Variability in Multi-Parameter Sensor Responses in the Distribution System and Source Water of a Water Utility for a Prototype Real Time Early Warning System to Monitor for Water Security

NWQMC Conference May 10, 2006

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Acknowledgements

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Distribution system modeler
Plant manager
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Project Objectives

- Work with EPA and Sandia and water utility to set up a prototype real-time water-monitoring system
- Select water-quality sensors based on:
  - Results from USEPA controlled experiments
  - Results of USGS field testing
- Select up to 15 sites based on distribution-system models
- Install sensors, monitor water quality for up to 12 months
- Evaluate the variability of water-quality data in the distribution system

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Objectives of Presentation

- Briefly report progress of USEPA/NHSRC for:
  - Threat Evaluation Vulnerability Assessment (TEVA)
  - Testing and Evaluation (T&E) Center pipe loop-experiments
  - DOD Edgewood Chemical Biological Center (ECBC) Biological Safety Level 3 (BSL-3) pipe-loop experiments
- Briefly report progress on USGS/USEPA National Homeland Security Research Center (NHSRC) project to support the implementation and testing of an early warning system (EWS)
- Preliminary evaluation of the variability of data from 11 real-time sensors placed in one distribution system

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The EPA Threat Ensemble and Vulnerability Assessment (TEVA) Research Program

Developing a suite of software tools for drinking water distribution system security

TEVA Computational Framework

EWS Design and Evaluation
- Sensor Performance Models
- Sensor Placement Tools
- Comparison of Designs
- Consequence Assessment Tools

Real-Time Response Tools
- Event Detection Tools
- Event reconstruction Tools
- Mitigation Tools (flushing, isolation, treatment, decontamination)

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EWS Research Plan

- EWS Conceptual Design
- Development of Prototypical Tools
  - TEVA Phase I
- Proof-of-Concept Studies
  - Simulation Studies and Test-beds
  - Laboratory Studies and Test-beds
- EWS Field Studies
  - TEVA Phase II
- EWS Pilot Studies
  - WaterSentinel

USGS/USEPA study here

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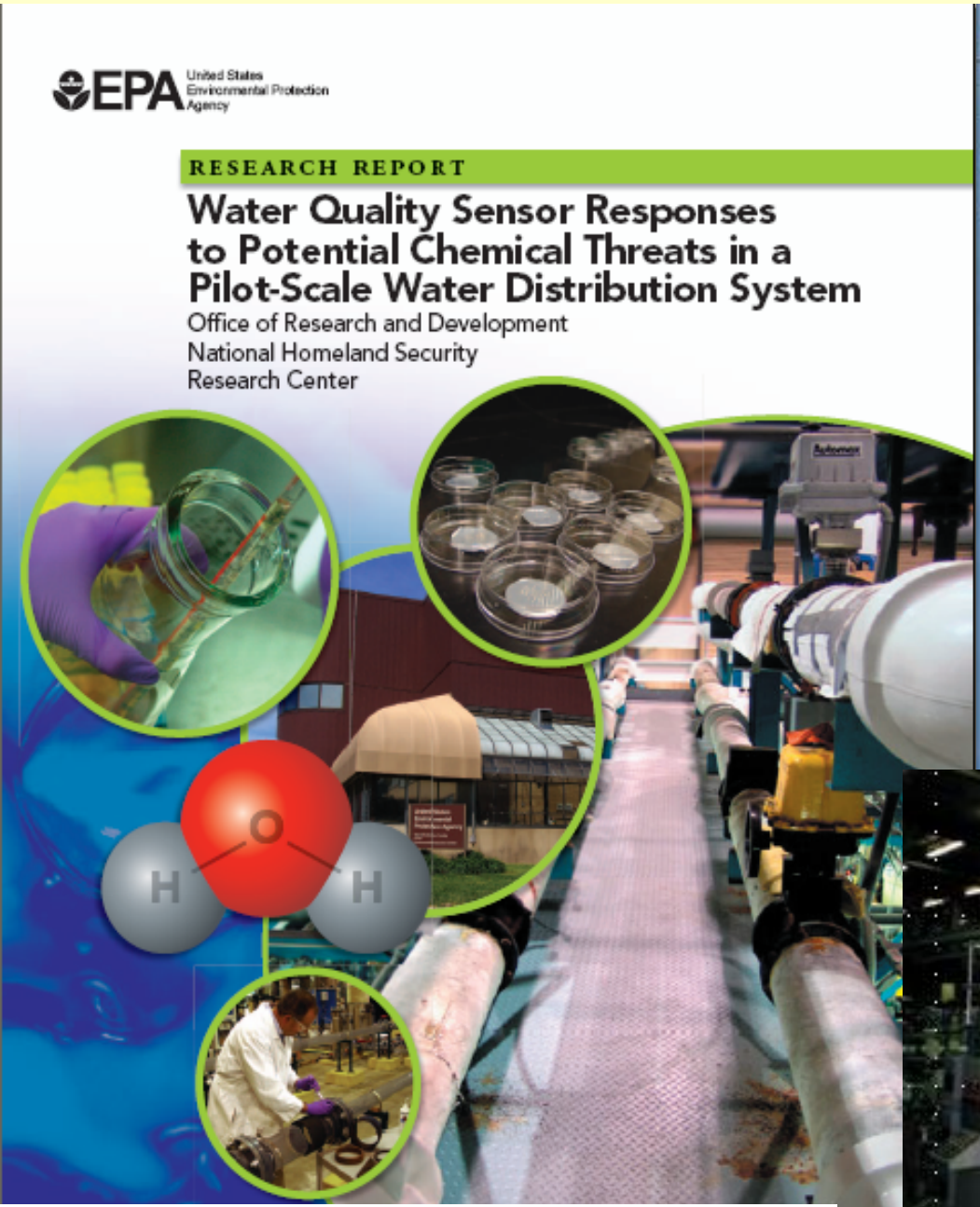
Purpose of the TEVA Research Program

Develop an effective and reliable contamination warning system for drinking water distribution systems

Results of USEPA T&E Center Pipe-Loop Experiments



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Disclaimer

- Any opinions expressed in this presentation are those of the author(s) and do not, necessarily, reflect the official positions and policies of the USEPA.
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Report is in review—hopefully available soon

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EPA's Research

- Instrumentation:
  - ATI A-15 Free chlorine analyzer
  - Hach CL-17 Free chlorine analyzer
  - Hach Astro TOC analyzer
  - Hach Aquatrend Panel (multi parameter)
  - Dascore Six Cense sonde (multi parameter)
  - Insitu Troll 9000 Sonde (multi parameter)
  - Hydrolab Datasonde 4a (multi parameter)
  - YSI 6600 (multi parameter)

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Contaminants tested

- Wastewater/ secondary effluent
- Potassium fericyanide
- Malathion Insecticide
- Aldicarb Insecticides
- Glyphosate Herbicde
- Ground Water
- Arsenic trioxide
- Nicotine
- E coli with growth media

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On-line Standard Water Quality Test Parameters

- pH, temperature
- ORP, specific conductance
- dissolved oxygen
- turbidity
- free & total chlorine
- TOC
- ammonia (NH_4^+-N)
- nitrate (NO_3^--N)
- chloride (Cl^-)

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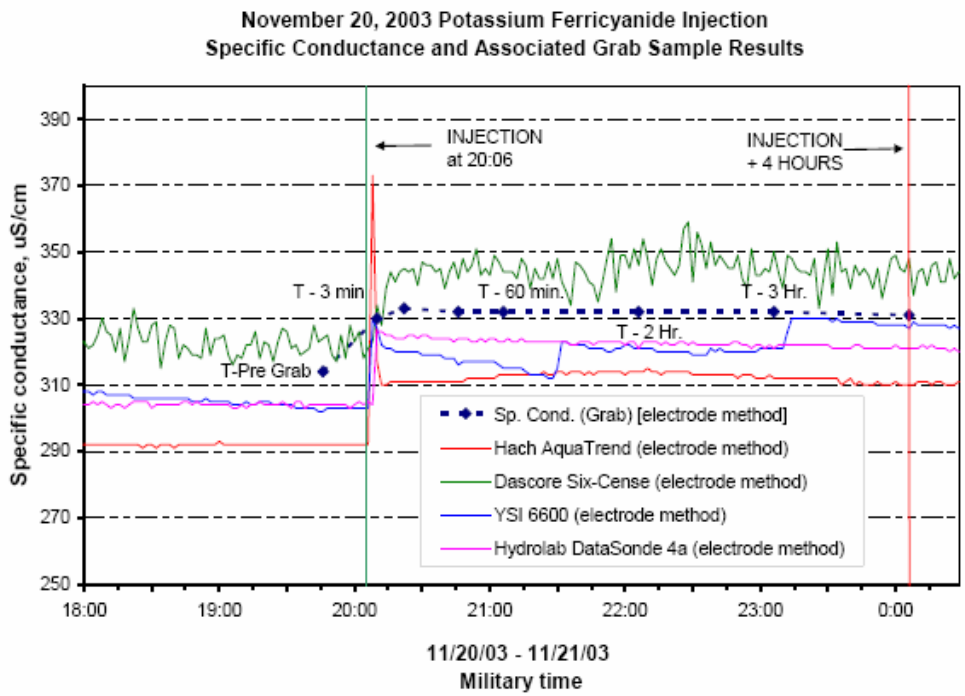
Figure 40. Specific Conductance Sensor Responses Upon Injection of 2 g/L Potassium Ferricyanide Solution (Test 2)



Selected Results of USEPA T&E Facility Pipe-Loop Experiments

Figure 65. Chlorine Sensor Responses to Upon Injection of Glyphosate Solution (Test 1)

