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

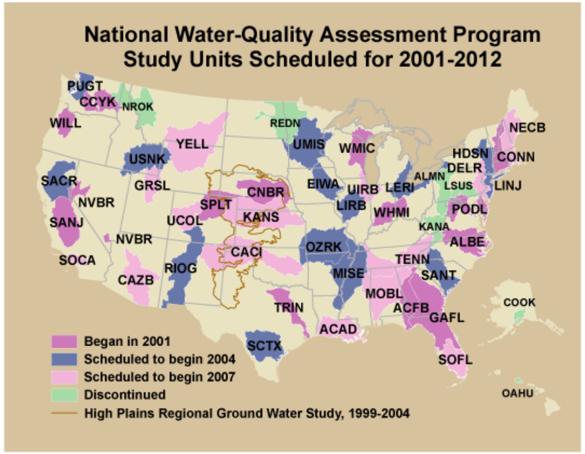
UNIVERSITY OF LOUISIANA Lafayette

Shapiro Symposium, March 2015

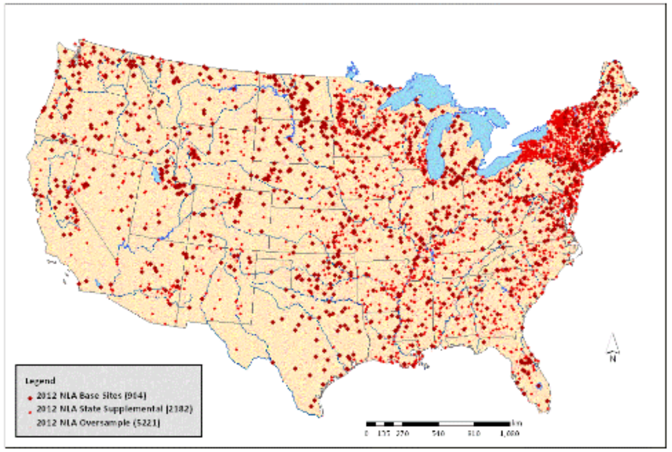
How do *we* monitor water quality?

The “we”:

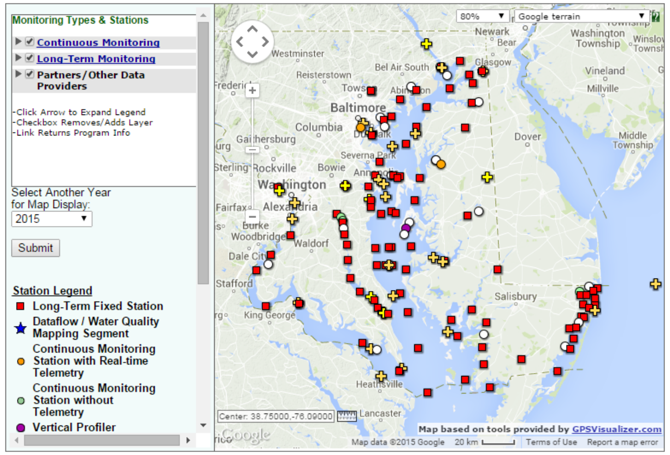
- Federal agencies
- Interstate commissions
- State agencies
- Counties, cities, parishes
- Non-profits
- Academics
- Citizens
- Industry
- Private/public sector utilities



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



EPA - National Lakes Assessment (2012)
http://water.epa.gov/type/lakes/lakessurvey_index

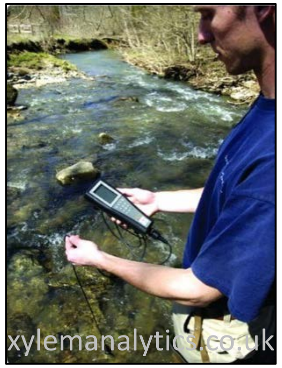


Maryland DNR - Eyes on the Bay
http://mddnr.chesapeakebay.net/eyesonthebay

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

How do we monitor water quality?

Discrete Sampling

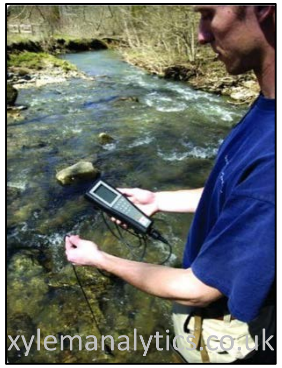


Space

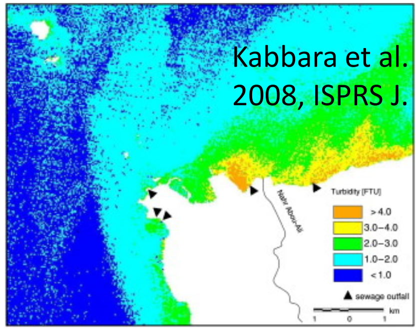
Time

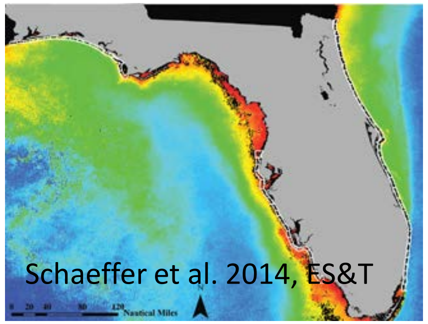
How do we monitor water quality?

