Advanced Sensors for Early-Warning Monitoring of Water Supplies

Presented for the Potomac River Basin Drinking Water Source Protection Partnership, August 25, 2004

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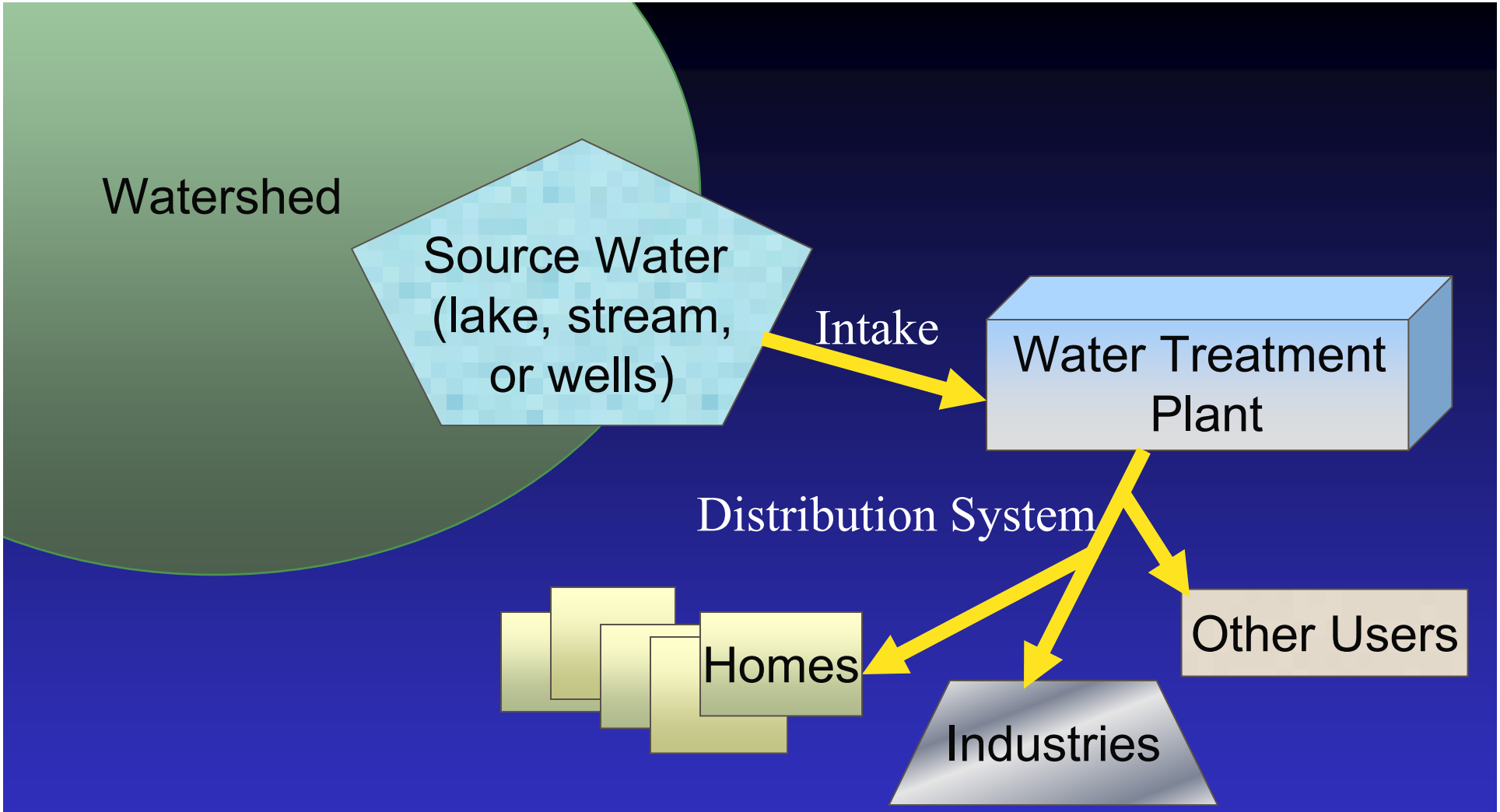
[The use of trade, product, or firm names in this presentation is for identification purposes only and does not imply endorsement by the U.S. Government.]



Early-warning monitoring is one component of a multiple-barrier approach to water security.

Advantages of Early-Warning Monitoring

- Develop understanding of baseline conditions
- Develop algorithms for identifying anomalous conditions
- Increase knowledge of natural variations in water quality
- Improve effectiveness of water-quality monitoring programs
- Optimize water treatment

Photograph by Declan McCullagh
http://www.mccullagh.org/image/950-18/potomac-river.html

Advantages of Early-Warning Monitoring

- Timely data to assess potential threats and respond before treatment systems are impacted, or water is distributed and consumed
- Detect accidental or intentional releases
- Ancillary data to help identify the source and timing of the release
- Characterization of contaminants, concentrations, and loads prior to mitigation by treatment
- Capability to archive a raw-water sample for forensics purposes