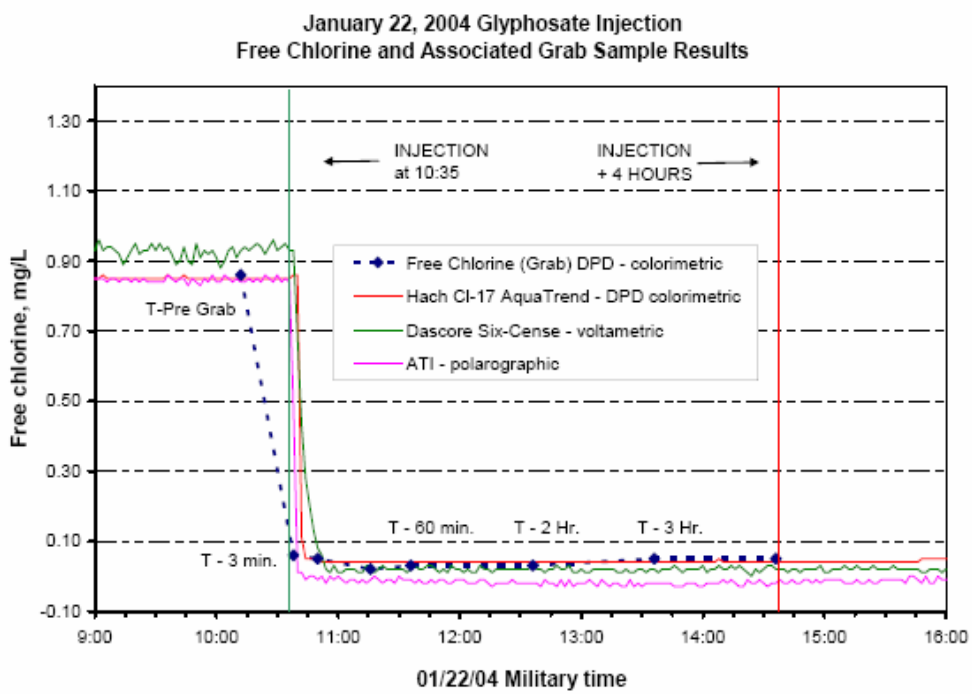
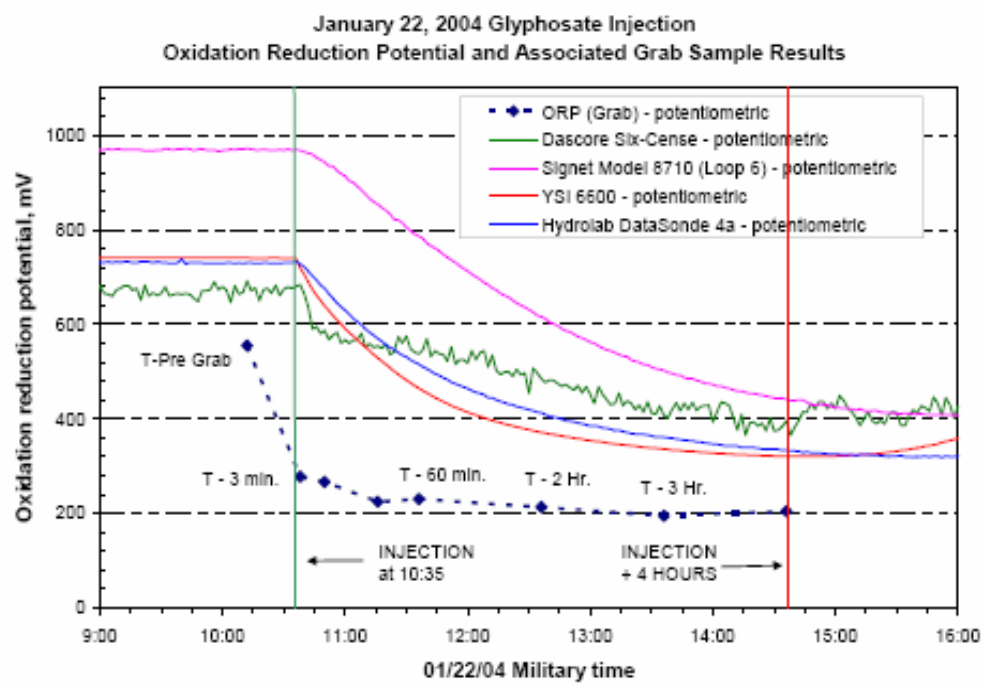
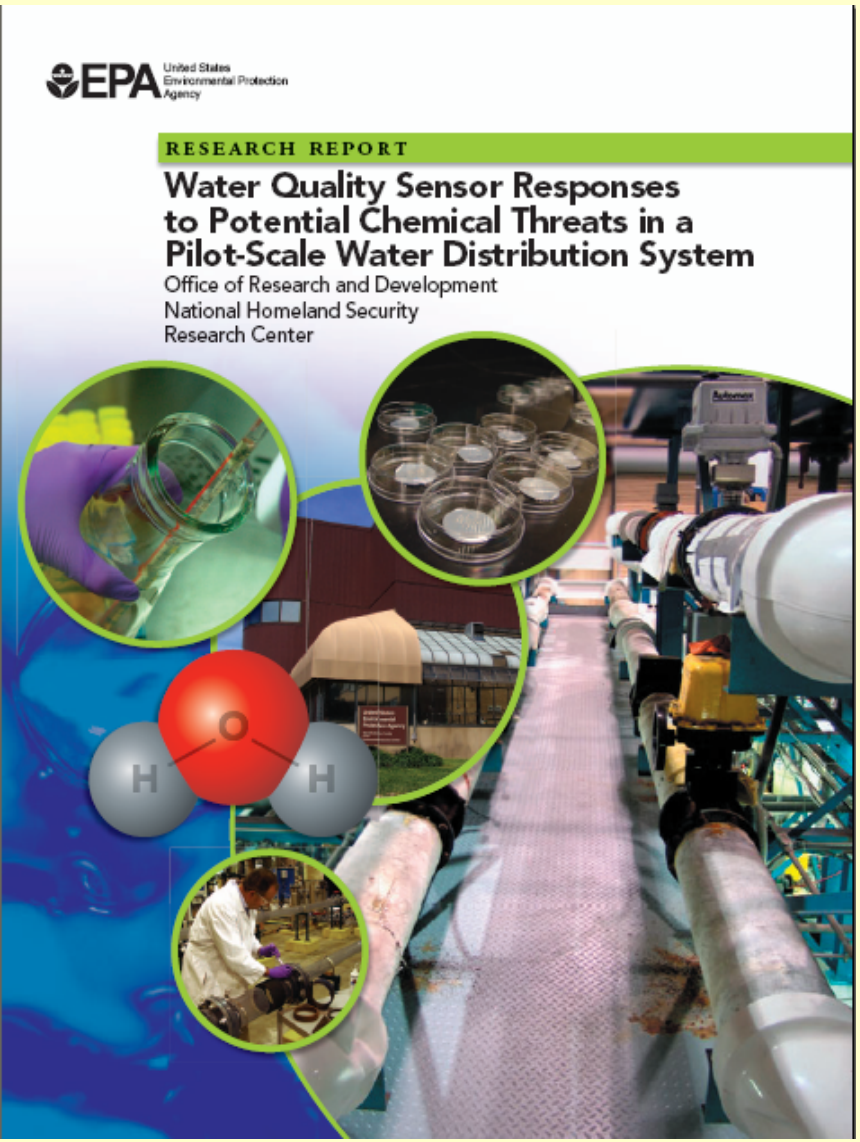


Figure 67. ORP Sensor Responses Upon Injection of Glyphosate Solution (Test 1)



Summary of Results of USEPA T&E Pipe-Loop Experiments



- No one sensor responds to all compounds
- A combination of sensors responds to a wide variety of compounds
- Several parameters are useful: conductance, TOC, total/free chlorine, chloride, ORP
- TOC had greater sensitivity & specificity than chlorine for organic compounds but at a greater cost
- DO, pH, T, ammonia, & nitrate tend to show no response, false positives, or little specificity
- Calibration of sensors ranged from weekly to monthly
- Additional costs for maintenance

Selected Results of USEPA/ECBC Pipe-Loop Experiments

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Initial Evaluation

Class	Example Contaminants
1	Diesel, Gasoline
2	Cyanide salts, Methoxyethylmercuric acetate, Aldicarb, Carbofuran, Dichlorvos, Dicrotophos, Fenamiphos, Mevinphos, Phorate, Methomyl, Oxamyl, Tetraethyl pyrophosphate, Paraquat
3	Arsenite salts, Strychnine, Nicotine salts
4	Mercuric chloride
5	Sodium fluoroacetate
6	VX (and EA2192)
7	Cesium-137 salt, Strontium-90 salt, Uranium-238 salt
8	Botulinum toxins
9	Ricin
10	*Francisella tularensis*, *Vibrio cholerae* 01, *Yersinia pestis*, *Burkholderia pseudomallei*
11	*Salmonella typhi*, *Bacillus anthracis*
12	PCBs
13	*Toxoplasma gondii*

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Edgewood ECBC

VX @ 2.0 mg/L

Measurement	Reporting Units	Principle of Detection	Baseline value	Peak Value Within 30 Minutes of Injection	Percent Change in Signal
Free chlorine (YSI 6600)	mg/L	Polarographic with Cl2 permeable membrane	0.72	0.39	46%
Total chlorine (Hach CI-17)	mg/L	Hach CI-17 (DPD reaction) colorimetric	1.15	0.7	39%
Free chlorine (ATI A15/62)	mg/L	Polarographic with Cl2 permeable membrane	0.75	0.44	41%
TOC (Hach Astro UV Process)	NTU	UV-persulfate oxidation, NDIR detection of CO_2	0.69	1.58	129%
Specific conductance (YSI 6600)	µS/cm	4 nickel electrodes	255	255	0%
Specific conductance (GLI 3422)	µS/cm	Titanium and stainless steel electrodes	237	239	1%
Oxidation-reduction potential (YSI 6600)	mV	Potentiometric, platinum electrode, Ag/AgCl reference electrode	746	755	1%

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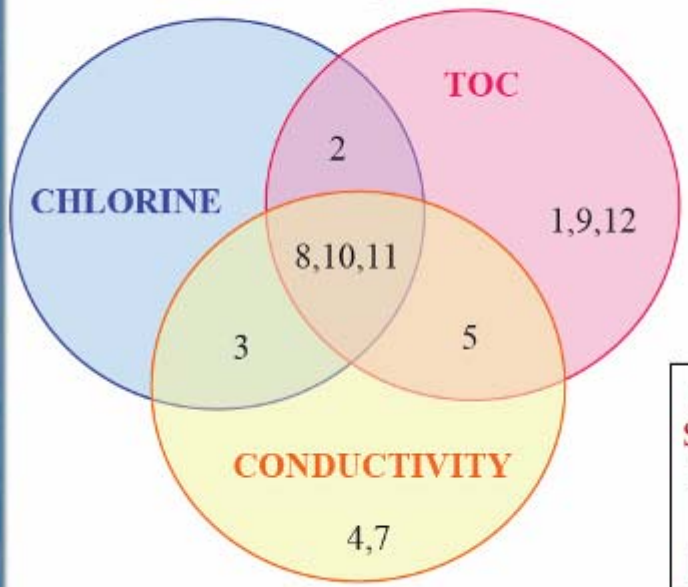
Initial Evaluation: Critical Water Quality Sensors



All 3 WQ Sensors are Needed to Detect 11 classes!

