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

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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

www.hach.com

www.xylemanalytics.co.uk
How do we monitor water quality?

Discrete Sampling

- www.hach.com
- www.xylemanalytics.co.uk

Continuous Monitoring

- www.fondriest.com

Remote Sensing

- Kabbara et al. 2008, ISPRS J.
- Schaeffer et al. 2014, ES&T
How do we monitor water quality?

Discrete Sampling

New Capabilities

Continuous Monitoring

Remote Sensing

www.hach.com

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Kabbara et al. 2008, ISPRS J.

Schaeffer et al. 2014, ES&T

www.xylemanalytics.co.uk
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
High temporal resolution of ion fluxes in semi-natural ecosystems – gain of information or waste of resources?

C. ALEWELL1,4, G. LISCHED1, U. HELL1, and B. MANDERSCHEID2

1 BITOK, 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@bitok.uni-bayreuth.de; phone: 49-921-355741; fax: 49-921-355790)

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

Hydrological Processes
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.5537

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

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F. Worrall1 and
J. J. McDonnell4

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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

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

Jason S. Lessels5 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

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

C. ALEWELL1,4, G. LISCHEID1, U. HELL1 and B. MANDEL2

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...long-term, low-frequency water quality... throwing the baby out with the bathwater

T. P. Burt1,*
N. J. K. Howden,2*
F. Worrall1 and
J. J. McDonald1

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2 Department of Civil Engineering, University of Bristol, Queen’s Building, University Walk, Bristol BS8 1UB, UK.

...data collection and reporting from marine dredging programmes... "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
Dieldrin
Demeton
Diazinon
Dieldrin
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
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
- Dieldrin
- 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
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- Toxaphene
- Tributyltin (TBT)
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- 4,4'-DDT

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

USGS Current Water Data for the Nation

Daily Streamflow Conditions
Monday, March 23, 2015 18:09ET
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*
- Suspended solids/turbidity*
- 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)

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)

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

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)

Ion-selective electrodes
- Issues of fouling, drift, specificity, etc.
- $

Optical spectrophotometry
- More stable, less fouling
- $$$

Nitrate sensors

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

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What still needs basic innovation

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

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

- 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)

Adoption
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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