Real-Time Continuous Water-Quality Data: Capabilities, Limitations, Applications, Costs, and Benefits

Presented by

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with contributions from Casey Lee, Pat Rasmussen, Xiaodong Jian, Chauncey Anderson, Rick Wagner, John Hem, and many others

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National Water-Quality Monitoring Council Conference

San Jose, California, May 9, 2006

Short-course Outline:

- Why, how, and where continuous WQ?
- Examples of continuous WQ data
  - Dissolved oxygen
  - Turbidity
- USGS protocols: O&M and QA
- Regression model development to estimate environmentally-relevant compounds
- Examples of applications
- Benefits and future

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Why monitor water quality continuously?

- Improves our understanding of hydrology and water quality and can lead to more effective resource management
- Captures seasonal, diurnal, and event-driven fluctuations
- Provides warning for water supply and recreation
- Improves concentration and load estimates with defined uncertainty (8,760 hourly values per year)
- Optimizes the collection of samples

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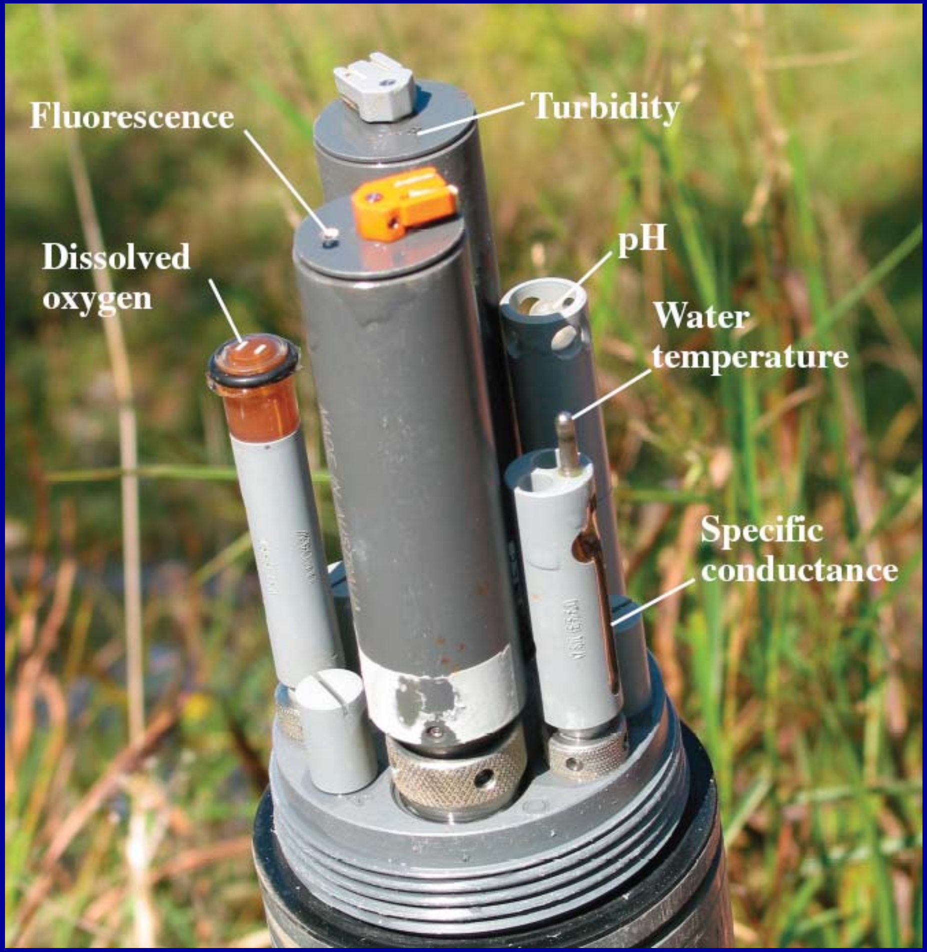
Improved tools now are available--
In-stream continuous monitors…



- pH
- Water Temperature
- **Dissolved Oxygen**
- Specific Conductance
- **Turbidity**
- ORP
- Fluorescence
- PAR
- Nitrate, ammonia, etc.
- New gizmos every year

USGS

Types of continuous water-quality sensors

- Electrometric
  - Gage height, temperature, pH, DO, SC
- Electromagnetic spectrum
  - Streamflow, turbidity, chlorophyll, nitrate
- In-stream analyzers (bench chemistries)
  - Nitrate, silicate, phosphorus, chloride, ….
- Labs in field at gage house
  - Aqualab (TCEQ), GC/MS- ORSANCO, etc…

USGS

Brief history of continuous water-quality monitoring

- Streamflow- more than 100 years
- Continuous estimated SC (Ohm)– Stabler (1911)—Daily samples—time-weighted composites with streamflow
- Continuous SC in Kansas- 1958, Albert
- YSI- Clark cell dissolved oxygen- 1963
- Hydrolab, 1968
- USGS monitors in 1970's at NASQAN sites
- Continuous real-time water quality in Kansas since 1998
- Large increase in the number of "gizmos" in last 10 years

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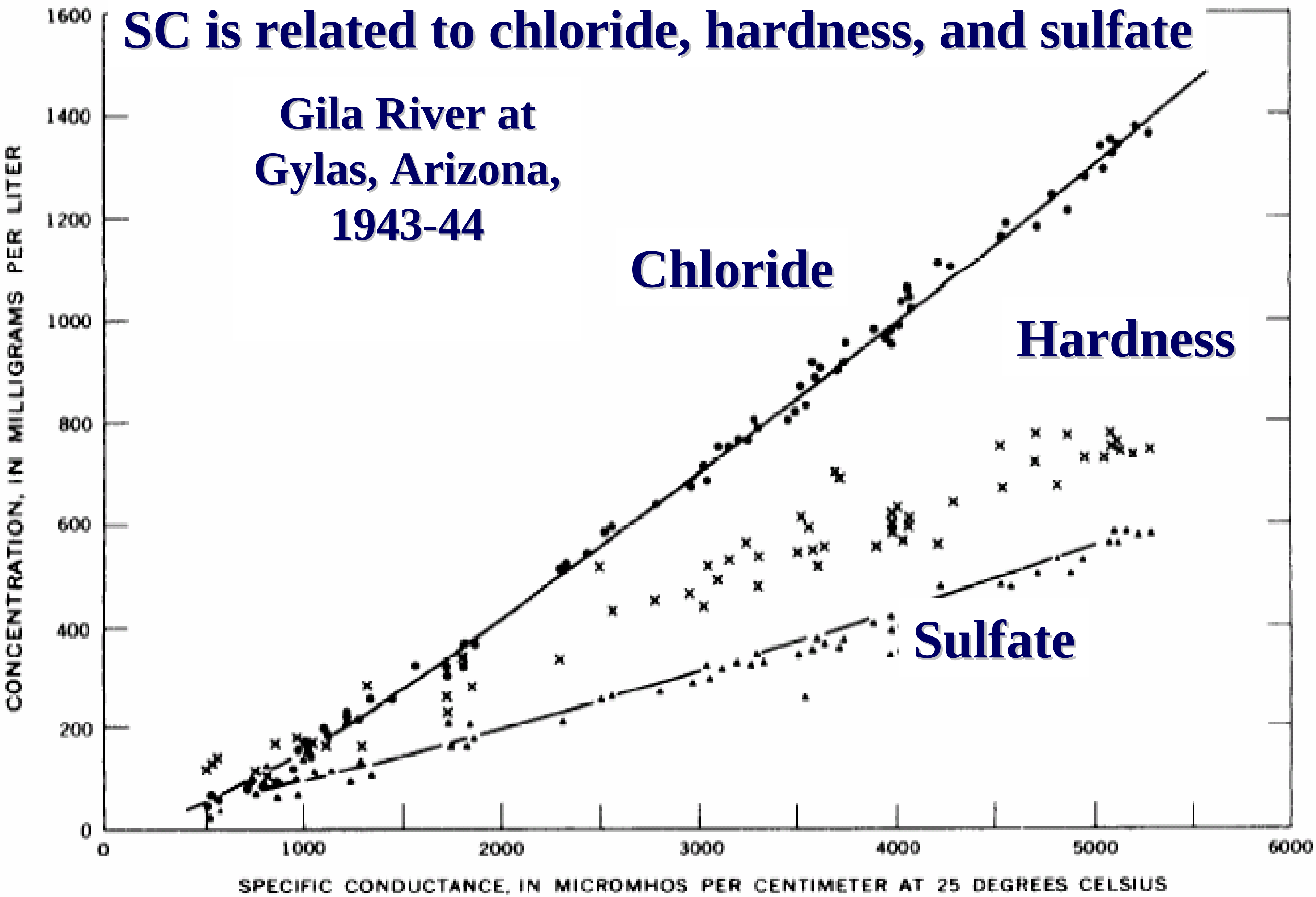
SC is related to chloride, hardness, and sulfate



From Hem, 1985, Study and interpretation of the chemical characteristics of natural water

Use of frequency distribution curves to evaluate water quality and compare basins