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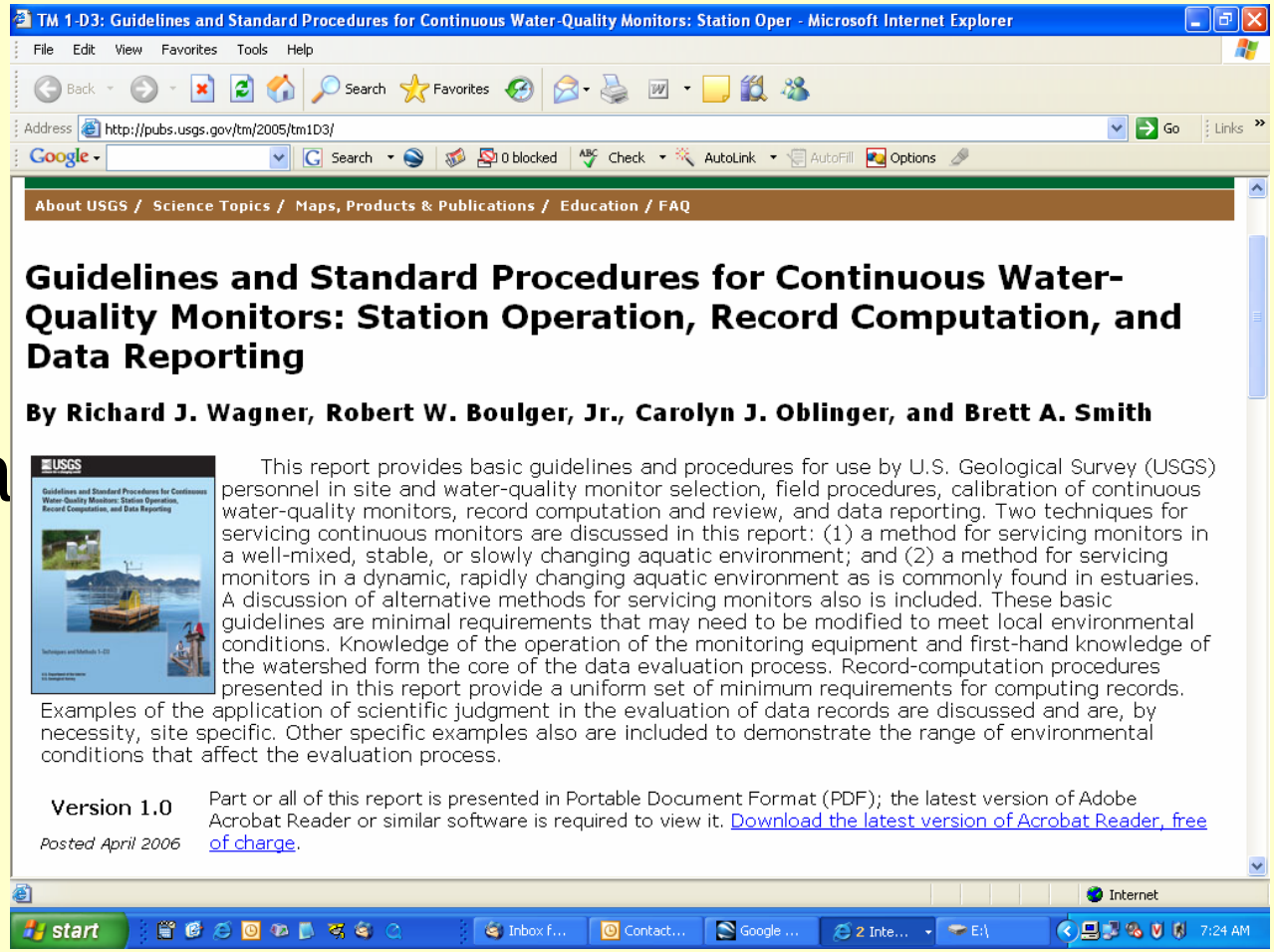
USGS/USEPA NHSRC Field Testing

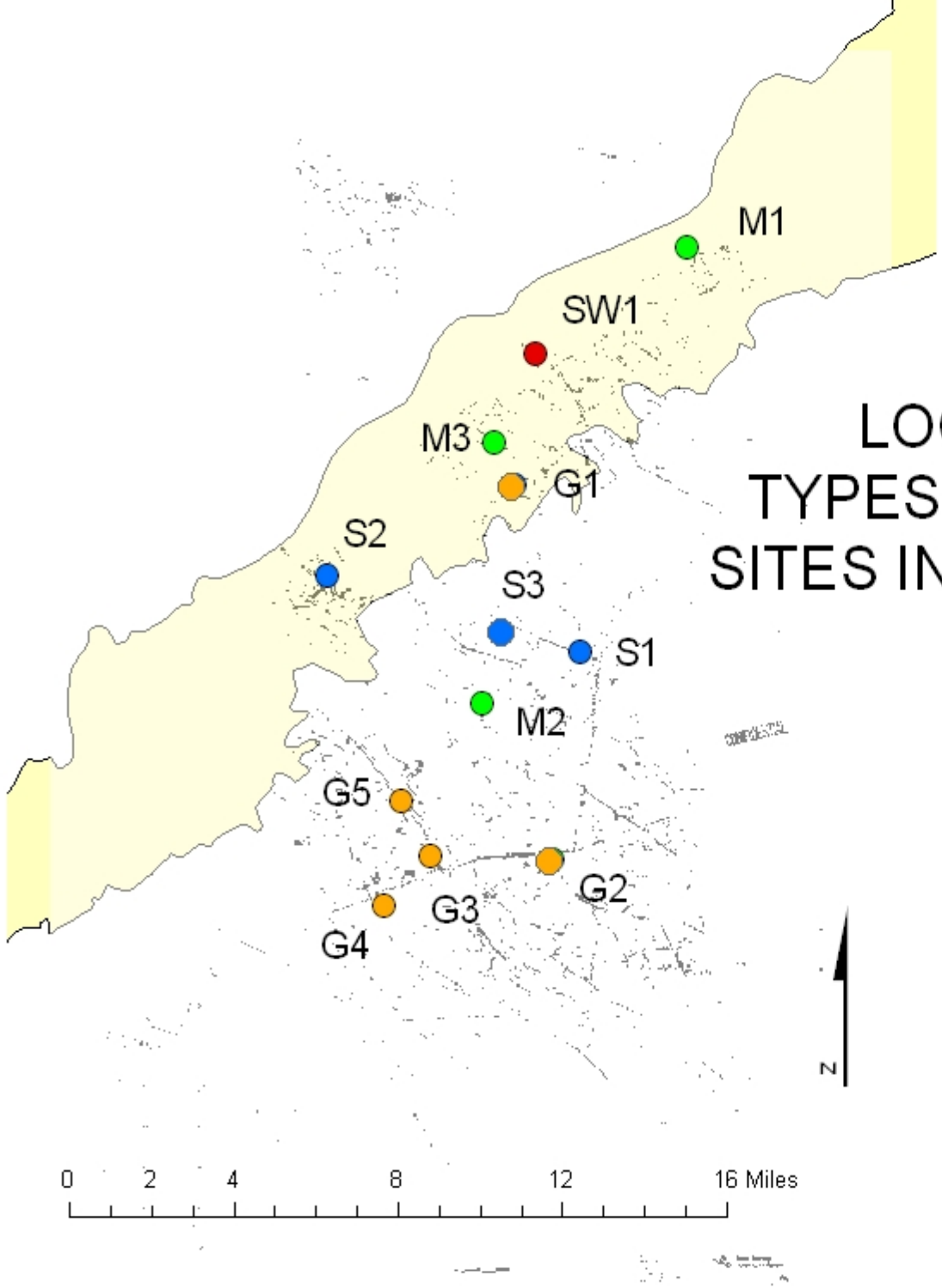
Quality Assurance Project Plan

- Detailed QAPP
- Followed USGS protocols
- Data stored in USGS NWIS data base
- Also stored in water utility SCADA



Typical site installation

- Sensor locations: based on distribution-system model
- YSI multi-probe: temperature, pH, specific conductance, oxidation-reduction potential, free chlorine (new)
- Must have drain, protection, access
- Additional sensors at one site
  - Total organic and inorganic carbon analyzer (General Electric)
  - UV-VIS spectrophotometer can (S::can Co.)



LOCATIONS AND TYPES OF MONITORING SITES IN THE STUDY AREA

EXPLANATION

- GROUND WATER
- SURFACE WATER INTAKE
- SURFACE WATER
- MIXED SW/GW

DISTRIBUTION SYSTEM

- LARGE PIPES
- SMALL PIPES
- AQUIFER OUTCROP AREA

Selected information of sampling sites

Station	Map identifier	Confinement Confined (C) or Semi-confined (S)	Source percent SW/GW	Travel time Age of Water (Days)	Elevated storage (Y/N)	Sensors	
						Begin	End
Source water						03/01/04	onoing
1	SW1		River			01/24/04	12/21/05
Distribution system sites							
1	S1	No wells	100/0	0.5	N	03/13/04	ongoing
2	S2	Backup wells	90/10	1 to 3	N	07/13/05	ongoing
3	S3	Backup wells	95/5	0.8 to 1.2	N	07/13/05	ogoing
4	G1	S	0/100	0.4 to 1.4	N	07/11/05	ongoing
5	G2	C	0/100	0.1 to 0.8	Y	03/03/06	ongoing
6	G3	C	0/100	0.01 to 1	N	03/03/06	ongoing
7	G4	C	0/100	0.01 to 0.5	N	03/03/06	ongoing
8	G5	C	0/100	0.01 to 0.1	N	03/03/06	ongoing
9	M1	S	50/50	1 to 2	N	07/01/04	03/01/06
10	M2	C	20/80	1 to 2.5	N	03/15/06	ongoing
11	M3	S	20/80	0.01 to 0.5	Y	03/02/06	ongoing

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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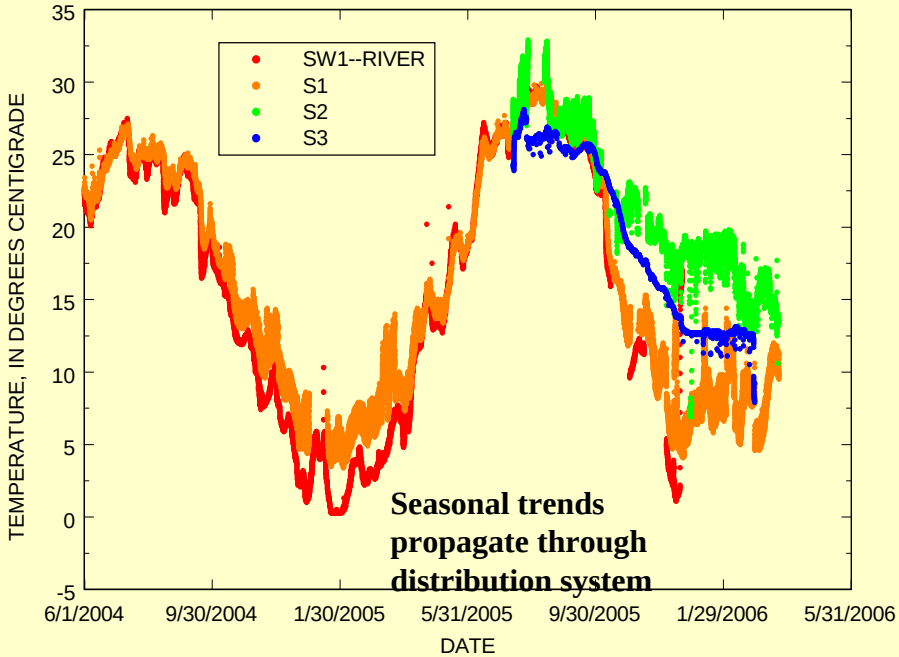
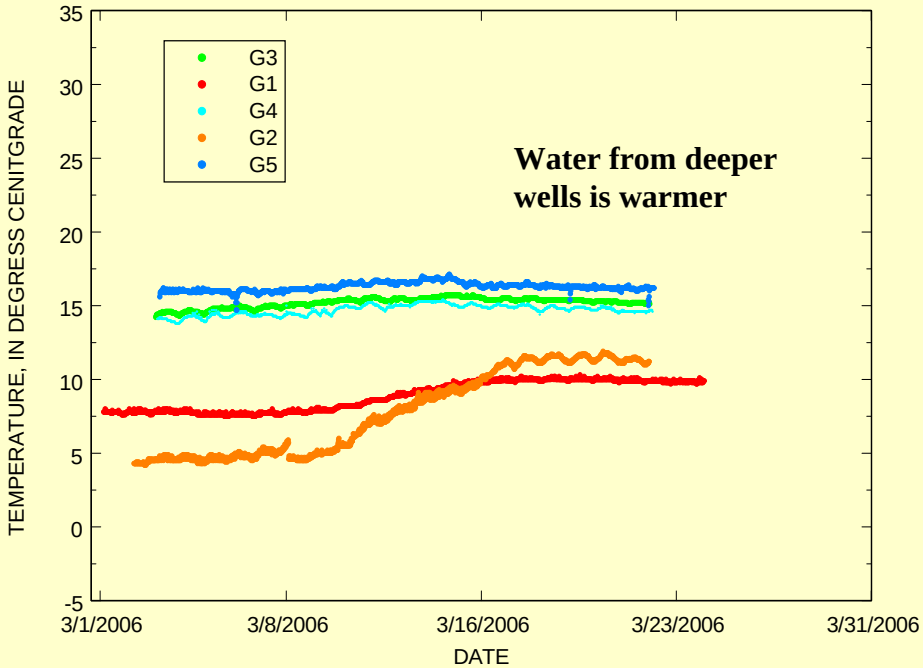
TEMPERATURE