Discrete Sampling

Remote Sensing



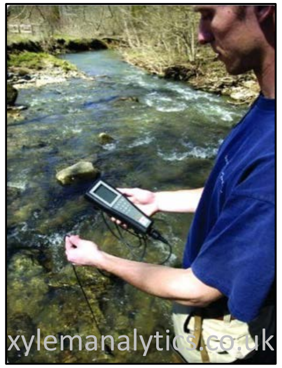


Continuous Monitoring

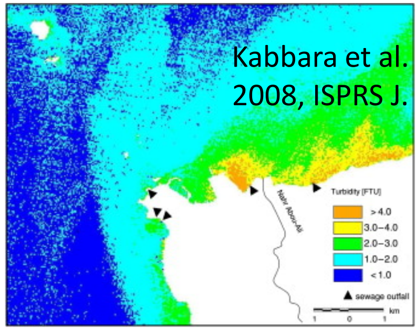
Space → Time

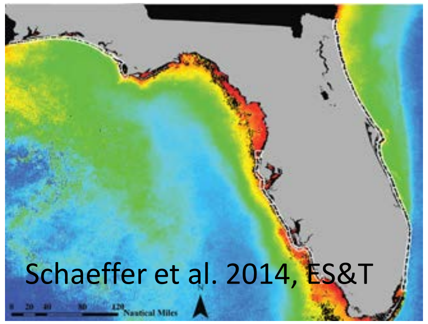
How do we monitor water quality?

Discrete Sampling



Remote Sensing



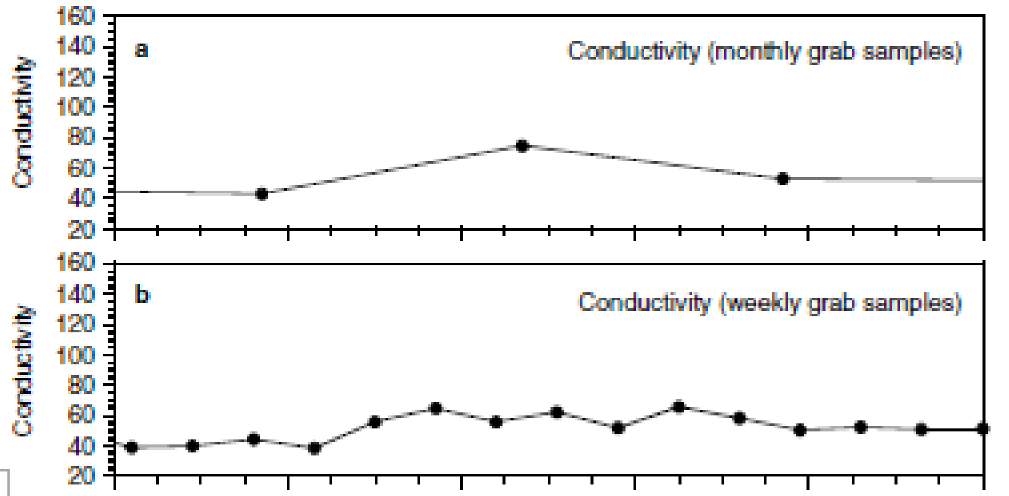


New Capabilities

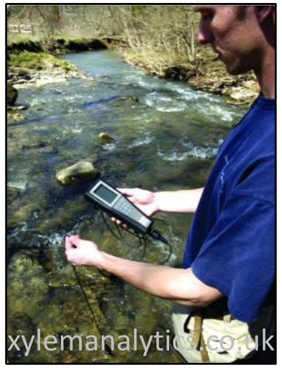
Continuous Monitoring

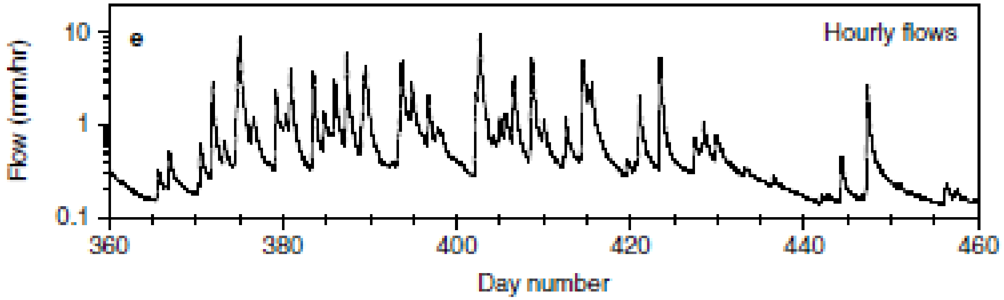
Space → Time

How do we monitor water quality?