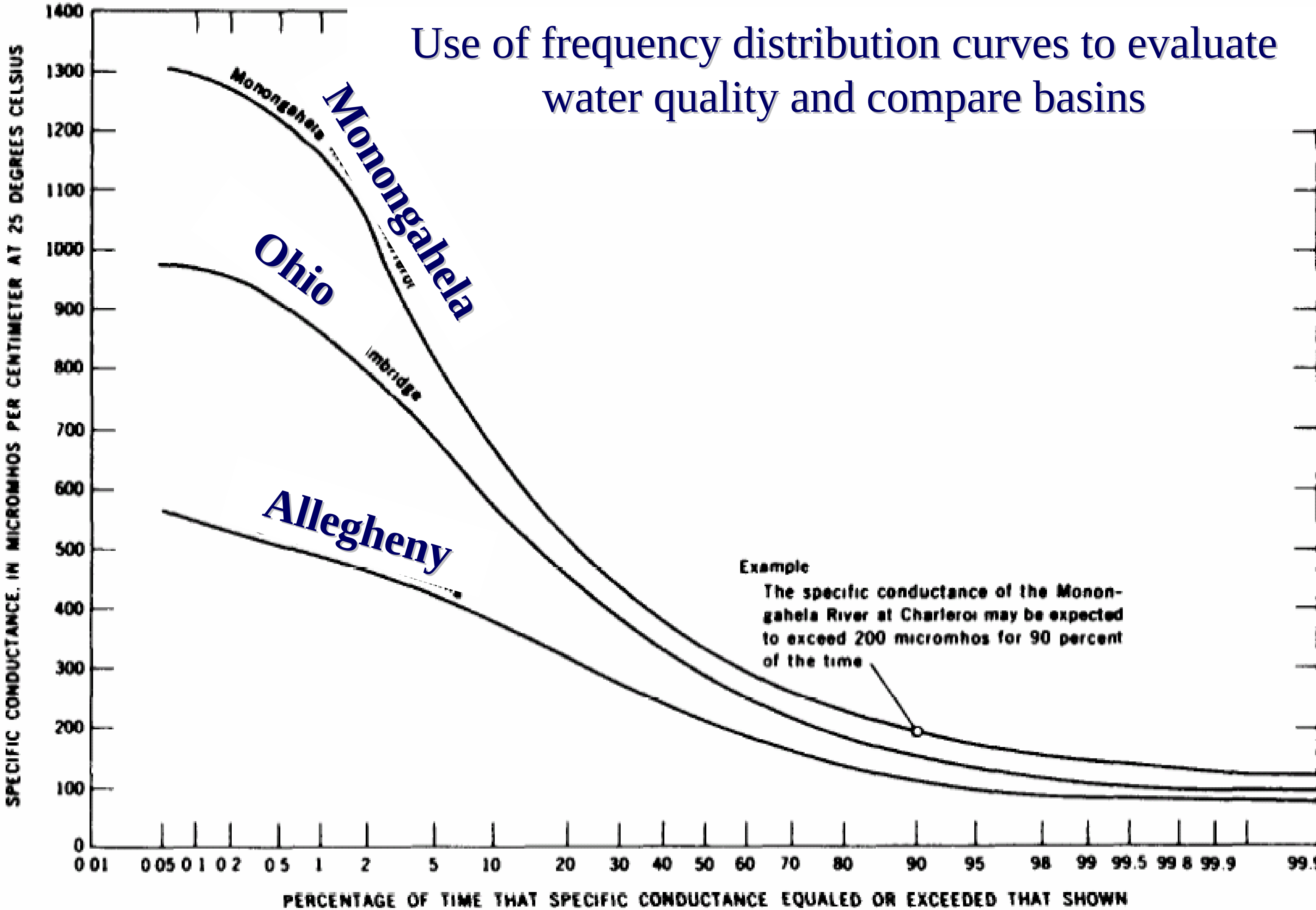


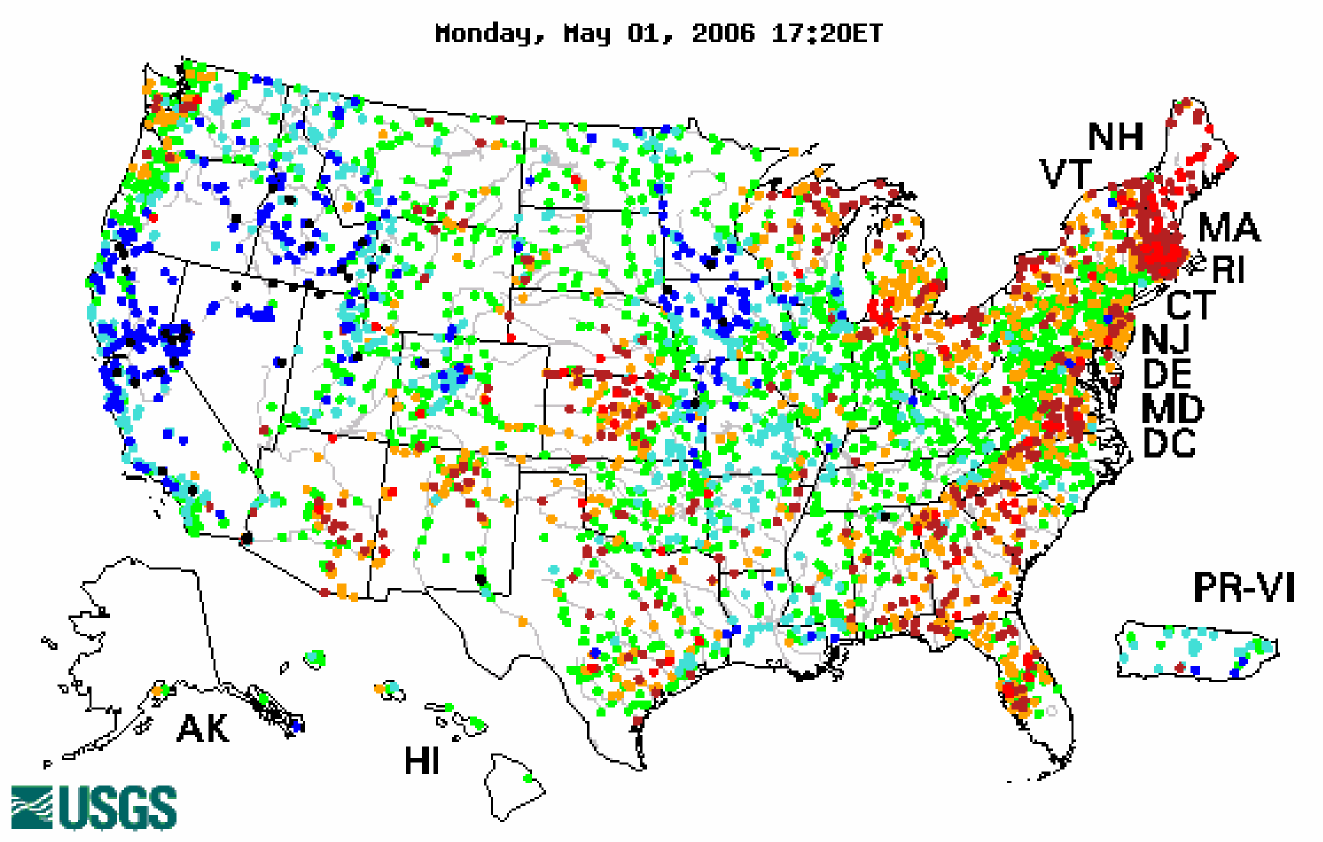
Figure 24. Cumulative frequency of conductance, Allegheny, Monongahela, and Ohio River waters, Pittsburgh area, Pennsylvania, 1944-50.

(From Hem, 1985, Study and interpretation of the chemical characteristics of natural water)

USGS streamflow network of 7,000+

WaterWatch -- *Current water resources conditions*

Animation of daily streamflow maps for May 2006



Explanation - Percentile classes						
Low	< 10	10 - 24	25 - 75	76 - 90	> 90	High

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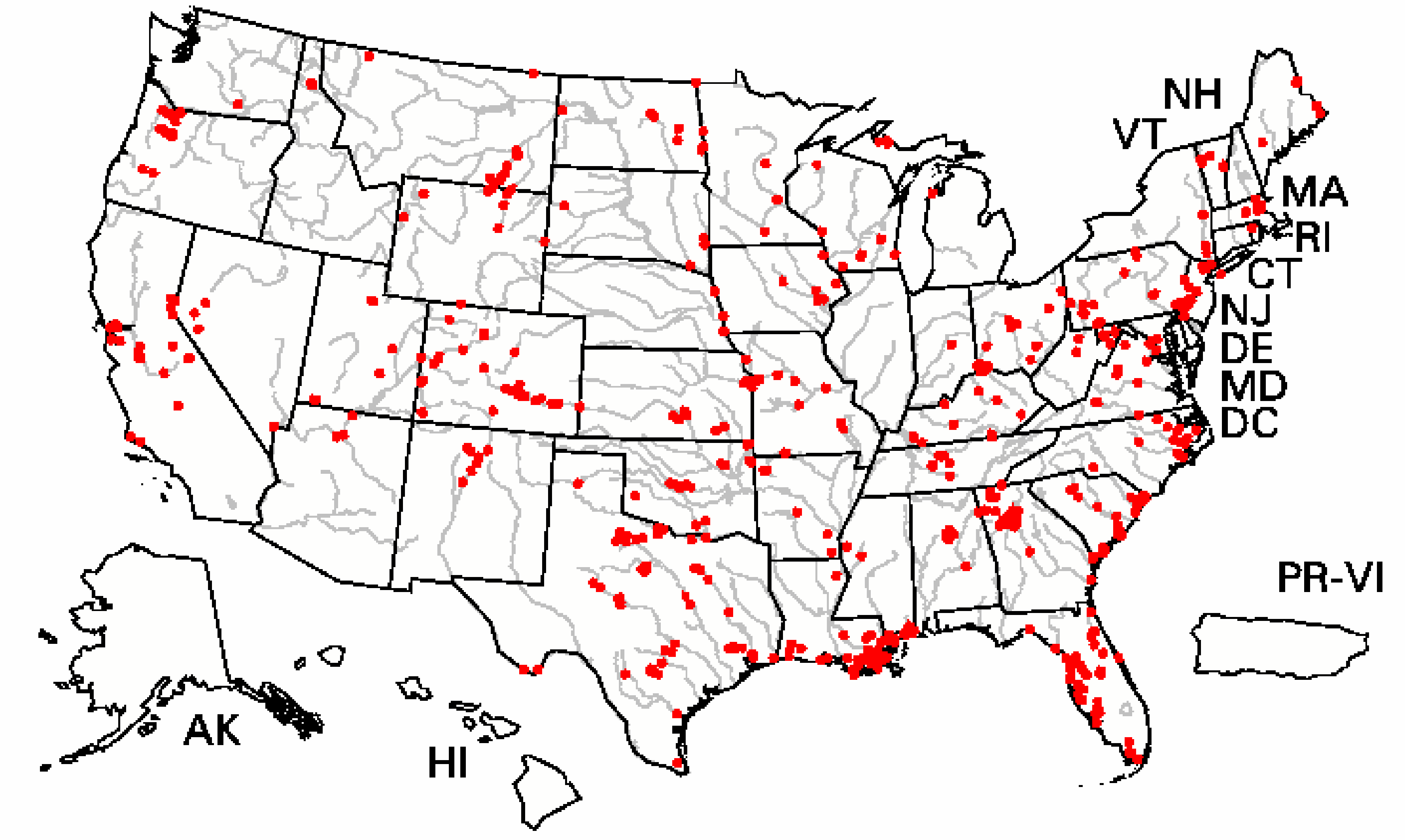
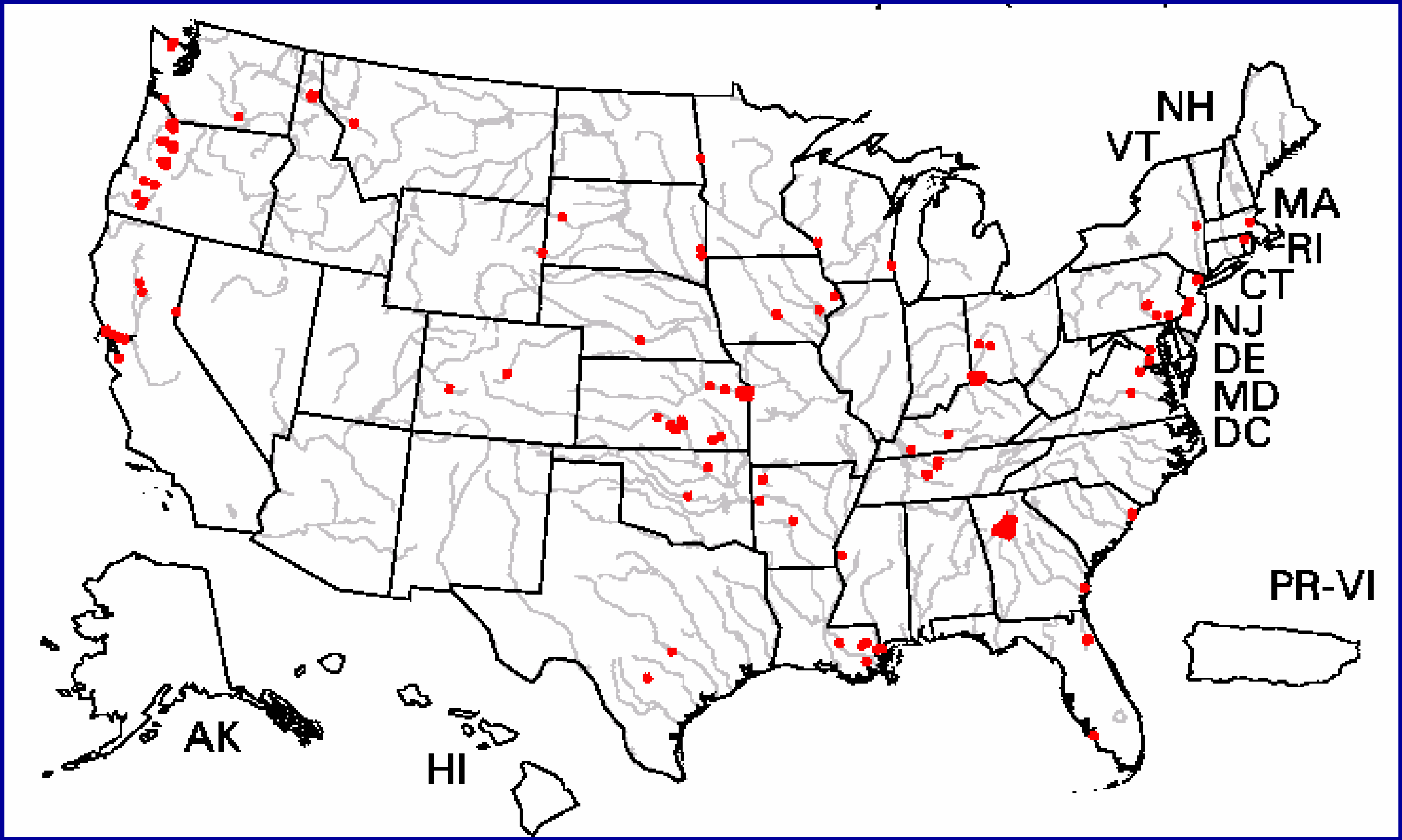
http://water.usgs.gov/waterwatch/