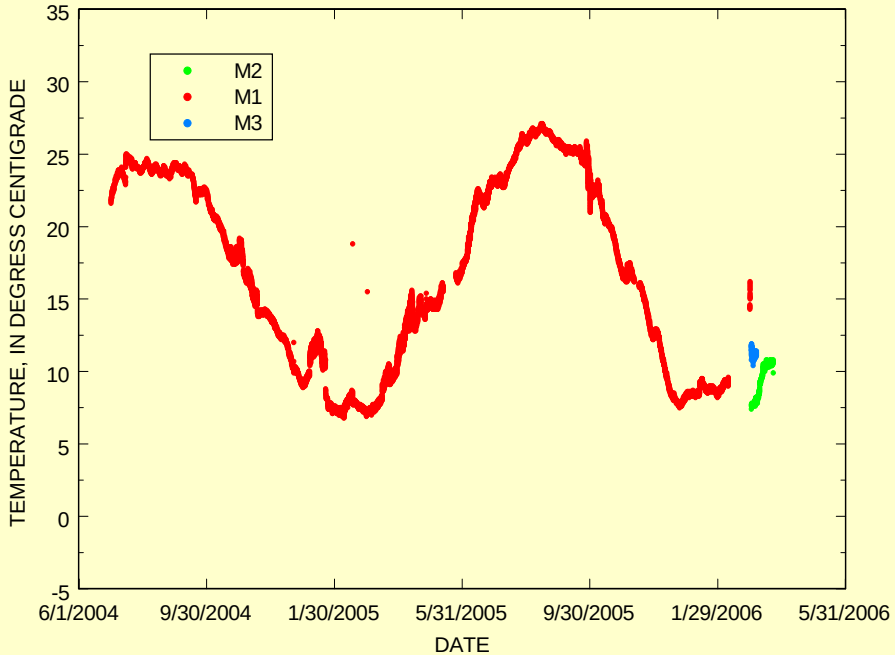
RIVER WATER AND SURFACE WATER DISTRIBUTION SITES



GROUND WATER DISTRIBUTION SITES



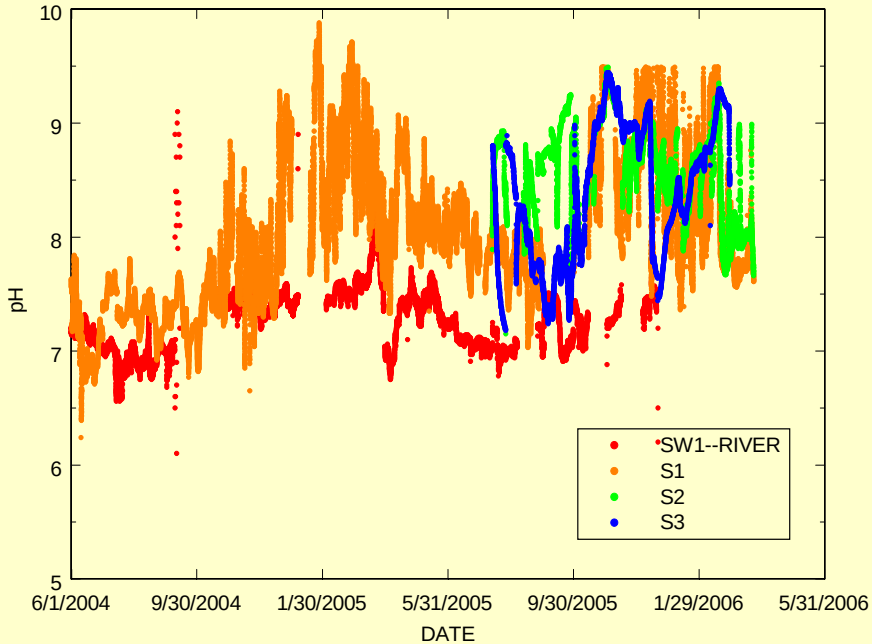
MIXED SURFACE AND GROUND WATER DISTRIBUTION SITES



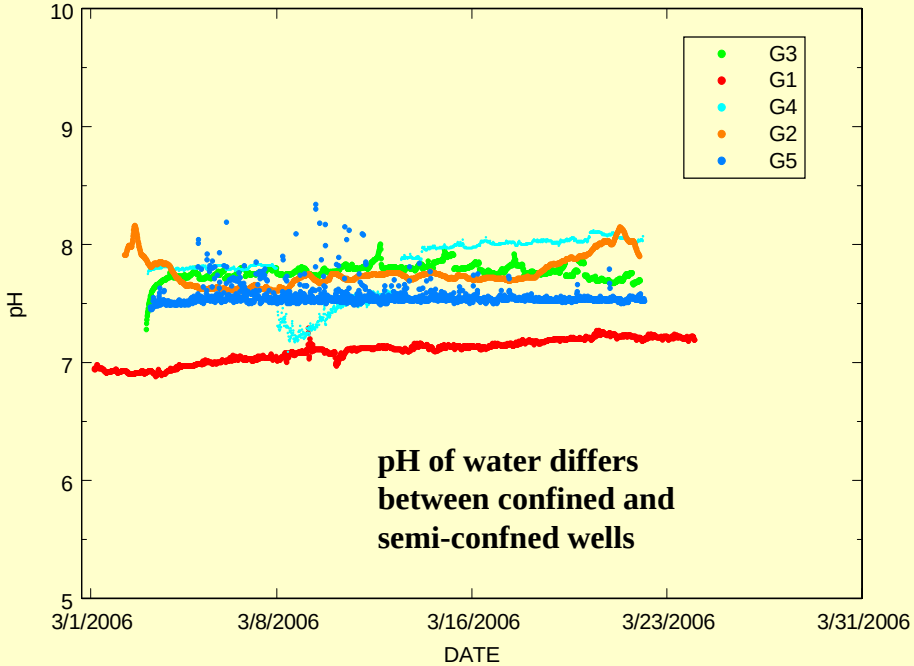
- Greater variability in surface-water sites than ground-water sites
- Variability in suface-water sites reflects source water from river and seasonal trends
- Some variability between ground-water sites because of well depth

pH

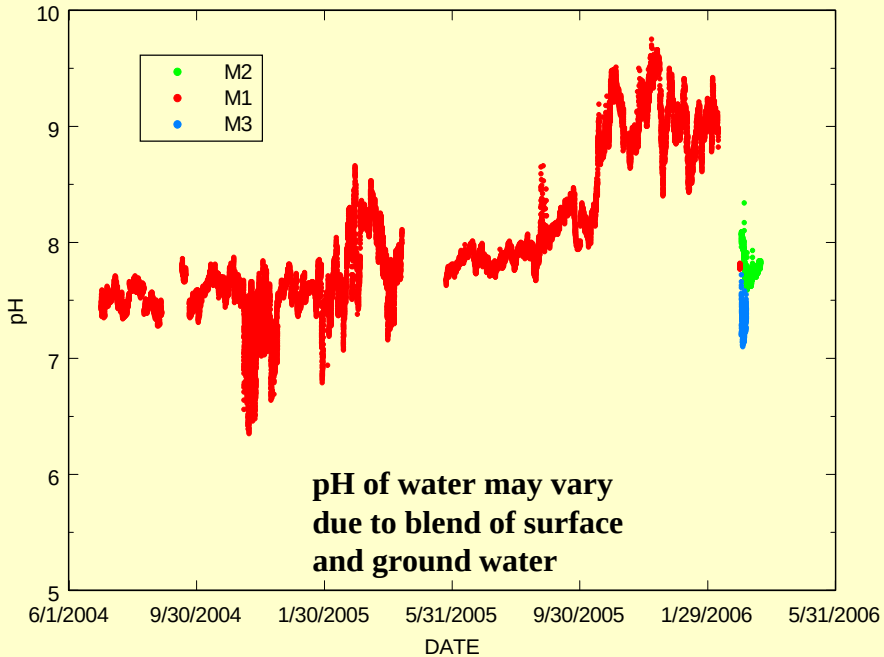
RIVER WATER AND SURFACE WATER DISTRIBUTION SITES



GROUND WATER DISTRIBUTION SITES



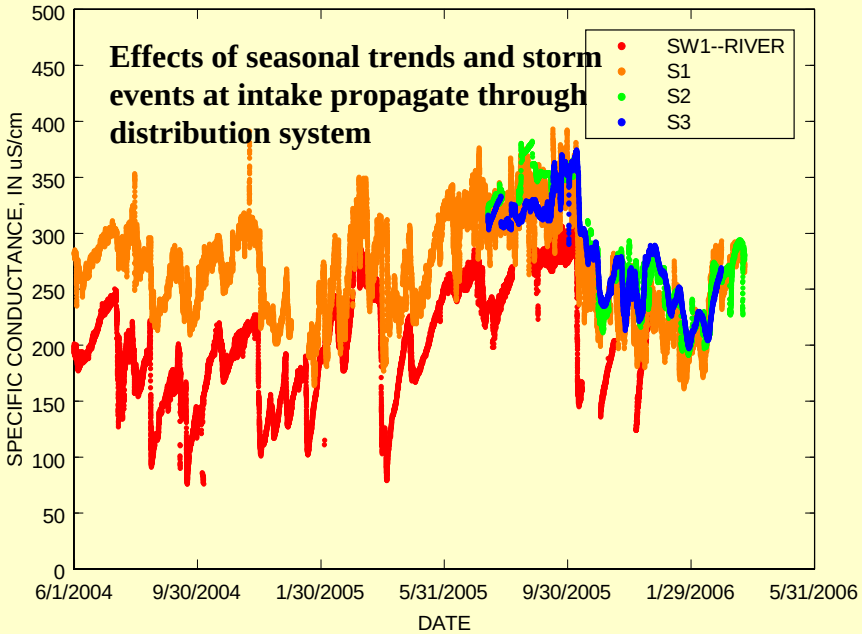
MIXED SURFACE AND GROUND WATER DISTRIBUTION SITES



