Real-Time Water-Quality Monitoring for Water Security Applications

General Meeting of the Federal Remediation Technologies Roundtable, Arlington, VA, Dec. 7, 2005

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Real-Time Water-Quality Monitoring for Water Security

- Can water-quality monitoring increase security?
- What sensors should be used?
- How reliable are the available sensors?
- What are the maintenance and replacement intervals?

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United States Government Accountability Office

GAO

Testimony

Before the Subcommittee on Environment and Hazardous Materials, Committee on Energy and Commerce, House of Representatives

For Release on Delivery
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DRINKING WATER

Experts' Views on How Federal Funding Can Best Be Spent To Improve Security

Statement of John B. Stephenson, Director
Natural Resources and Environment

GAO
Accountability * Integrity * Reliability

GAO-04-1098T

"The need to develop near real-time monitoring technologies which would be particularly useful in quickly detecting contaminants in water that has already left the treatment plant for the consumer, ***has by far the strongest support"***

Nearly 100% of experts consider this a high priority.

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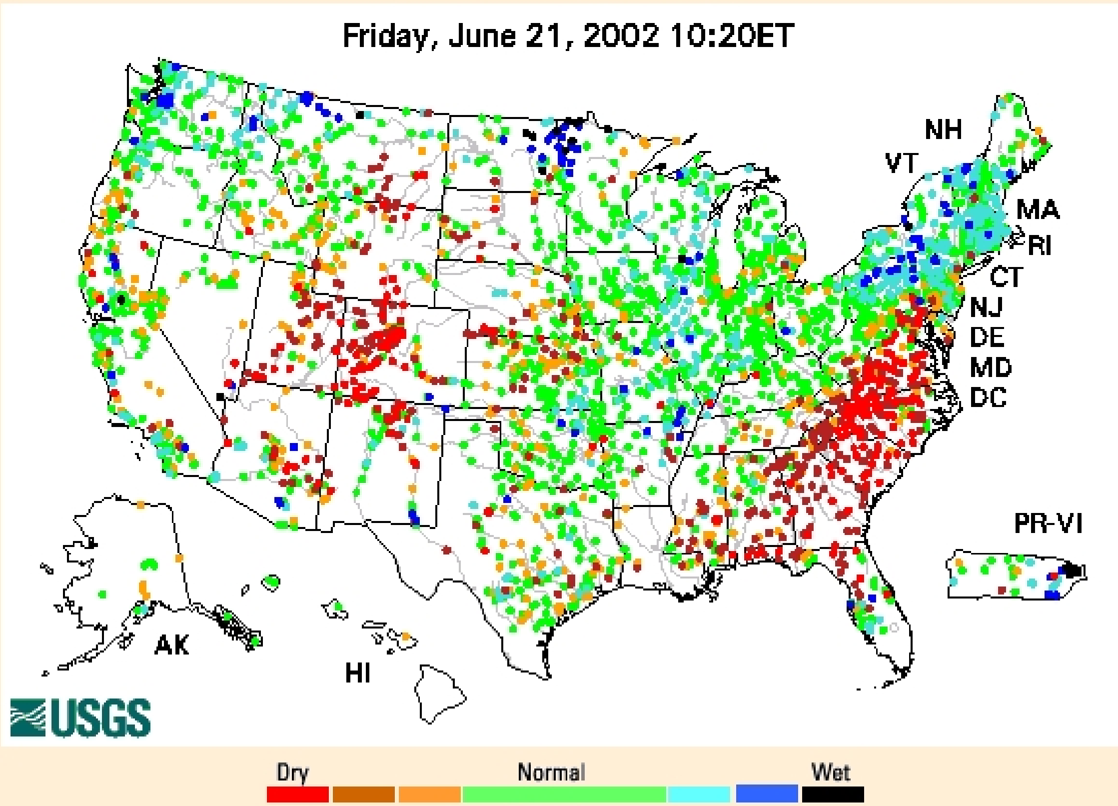
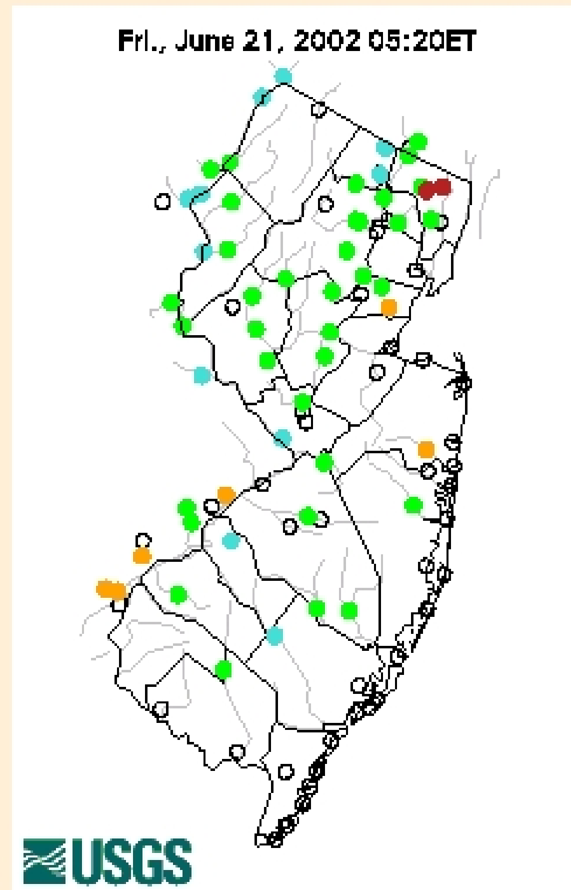
Existing USGS real-time systems

Map of real-time streamflow compared to historical streamflow for the day of the year (United States)



Daily Streamflow Conditions

Select a site to retrieve data and station information.



Objectives of the Overall Water Security Research Program

- To develop a real-time water-quality monitoring system for drinking water safety and security
- To evaluate available sensors for use in such a system
- To install and test the system in water distribution systems

Site Installations

- **<u>5 distribution-system sites established</u>**
- Free Chlorine, Specific Conductance, pH, Oxidation-Reduction Potential, and temperature measured at all sites
- Total Organic Carbon and UV/VIS (on loan) at one site
- Additional sites based on model results to be installed (locations optimized for public health protection) – pending logistical issues

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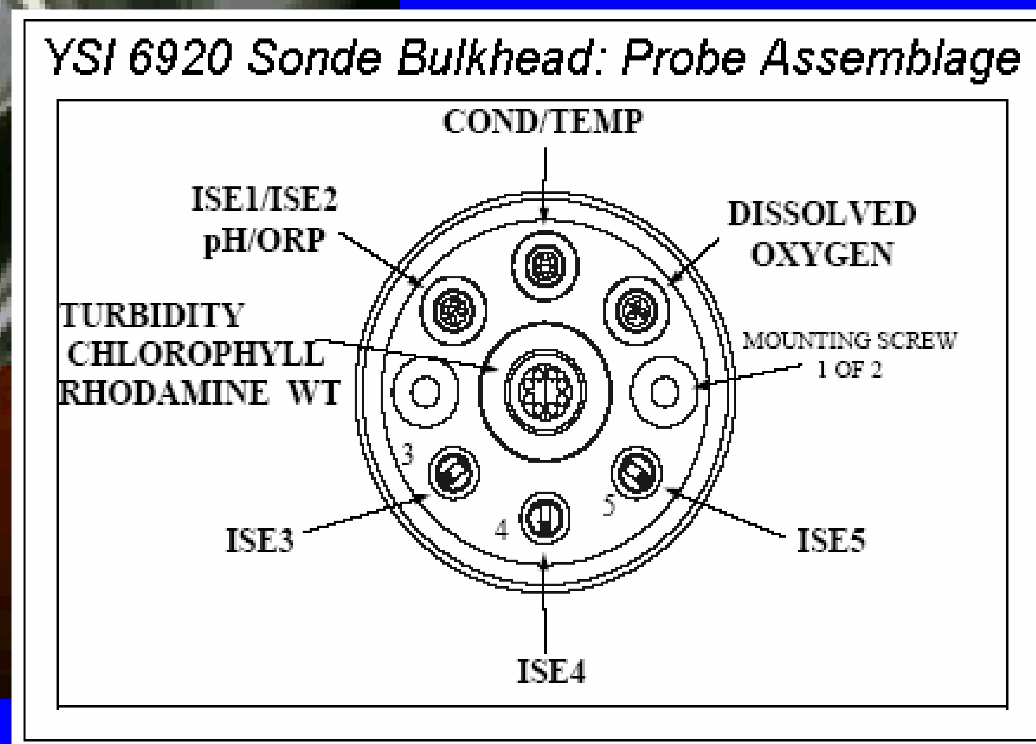
Water-Quality Monitoring System



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Typical site installation

- Sensor locations: Based on distribution-system modeling
  - Water utility facilities, pumping stations, homes, government buildings, hospitals…
- Sensors: free chlorine, oxidation-reduction potential, specific conductance, pH, temperature

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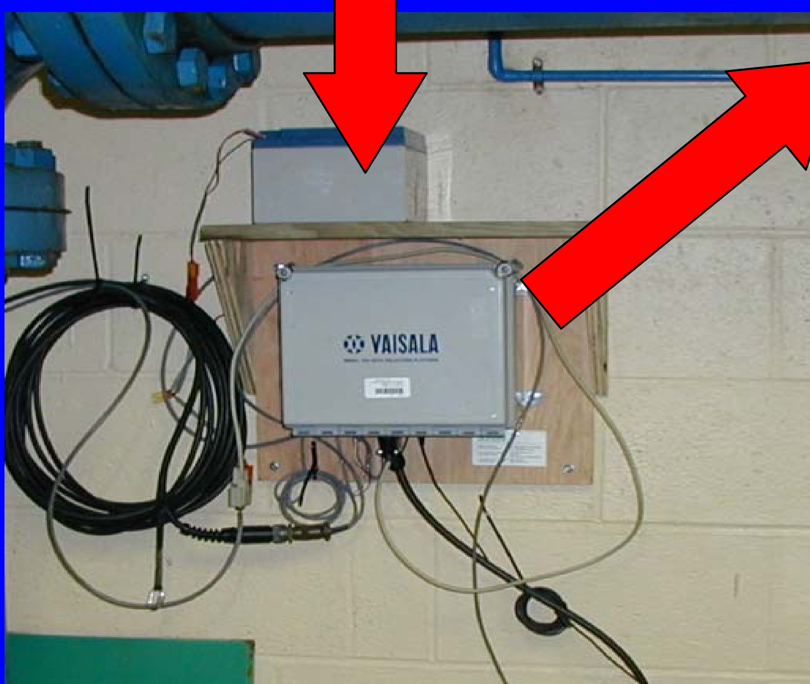
Data telemetry and management : Sensors data transmitted to USGS secure webpage using satellite telemetry



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USGS Real-Time Water Data for USGS 405307074090201 TAP WATER AT MAIN AVENUE AT CLIFTON NJ - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://waterdata.usgs.gov/nj/nwis/uv?dd_cd=01%2C02%2C03%2C04%2C05%2C06%2C07%2C09%2C16&format=gif&period=7&site_no=405307074090201

USGS

District Access

Water Resources

Data Category: Real-time

Geographic Area: New Jersey

USGS 405307074090201 TAP WATER AT MAIN AVENUE AT CLIFTON NJ (internal access only)

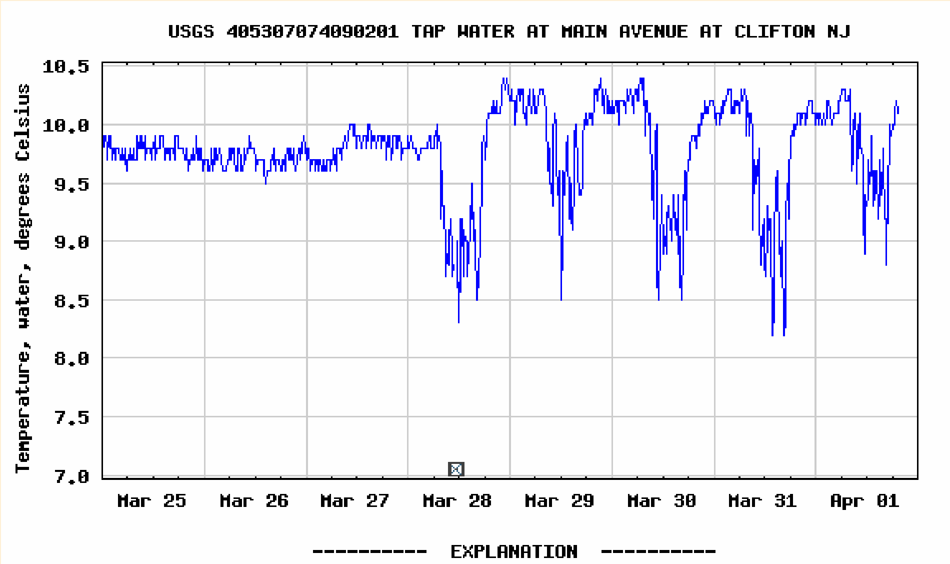
PROVISIONAL DATA SUBJECT TO REVISION

Available data for this site: Real-time GO

Available Parameters	Output format	Days	
All 9 parameters available at this site 00010 Temperature, water (DD 01) 00095 Specific cond at 25C (DD 02) 00300 Dissolved oxygen (DD 03)	Graph	7 (1-31)	get data