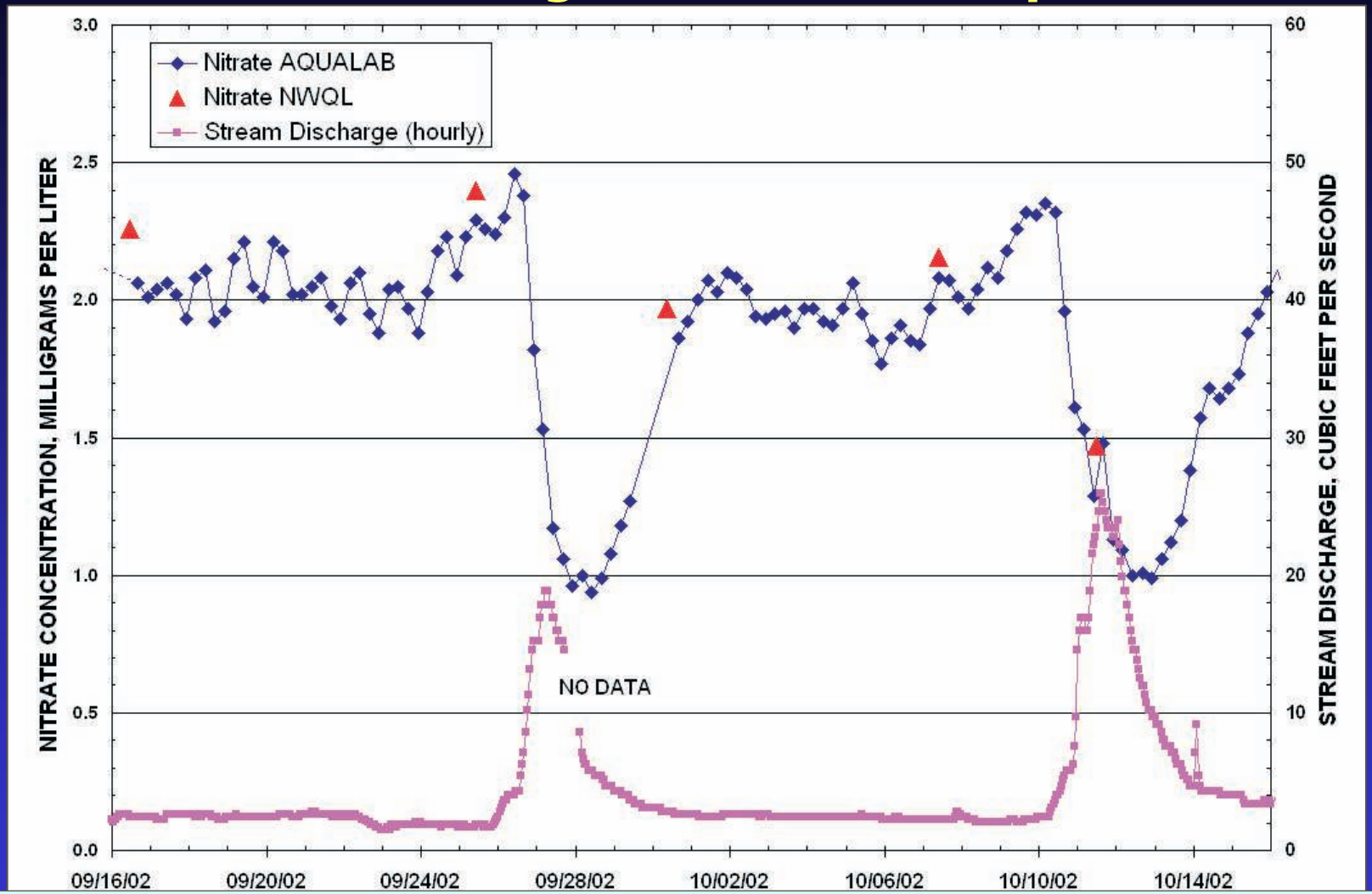
Challenges of Early-Warning Monitoring

- Raw source water can be difficult to monitor:
  - -Flow
  - -Large debris
  - -Smaller particles
  - -Biological activity
  - -Variations in water chemistry
  - -Temperature changes (also ice)

Photograph from the Alice Ferguson Foundation 2004 Potomac River Watershed Cleanup

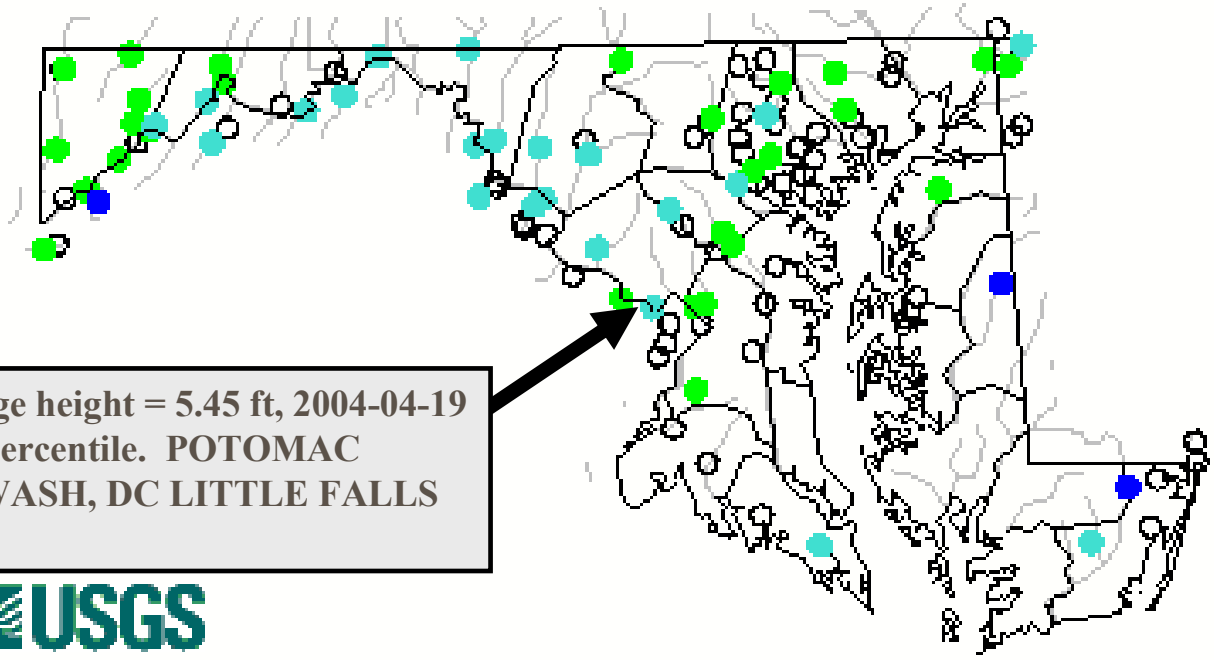
- Maintenance needs can be difficult to predict
- Representative sampling can be difficult to achieve
- Periodic verification sampling is recommended to confirm that sensor readings represent actual field conditions