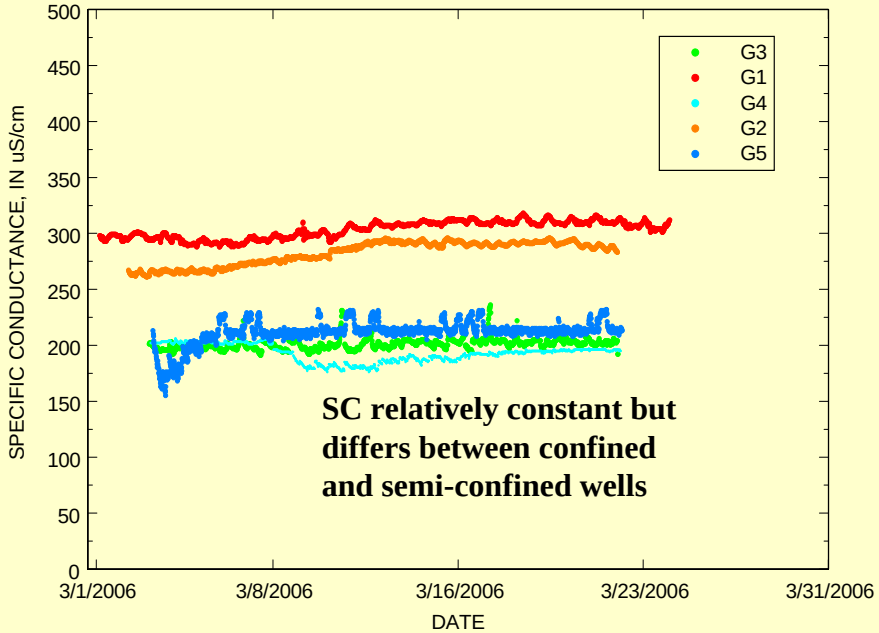
- Greater variability in surface-water sites than ground-water sites
- Variability in surface-water sites reflects source water from river
- Some variability between ground-water sites

Specific conductance

RIVER WATER AND SURFACE WATER DISTRIBUTION SITES



GROUND WATER DISTRIBUTION SITES



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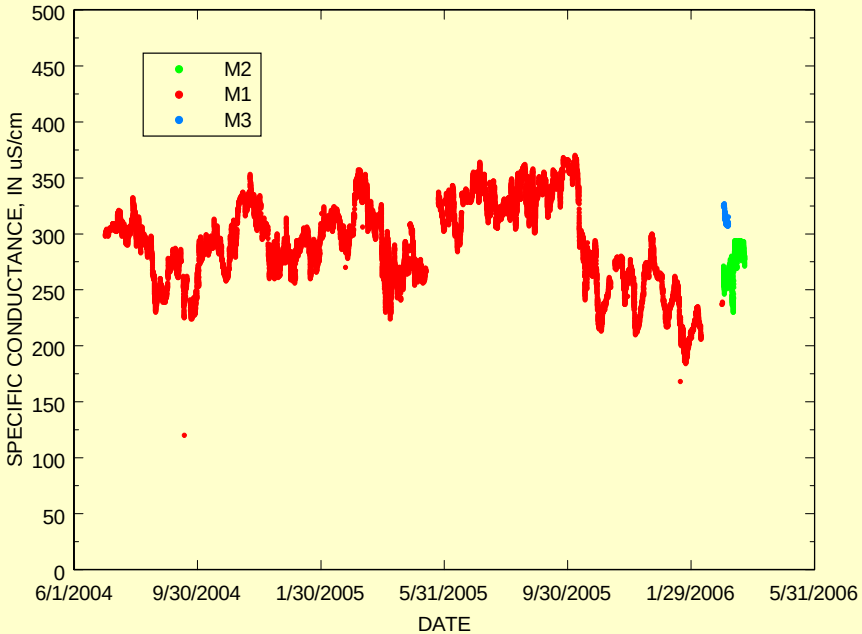
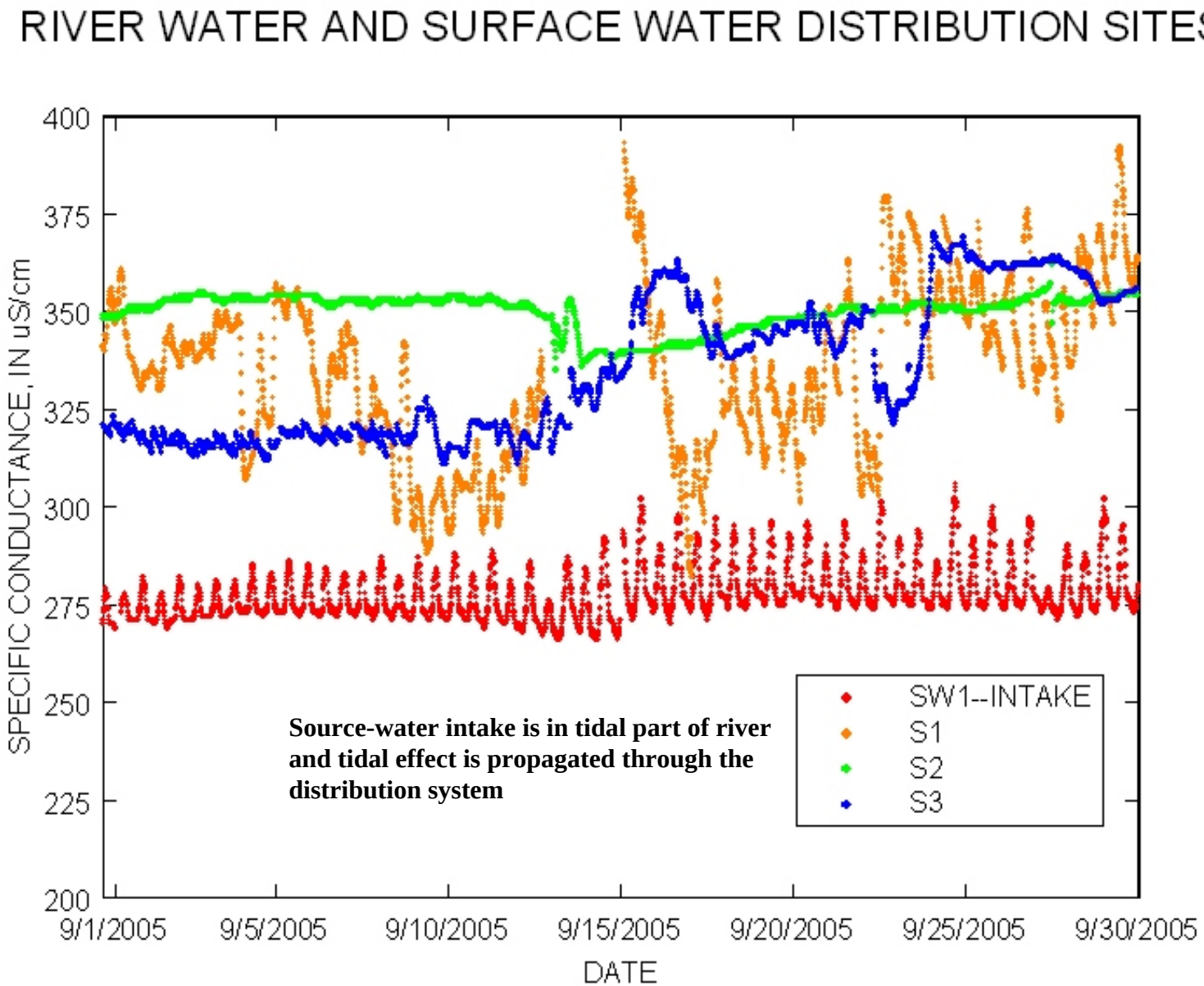
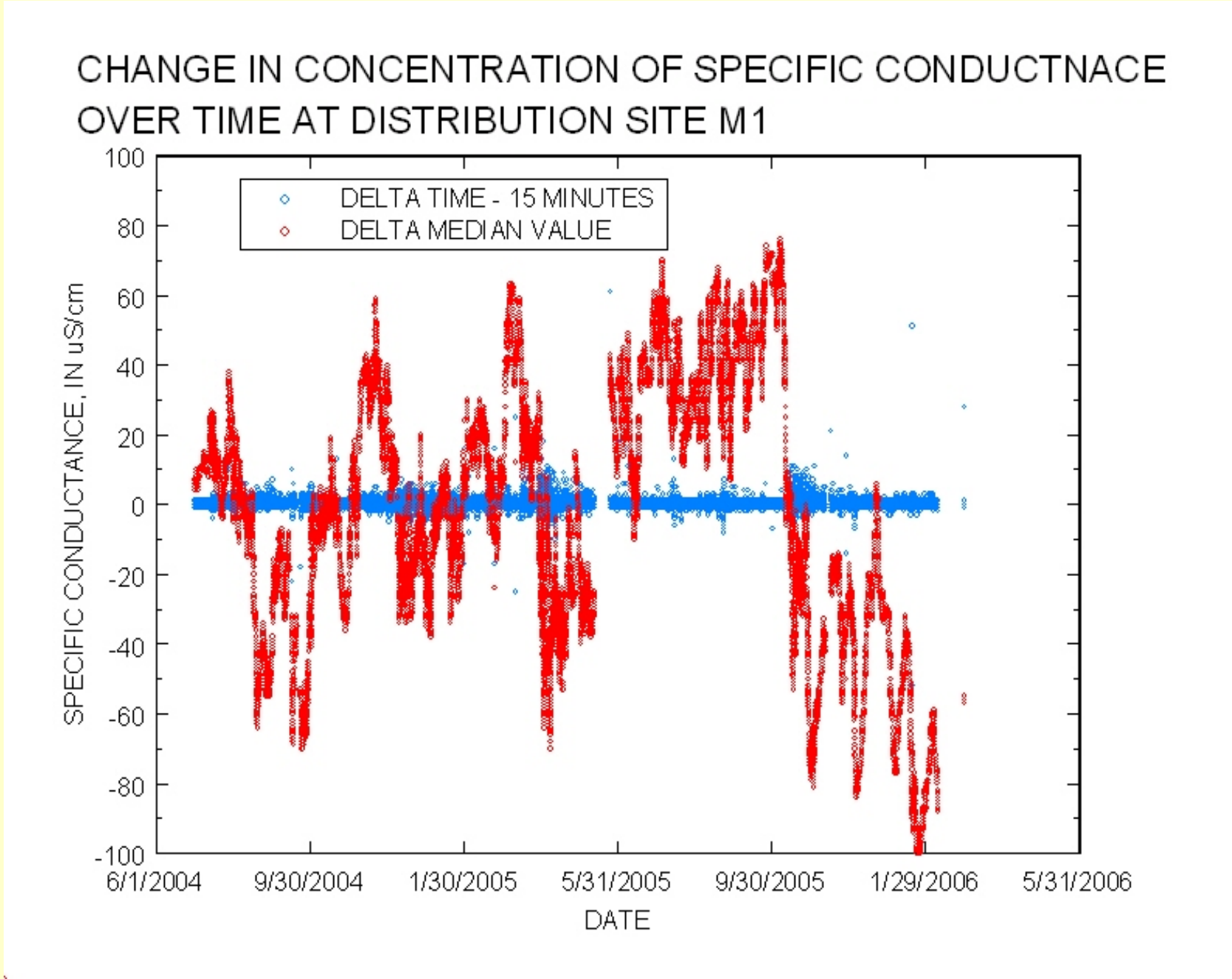