Temperature, water, degrees Celsius

Most recent value: 10.1 04-01-2005 19:15



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Internet

start | USGS Presentations | Microsoft PowerPoint ... | USGS Real-Time Wat... | 7:33 PM

USGS 405307074090201 TAP WATER AT MAIN AVENUE AT CLIFTON NJ (internal access only)

PROVISIONAL DATA SUBJECT TO REVISION

Available data for this site: Real-time GO

Available Parameters	Output format	Days	
All 9 parameters available at this site 00010 Temperature, water (DD 01) 00095 Specific cond at 25C (DD 02) 00300 Dissolved oxygen (DD 03)	Table	7 (1-31)	get data

Date / Time	Temper-ature, water, deg C (DD 01)	Oxi-dation re-duction poten-tial, mV (DD 16)	Specif. conduc-tance, wat unf uS/cm 25 degC (DD 02)	Dis-solved oxygen, mg/L (DD 03)	Dis-solved oxygen, percent of sat-uration (DD 04)	pH, water, unfltrd field, std units (DD 05)	Turb-idity, IR LED light, det ang 90 deg, FNU (DD 06)	DCP battery voltage volts (DD 07)	Esti-mate of DCP trans. power, dB (DD 09)
03/25/2005 00:00	9.7	654	411	13.3	110	8.50	.0	13.7	
03/25/2005 00:15	9.9	648	410	13.2	110	8.51	.1		
03/25/2005 00:21									46.0
03/25/2005 00:30	9.9	643	411	13.3	110	8.52	.1		
03/25/2005 00:45	9.9	644	410	13.3	110	8.51	.2		
03/25/2005 01:00	9.8	645	412	13.3	110	8.51	.1	13.7	
03/25/2005 01:15	9.7	645	412	13.3	110	8.51	.1		
03/25/2005 01:21									46.0
03/25/2005 01:30	9.9	640	411	13.3	110	8.52	.0		
03/25/2005 01:45	9.9	638	410	13.3	110	8.53	.0		

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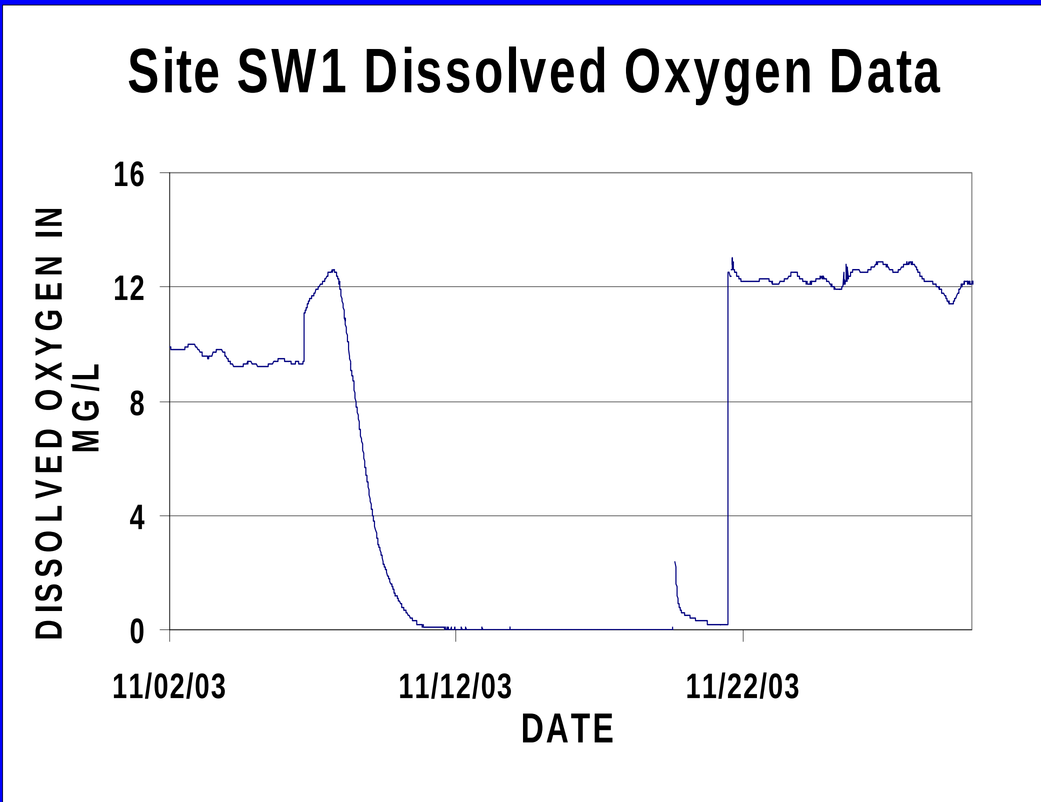
Some Realities of Field Work with Sensors

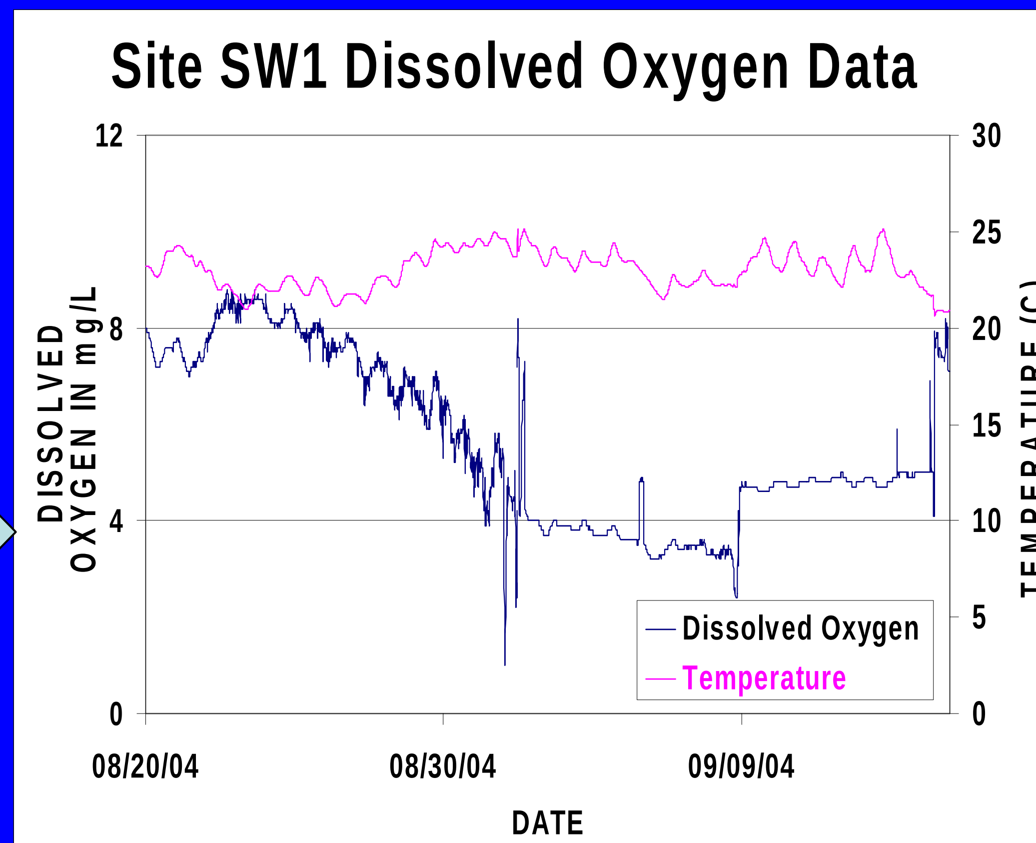
- Often heard questions and comments:
  - Did anyone bring the manual for this thing?
  - Oh, No, not again!
  - Do we have a spare?
  - Did I really spend (X) years in college to do this?
  - If one more thing goes wrong I will miss (fill in favorite 9:00 pm TV show).

Example 3: Dissolved Oxygen Sensor Membrane Replacement



Sudden decline in response indicates membrane needs to be replaced.

Gradual decline in response, noticeable as higher-than-normal calibration drift. Membrane needs to be replaced.



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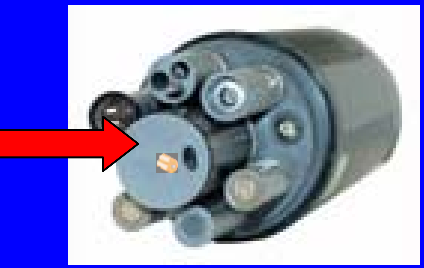
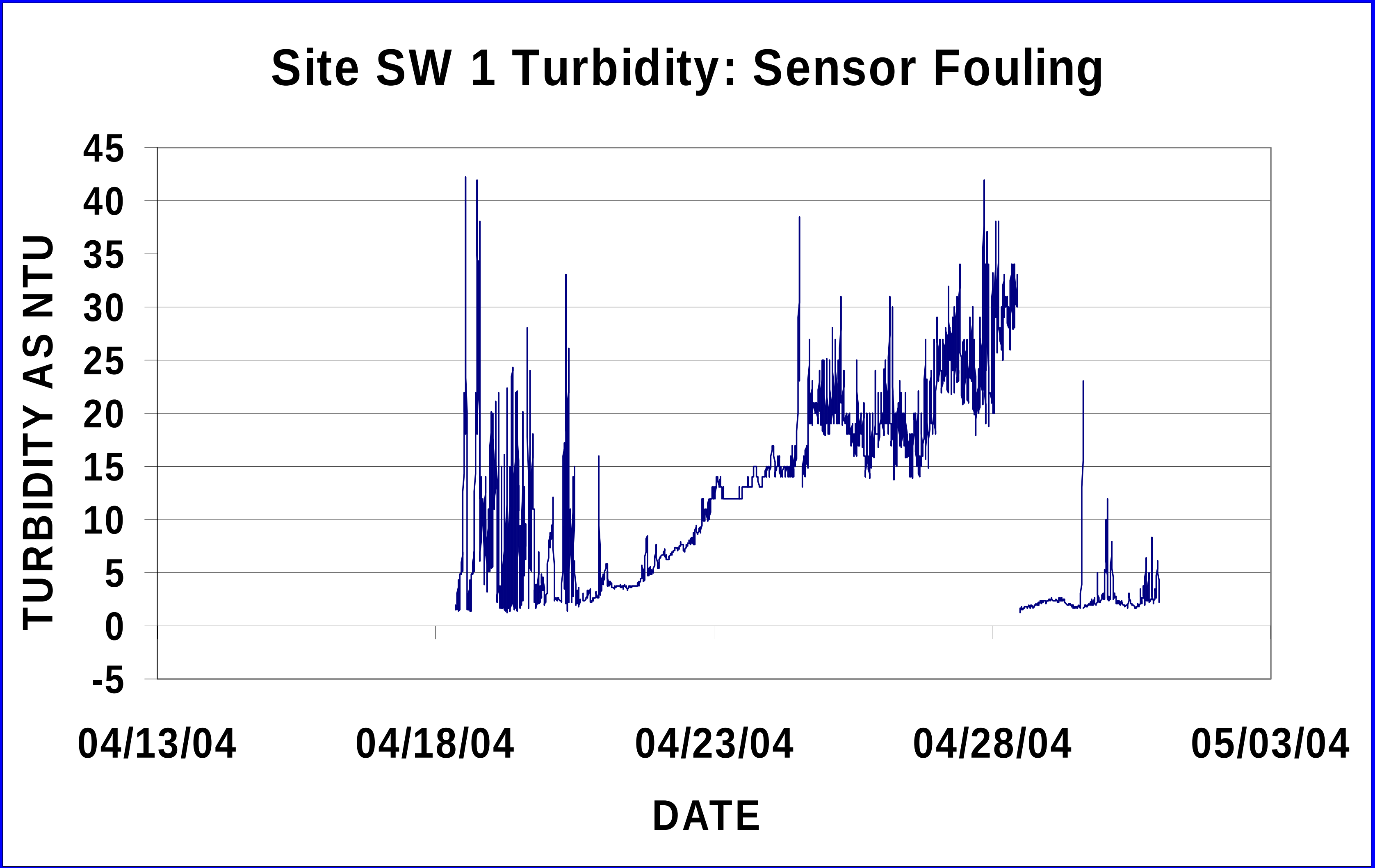
Example 4: Turbidity Sensor Fouling

