQ	Deployment of optical nitrate sensors	<a href="#">Download full method now (PDF file)</a>	31
TM1-05 Data Processing	USGS-OWQ	Data Processing Procedures for Optical Nitrate Sensors	<a href="#">Download full method now (PDF file)</a>	31

**RESULTS:** Your search for "nitrate sensor" returned: 3 results. [Back to search](#) Page 1 of 1

Modify your search: nitrate sensor  SEARCH

**WHO WE ARE**

Submit a method  
NWQMC  
ACWI  
Contact us

**LEGAL**

Terms of use  
Accessibility  
FOIA  
Privacy  
Policies and notices

NWQMC USGS EPA

# What we monitor well

## Physical properties:

Temperature  
Flow/current  
Stage/height

## Chemical properties:

Conductivity\*

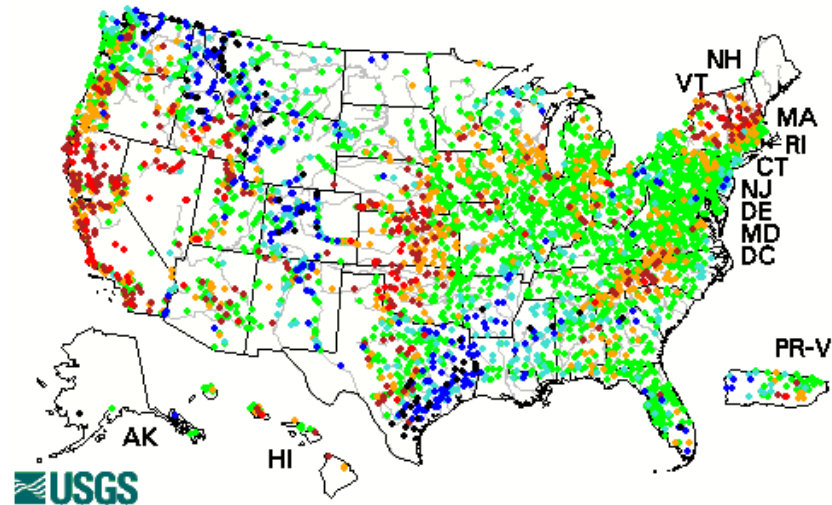