Continuous Monitoring vs. Discrete Sample Collection



Nitrate in samples collected and analyzed continually (AQUALAB), and discrete samples analyzed by the National Water Quality Laboratory (NWQL), for various stream-discharge conditions at Morgan Creek, Maryland. *[Graph by Michael J. Brayton, U.S. Geological Survey]*

Mon., Apr. 19, 2004 14:08ET



Q=28400 cfs, Gage height = 5.45 ft, 2004-04-19 10:15:00, 76-90 percentile. POTOMAC RIVER NEAR WASH, DC LITTLE FALLS PUMP STA

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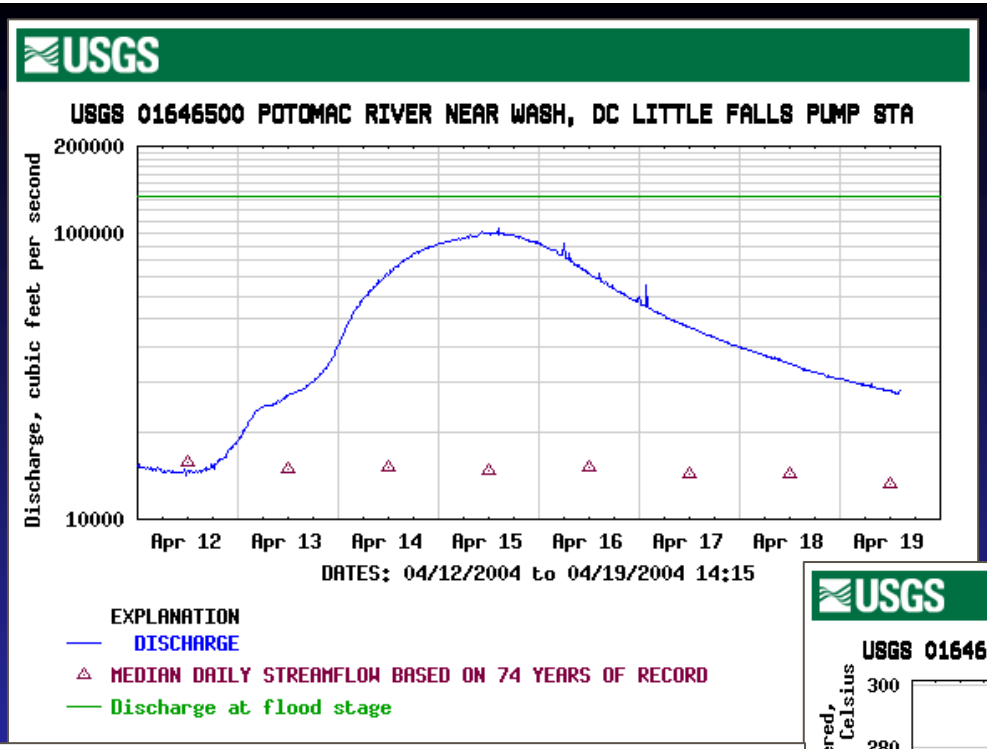
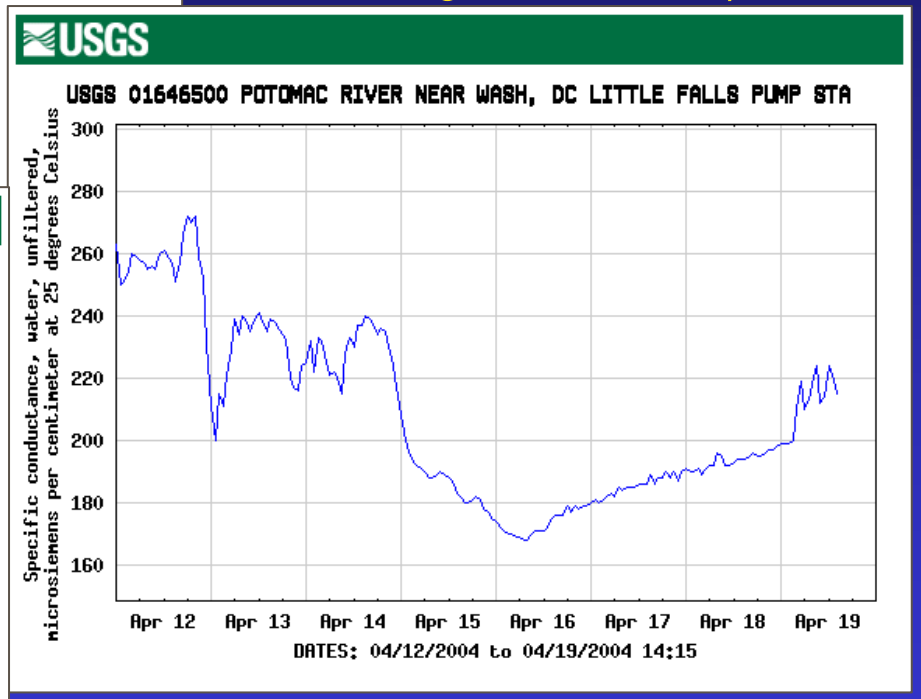
Explanation

- New record high for day
- ≥ 90th percentile
- 75th- 89th percentile
- 25th- 74th percentile
- 10th- 24th percentile
- < 10th percentile
- New record low for day
- Not ranked