Discrete Sampling



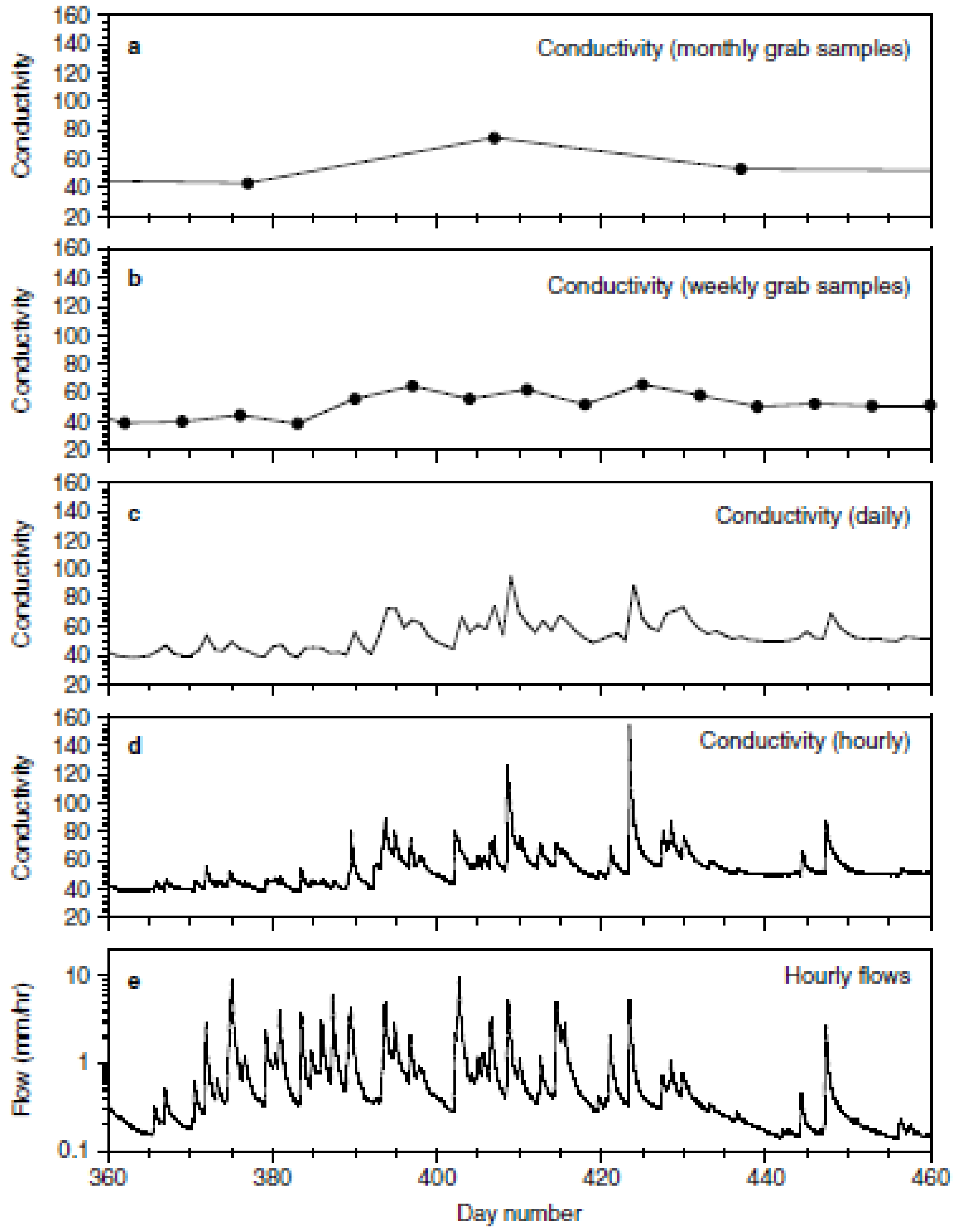


From: Kirchner et al. 2004, Hydrologic Processes

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



Biogeochemistry **69:** 19–35, 2004.

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

C. ALEWELL[1,*], G. LISCHEID[1], U. HELL[1] and B. MANDERSCHEID[2]

*[1]BITÖK, University of Bayreuth, Bayreuth, D-95440, Germany; [2]ZADI, Information Centre for Genetic Resources (IGR), Bonn, D-53177, Germany; *Author for correspondence (e-mail: christine.alewell@bitoek.uni-bayreuth.de; phone: 49-921-555741; fax: 49-921-555799)*

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
Hydrol. Process. **25**, 828–830 (2011)
Published online 1 February 2011 in Wiley Online Library (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,[1]*
N. J. K. Howden,[2]
F. Worrall[3] and
J. J. McDonnell[4]

[1] *Department of Geography, Durham University, Science Laboratories, South Road, Durham DH1 3LE, Durham, UK*
[2] *Department of Civil Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1 TR, UK*
[3] *Department of Earth Sciences, Durham University, Science Laboratories, South Road, Durham DH1 3LE, UK*
[4] *Department of Forest Engineering, Resources and Management, Oregon State University, Corvallis, Oregon 97331, USA*

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
Hydrol. Process. **18**, 1353–1359 (2004)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.5537

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

James W. Kirchner[1]*
Xiahong Feng[2]
Colin Neal[3]
Alice J. Robson[3]

[1] *Department of Earth and Planetary Science, University of California, Berkeley, CA, USA*
[2] *Department of Earth Sciences, Dartmouth College, Hanover, NH, USA*
[3] *Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, UK*

Ecological Indicators 45 (2014) 529–537

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

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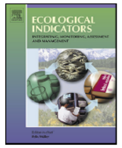


Too much data is never enough: A review of the mismatch between scales of water quality data collection and reporting from recent marine dredging programmes

CrossMark

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

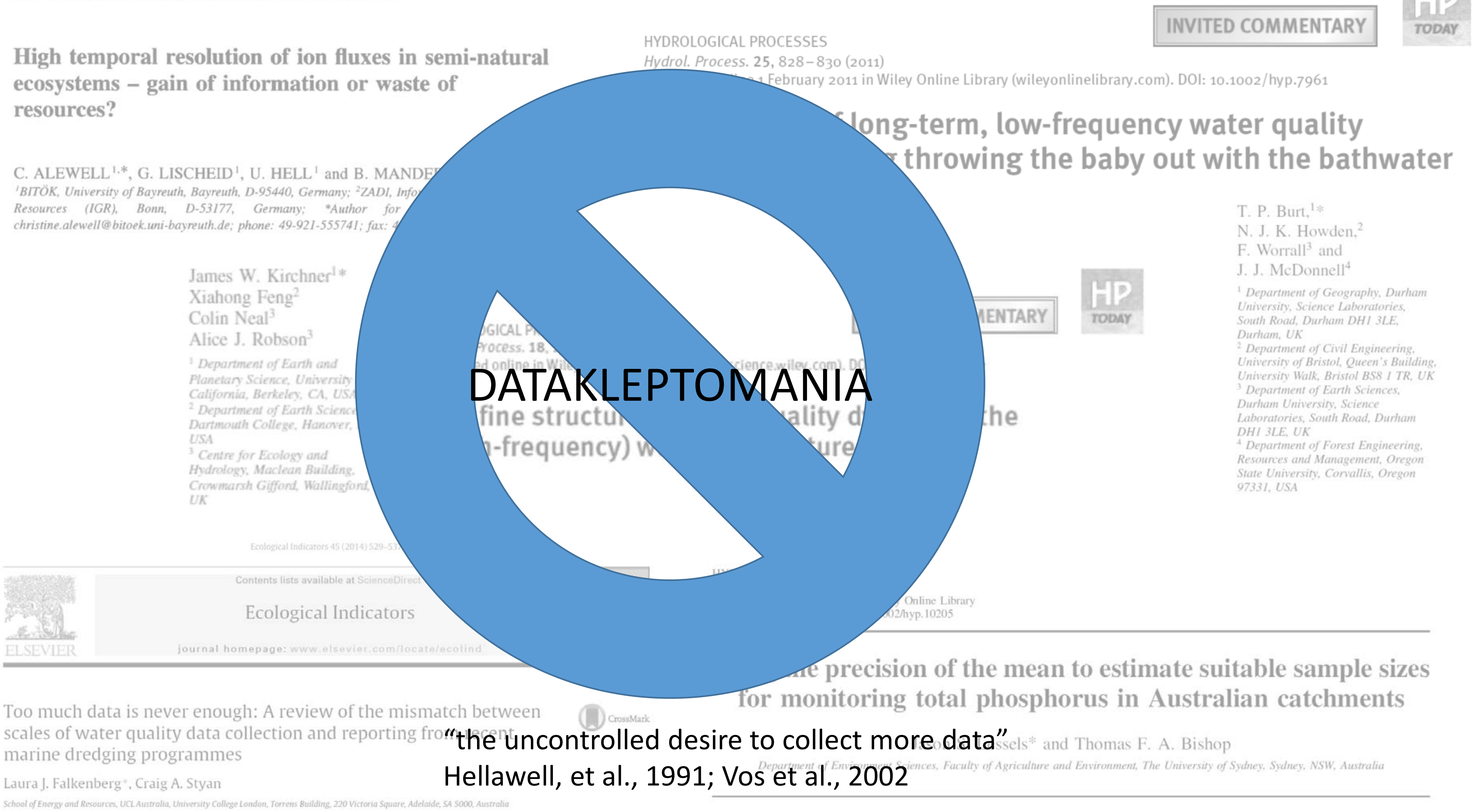
HYDROLOGICAL PROCESSES
Hydrol. Process. **29**, 950–964 (2015)
Published online 7 May 2014 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/hyp.10205