## USGS Current Water Data for the Nation

--- Predefined displays ---  
Introduction ▼ go

## Daily Streamflow Conditions

Monday, March 23, 2015 18:00ET



# What we monitor well



## Physical properties:

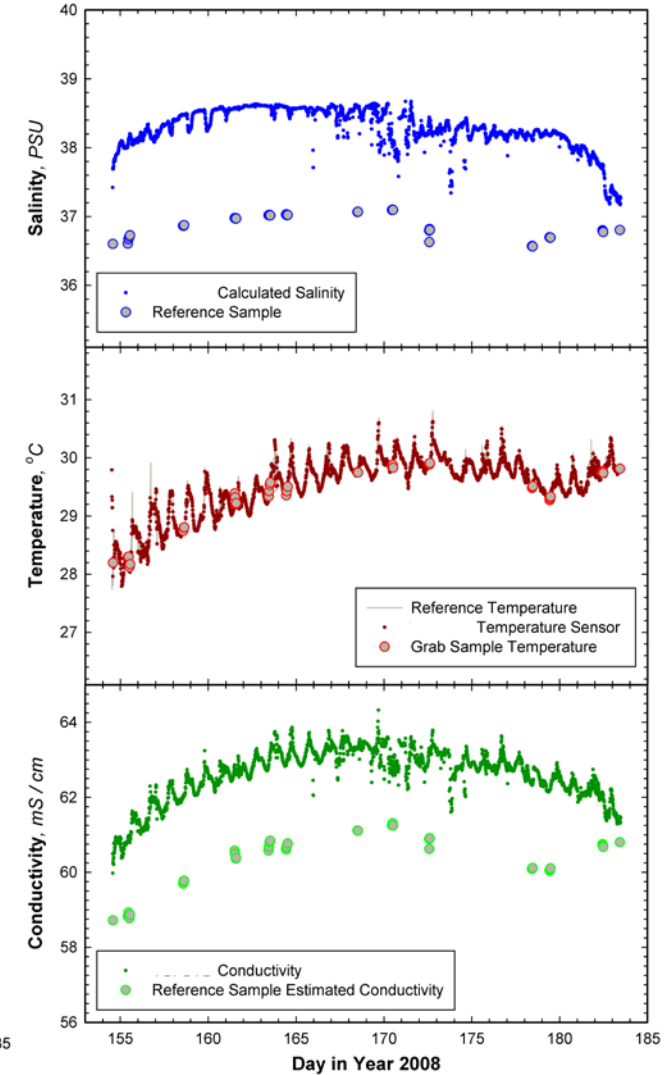
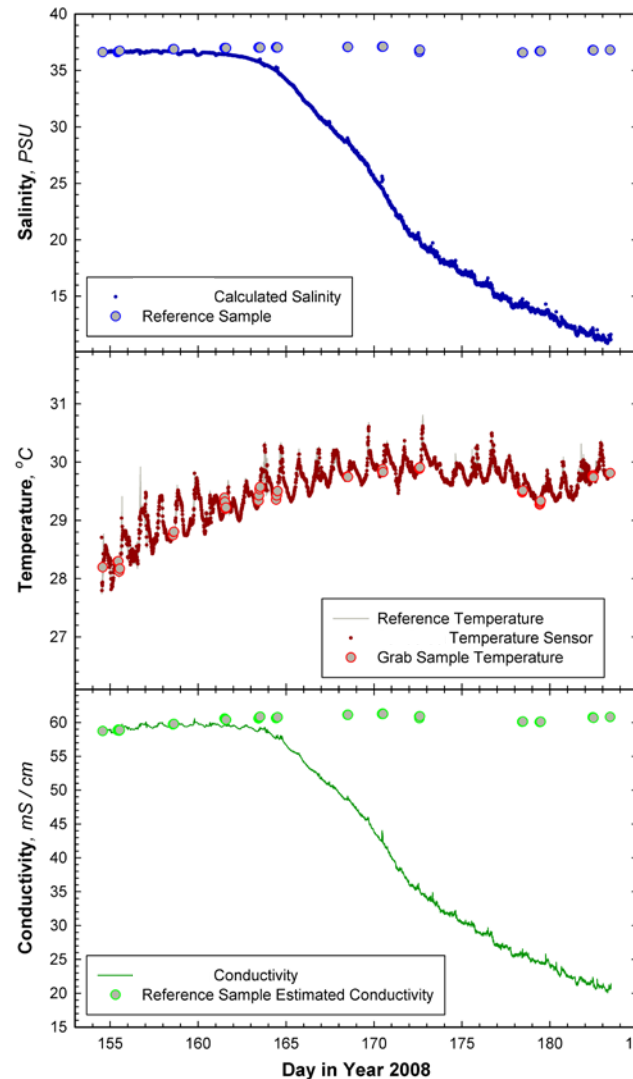
Temperature  
Flow/current  
Stage/height

## Chemical properties:

Conductivity\*

**Mature ≠ Accurate**

\*Continued need for QA/QC when using sensors.





# What has improved in recent years

## Physical properties:

Temperature  
Flow/current  
Stage/height

## Chemical properties:

Conductivity\*

## Physical properties:

Suspended solids/turbidity\*

## Chemical properties:

Nutrients (dissolved N, P)\*

Dissolved oxygen\*

pH

## Biological constituents:

Algal biomass (Chl)