Where is USGS operating continuous WQ sites?



Specific conductance at 612 sites

Where is USGS operating continuous "turbidity"?



211 sites. Most sites are in Oregon (34), Georgia (34), Kansas (17), and 10 each in California, Kentucky, and Virginia

Many links to continuous water-quality data are now available compared to 5 years ago

- ks.water.usgs.gov/Kansas/rtqw/
- tongueriverrmonitoring.cr.usgs.gov/
- www.glo.state.tx.us/coastal/beachwatch
- www.dmww.com/empact_p2.asp
- www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/swqm_realtime_swf.html#data
- http://www.mysticriveronline.org

USGS

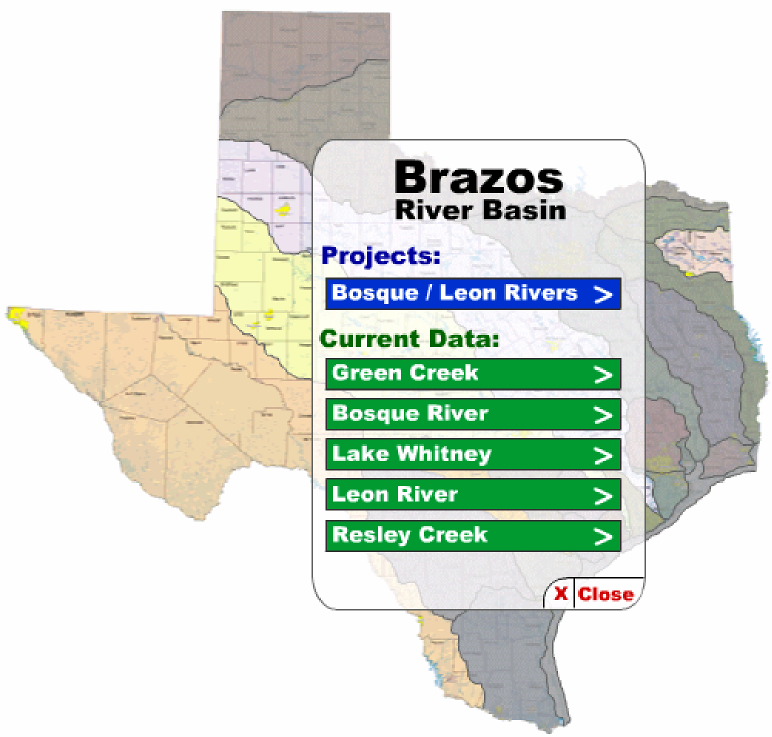
Texas Commission on Environmental Quality

http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/swqm_realtime_swf.html#data

Continuous Water Quality Station Information and Data by River Basin

The map below uses Macromedia Flash . If you do not have the free Macromedia Flash player, download it Exit... here, or visit our alternate Continuous Water Quality Monitoring Stations page, which doesn't use Flash.

- Mouse over the map to highlight different river basins.
- Click on a basin to see available data collected from that particular basin.
- Gray areas on the map are basins for which no data are available.



- Maintained by: Stephenville Special Project Office of the TCEQ DFW Regional Office

Area Map	Wide Aerial Photo	Overall site view	Closeup Aerial Photo	Street level Map

Upstream

Left Bank

Right Bank

Downstream

Current Measurements at Green Creek Water Site C701

Monthly Summary Report for Parameters at Green Creek Water Site C701

USGS

CAMS 701 Green Creek Water Site C701 | **Select a different site**

Month: April **Day:** 28 **Year:** 2006 **Time Format:** 12 Hour (AM/PM) | Generate Report

☑ Highlight validated data

The table below contains hourly averages for all the pollutants and meteorological conditions measured at Green Creek Site C701 for **Friday, April 28, 2006**. All times shown are in Central Standard Time.

Parameter Measured	Morning												Afternoon			
	Mid	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	Noon	1:00	2:00	3:00
Precipitation	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	FEW	NA	NA
Water Flow Rate	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	NA	NA
Water Velocity	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	NA	NA
Water Level	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	PMA	NA	NA
Water Ammonia	***0.13***	0.13	0.13	0.13	**0.14**	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	FEW	NA	NA
Water Nitrate	0.79	0.79	0.76	***0.68***	0.68	0.68	0.68	0.68	0.77	**0.85**	0.85	0.85	0.85	FEW	NA	NA
Turbidity	***12.01***	13.51	17.50	20.00	21.00	**21.50**	20.00	19.00	19.50	20.00	19.00	19.00	19.50	FEW	NA	NA
Water Total Reactive Phosphate	***0.076***	0.077	0.078	0.078	0.078	0.078	0.078	0.079	**0.080**	0.080	0.080	0.080	0.080	FEW	NA	NA
Parameter Measured	Mid	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	Noon	1:00	2:00	3:00
	Morning												Afternoon			

Maximum values for each parameter are **bold** within the table. Minimum values are ***bold italic***.

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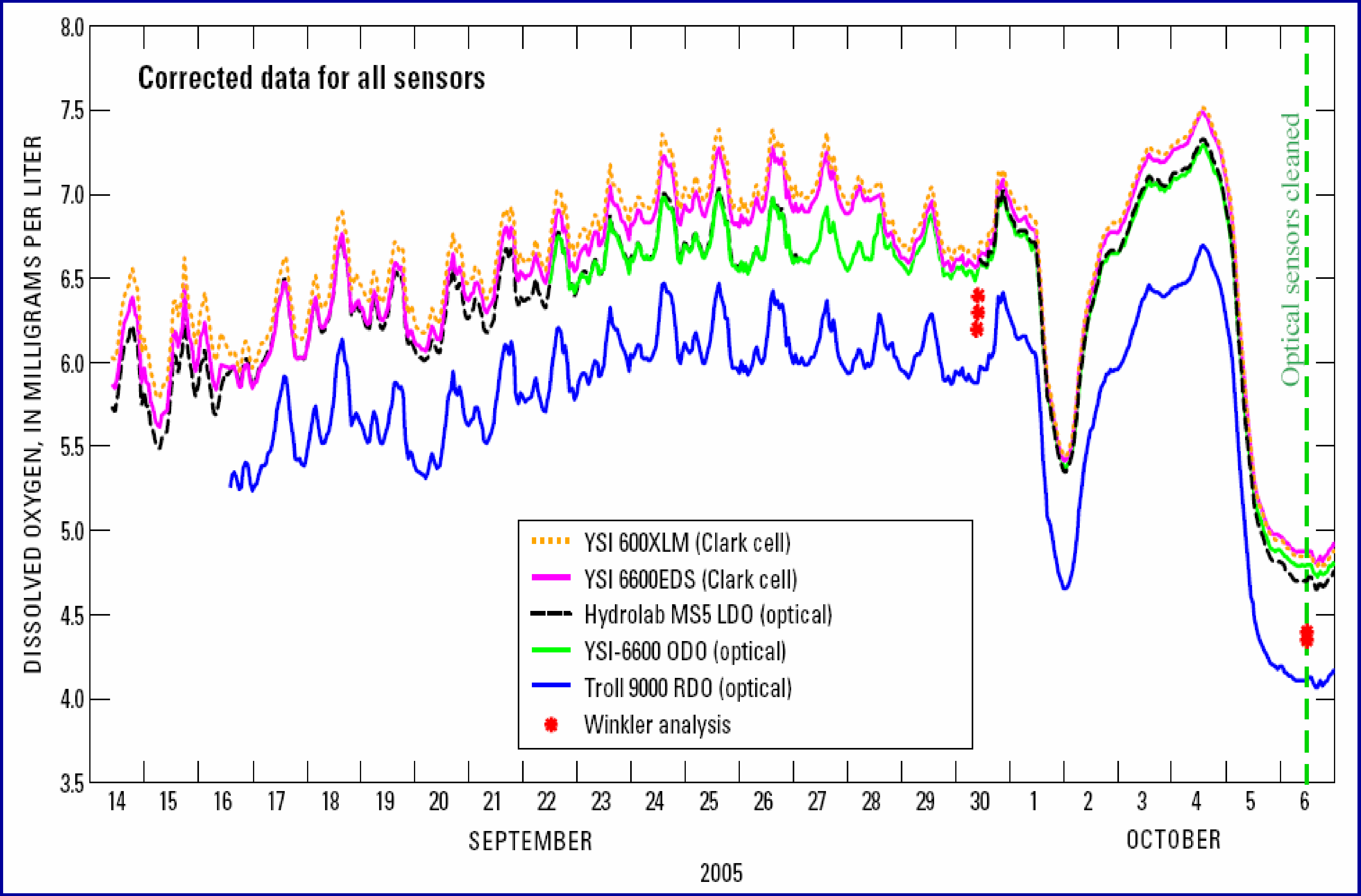
Examples of comparisons of different dissolved oxygen (DO) and turbidity instruments

YSI ROX

YSI Extended Deployment System (EDS)

Clark cell/optical DO methods are similar, but not equal



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USGS Open-File Report 2006-1047

The murkiness of turbidity measurement

- **Operationally defined by method used and instrument configuration using nephelometry**