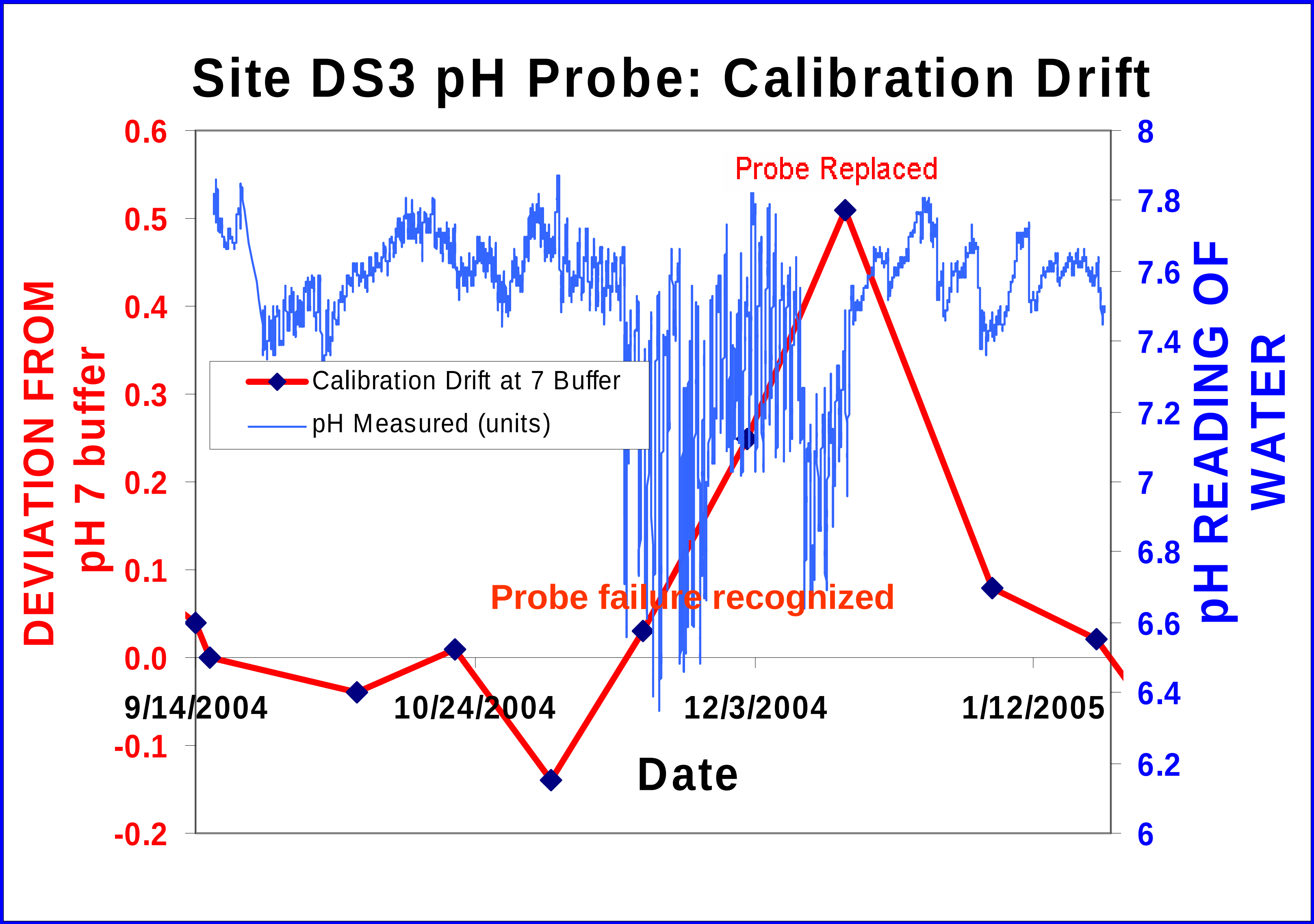


Wiper keeps particles from building up on window.

Removal of wiper causes inaccurately high readings



Example 1: pH Sensor that Needs to be Replaced



As probe signal degrades, response in buffer **deviates farther from standard value**.

Result: Data from 11/04 – 12/04 **not accurate**, and variability not representative of true system conditions

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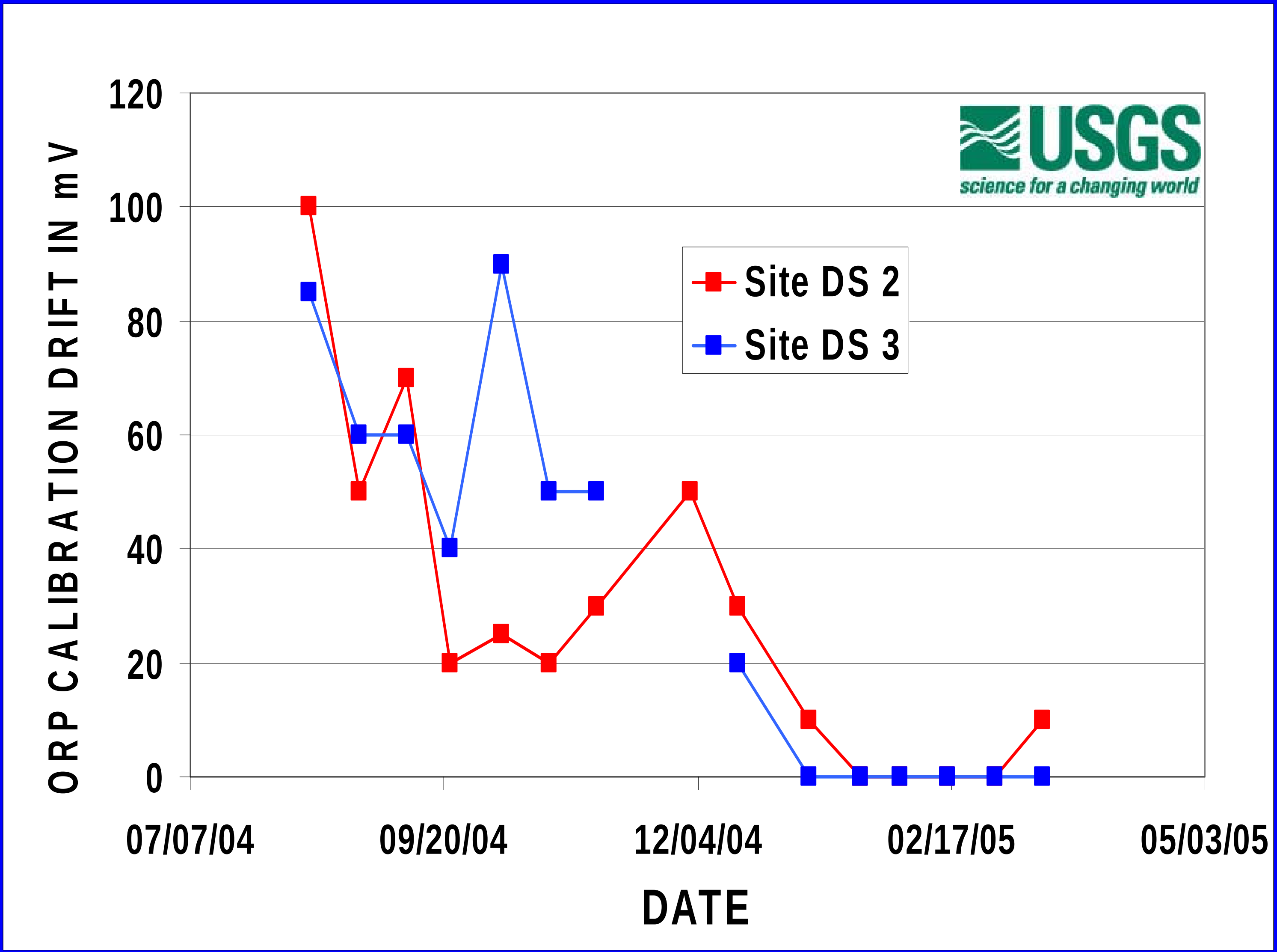
Example 2: Oxidation-Reduction-Potential (OPR) Sensor Performance: Calibration Drift of New Sensors



New sensors: Response (mV reading) increases after deionized water rinse

Possible reason:

Platinum electrode builds up an oxide coating which is removed by de-ionized water.

Over time coating becomes resistant to rinsing, reducing post-cleaning calibration drift

What does this mean? Must account for post-cleaning variability on newer probes!


P2-D


SIEVERS 900
On-Line TOC Analyzer


VAISALA
STOP
6600

Summary of Observations of the Sensors Tested

- **pH:** Mostly stable and accurate. Requires replacement after 1-2 years. Drift noticed over time, electrode requires reconditioning every 4-5 months.
- **SC sensor:** excellent performance
- **ORP sensor:** very accurate after initial "break-in" time
- **Chlorine residual sensor:** still beta testing, needs membrane replacement every 1-2 months. Needs calibration every 2 weeks.

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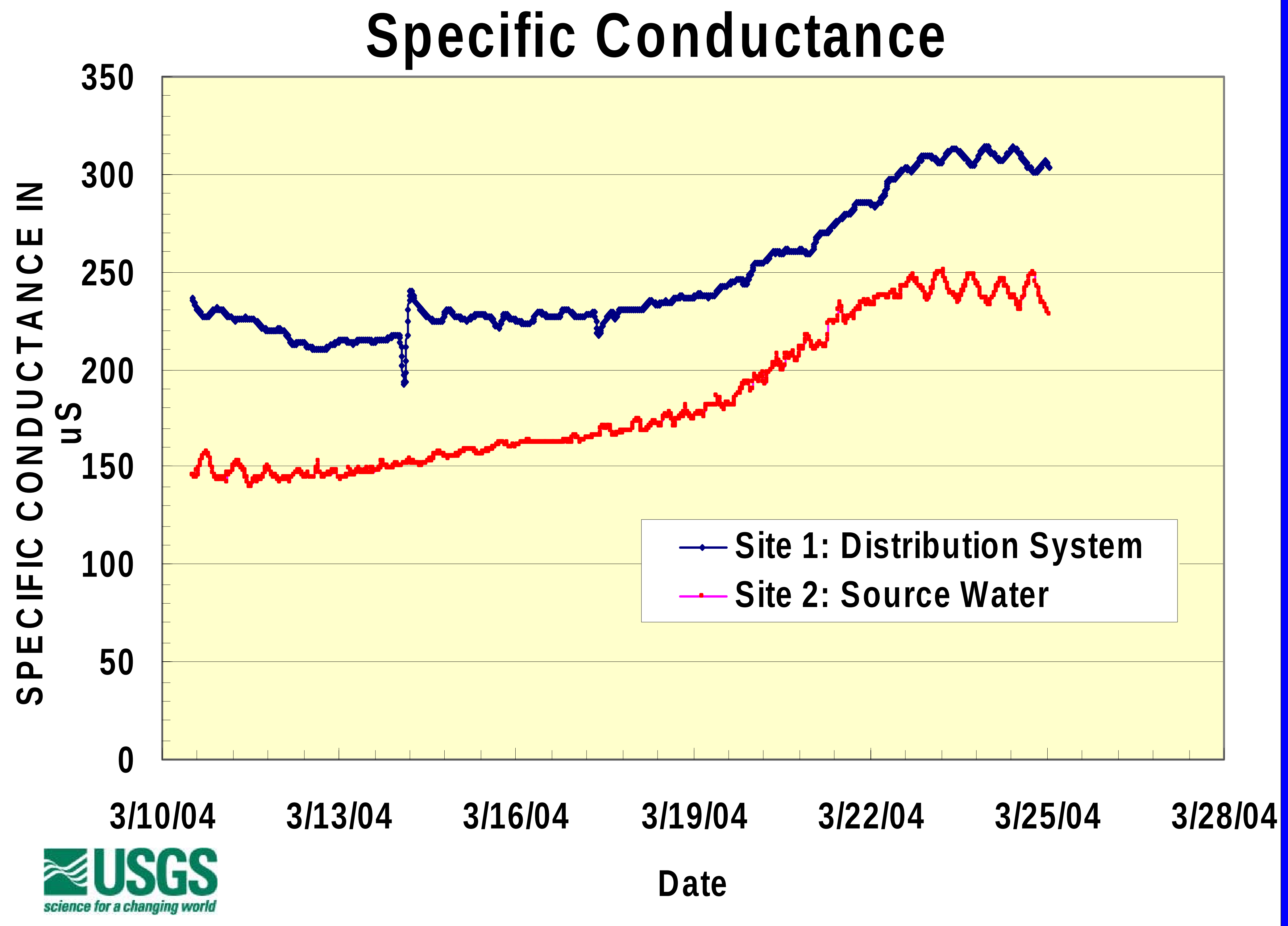
Sensor Performance: Key Issues