# What has improved in recent years

## Physical properties:

Suspended solids/turbidity\*

## Chemical properties:

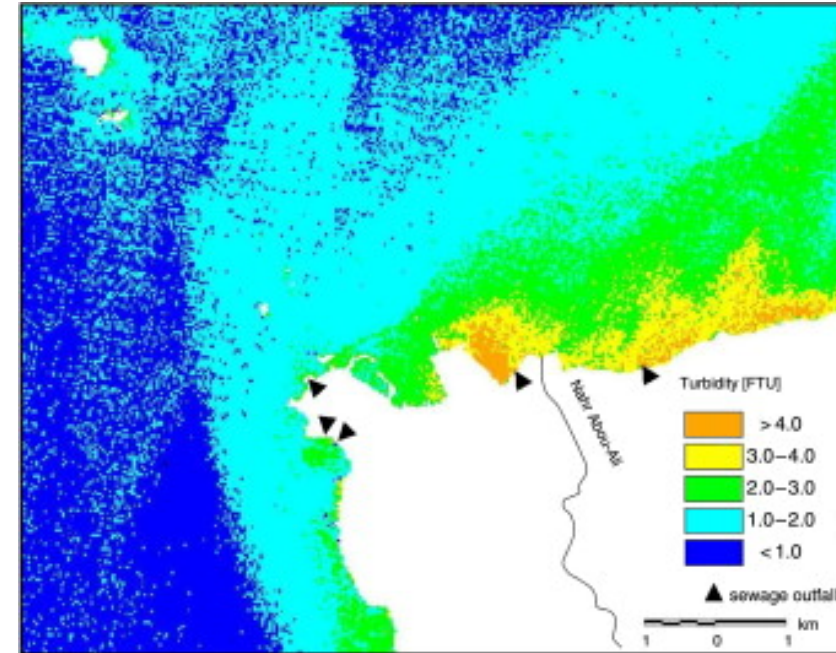
Nutrients (dissolved N, P)\*

Dissolved oxygen\*

pH

## Biological constituents:

Algal biomass (Chl)



Kabbara et al. 2008, ISPRS J.

**New algorithms allow use of satellite data (e.g. Landsat) for monitoring turbidity in shallow, coastal waters**

# What has improved in recent years

Physical properties:

Suspended solids/turbidity\*

Chemical properties:

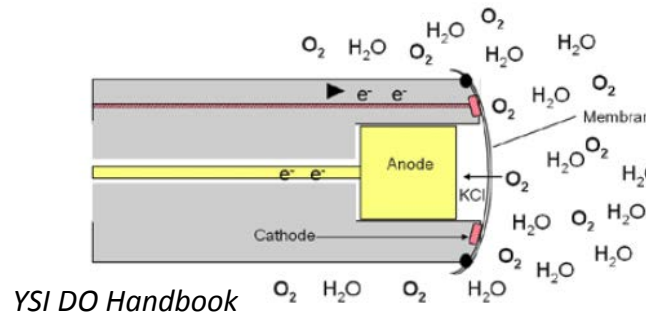
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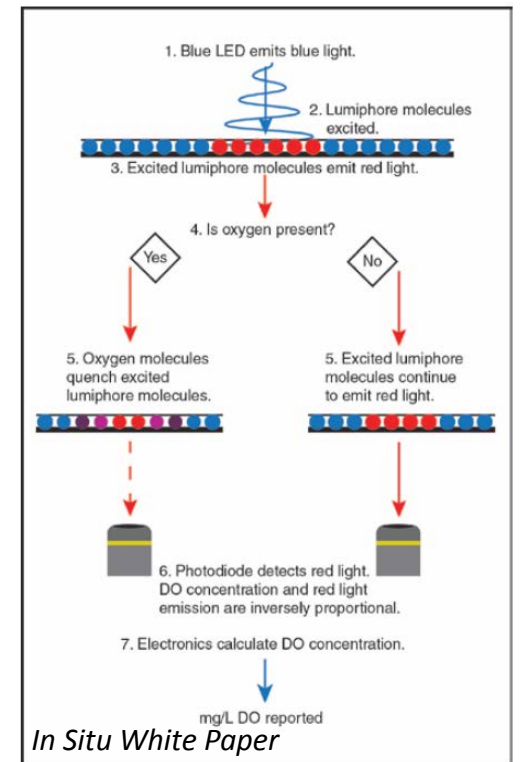
Biological constituents:

Algal biomass (Chl)



1960's - Electrochemical DO measurement

- Clark cell electrodes: high cost for replacing membranes, flow dependent



2000's - Optical /luminescence DO measurement

- Lower replacement costs
- More resistant to fouling

**ASTM D888 - 12e1: Standard Test Methods for Dissolved Oxygen in Water (2012)**

Test Method A - Titrimetric Procedure

Test Method B - Instrumental Probe Procedure - Electrochemical

Test Method C - Instrumental Probe Procedure - Luminescence-Based Sensor



# What has improved in recent years

## Physical properties:

Suspended solids/turbidity\*

## Chemical properties:

Nutrients (dissolved N, P)\*

Dissolved oxygen

pH

## Biological constituents:

Algal biomass (Chl)