- **"an expression of the optical properties of a sample that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a sample. (Turbidity of water is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes)"**

http://water.usgs.gov/pubs/circ/2003/circ1250/
http://water.usgs.gov/owq/FieldManual/Chapter6.7

USGS

Factors affecting turbidity

Properties of water matrix	Effect on Measurement	Direction of effect	Instrument designs to compensate
Color	Absorption of light beam	Negative (-)	•Near-IR •Multiple detectors
Particle Size: •Large •Small	λ – Dependent	+ (Near IR) - (White)	•White Light •Near IR
Particle Density	Increases forward & back scattering	Negative (-)	•Multiple Detectors •Backscatter

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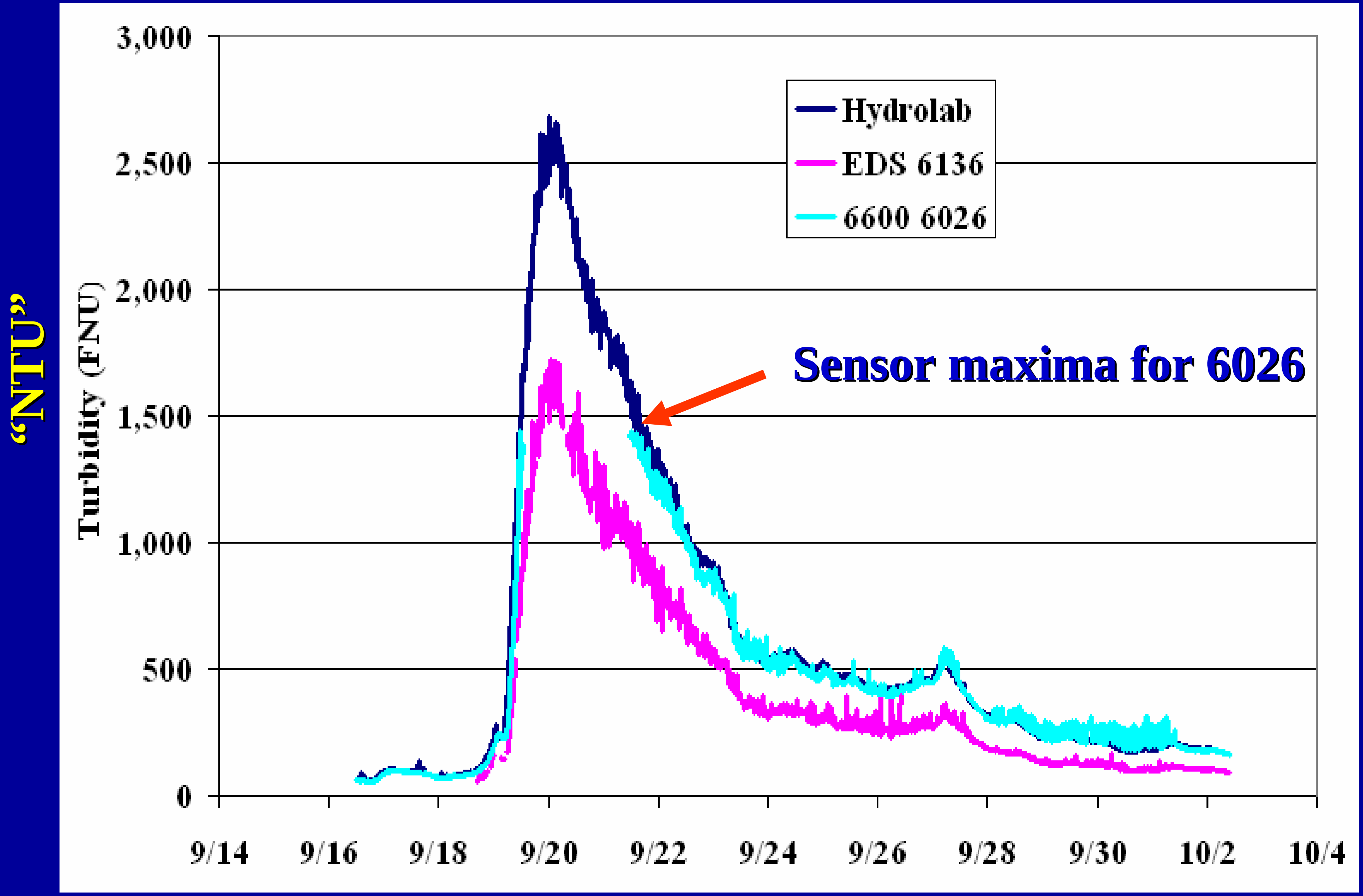
Are these 3 turbidities comparable/equivalent?



2003

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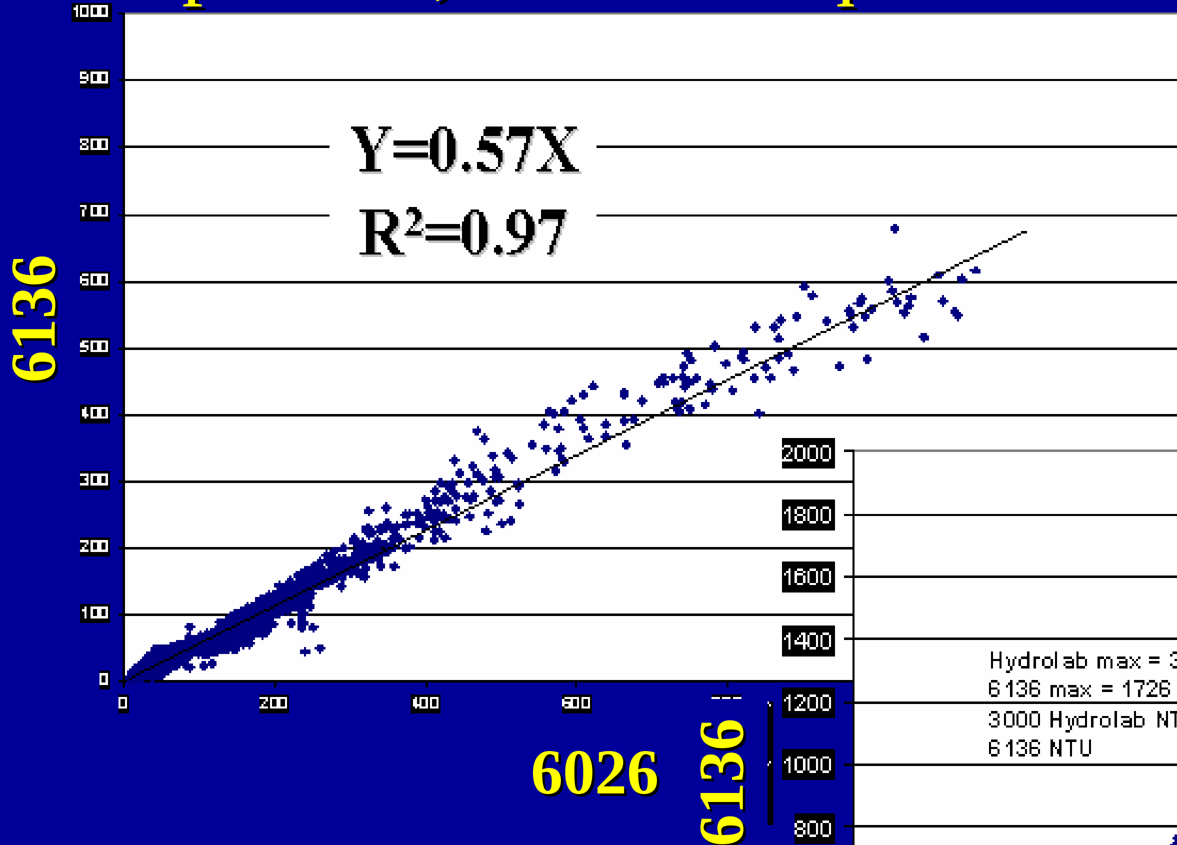
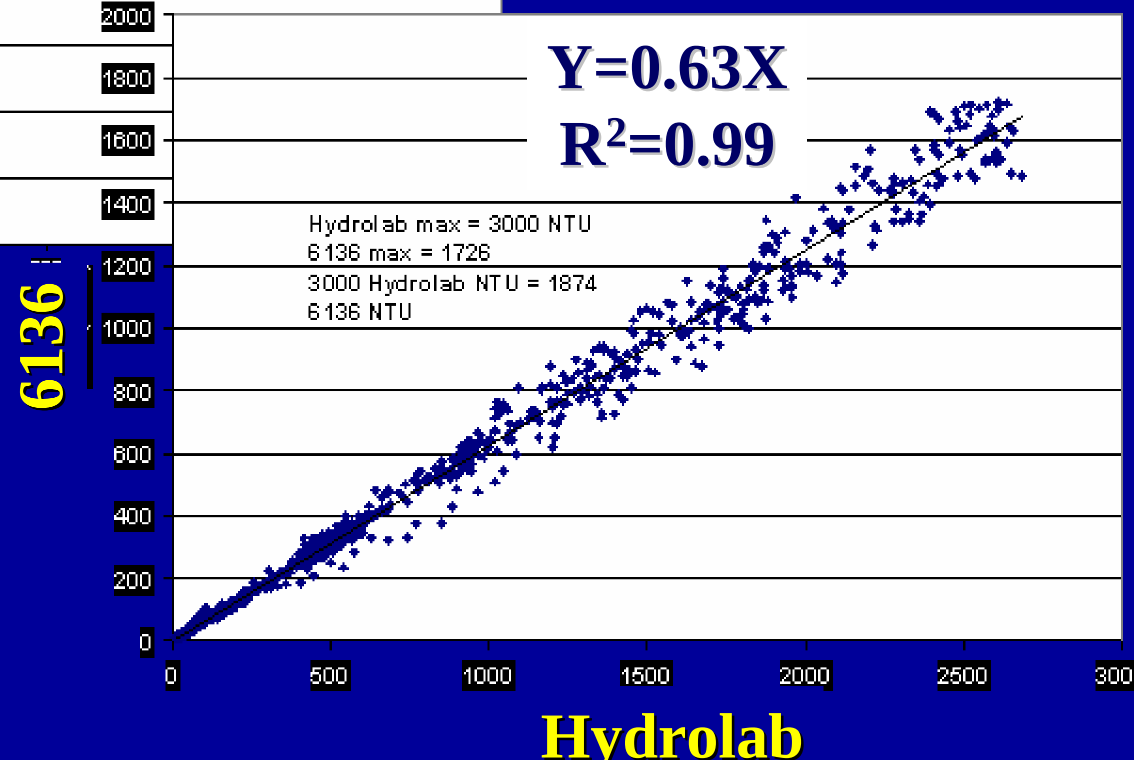
YSI 6026, 6136, and Hydrolab "3,000" turbidity are comparable, but not "equal"



Measurement method needs to be stored with data



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Data must be quality-assured