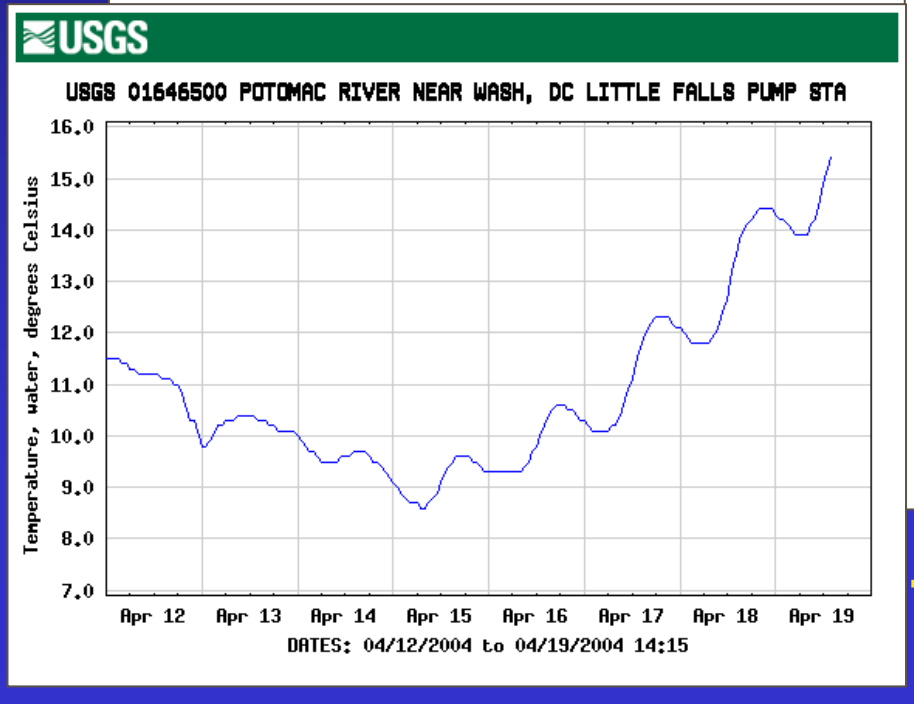
http://md.waterdata.usgs.gov/nwis/rt



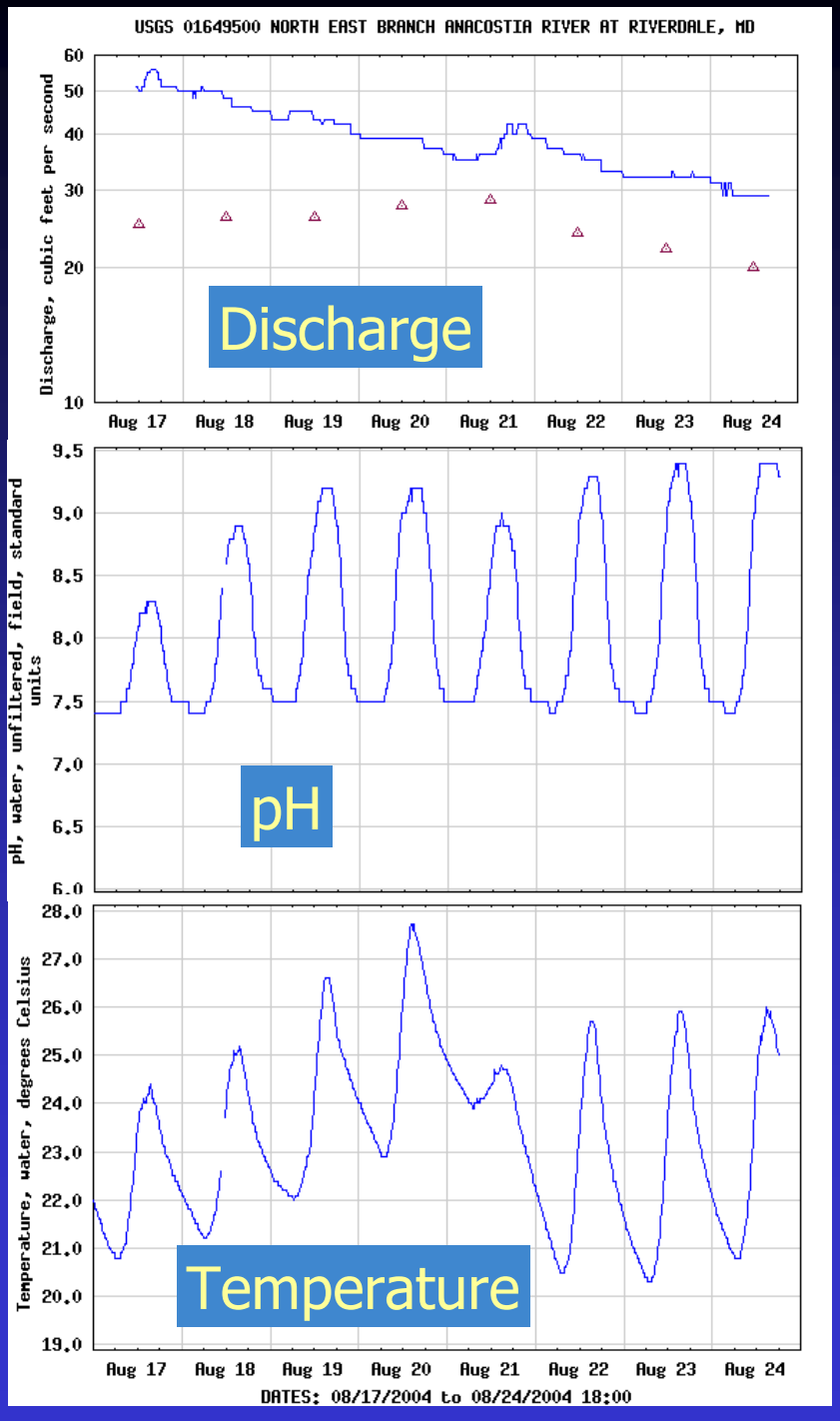
Discharge (cubic feet per second)