Nitrate sensors

Ion-selective electrodes

- Issues of fouling, drift, specificity, etc.
- \$

Optical spectrophotometry

- More stable, less fouling
- \$\$\$



Phosphate sensors

- \$\$\$

# What has improved in recent years

## Physical properties:

Suspended solids/turbidity\*

## Chemical properties:

Nutrients (dissolved N, P)\*

Dissolved oxygen

pH

## Biological constituents:

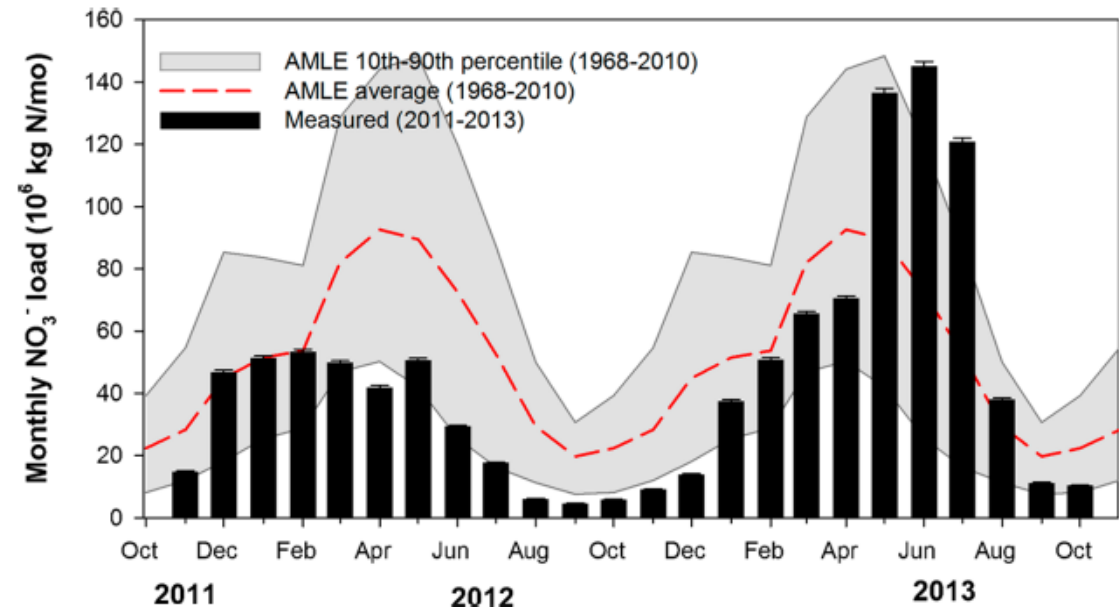
Algal biomass (Chl)



Optical nitrate sensors

- More stable, less fouling
- \$\$\$

**Continuous nitrate monitoring changes how we understand and model nutrient fluxes (e.g. from MRB)**



# What has improved in recent years

## Physical properties:

Suspended solids/turbidity\*

## Chemical properties:

Nutrients (dissolved N, P)\*

Dissolved oxygen

pH

## Biological constituents:

Algal biomass (Chl)



## Nutrient Sensor Challenge

### A Water Sensor Market Stimulation Challenge

Federal agencies, the Alliance for Coastal Technologies, and other partners **CHALLENGE YOU** to join the effort to develop affordable, accurate, and reliable nutrient sensors!

Registration closes March 16, 2015



### Nutrient Sensor Features

- Measures dissolved nitrate and/or phosphate
- Provides real-time data
- Easy to use
- Less than \$5,000 purchase price
- Unattended deployments for 3 months
- Highly accurate and precise

### Benefits to Participants

- High-visibility exposure
- Verified sensor performance through no-cost beta- and verification testing
- Leadership in an emerging market
- Access to potential partners, supporters, and customers



#### What about the market?

The market for affordable nutrient sensors spans the globe, and is growing across the U.S.

[Check out the potential market.](#)



#### Calling all sensor innovators!

We encourage innovators with technologies in all phases of development to participate.

[Register to participate.](#)



#### Sensor users: provide your input

This is a market stimulation Challenge, which means that end users have a key role to play. Let us know how you would use sensors.