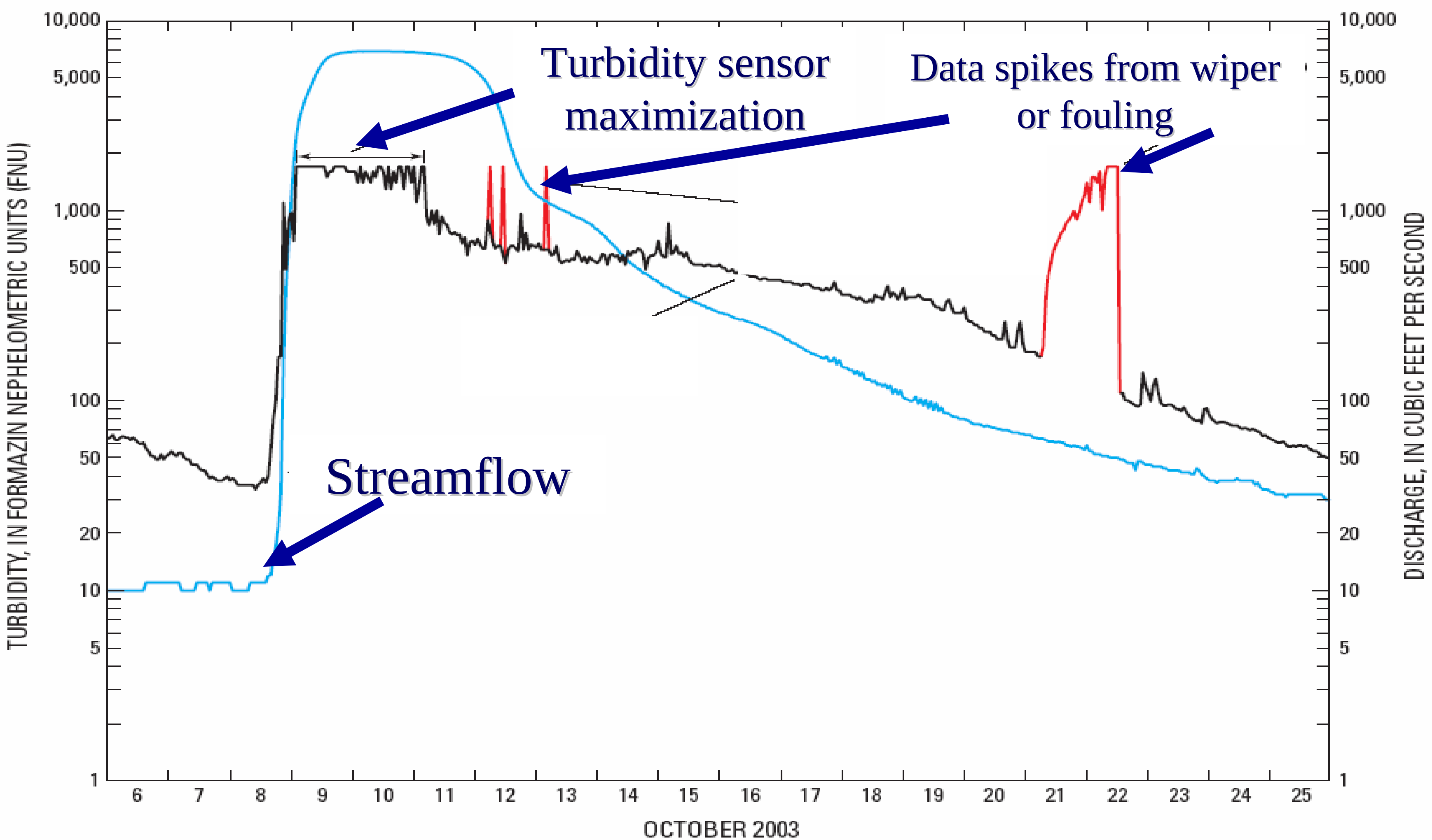
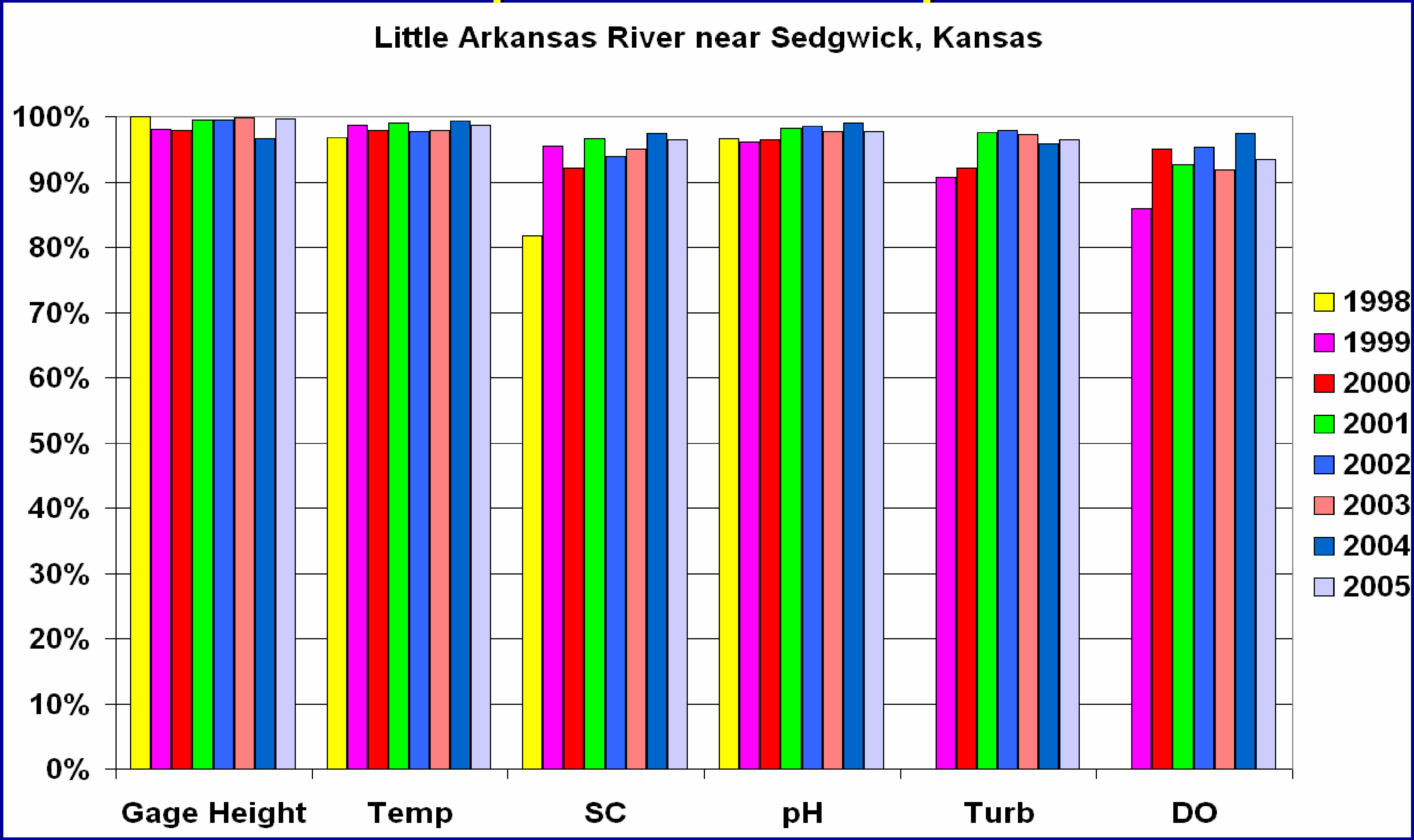


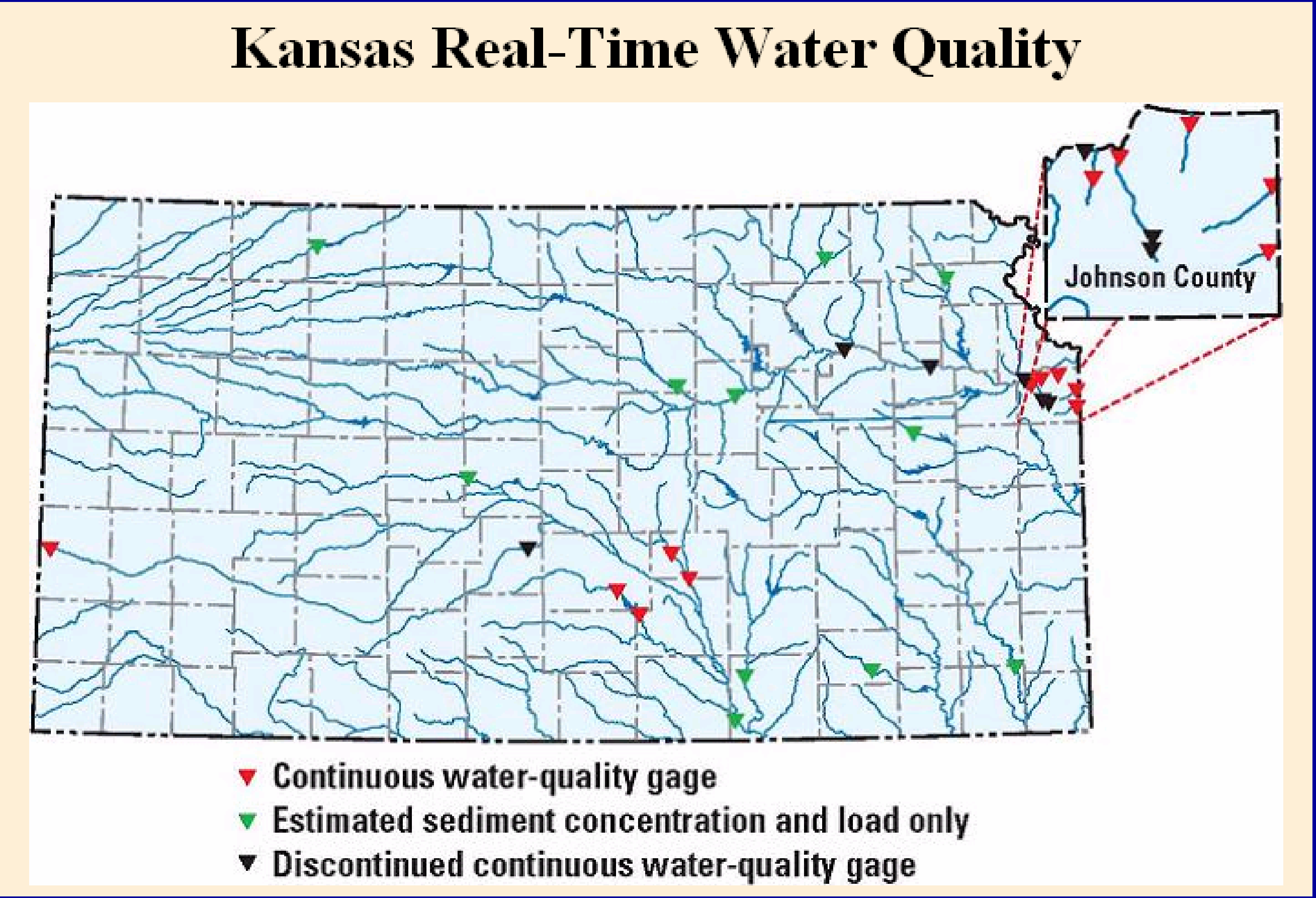
Figure 6. Turbidity values at the Little Arkansas River at Highway 50 near Halstead, Kansas, October 2003.