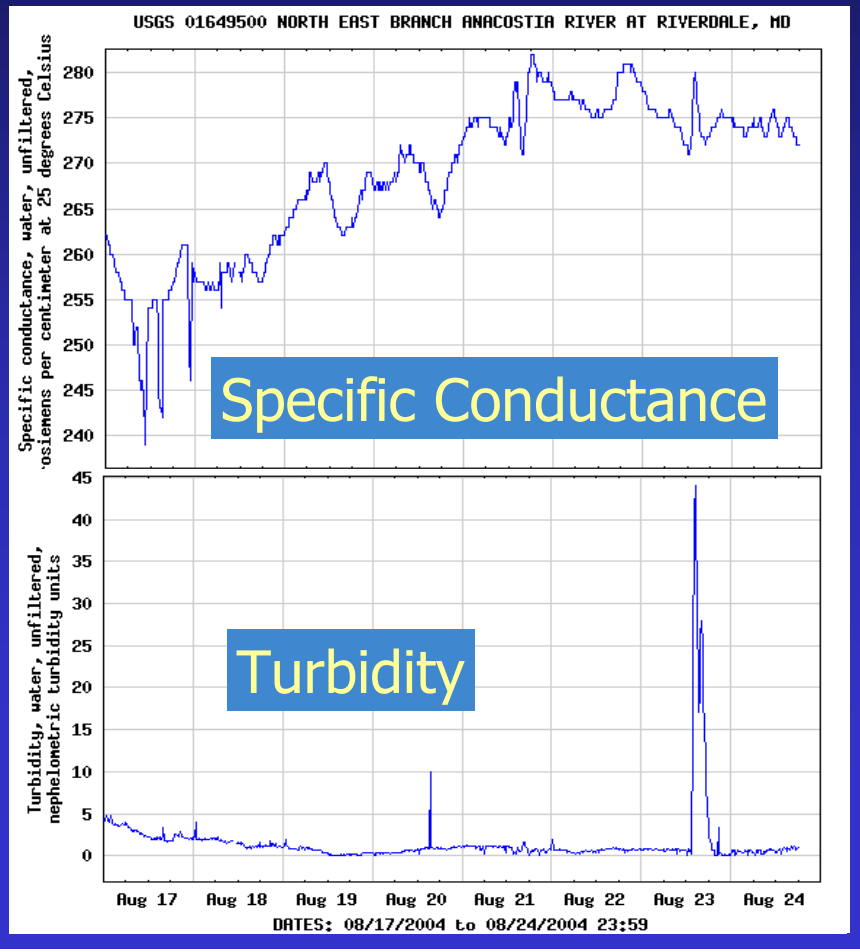


Specific conductance (microsiemens per cm at 25 degrees Celsius)



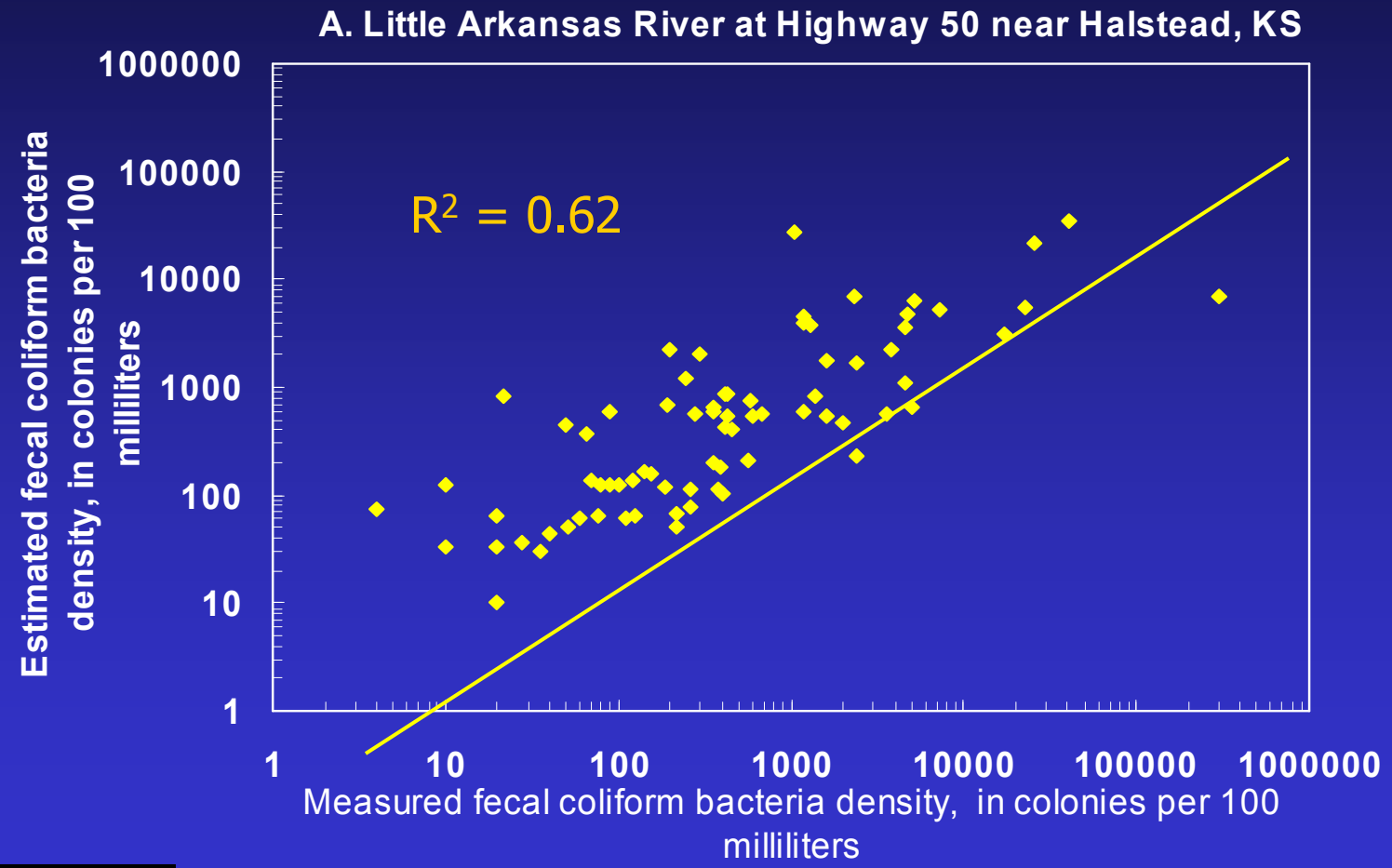
Temperature (degrees Celsius)


USGS 01649500 NORTH EAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD
Discharge, cubic feet per second
60
50
40
30
20
10
Discharge
Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
pH, water, unfiltered, field, standard units
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
pH
Temperature, water, degrees Celsius
28.0
27.0
26.0
25.0
24.0
23.0
22.0
21.0
20.0
19.0
Temperature
DATES: 08/17/2004 to 08/24/2004 18:00