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



“the uncontrolled desire to collect more data”
Hellawell, et al., 1991; Vos et al., 2002

How do we monitor *water quality*?

Acrolein

Aesthetic Qualities

Aldrin

Alkalinity

alphaEndosulfan

Aluminum

Ammonia

Arsenic

Bacteria

betaEndosulfan

Boron

Carbaryl

Cadmium

Chlordane

Chloride

Chlorine

Chloropyrifos

Chromium (III)

Chromium (VI)

Color

Copper

Cyanide

Demeton

Diazinon

Dieldrin

Endrin

gamma-BHC (Lindane)

Gases, Total Dissolved

Guthion

Hardness

Heptachlor

Heptachlor Epoxide

Iron

Lead

Malathion

Mercury

Methylmercury

Methoxychlor

Mirex

Nickel

Nonylphenol

Nutrients (Total Phosphorus, Total Nitrogen, Chlorophyll a and Water Clarity)

Oil and Grease

Oxygen, Dissolved Freshwater

Oxygen, Dissolved Saltwater

Parathion

Pentachlorophenol

pH

Phosphorus Elemental

Polychlorinated Biphenyls (PCBs)

Selenium

Silver

Solids Suspended and Turbidity

Sulfide-Hydrogen Sulfide

Tainting Substances

Temperature

Toxaphene

Tributyltin (TBT)

Zinc

4,4'-DDT

Recommended Aquatic Life Criteria
http://water.epa.gov/scitech/swguidance/standards/criteria

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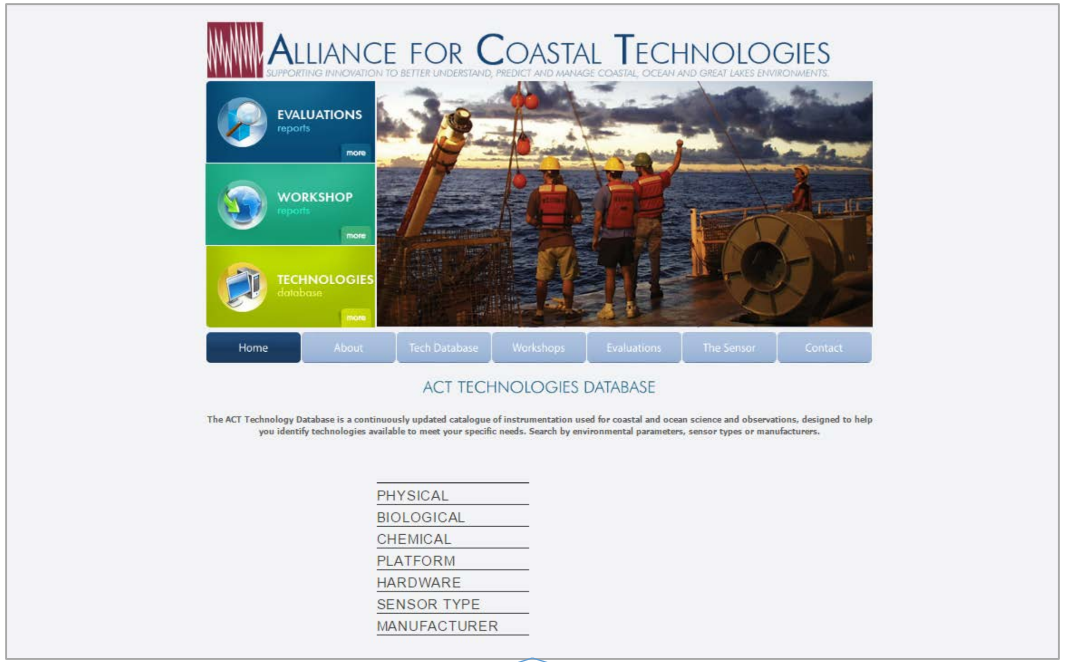
http://www.act-us.info/database