From Water Quality Monitor guidelines-Wagner and others, 2006

Records 90+percent complete



http:// ks.water.usgs.gov/Kansas/rtqw/



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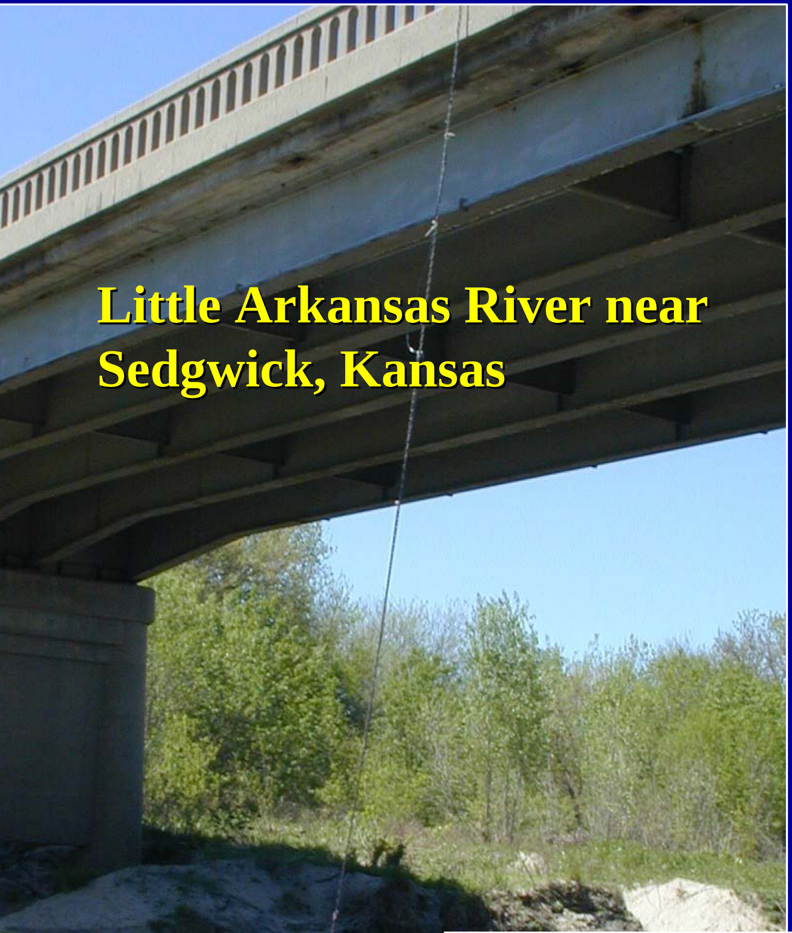
Approach:



Little Arkansas River near Sedgwick, Kansas

- Add water-quality monitors at streamgages and transmit data "real" time
- Collect water samples over the range of hydrologic and chemical conditions
- Develop site-specific regression models using samples and sensor values
- Estimate concentrations and loads
- Publish regression models
- Display estimates, uncertainty, and probability on the Web
- Continued sampling to verify

http://ks.water.usgs.gov/Kansas/rtqw/

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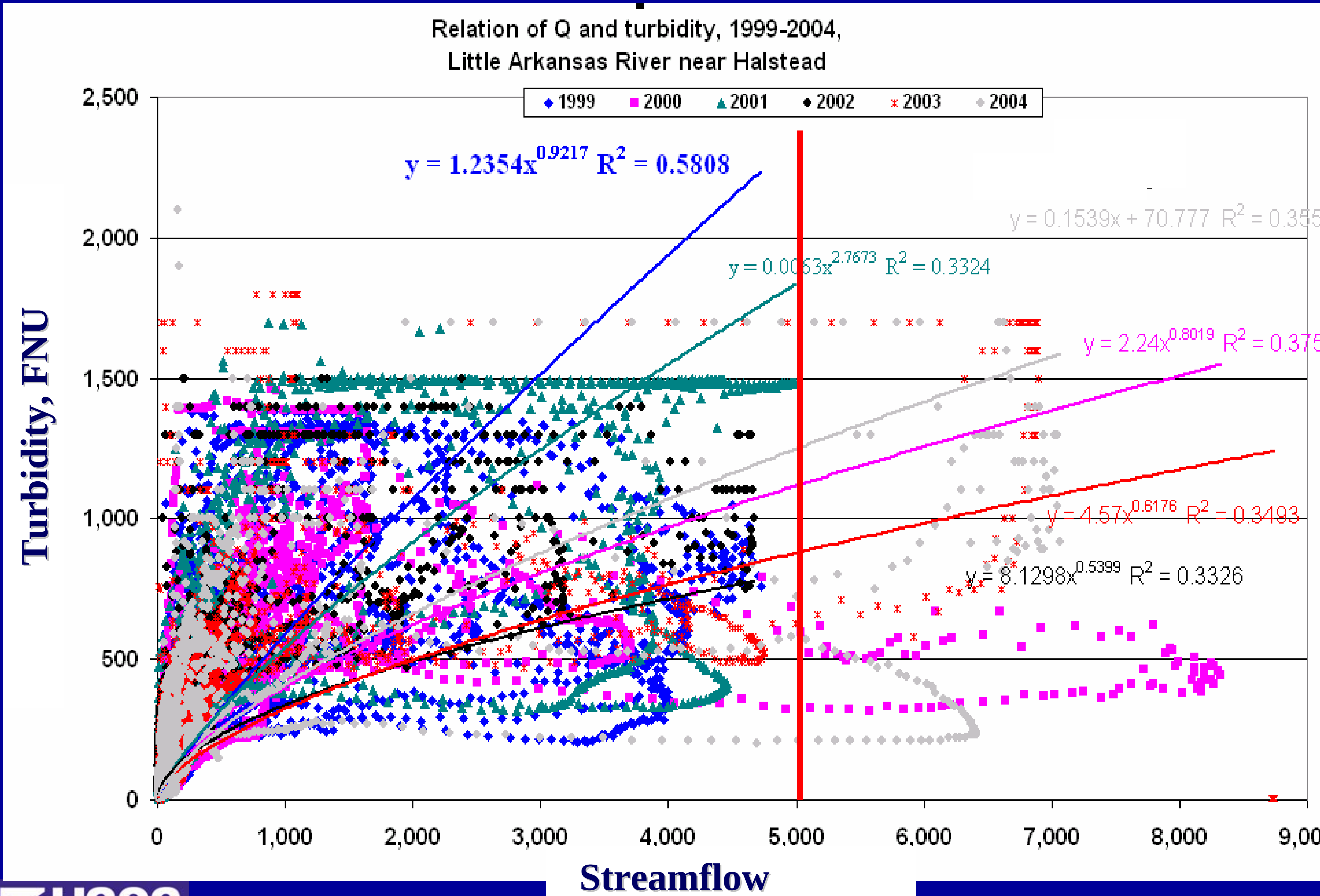
Streamflow relation to water quality is complex and variable



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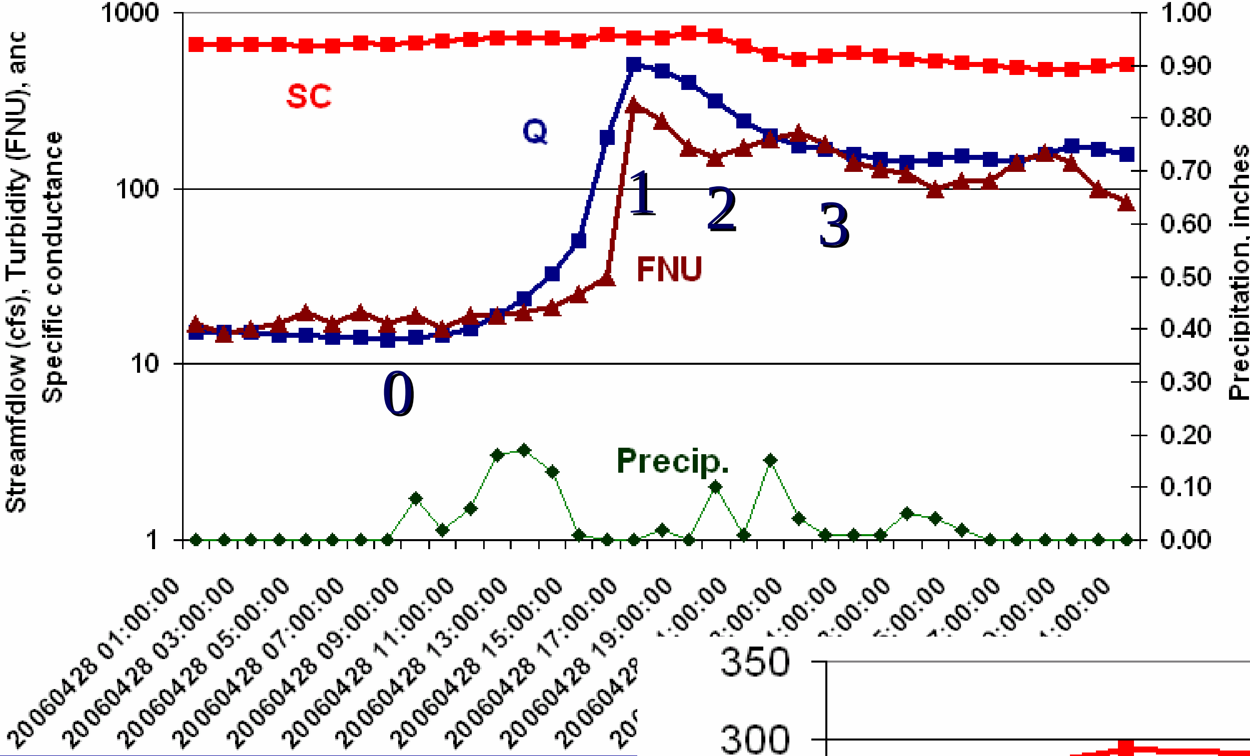
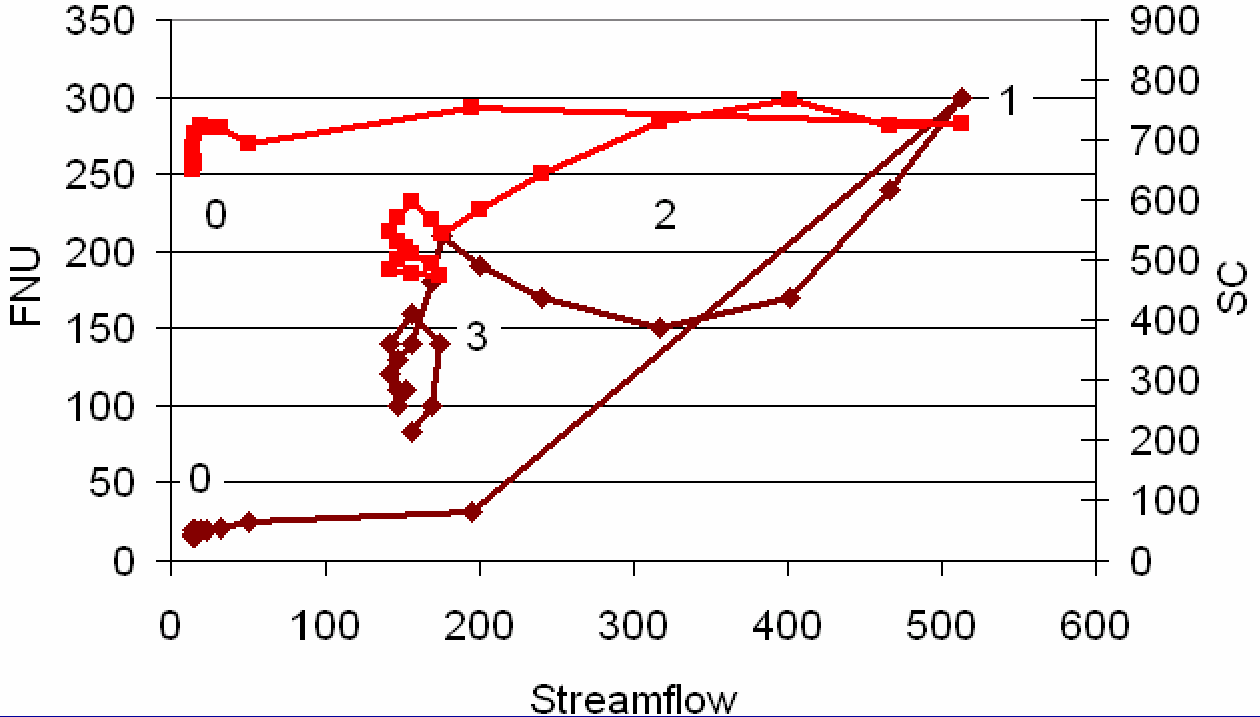