USGS 01649500 NORTH EAST BRANCH ANACOSTIA RIVER AT RIVERDALE, MD
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
280
275
270
265
260
255
250
245
240
Specific Conductance
Turbidity, water, unfiltered, nephelometric turbidity units
45
40
35
30
25
20
15
10
5
0
Turbidity
Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
DATES: 08/17/2004 to 08/24/2004 23:59

Estimated vs. Measured Bacteria Densities

$$\log_{10}(FCB) = 0.960 \log_{10}(NTU) + 0.771$$



http://ks.water.usgs.gov/Kansas/studies/TMDL/mtgs/pras.ppt.html (Rassmusen and others, 2000)

Traditional Real-Time Parameters

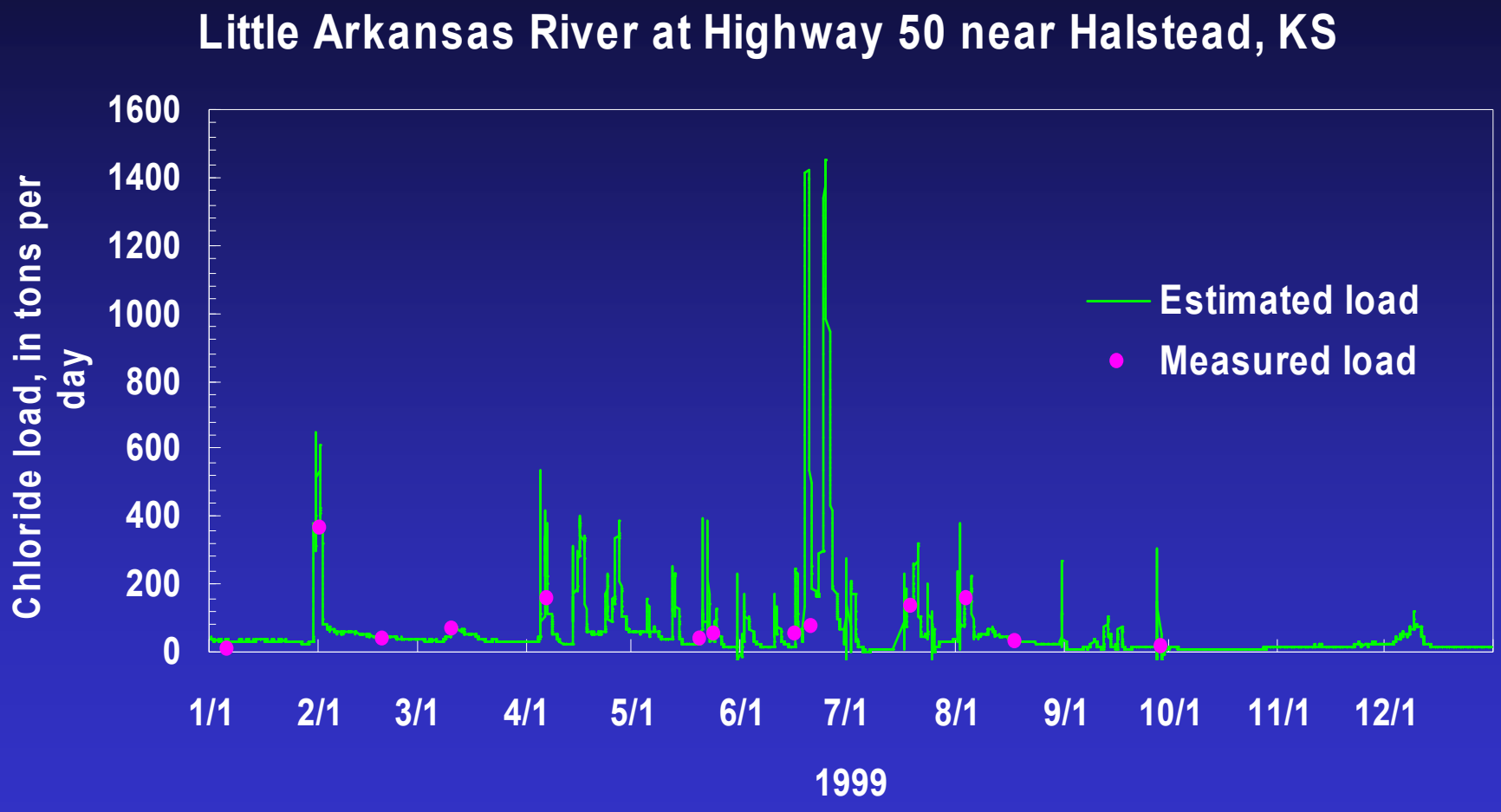
Parameter	Potential Application
Water Temperature	Affects general water chemistry. Necessary for temperature compensation in sensors.
Specific Conductance	Indicator for nutrients and some pesticides. Used to predict chloride, alkalinity, dissolved solids, sulfate, and triazine compounds (Kansas District--Christensen, Jian, and Ziegler)
pH	Affects chemical speciation of metals and other contaminants. Can accelerate or impede biodegradation of organic compounds.
Dissolved O_2	Indicator of oxygen depletion due to algal blooms or increased BOD.
Turbidity	Indicator for suspended solids, including pathogens and sediment. Used to predict fecal coliform, E. Coli, suspended sediment, total N, and total P (Kansas District)
ORP	Indicator of redox conditions, which can affect contaminant chemistry.
UV Absorbance	Indicator of aromatic hydrocarbons, including PAHs associated with fuels and some DBP precursors
Fluorescence	Indicator of some organic materials, including chlorophyll, which can be associated with algae blooms and taste & odor problems.
Discharge	Used to calculate contaminant loads and to estimate concentrations when measurements are not available (regression/prediction). Useful for trend analysis.