- **The need for sensor maintenance or replacement is not always obvious by data observation alone:**
  - **Data from a nonresponsive sensor may look reasonable**
- **Sensors must be maintained properly:**
  - **Calibration drift affects data accuracy and precision**
  - **Quality assurance includes assessing and correcting data to reflect drift**
  - **Shorter maintenance intervals and more frequent calibrations reduce chances of significant sensor drift and improve data accuracy**



Specific Conductance
SPECIFIC CONDUCTANCE IN uS
350
300
250
200
150
100
50
0
3/10/04
3/13/04
3/16/04
3/19/04
3/22/04
3/25/04
3/28/04
Date
Site 1: Distribution System
Site 2: Source Water
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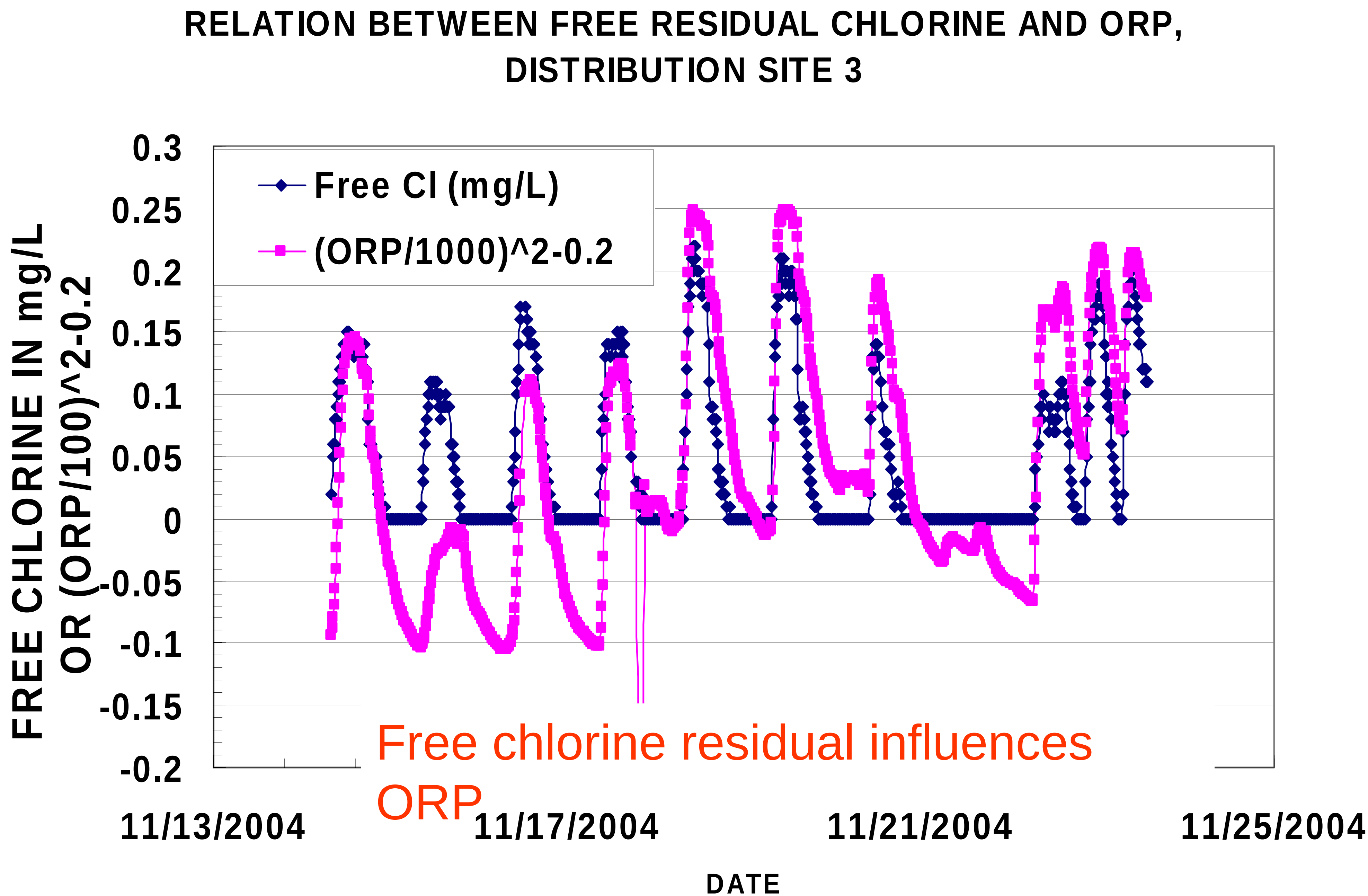

Free chlorine residual influences ORP

Current Work: Characterizing water-quality variability in a distribution system

- USEPA
  - Conduct controlled laboratory experiments
  - Select sites based on distribution-system modeling
- Sandia National Laboratories (SNL)
  - Develop distribution-system and sensor network models
- USGS
  - Establish and operate a network of field sites
  - Collect and manage water quality data
  - Prepare interpretive reports
- Cooperating Water Utility
  - Provide and allow access to distribution system sites
  - Provide distribution system description and model
  - Support the field effort by preparing water and electrical connections and drains

New Technologies Being Tested At Site DW3

- First commercial use of chlorine probe in a YSI multiparameter water-quality monitoring system
- Total organic and inorganic carbon analyzer (General Electric)
- UV-VIS spectrophotometer with software for estimating water-quality parameter values and detecting unexpected changes in water quality (S::can Co.)

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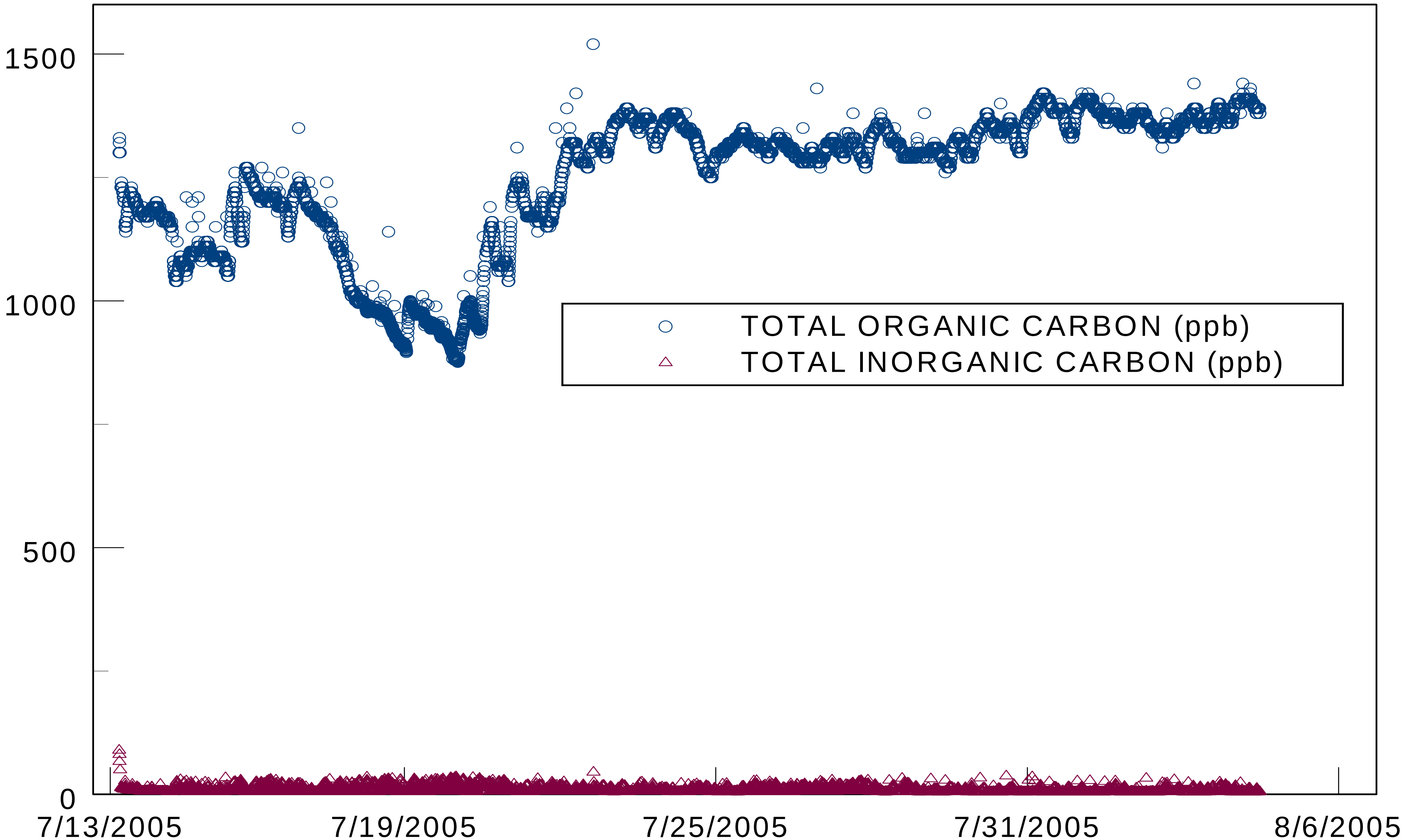
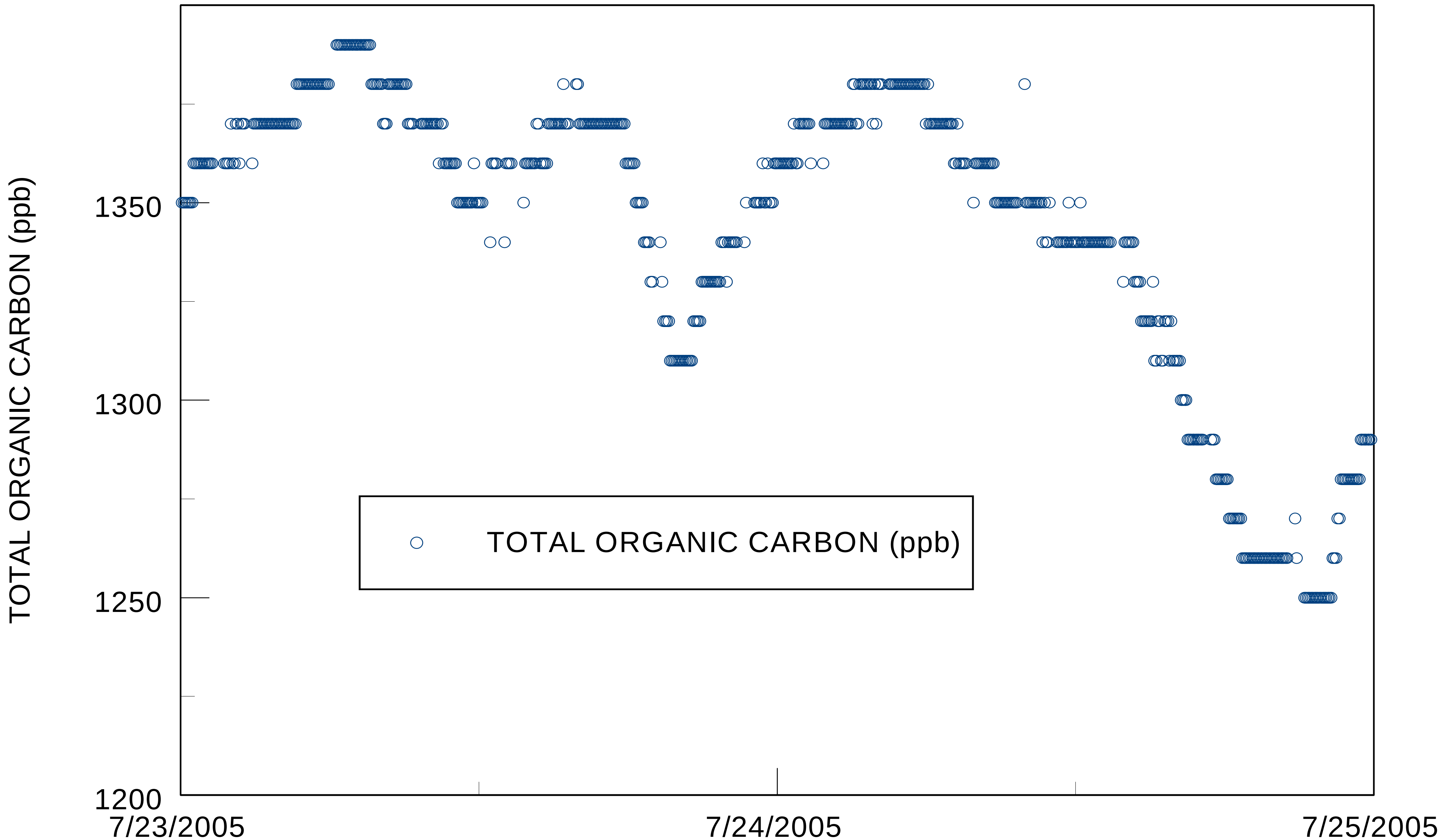
Total Organic and Inorganic Carbon in Drinking Water, Site DW3