- Greater variability in surface-water sites than ground-water sites
- Variability in surface-water sites reflects source water from river
- Some variability between ground-water sites

Specific conductance—1 month

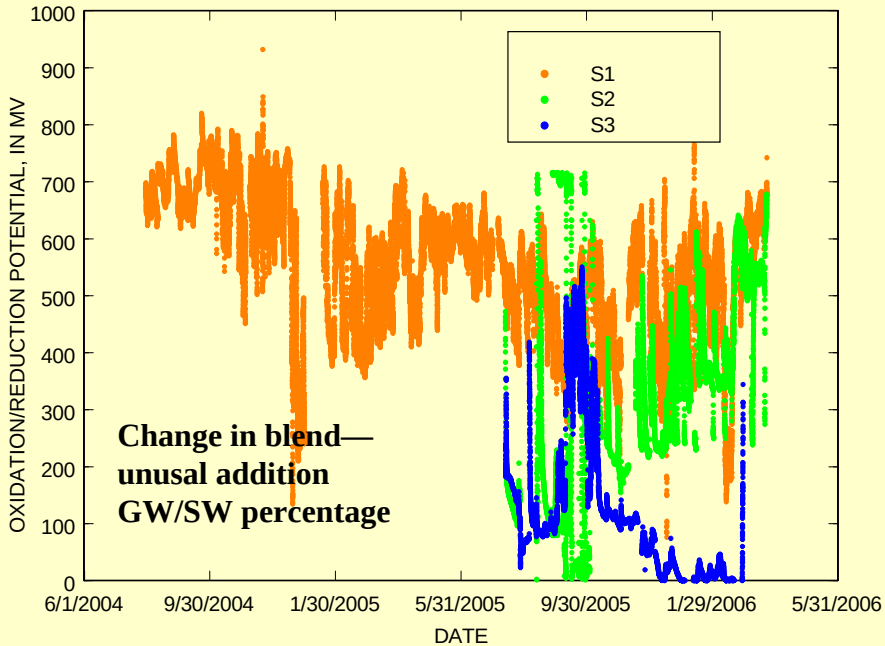


CHANGE IN SPECIFIC CONDUCTANCE

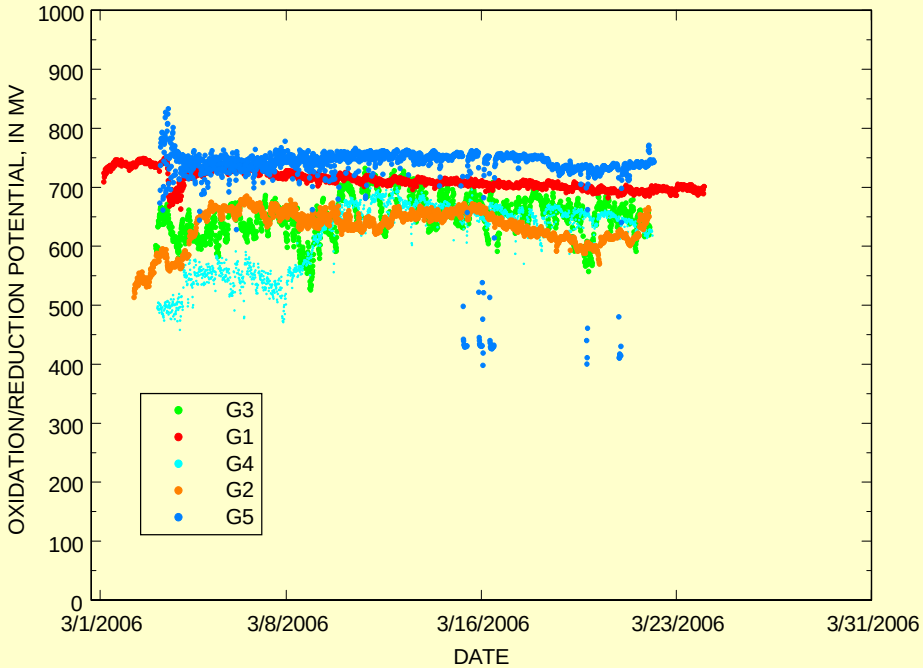


Oxidation/Reduction Potential

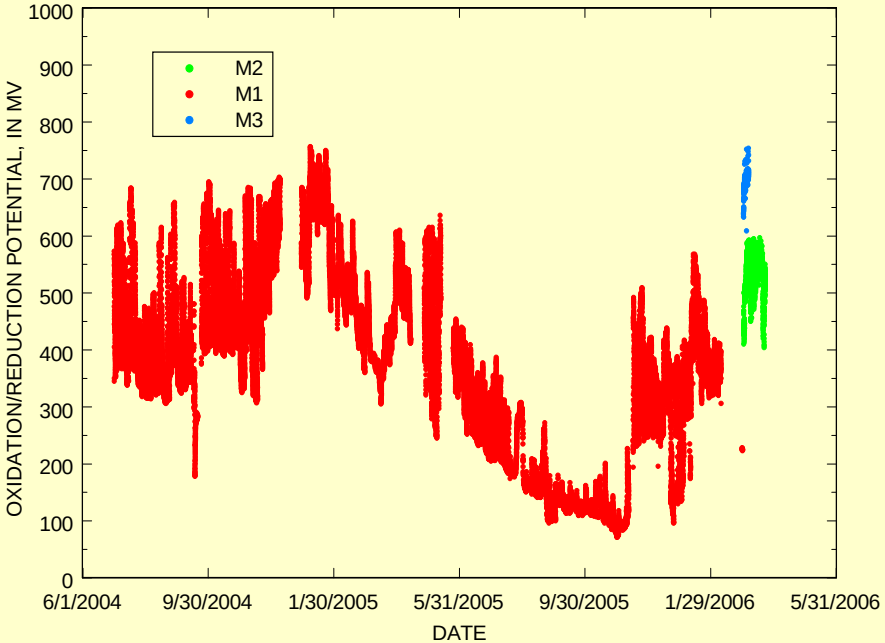
SURFACE WATER DISTRIBUTION SITES



GROUND WATER DISTRIBUTION SITES



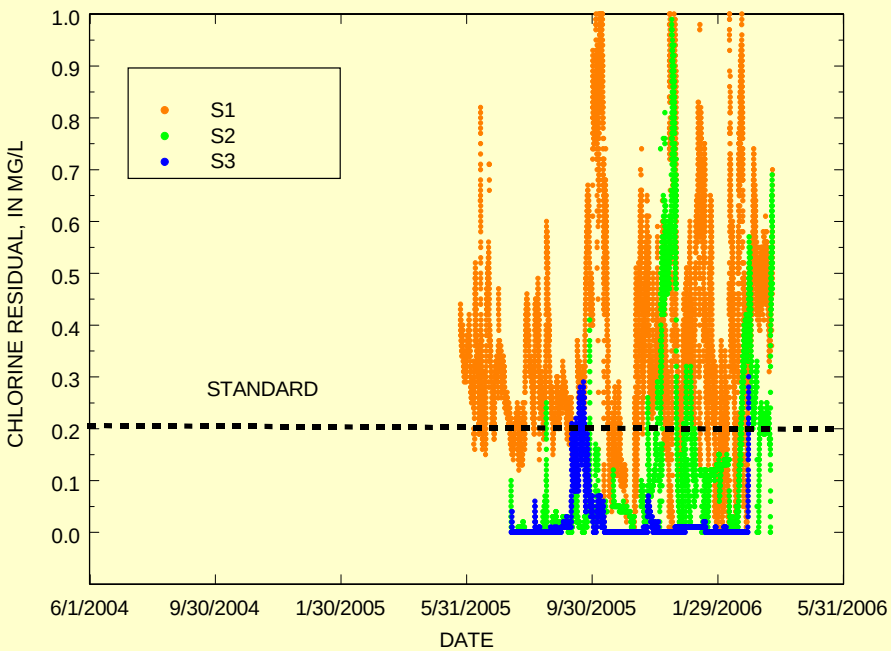
MIXED SURFACE AND GROUND WATER DISTRIBUTION SITES



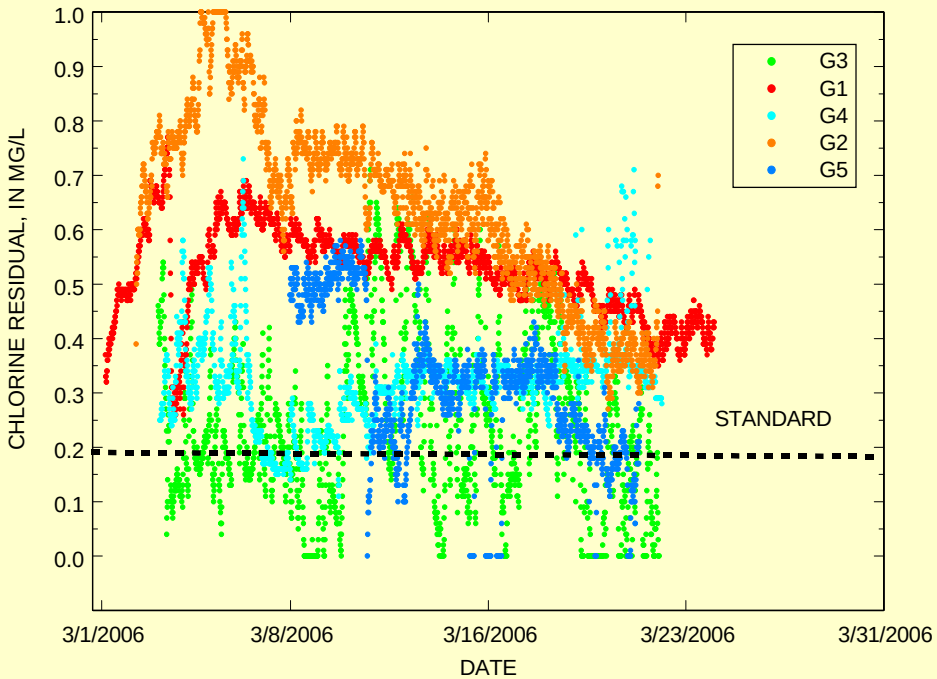
- Greater variability in surface-water sites than ground-water sites
- Variability in surface-water sites reflects blending of SW and GW sources in fall of 2005
- Some variability between ground-water sites
- ORP strongly related to chlorine residual