[Share your input.](#)

# What still needs basic innovation

## Physical properties:

Temperature  
Flow/current  
Stage/height

## Chemical properties:

Conductivity\*

## Physical properties:

Suspended solids/turbidity

## Chemical properties:

Nutrients (dissolved N, P)\*

Dissolved oxygen

pH

## Biological constituents:

Algal biomass (Chl)

## Chemical properties:

Total nutrients

Micronutrients

Metals

Organics

## Biological constituents:

Bacteria - pathogens,  
indicators\*

Microbiological threats

Biological diversity



# What still needs basic innovation



Biosensors & Bioelectronics 14 (1999) 599–624

**BIOSENSORS  
&  
BIOELECTRONICS**

www.elsevier.com/locate/bios

Review

## Biosensors for detection of pathogenic bacteria

Dmitri Ivnitski, Ihab Abdel-Hamid, Plamen Atanasov, Ebtisam Wilkins \*

*Department of Chemical and Nuclear Engineering, University of New Mexico, Albuquerque, NM 87131, USA*

Received 23 November 1998; received in revised form 1 June 1999; accepted 19 July 1999

*J. Vis. Exp.*, 2013 Apr 23;(74):e4282. doi: 10.3791/4282.

### **Bacterial detection & identification using electrochemical sensors.**

Halford C<sup>1</sup>, Gau V, Churchill BM, Haake DA.

⊕ **Author information**

#### **Abstract**

Electrochemical sensors are widely used for rapid and accurate measurement of blood glucose and can be adapted for detection of a wide variety of analytes. Electrochemical sensors operate by transducing a biological recognition event into a useful electrical signal. Signal transduction occurs by coupling the activity of a redox enzyme to an amperometric electrode. Sensor specificity is either an inherent characteristic of the enzyme, glucose oxidase in the case of a glucose sensor, or a product of linkage between the enzyme and an antibody or probe. Here, we describe an electrochemical sensor assay method to directly detect and identify bacteria. In every case, the probes described here are DNA oligonucleotides. This method is based on sandwich hybridization of capture and detector probes with target ribosomal RNA (rRNA). The capture probe is anchored to the sensor surface, while the detector probe is linked to horseradish peroxidase (HRP). When a substrate such as 3,3',5,5'-tetramethylbenzidine (TMB) is added to an electrode with capture-target-detector complexes bound to its surface, the substrate is oxidized by HRP and reduced by the working electrode. This redox cycle results in shuttling of electrons by the substrate from the electrode to HRP, producing current flow in the electrode.

University of Southampton

## New sensor to detect harmful bacteria on food industry surfaces

11 June 2014



A new device designed to sample and detect foodborne bacteria is being trialled by scientists at the University of Southampton.