Continuous data is necessary to understand the water-quality response to streamflow



0. Q inc. within 15 min.

1. source limit reached

2. new trib or bank collapse source

3. response to precip and new tribs

Mill Creek April 28-29, 2006 hysteresis

Continuous water-quality technology and estimates

- Real-time water quality is technology driven and must stay current
- Need to understand the measurement technology and limits
- Data storage can and must be differentiated
- New challenge is how to interpret the wealth of the time-dense data that challenges our assumptions

Next Up Data and QA, followed by statistical estimation approach

Any questions/comments/discussion/concerns?

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Real-Time and Quality Assurance Aspects of Continuous Water-Quality Monitor Data

Trudy Bennett
USGS Kansas Water Science Center

Water-Quality Monitoring Conference
San Jose, CA
May 9, 2006

USGS

Quality-assurance of real-time water-quality monitor data

- GOAL is to optimize retained data of known quality
  - Identify transmission problems
  - Recognize erroneous data due to fouling or calibration drift
  - Recognize erroneous data due to sensor or monitor malfunction

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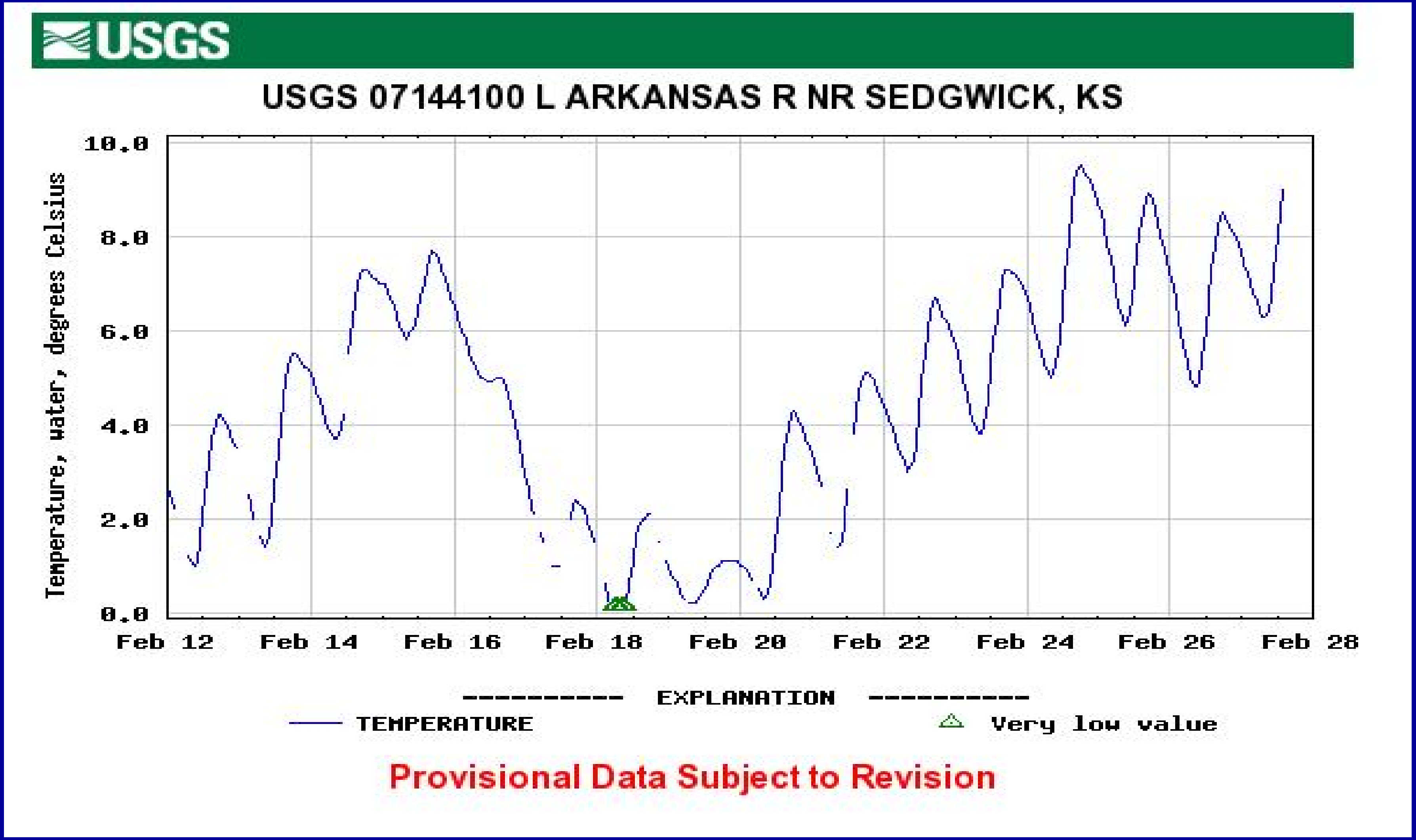
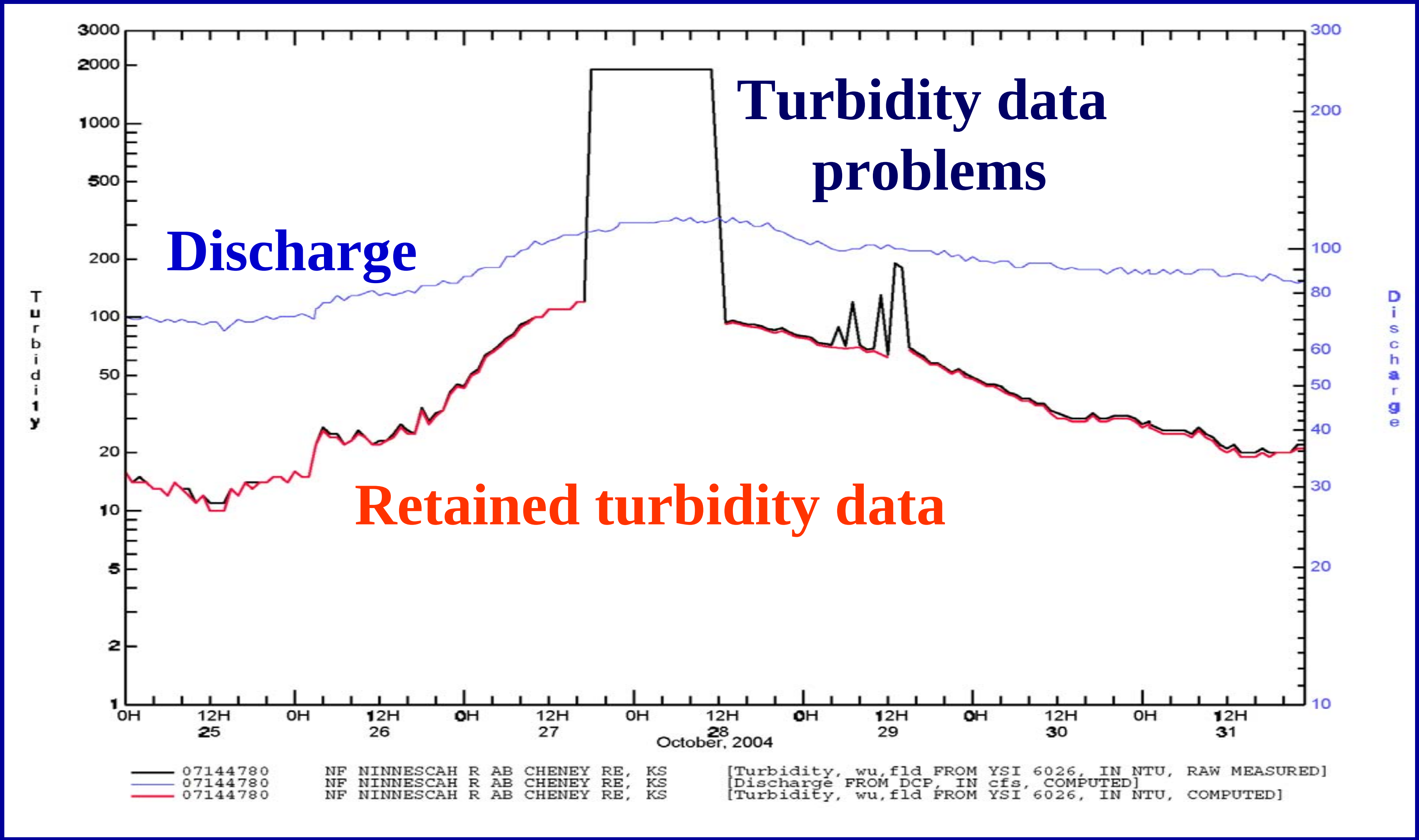
Transmission Problems