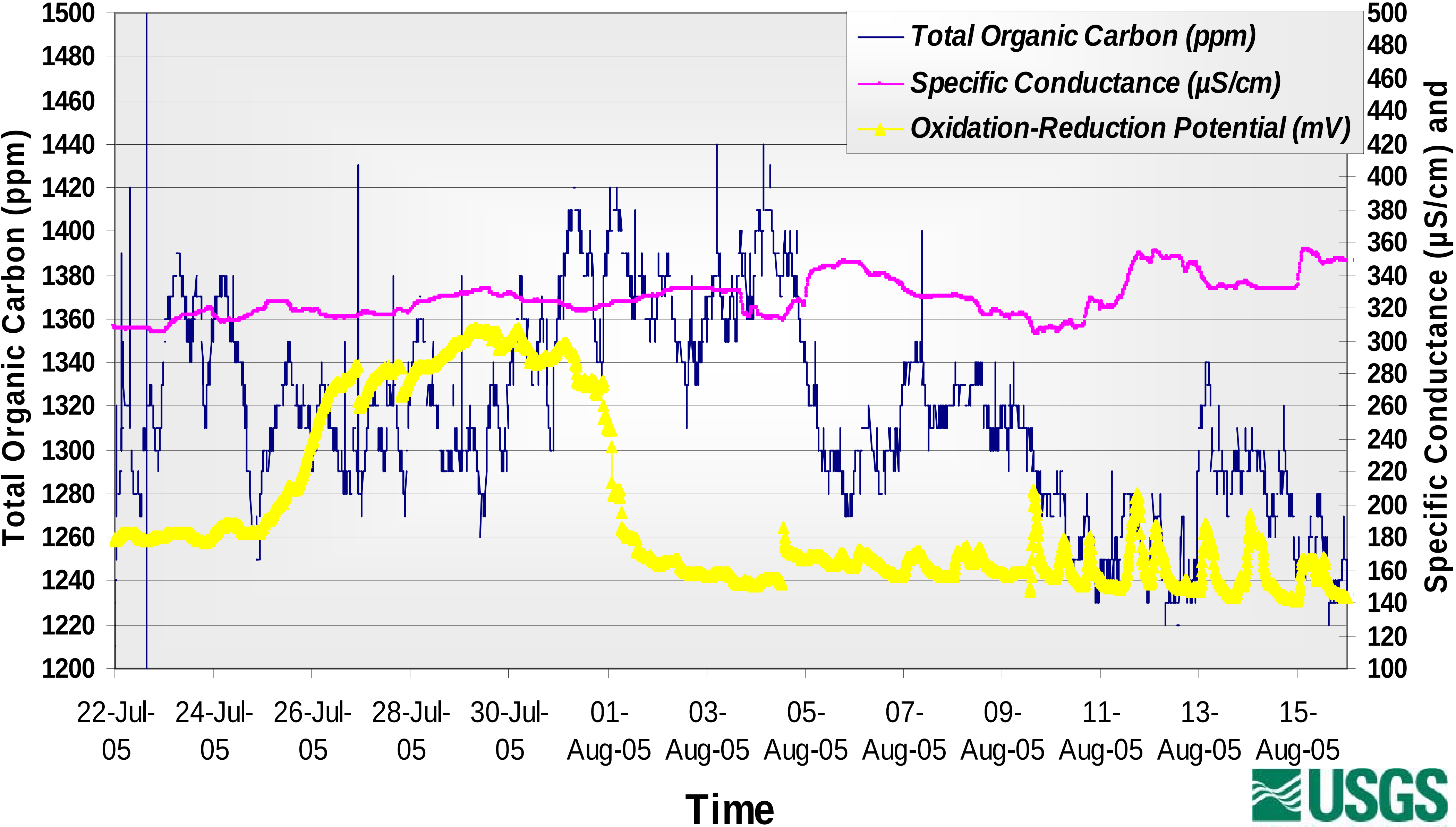
Trends observed: Most carbon is organic, concentration is within a narrow range (800-1600 ppb), some outliers are present

Total Organic Carbon in Drinking Water, Site DW3



Trends observed: Little variability in 2-day period, twice-daily peak concentrations resembling tidal pattern, "step function" concentration pattern

Specific Conductance, Total Organic Carbon, and Oxidation Reduction Potential - in the absense of Chlorine Residual



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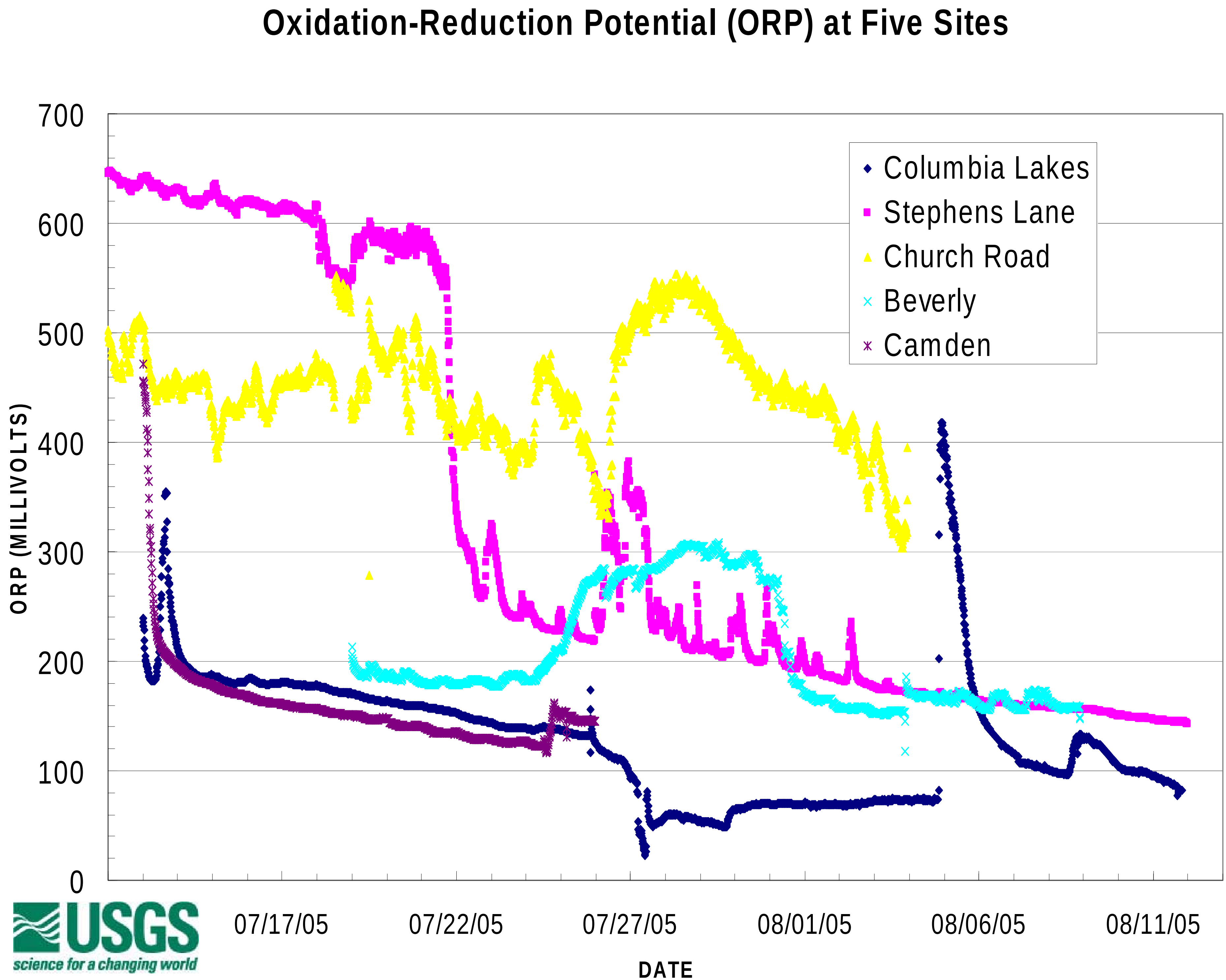

Oxidation-Reduction Potential (ORP) at Five Sites
700
600
500
400
300
200
100
0
ORP (MILLIVOLTS)
Columbia Lakes
Stephens Lane
Church Road
Beverly
Camden
07/17/05
07/22/05
07/27/05
08/01/05
08/06/05
08/11/05
DATE
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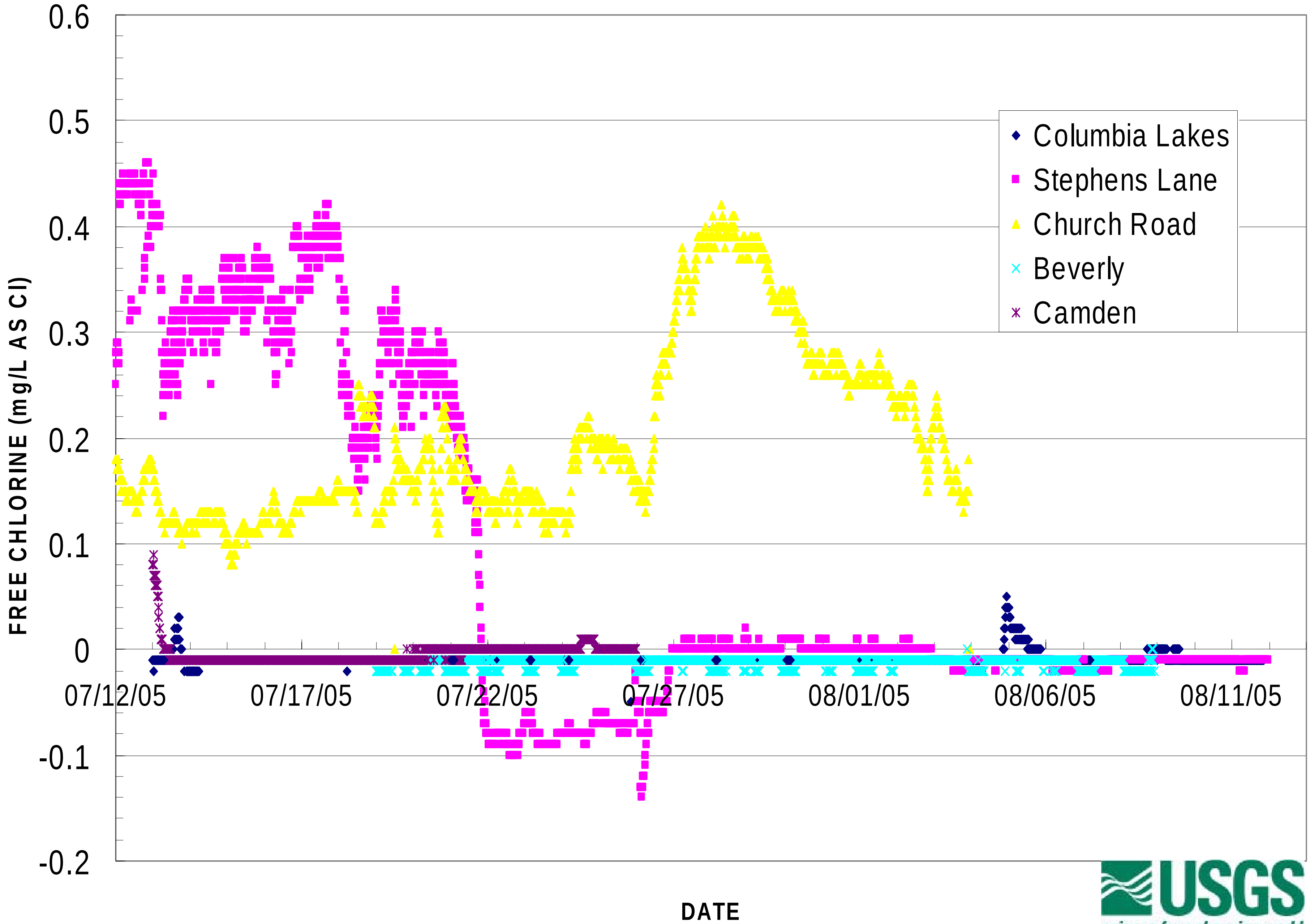
Free Chlorine Residual at Five Sites