Chlorine residual

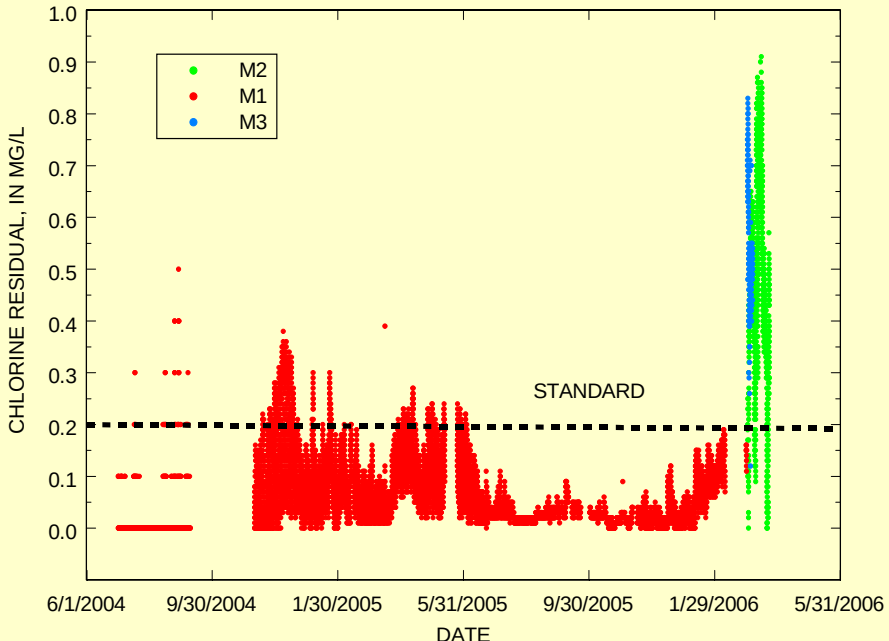
SURFACE WATER DISTRIBUTION SITES



GROUND WATER DISTRIBUTION SITES

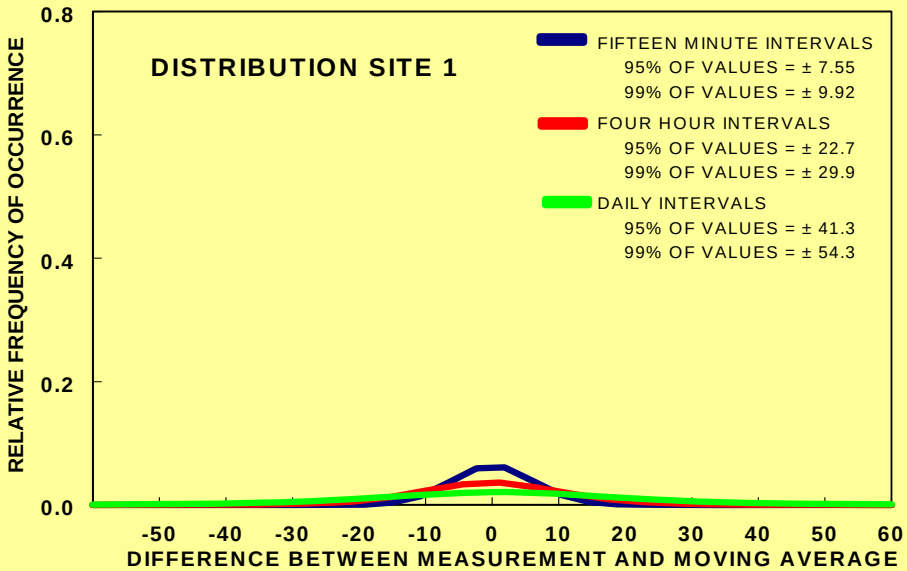


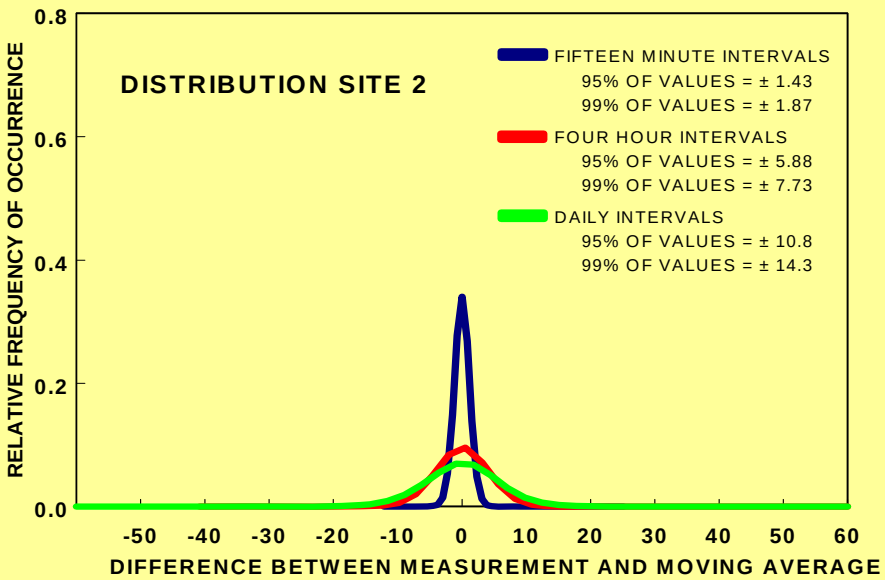
MIXED SURFACE AND GROUND WATER DISTRIBUTION SITES

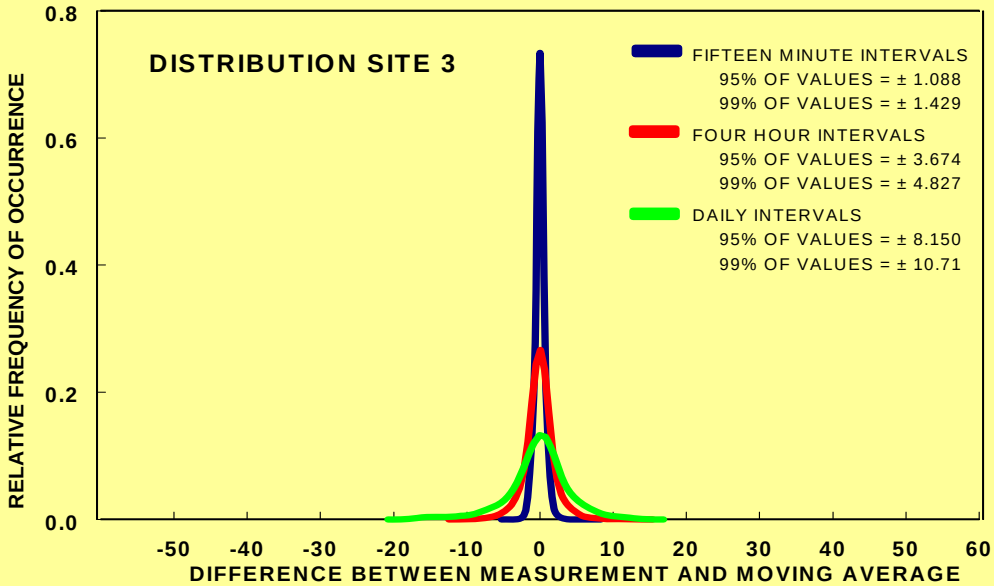


- Greater variability in surface-water sites than ground-water sites
- Variability in surface-water sites more difficult to control
- Some variability between ground-water sites

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







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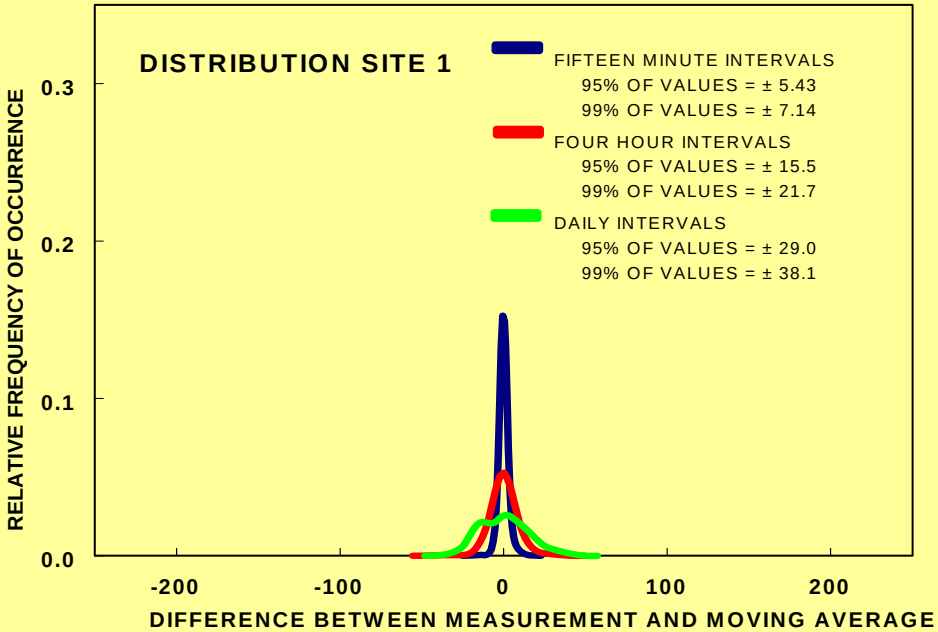
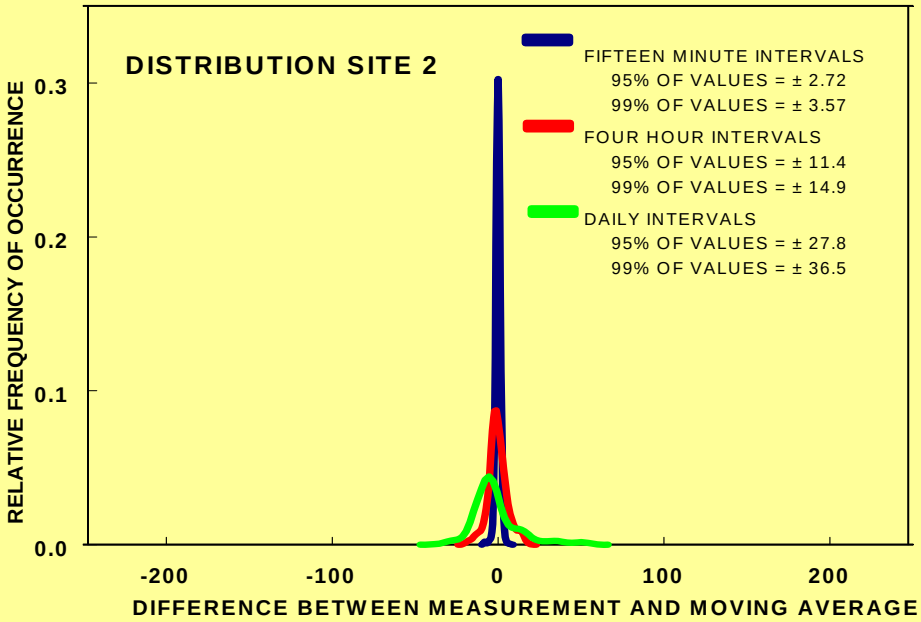
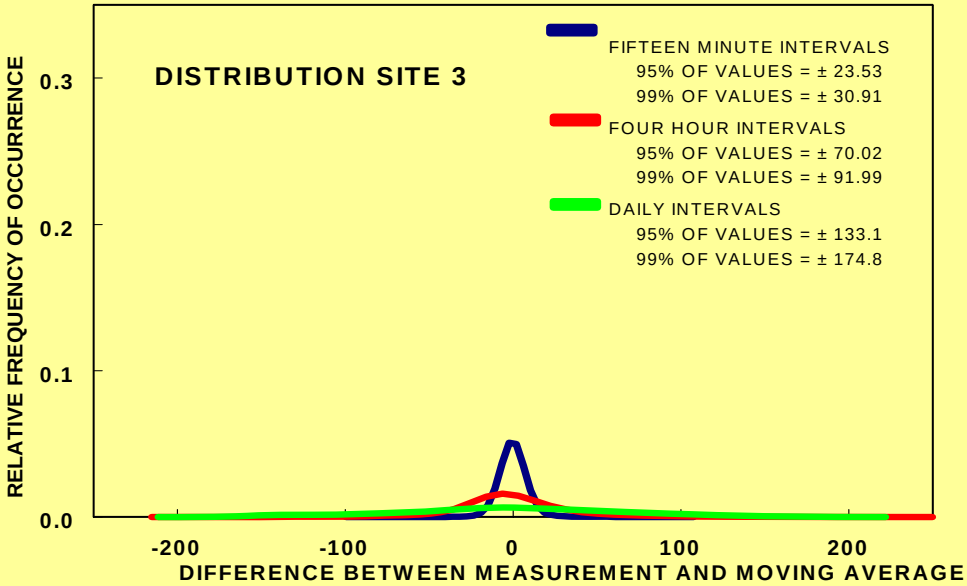
OXIDATION-REDUCTION POTENTIAL (ORP, mV): DISTRIBUTION OF DIFFERENCES BETWEEN MEASUREMENTS AND MOVING AVERAGES OVER 3 TIME INTERVALS