Stream Discharge:

$$\left(\begin{array}{c}\textbf{Stream Discharge}\\ \text{(volume/time)}\end{array}\right) \times \left(\begin{array}{c}\textbf{Contaminant Concentration}\\ \text{(mass/volume)}\end{array}\right) = \left(\begin{array}{c}\textbf{Contaminant Load}\\ \text{(mass/time)}\end{array}\right)$$

Allows for understanding contaminant loads and predicting travel times

Real-Time Loads



USGS

http://ks.water.usgs.gov/Kansas/studies/TMDL/mtgs/pras.ppt.html

Rassmusen, Christensen, Ziegler, and Jian

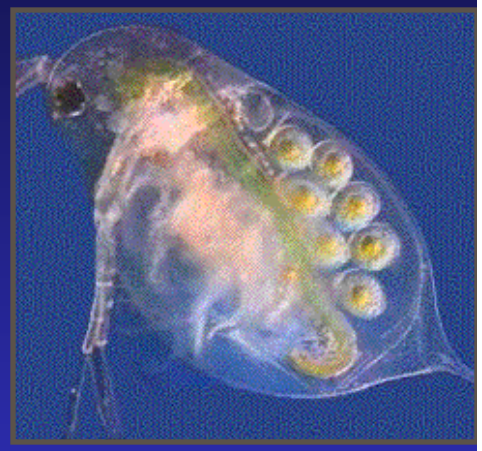
Advanced Sensors for Water Monitoring

Categorized based on parameters measured:

- "Biosensors" to monitor whole water toxicity
- Basic parameters
- Inorganics (dissolved anions, cations, metals)
- Organics (purgeable/nonpurgeable)
- Pathogens (viruses, bacteria, spores, etc.)
- Radioactivity

Biosensors for Whole Water Toxicity

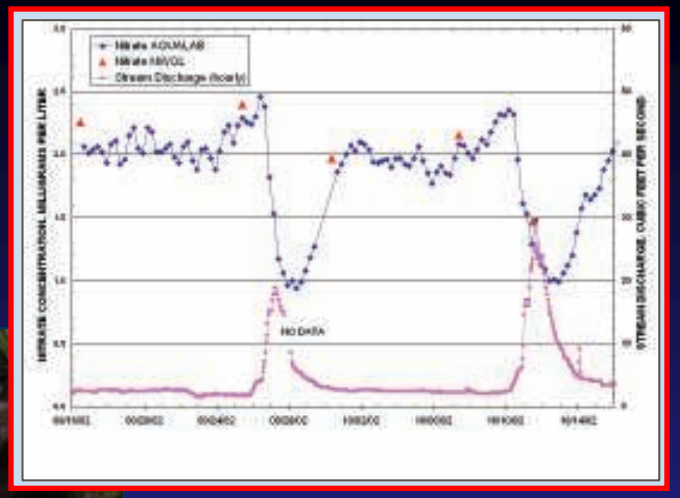
- Fish (U.S. Army Center for Environmental Health Research)
- Clams and mussels
- Daphnia (*The bbe Daphnia Toximeter*)
  http://www.bbe-moldaenke.de/english/produkte3_e.html
- Algae (*The bbe Algae Toximeter*)
  http://www.bbe-moldaenke.de/english/produkte3_e.html
- Luminescent Bacteria (*Microtox, DeltaTox)*
  http://www.azurenv.com



U.S. EPA Environmental Technology Verification (ETV) Program
http://www.epa.gov/etv

Basic Parameters and Inorganic Compounds

- Basic parameters: Orion, Hach, HydroLab, Stevens Water, Turner Designs, YSI Inc., General Oceanics Inc., etc.
  http://www.stevenswater.com/
  http://www.ysi.com/
- Nitrate, perchlorate, CN^-, some nerve agents: ATR-FTIR
  http://pubs.acs.org/cen/coverstory/8113/8113pittcon4.html
- Cyanide, mustard gas, and other nerve agents: SERS
  http://pubs.acs.org/cen/coverstory/8113/8113pittcon4.html
- Nitrate, ammonia, phosphate, organic carbon, and basic parameters: Stevens AQUALAB Analyzer
  http://www.stevenswater.com/water_quality_sensors/aqualab.html

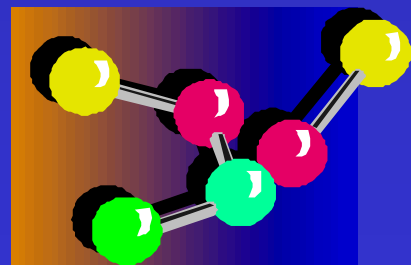


USGS Scientists preparing to install the Greenspan (now Stevens) AQUALAB Analyzer at Morgan Creek, Maryland.

[Photo by James R. Jeffries, U.S. Geological Survey]