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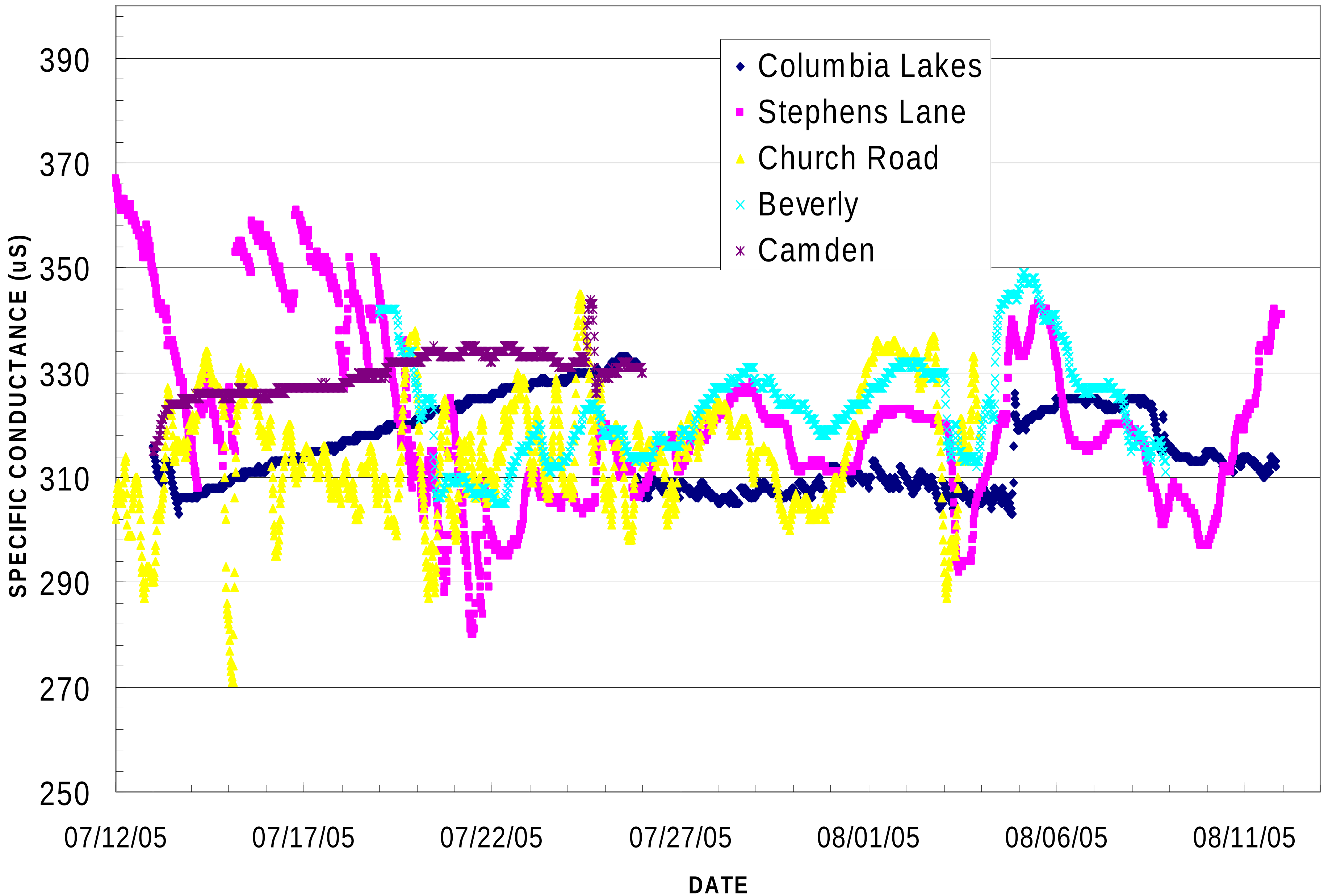
Specific Conductance at Five Sites



Analysis of Water-Quality Variability

- Spatially
  - Age of water
  - Distance between monitoring sites
  - Type of water (SW, GW, mixed)
- Temporally
  - 15-minute intervals (or more frequent if needed)
  - Hourly
  - Daily
  - Weekly
  - Monthly
  - Seasonally
  - Annually

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Explanation of the Density Diagram

A "smoothed histogram", showing the shape of a data set.

X axis: **The difference between each measurement (e.g., pH) and the mean of measured values (moving average) within a time increment (15 minutes, 4 hours or 24 hours).**

Y axis: **Density, or relative frequency of occurrence, of a range of X values**

Evaluating density diagrams: **Relative magnitudes of density values (not the actual values) are most informative for understanding the shape of the data.**

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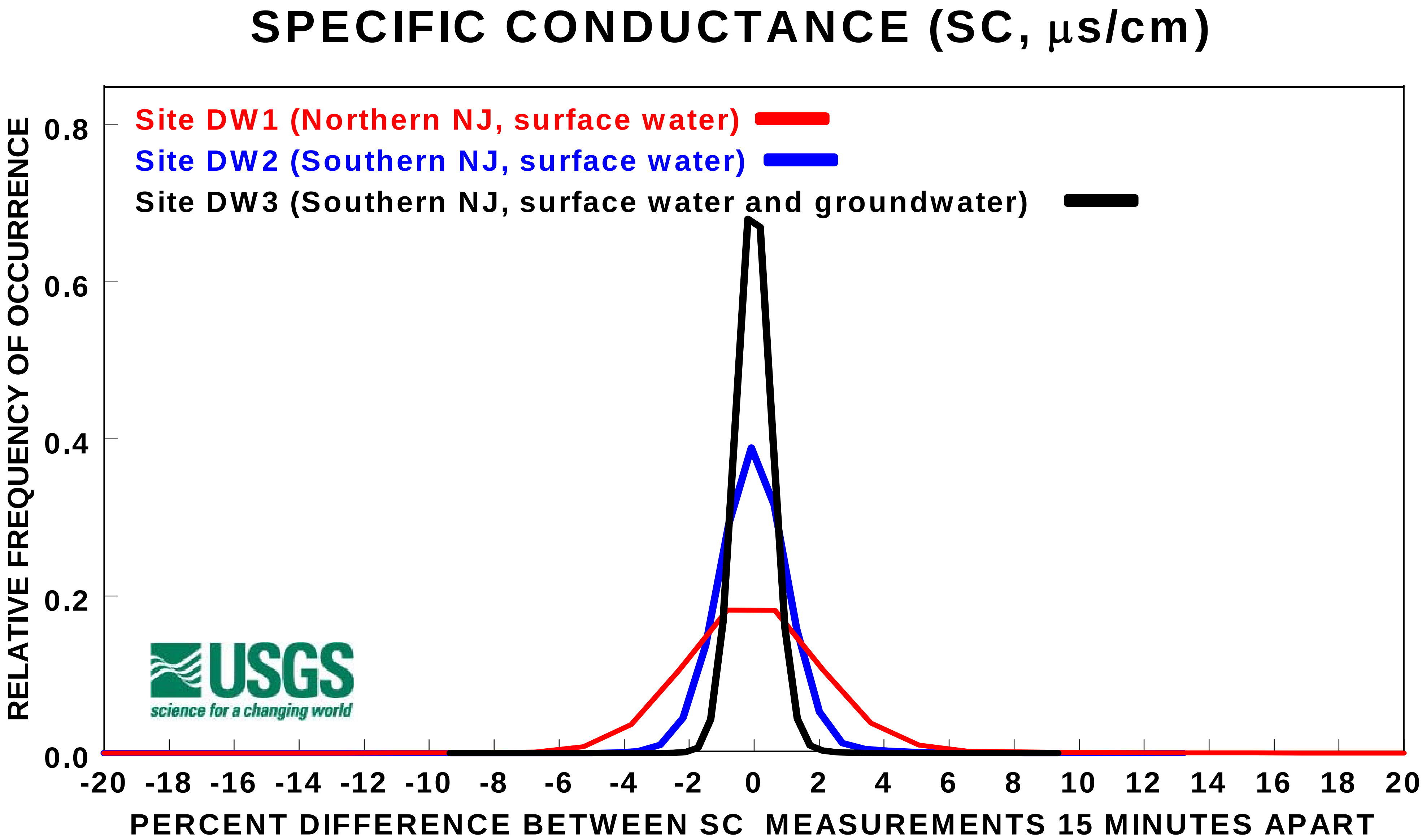
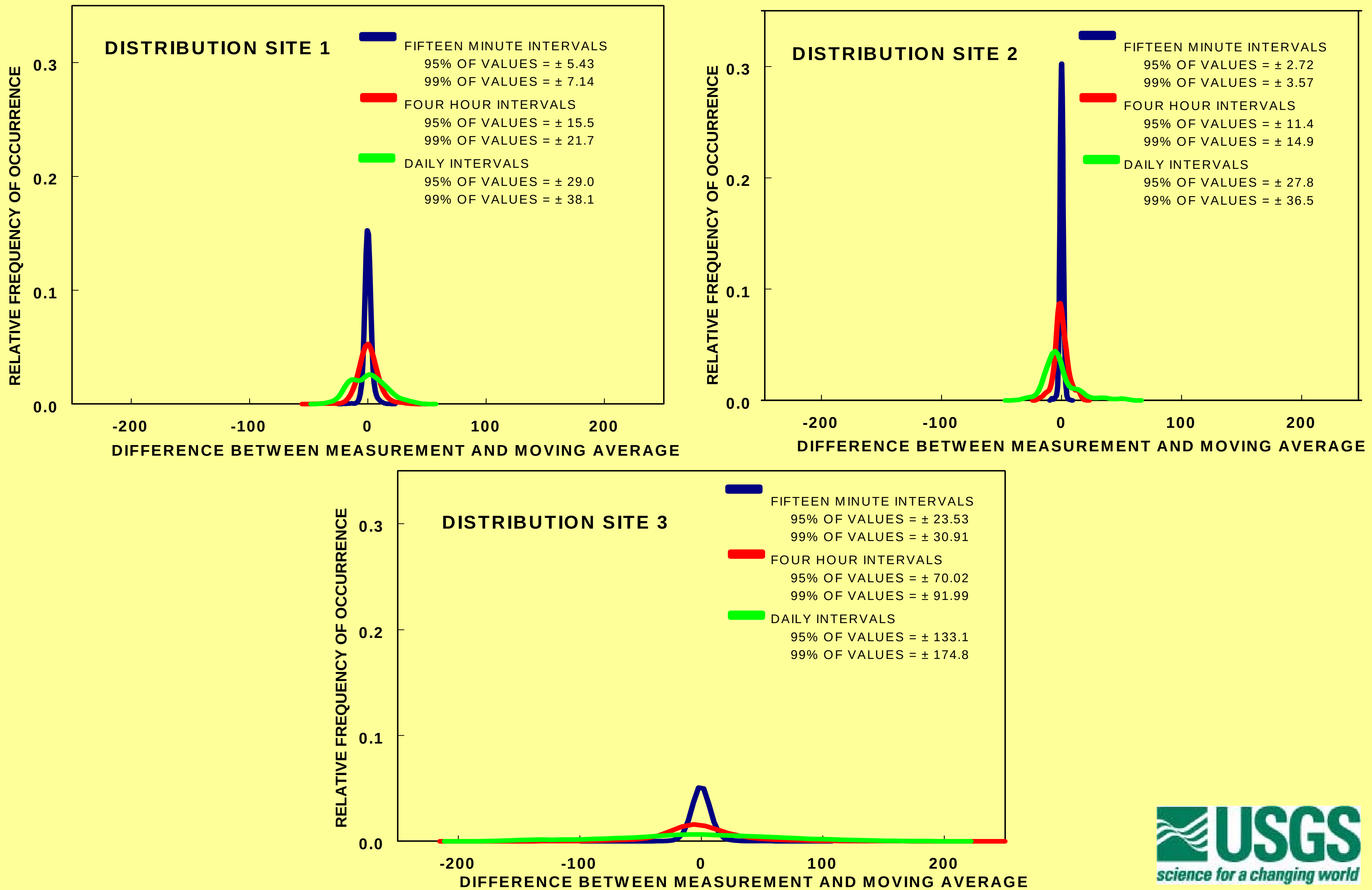
Comparison of Temporal Water-Quality Variability Among 3 Distribution-System Sites