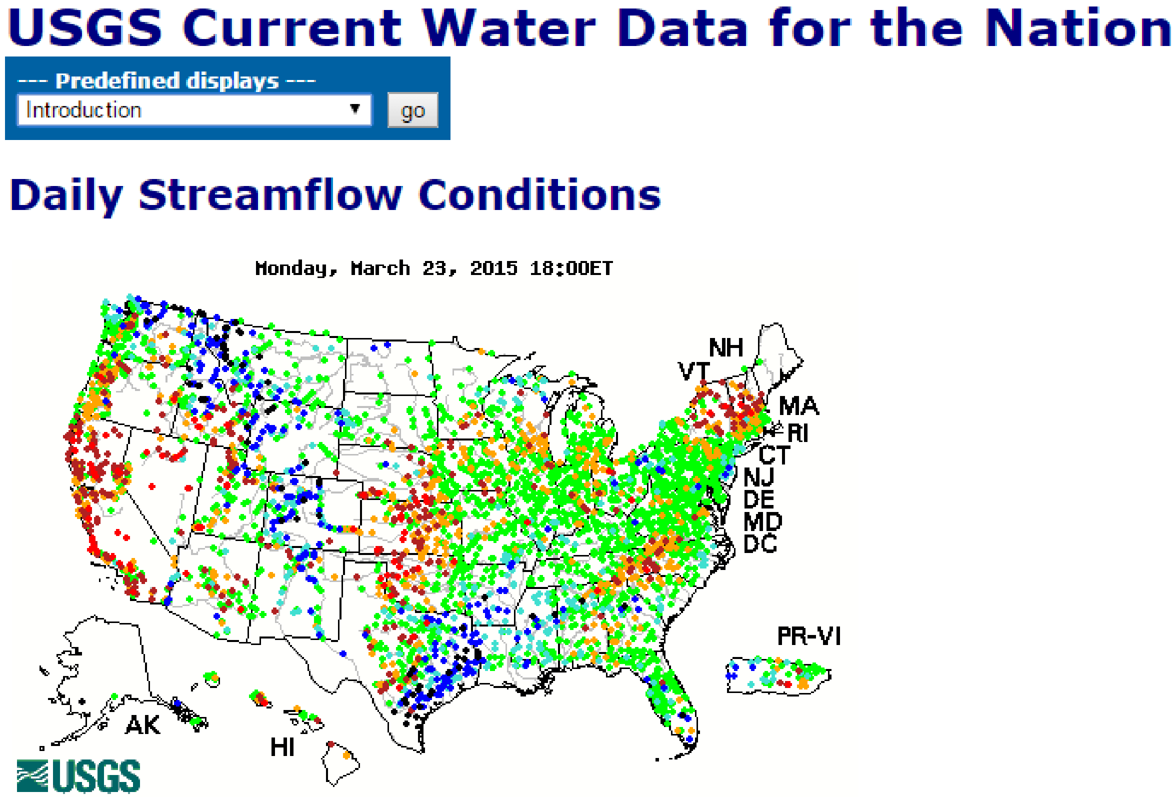


https://www.nemi.gov/home

What we monitor well

Physical properties:

Temperature
Flow/current
Stage/height



Chemical properties:

Conductivity*

What we monitor well

Physical properties:

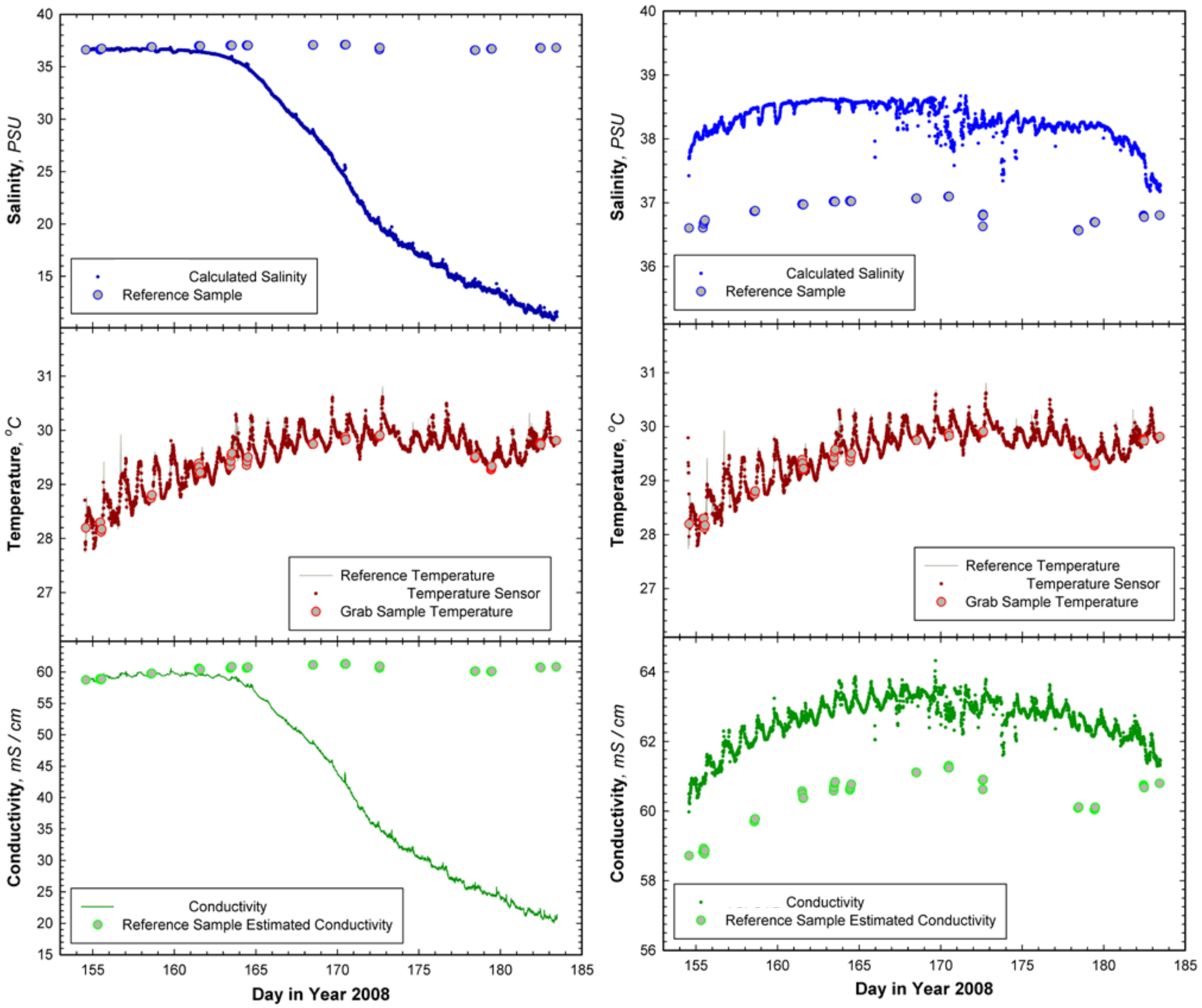
Temperature
Flow/current
Stage/height

Chemical properties:

Conductivity*

Mature ≠ Accurate

*Continued need for QA/QC when using sensors.



Slide courtesy of M. Tamburri, ACT

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*

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Biological constituents:

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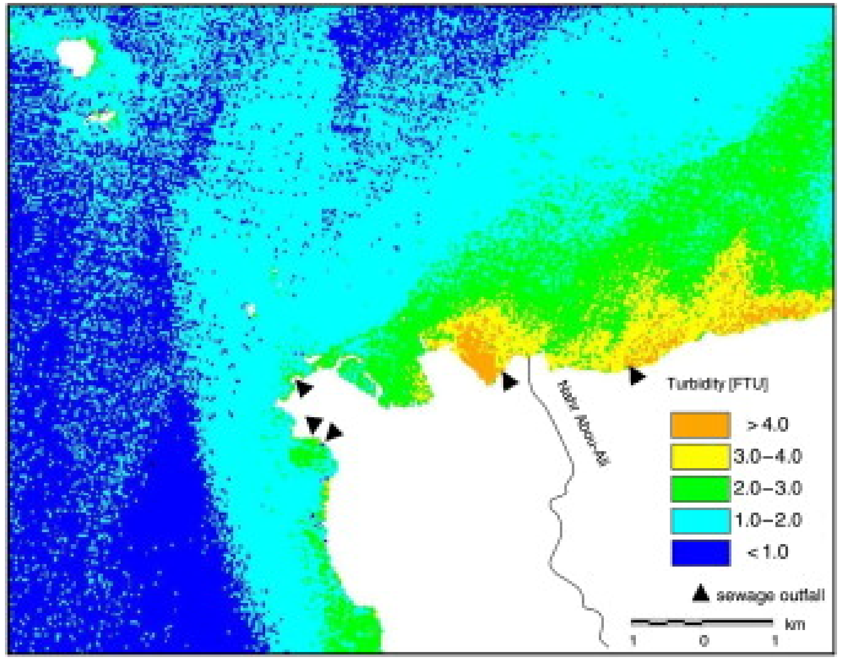


Kabbara et al. 2008, ISPRS J.

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:

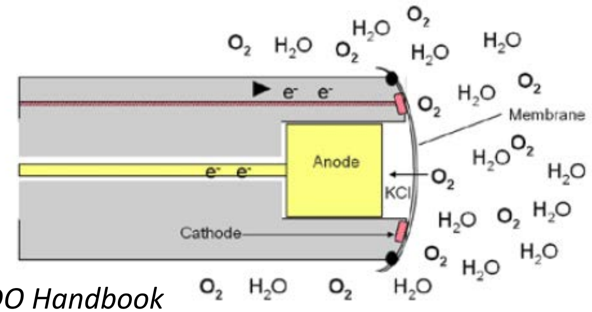
Nutrients (dissolved N, P)*

Dissolved oxygen*

pH

Biological constituents:

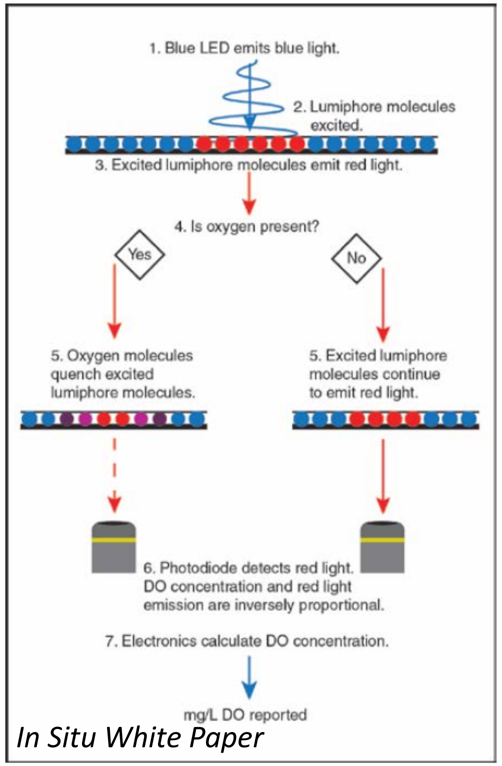
Algal biomass (Chl)



YSI DO Handbook

1960’s - Electrochemical DO measurement

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



In Situ White Paper

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:

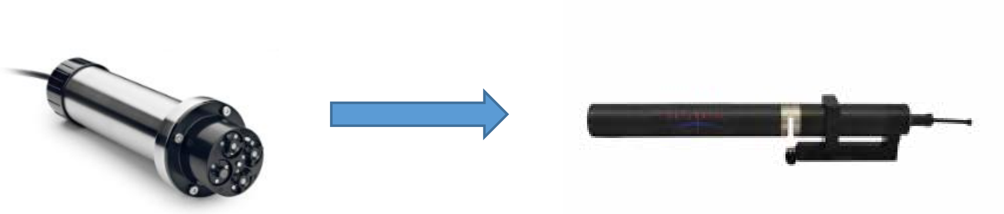
Nutrients (dissolved N, P)*

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

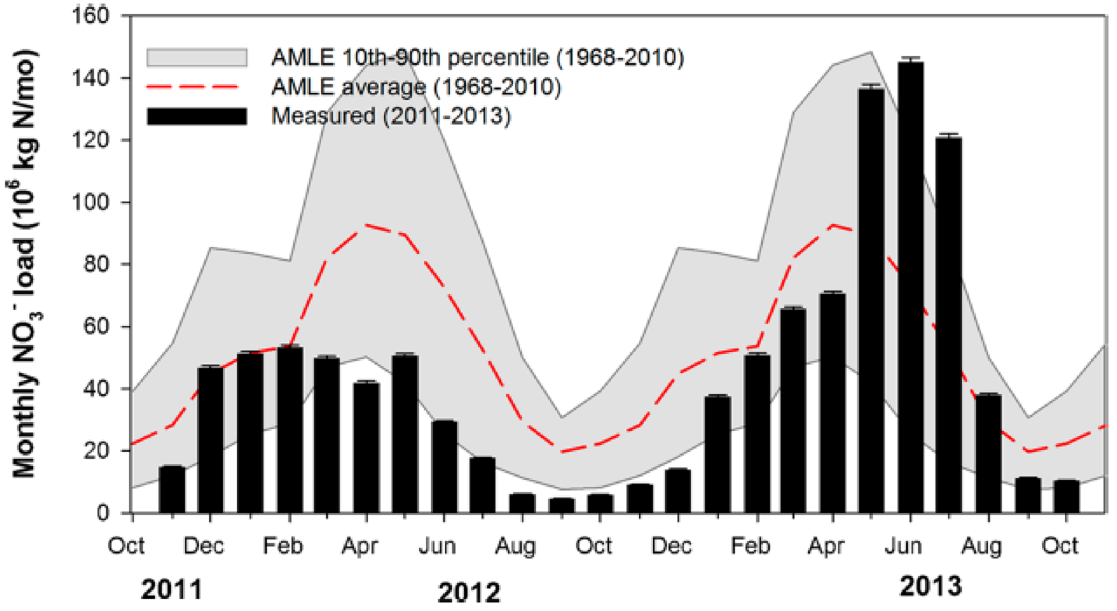
Biological constituents:

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)



Pellerin et al. 2014 ES&T

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)

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

ELSEVIER

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[1], Gau V, Churchill BM, Haake DA.

⊕ Author information

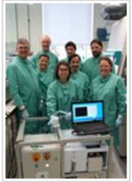
Abstract

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.