## Biological constituents:

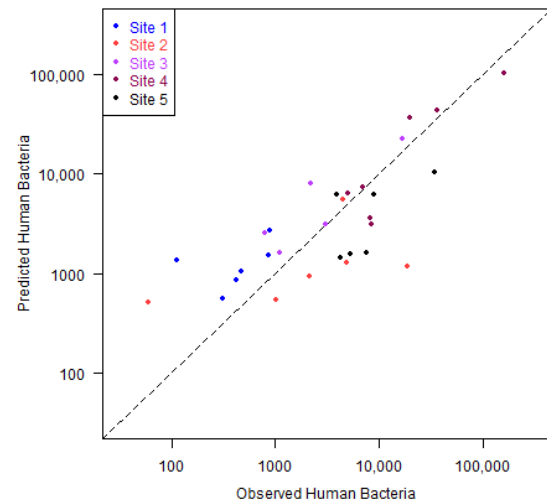
Bacteria - pathogens,  
indicators\*

Microbiological threats  
Biological diversity

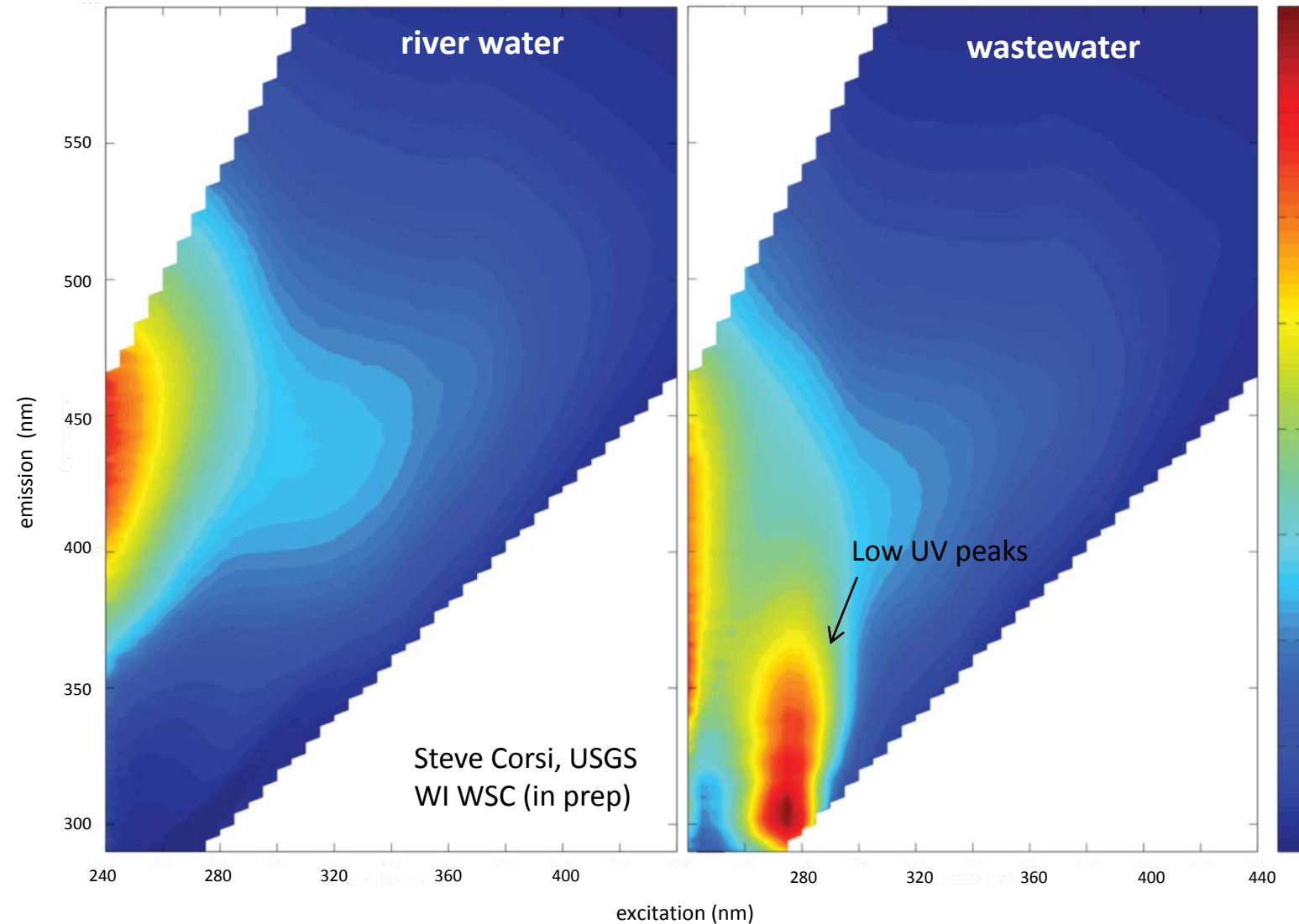
# Promising new approaches: Using proxies

## Wastewater Sensor Development

- Several manufacturers developing/ testing sensors for low UV protein-like fluorescence peaks as wastewater indicators
- Model predictions of human-specific bacteria for targeted sampling