OXIDATION-REDUCTION POTENTIAL (ORP, mV): DISTRIBUTION OF DIFFERENCES BETWEEN MEASUREMENTS AND MOVING AVERAGES OVER 3 TIME INTERVALS



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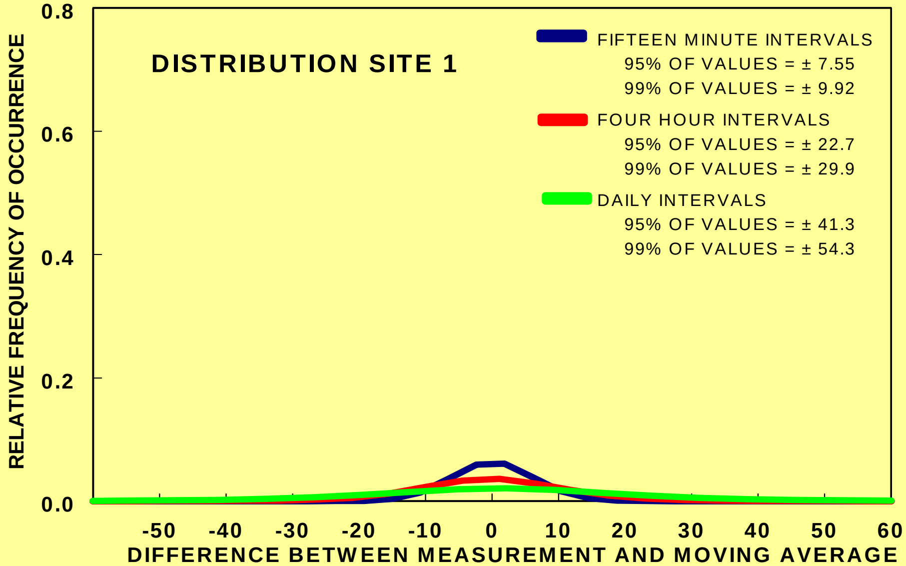
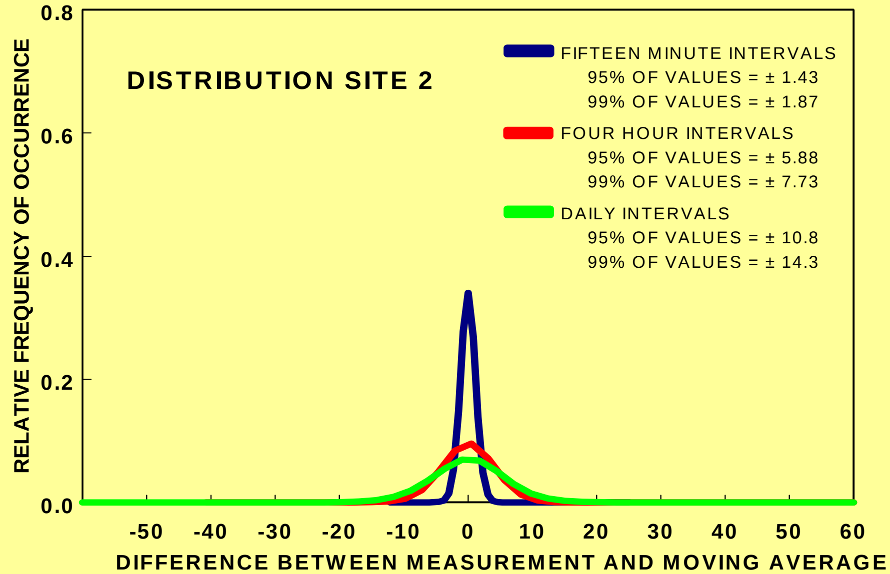
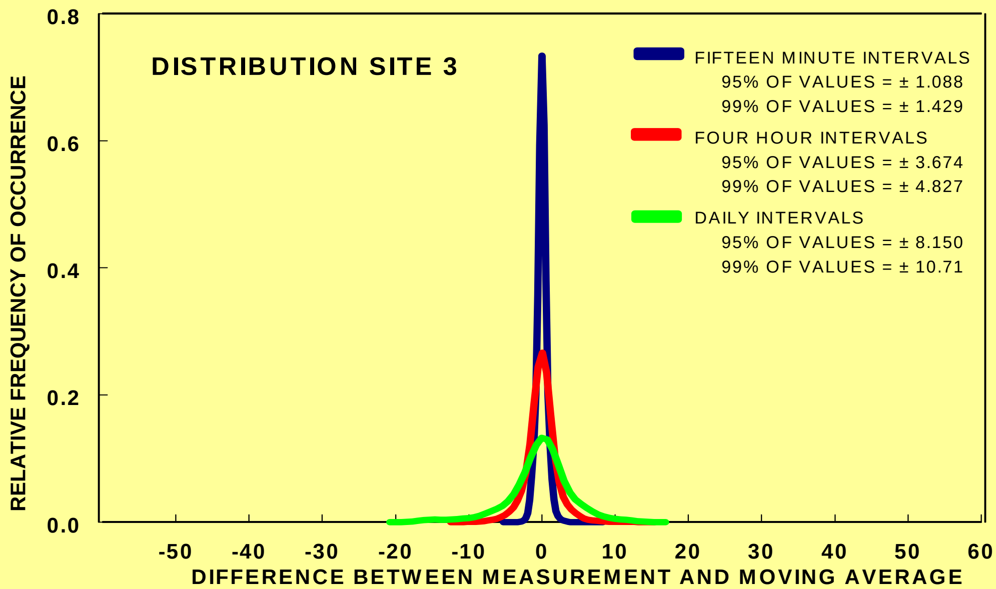
SPECIFIC CONDUCTANCE (uS/cm): DISTRIBUTION OF DIFFERENCES BETWEEN MEASUREMENTS AND MOVING AVERAGES OVER 3 TIME INTERVALS







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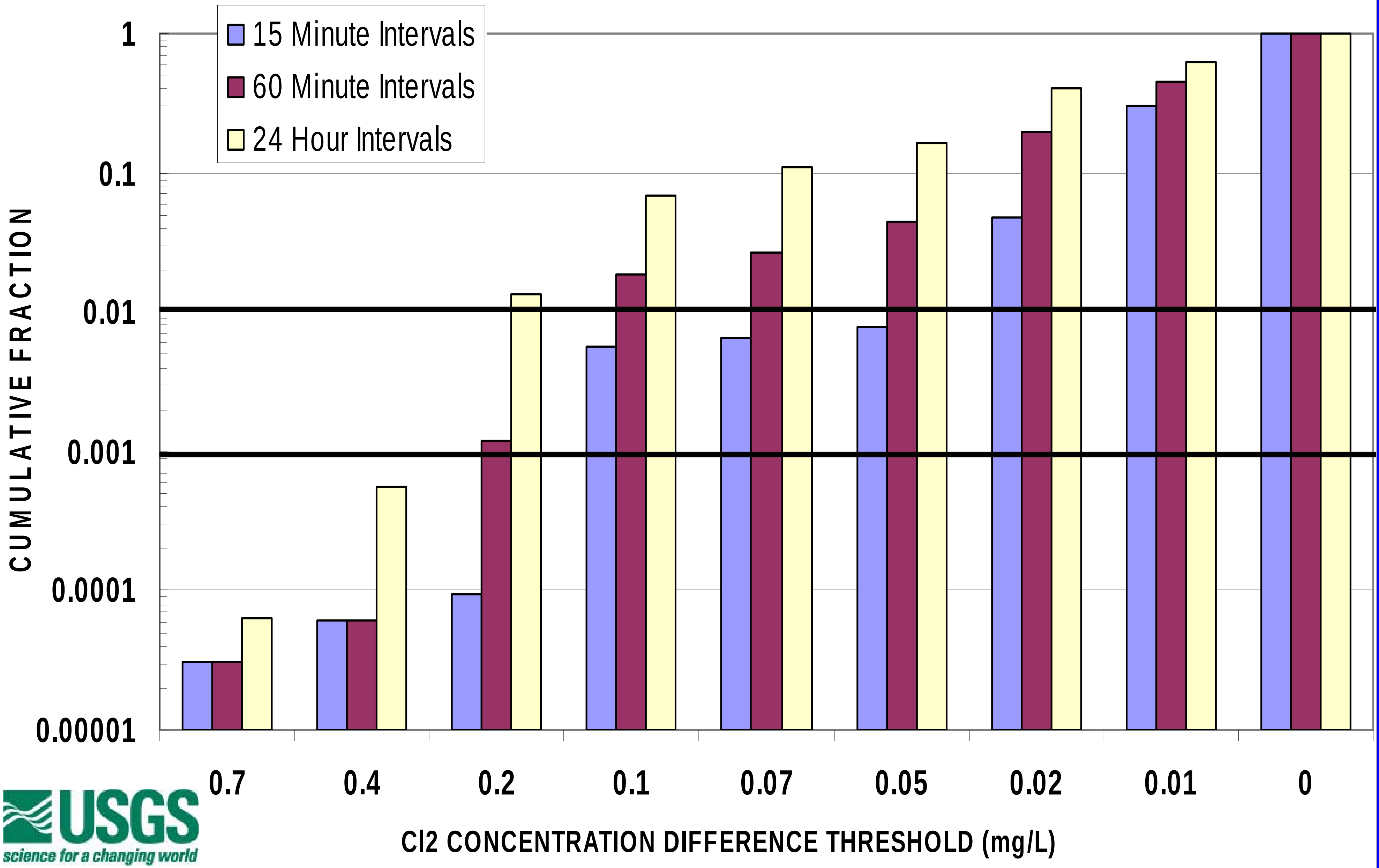
Beverly Free Chlorine Data Through 09/07/05: Cumulative Fractions of Samples Having Consecutive-Concentraton Differences At or Above Thresholds