<u>Biological constituents:</u>

Bacteria - pathogens, indicators*

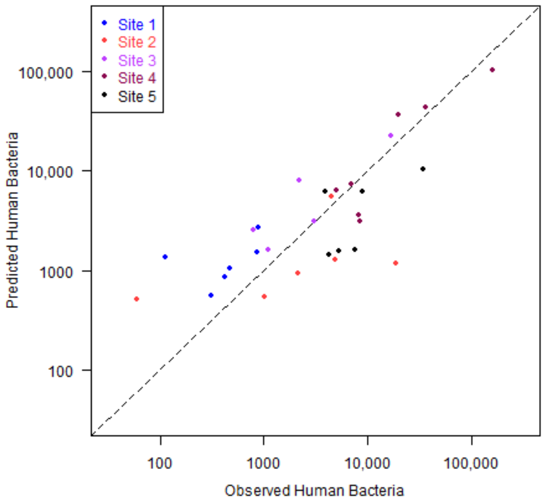
Microbiological threats

Biological diversity

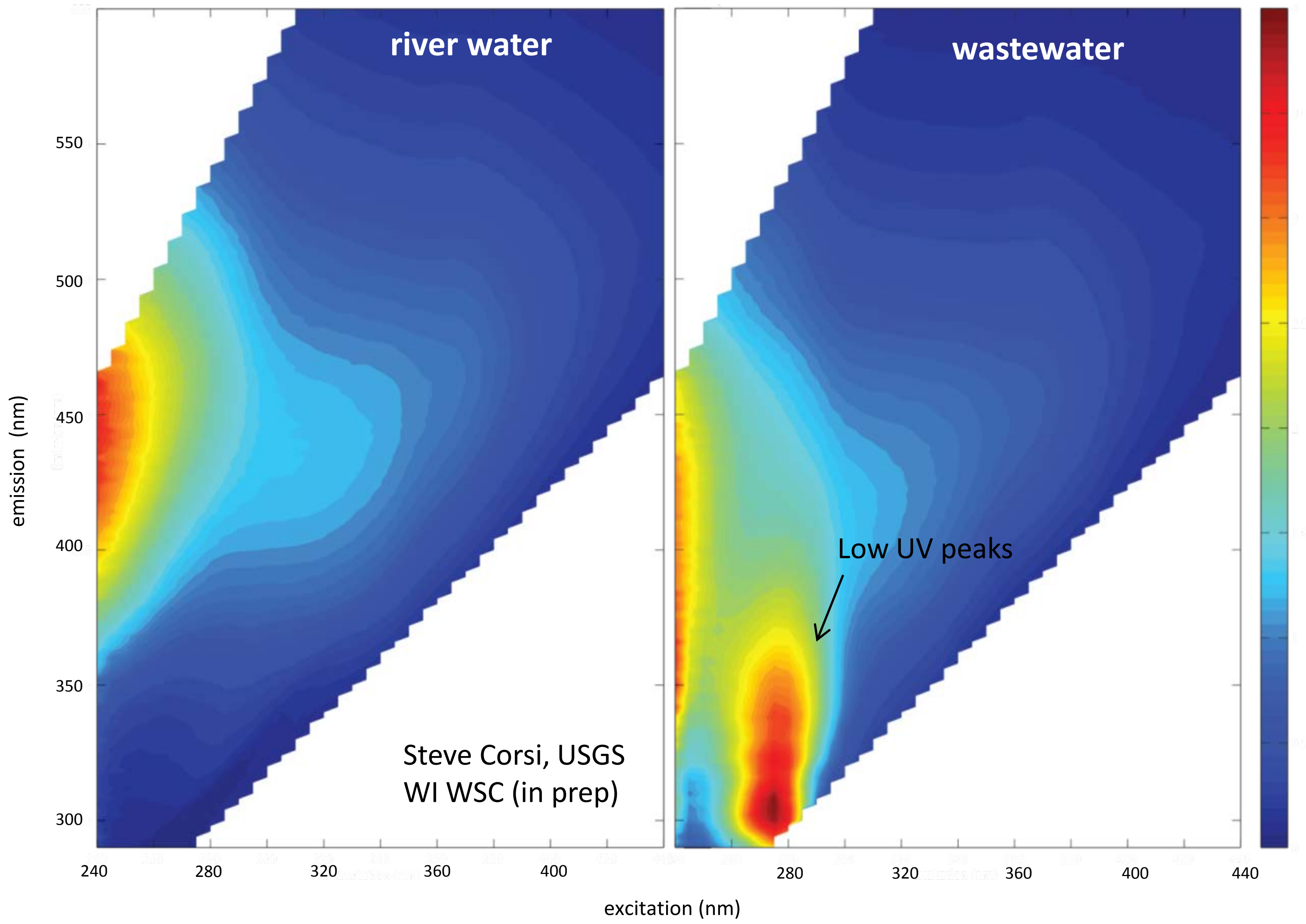
Promising new approaches: Using proxies

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

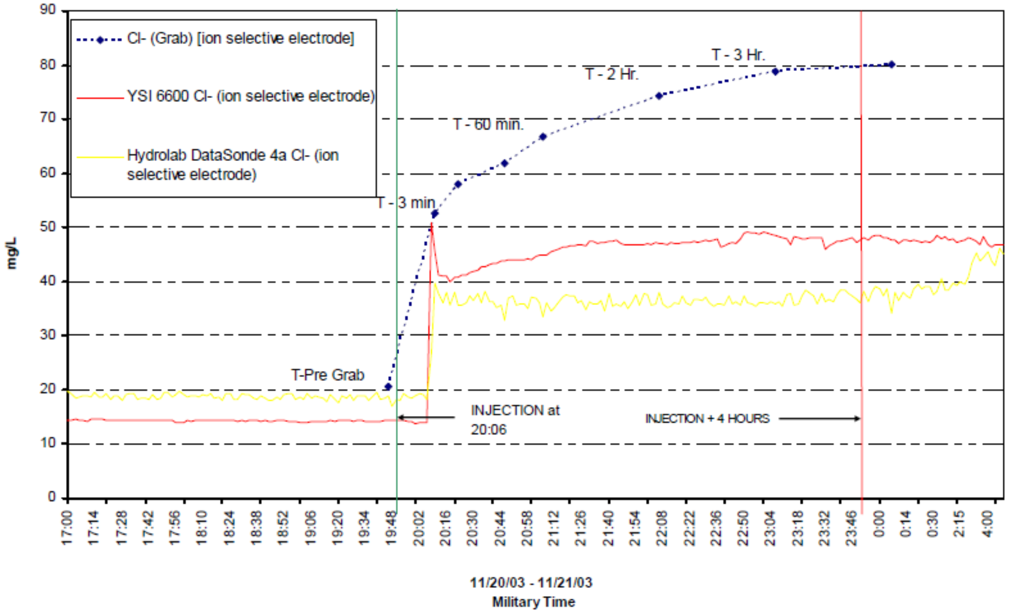


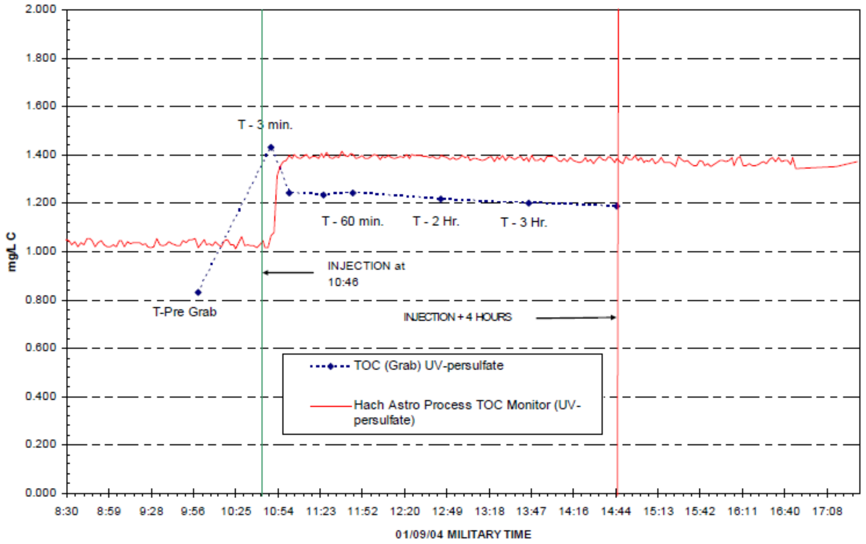
Slide courtesy of B. Pellerin, USGS

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^{-}) 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

IOOS®
INTEGRATED OCEAN OBSERVING SYSTEM

Ocean Technology Transition Project

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

Nutrient Sensor Challenge

ALLIANCE FOR COASTAL TECHNOLOGIES

NWQMC
NEMI
National Environmental Methods Index

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!

Beth A. Stauffer, Ph.D.
stauffer@louisiana.edu

UNIVERSITY OF LOUISIANA Lafayette