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Project Summary

- USEPA/NHSRC is using the TEVA program to design an effective and reliable warning system for distributions systems
- Some sensors are showing promise in the laboratory
- Field experiments are ongoing with some useful results
- Must include costs for operation and maintenance in overall cost estimates of EWS
- Need backup sensors in case of failures

Summary of Field Results to Date

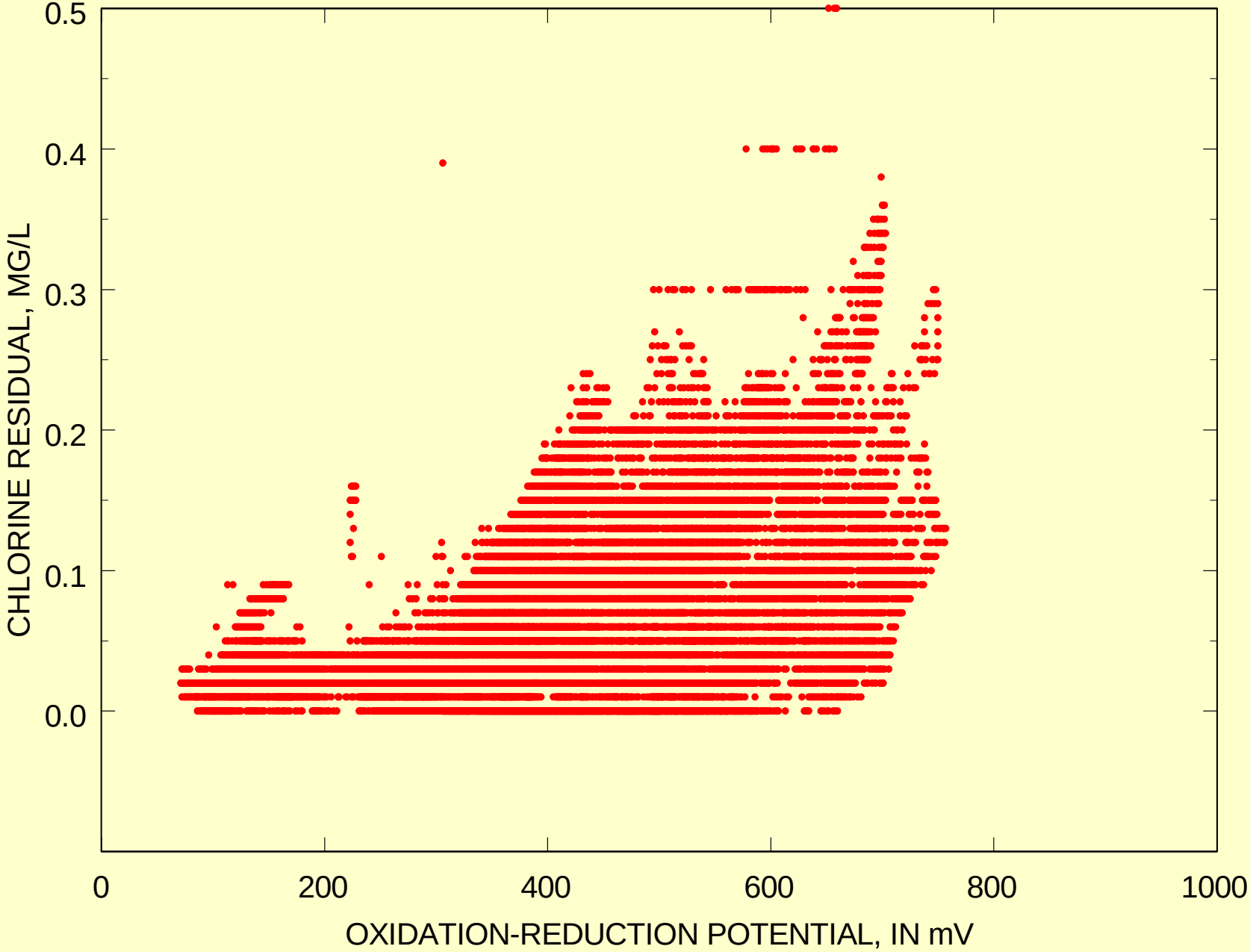
- Variability in sensor (T, pH, SC, ORP, and Cl) responses at distribution sites was:
  - greater at surface-water sites than at ground-water sites
  - similar between surface water intake at River and surface-water distribution sites
- Need to evaluating variability over different time intervals
  - Seasonal, daily, hourly, N-1
- One size doesn’t fit all

Future plans

- Continue monitoring—nine more months if funding comes through
- Move sensors around to other locations
  - Before and after elevated storage sites
  - To end of pipes at deliveries to a firehouse or police station
- Add sensors if we can identify partners
- Final report—Open file data report
- Work with USEPA and Sandia Labs on interpreting the variability of data and development of early warning response algorithms

End of show

RELATION OF OXIDATION REDUCTION POTENTIAL TO CHLORINE RESIDUAL AT DISTRIBUTION SITE M1



Explanation of the Density Diagram

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

X axis: The difference between each measurement (e.g., conductance) 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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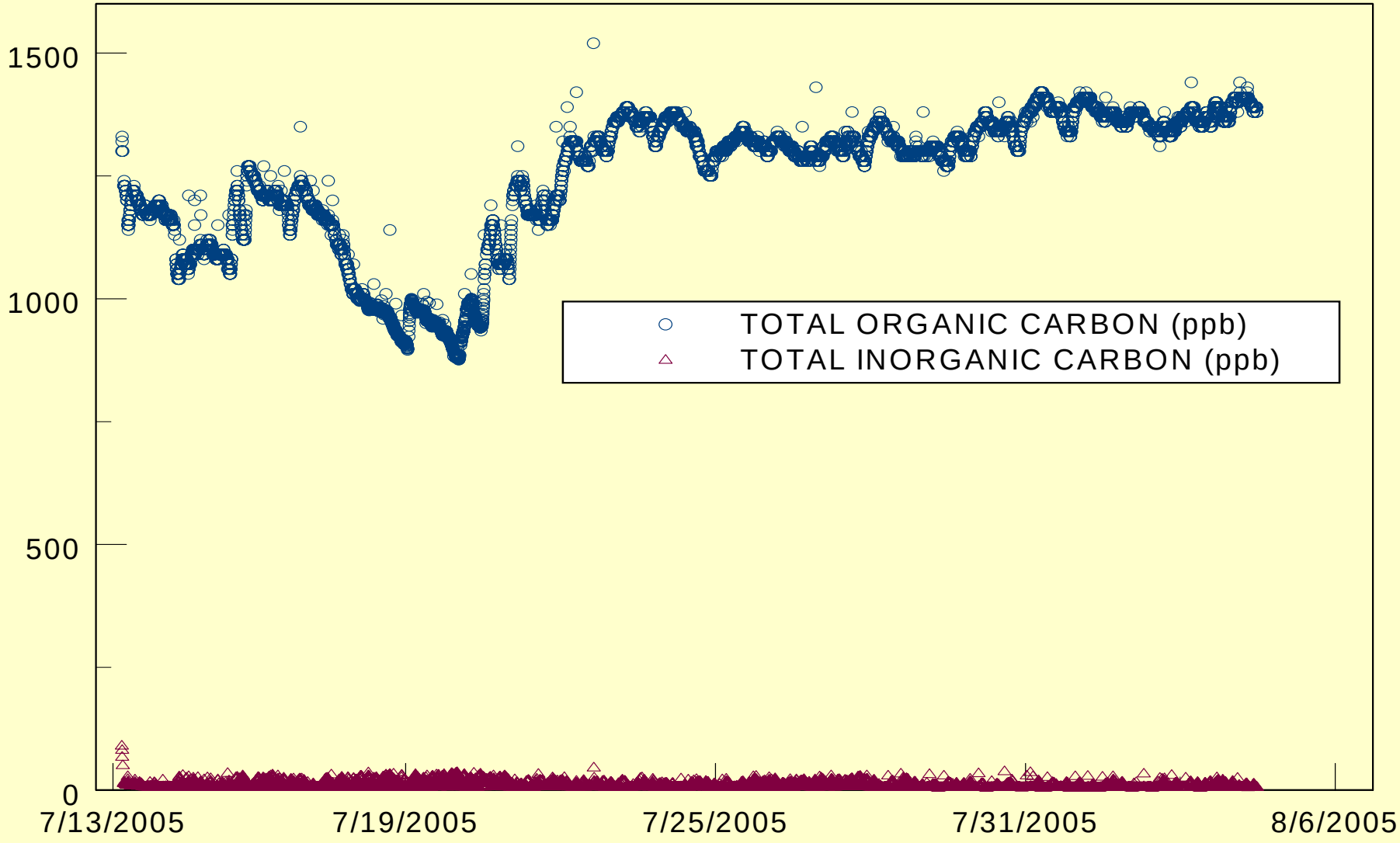
Total Organic and Inorganic Carbon in Drinking Water, Site DW3



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

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