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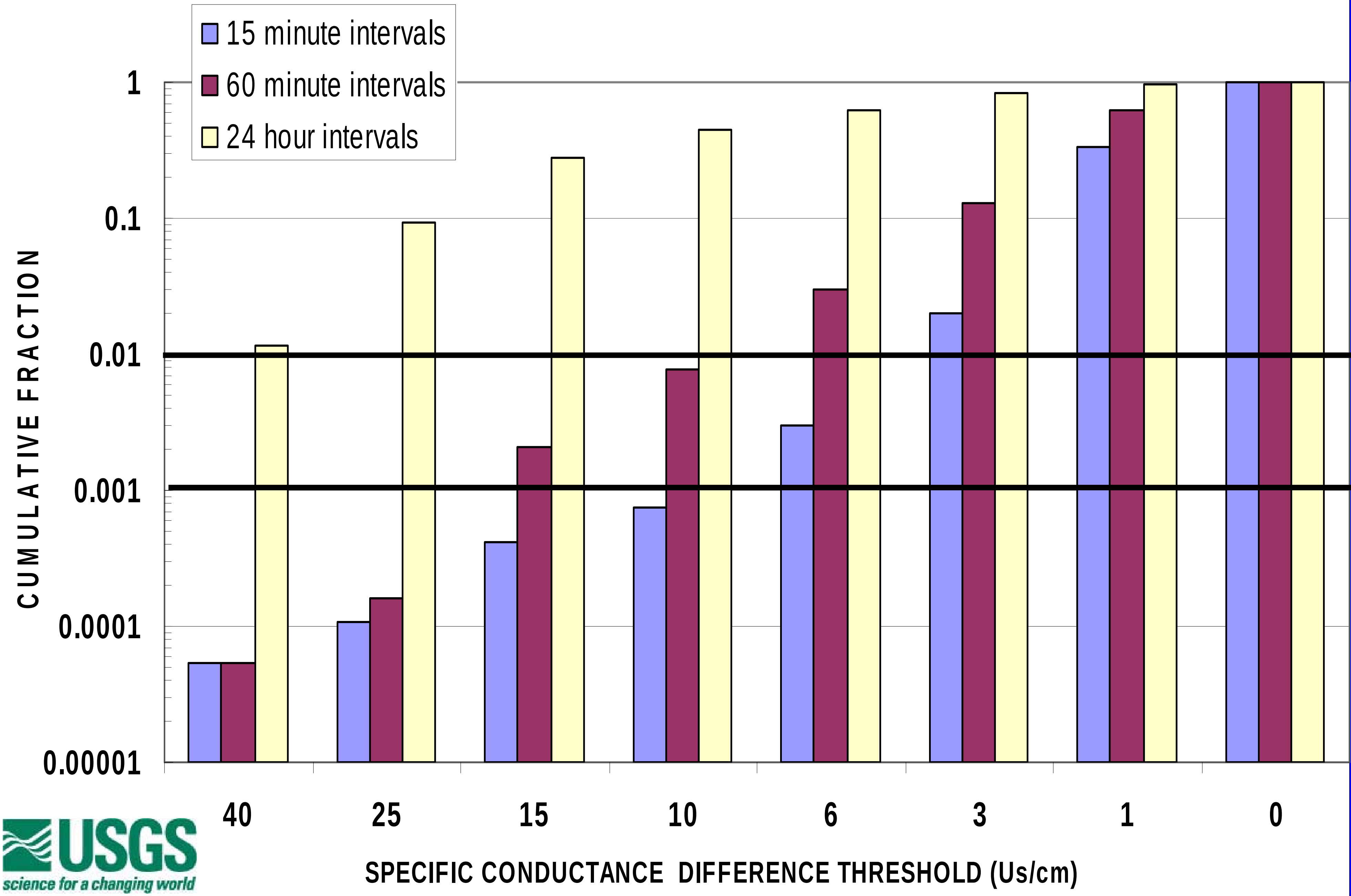
Beverly Specific Conductance Data Through 09/07/05: Cumulative Fractions of Samples Having Consecutive-Concentraton Differences At or Above Thresholds



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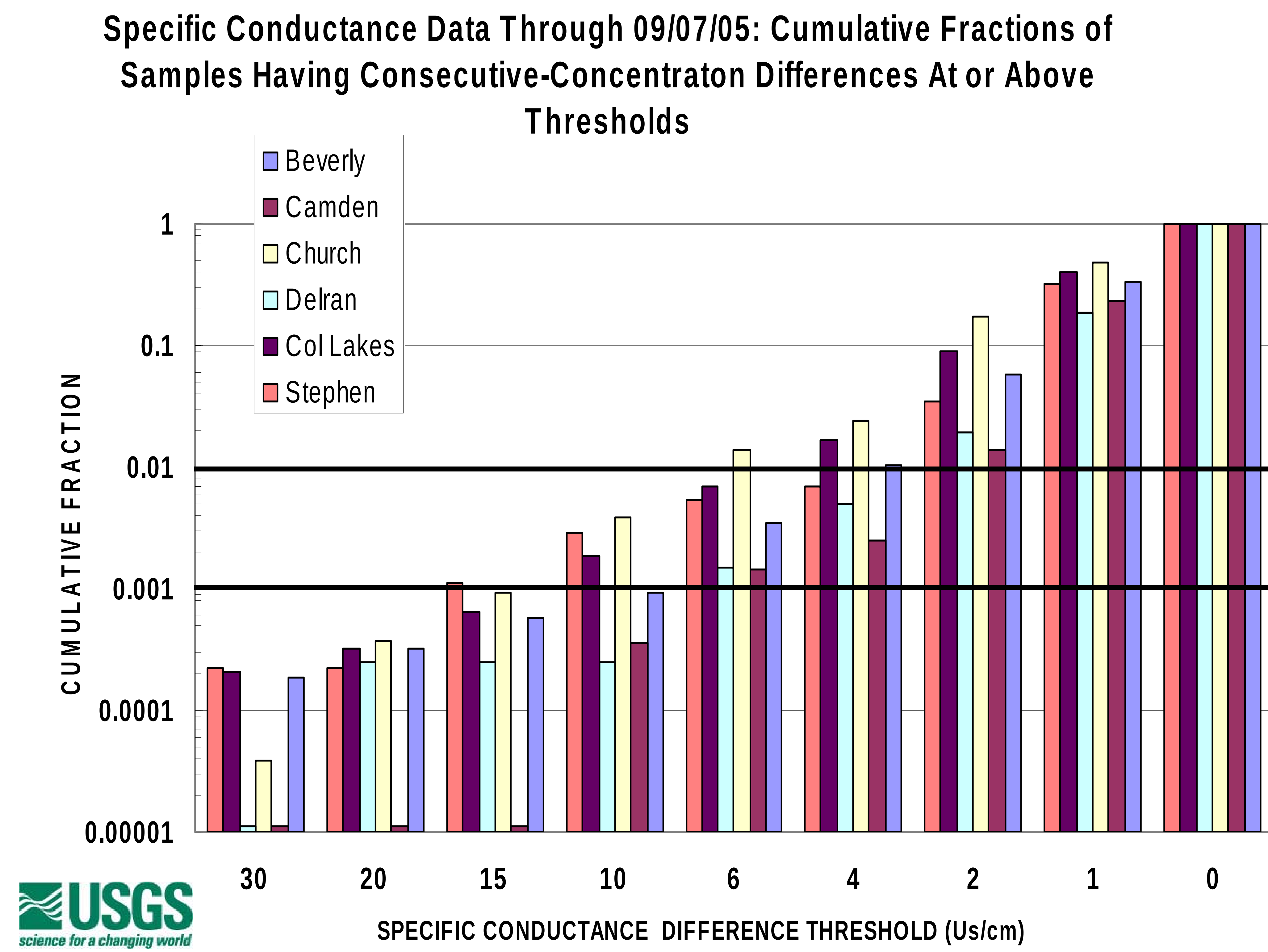

Specific Conductance Data Through 09/07/05: Cumulative Fractions of Samples Having Consecutive-Concentraton Differences At or Above Thresholds
Beverly
Camden
Church
Delran
Col Lakes
Stephen
CUMULATIVE FRACTION
1
0.1
0.01
0.001
0.0001
0.00001
30
20
15
10
6
4
2
1
0
SPECIFIC CONDUCTANCE DIFFERENCE THRESHOLD (Us/cm)
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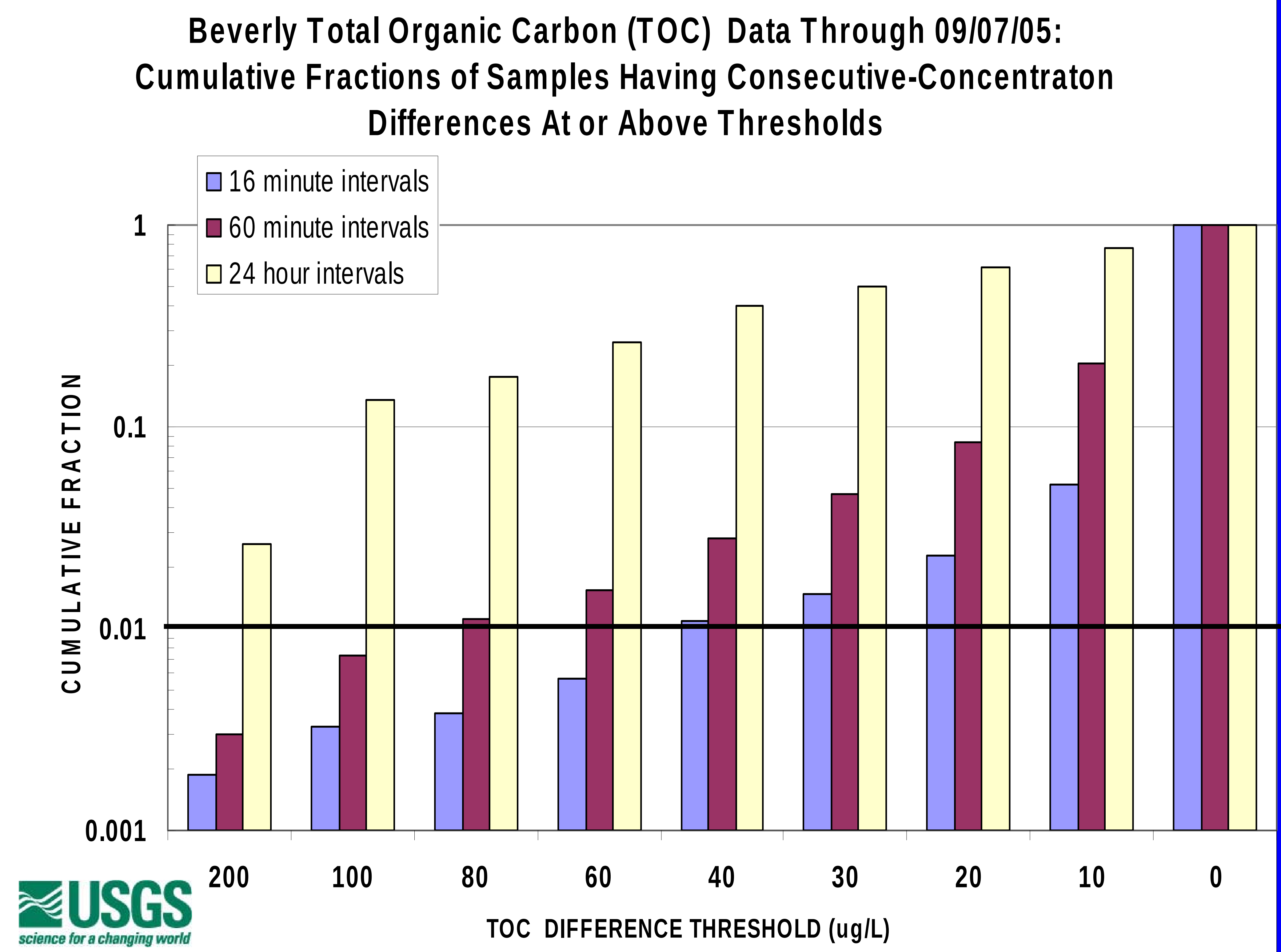
Beverly Total Organic Carbon (TOC) Data Through 09/07/05:
Cumulative Fractions of Samples Having Consecutive-Concentraton
Differences At or Above Thresholds
16 minute intervals
60 minute intervals
24 hour intervals
CUMULATIVE FRACTION
1
0.1
0.01
0.001
200
100
80
60
40
30
20
10
0
TOC DIFFERENCE THRESHOLD (ug/L)

Long Term Program Objectives

- Distribution system sites will serve as practical test beds for sensors and EWS components in the field
- Potential model calibration effort using a tracer in a sub-area of the distribution system
- Support collaborative efforts of the EPA/NHSRC and Sandia National Laboratories (SNL) to characterize water-quality variability for distribution systems

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What will be learned?

- Use of hydrologic and water-quality model to select sensor location
- Natural variability of water-quality characteristics in a distribution system
- Capabilities, limitations and maintenance requirements of sensors

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Summary

- Overall Program Goal: Design and test a network of water-quality sensors for drinking water safety and security
- Sensors have been selected, site design and telemetry were developed, and water-quality data are being collected at 6 sites
- Real-time data will be used to determine the temporal and spatial variability of water quality in a distribution system
- *Most important question remaining:* Will introduction of contaminants of concern cause detectable changes in water quality?

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