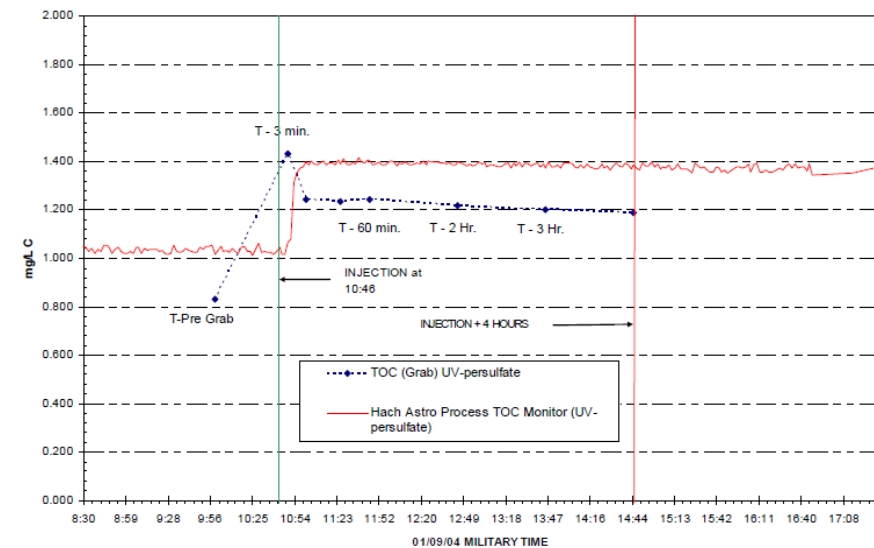
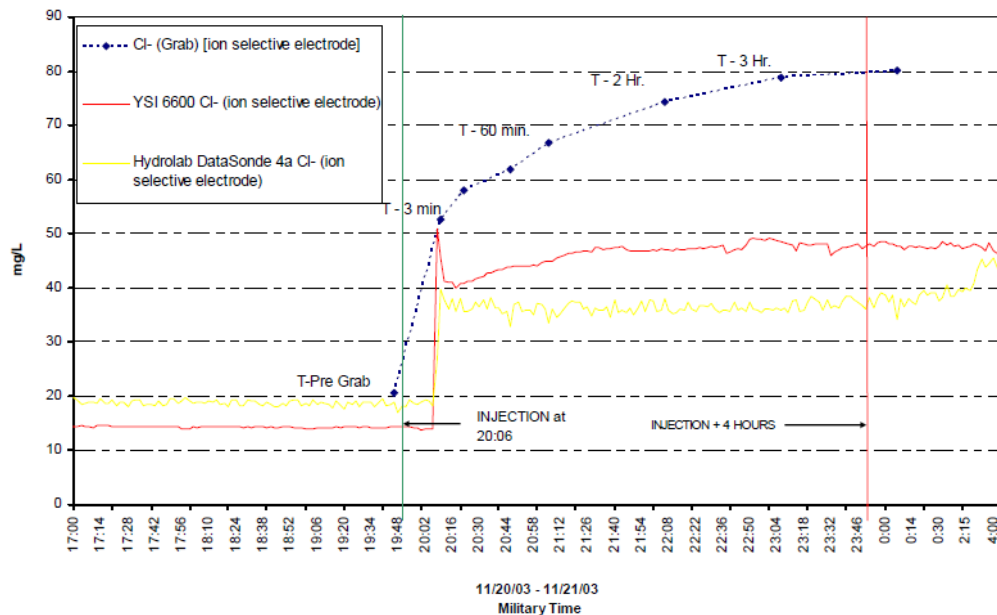
Pred vs. obs human-specific bacteria (*Lachnospiraceae* 2) in the Menomonee R. from lab optical measurements



# Promising new approaches: Using proxies

## Combined use of existing sensors to detect threats/pollutants

- Utilize existing sensor systems for online monitoring and event detection
- US EPA ORD National Homeland Security Research Center  
CANARY: On-line Water Quality Parameters as Indicators of Distribution System Contamination. (*J Hall, et al., 2007. J of AWWA*)



Response of chlorine (Cl<sup>-</sup>) and total organic carbon (TOC) sensors to input of potassium ferrocyanide (left) and malathion pesticide (right) (Hall et al., 2007. J of AWWA)

# Ways to stimulate Innovation and Adoption

## Innovation/Acceleration



Ocean Technology Transition Project

IOOS advances technology through the transition of ocean, coastal, and marine sensors and platforms to operations



## Adoption

- Renewed emphasis on understanding uncertainty around WQ data

2014 National Water Quality Monitoring Conference Session:  
*Continuous Monitoring: Uncertainty and Bias and Prediction... Oh My!*

Stewart Rounds, USGS

- Rigorous statistical approaches (e.g. “GUM” Guide to the Expression of Uncertainty in Measurement)
- Simpler statistical approaches (e.g. root mean square error)





# Closing thoughts

- Water quality monitoring has come a long way and is continuing along an exciting path of innovation
- Advanced monitoring is already changing the way we understand, model, and manage systems
- There are many parameters we can monitor well and reliably...
- ... but many more that are still in need of basic innovation
- Exciting near-term advancements include:
  - Using proxies
  - Accelerating on-the-cusp technologies
  - Better understanding/quantifying uncertainty

*Thank you!*

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