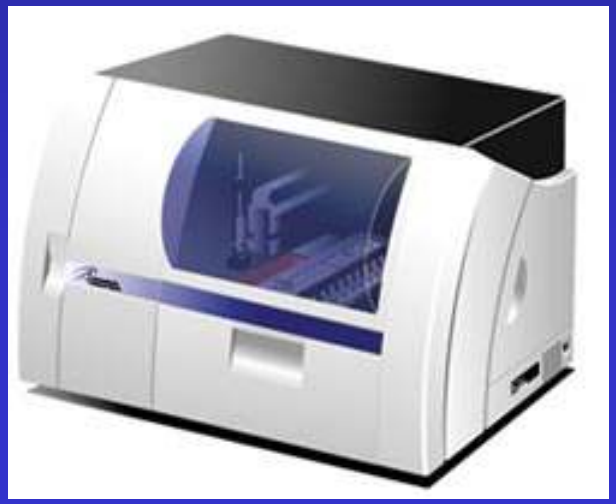
Organic Compounds

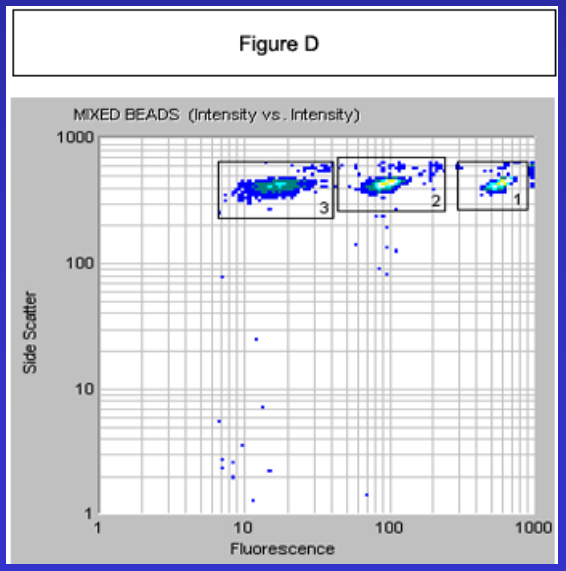
- Hydrocarbons:
  - Strategic Diagnostics, Inc. http://www.sdix.com
  - Turner Designs TD-4100 http://www.turnerdesigns.com
- Pesticides, Herbicides:
  - Strategic Diagnostics, Inc. Rapid Immunoassays http://www.sdix.com
- Some pesticides and nerve agents:
  - Molecularly Imprinted Polymers http://www.jascoinc.com/
- Volatile organic compounds, chemical warfare agents:
  - Portable PT-GC-MS http://www.inficonvocmonitoring.com
  - DSIT-MS http://www.tri-corders.com/
  - Py-GC-IMS (under development)

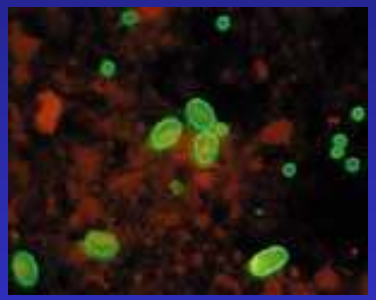


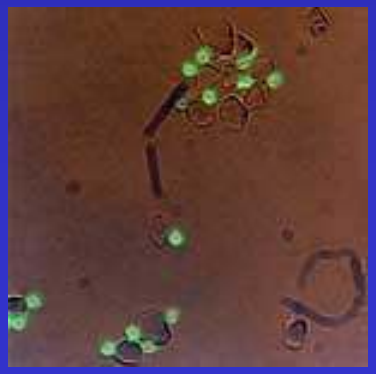
Pathogens

- Fluid Imaging Technologies, Inc.
  http://www.fluidimaging.com/ (FlowCam)
- Integrated Virus Detection System (IVDS): tangential-flow ultrafiltration, particle-size distribution (Wick & McCubbin, 2003, Toxicology Mechanisms and Methods, Vol 9 No 4)
- Advanced Analytical RDB-3000
  http://www.aati-us.com









Pathogens

- Hand-Held Antibody/Antigen Tests (HAAs) and other immunoassay-based techniques (pre-concentration needed to improve detection limits)
- Real-time PCR:
  - Cephid: http://www.smartcycler.com/
  - Applied Biosystems: http://home.appliedbiosystems.com/
  - R.A.P.I.D. (Ruggedized Advanced Pathogen Identification Device) http://www.idahotech.com/products/
- Colilert for E. Coli.: http://www.idexx.com/water/products/
- CANARY B-cells: http://www.innovativebiosensors.com/
- Chemical methods
  - MALDI & other "soft" ionization techniques
  - Raman Chemical Imaging Microscope http://www.chemimage.com/products/

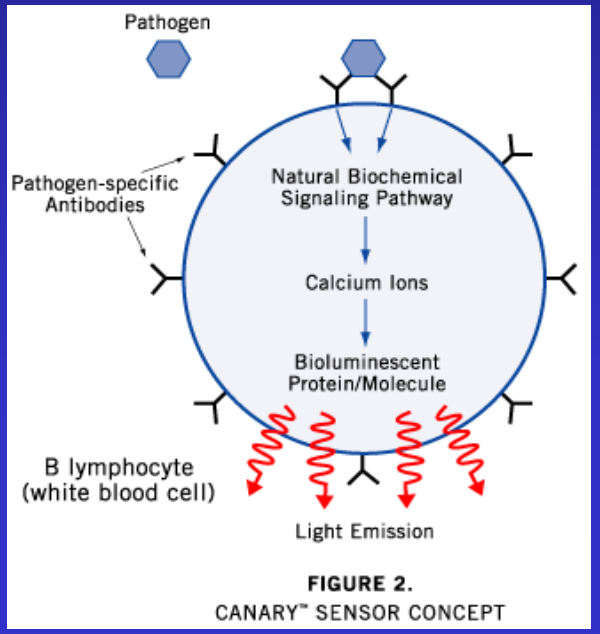


FIGURE 2.
CANARY™ SENSOR CONCEPT

Considerations for Sensor Selection

- **Suite of analytes or indicators of interest**
- **Degree of maturity of the technology**
  - Can you purchase it?
  - Has it been lab tested?
  - Has it been field tested?
  - Does it have a history of sound performance in field?
- **Is it automated? In-situ?**
- **How does it compliment other sensor capabilities?**

Technical Considerations for Early-Warning Monitoring

- Secure and timely data transmission
- Instrument testing and maintenance
- Automated data processing
- Continual updating of algorithms
- Response plan, in case of "event"

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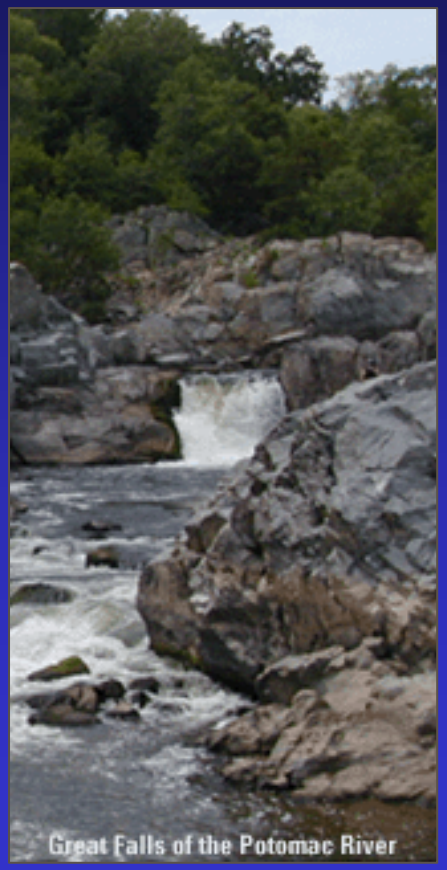
Great Falls of the Potomac River