Turbidity Sensor Buried in Sand



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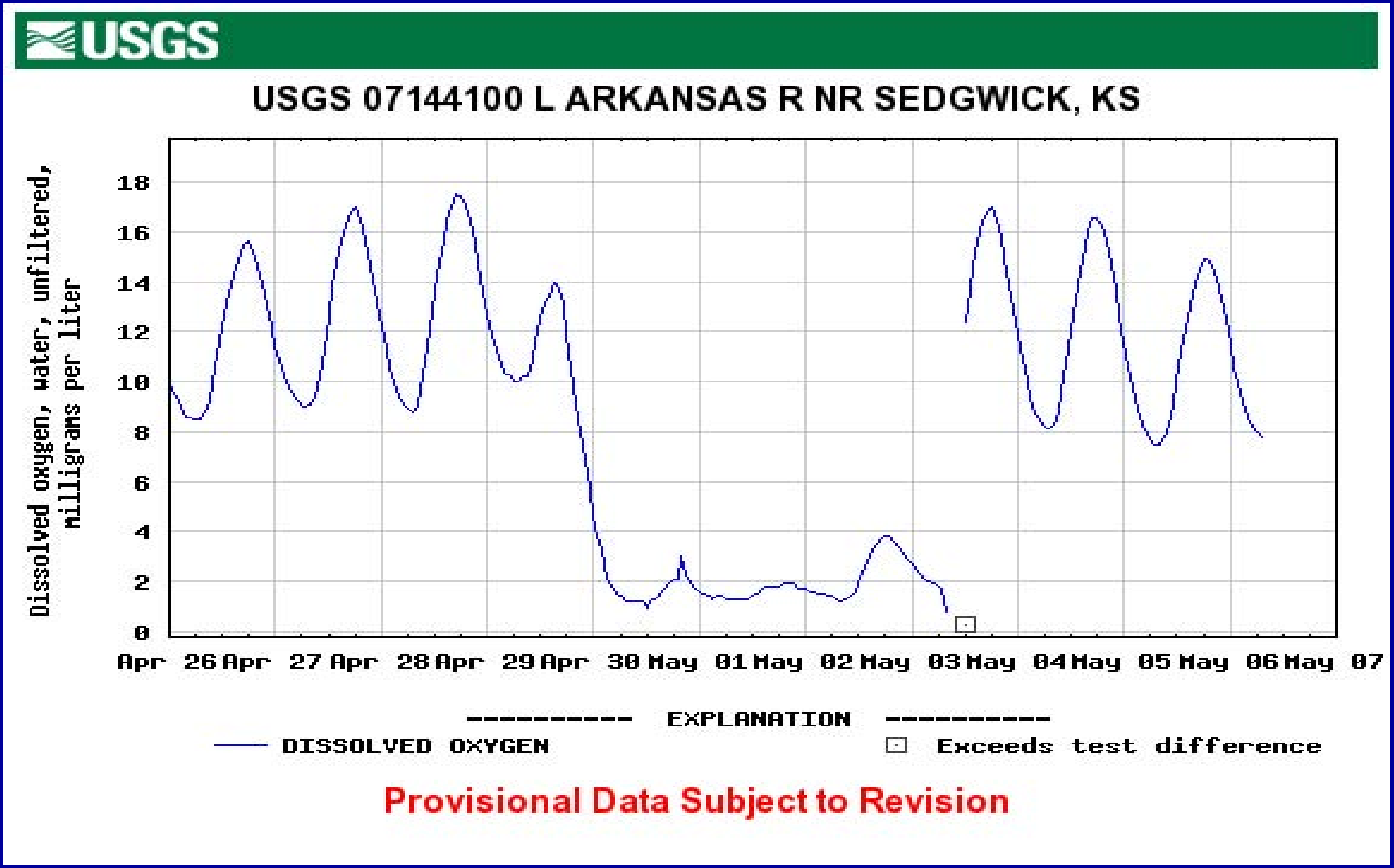
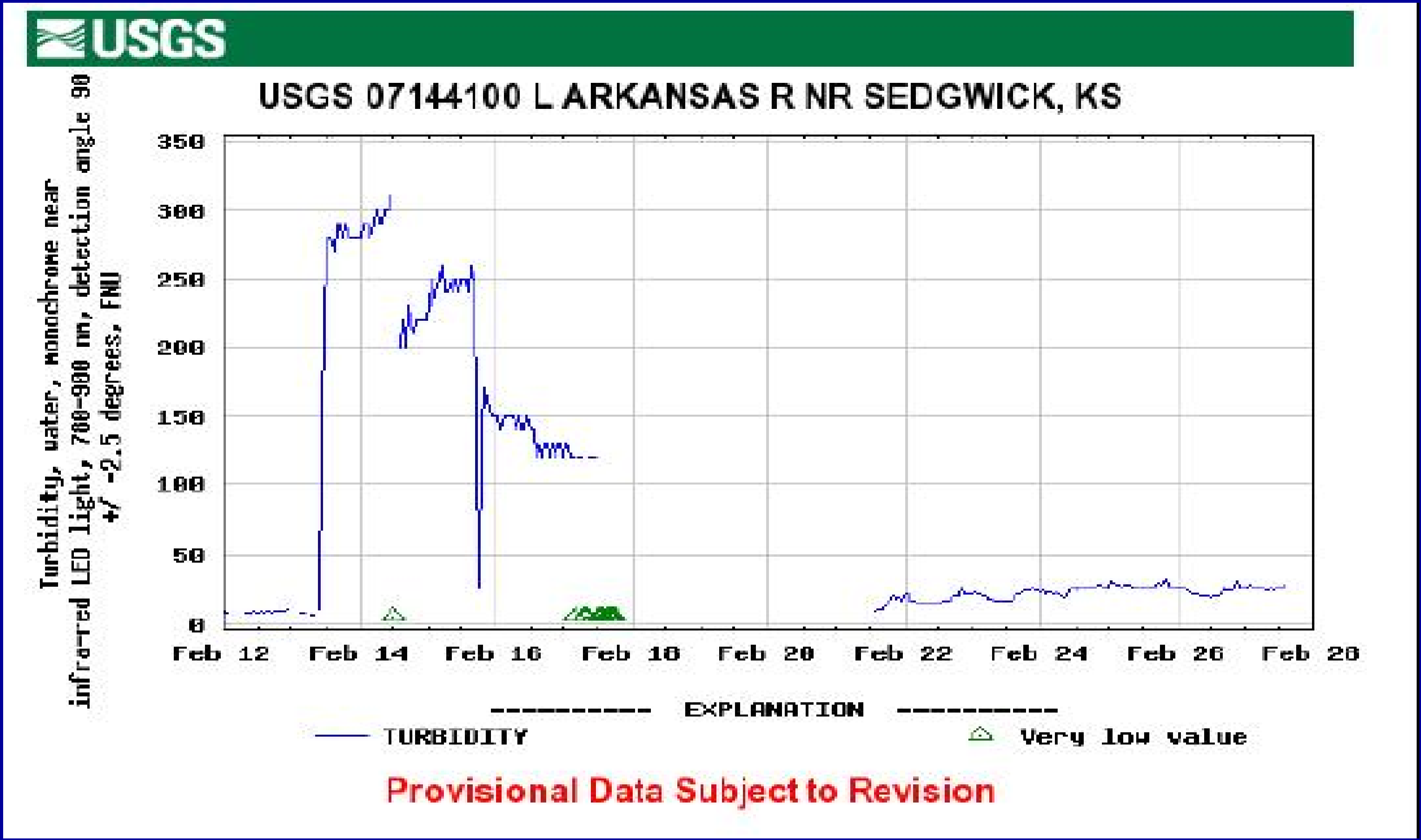
DO Sensor Calibration Failure



Turbidity Sensor Failure



QA/QC of Web Data

- GOAL is to Optimize Accuracy of Data Viewed on Web
  - Delete erroneous data
  - Resolve data problems
  - Apply corrections to update data for fouling and/or calibration drift
  - Update Web

QA/QC Critical Steps of Transmitted Data

1. Daily Office Review of Transmitted Data
2. Field Work Protocols
3. Record Working Process

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Step 1. Daily Office Review

1. Daily Review of Transmitted Data
2. Delete Erroneous Data
3. Set Thresholds (recommended)
4. Remove Site or Parameter from Web (last option)

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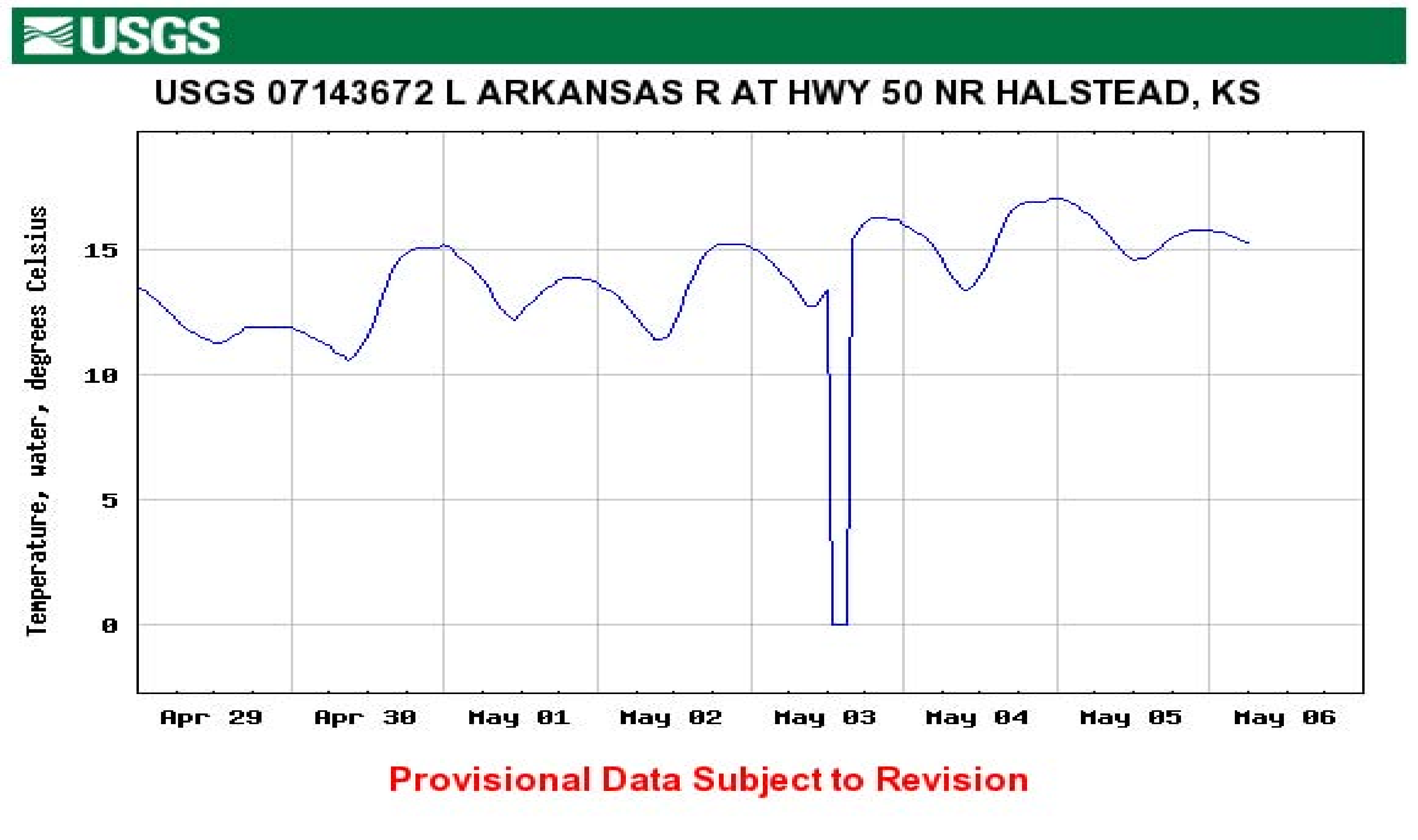
Zero Values Caused when Monitor was Serviced



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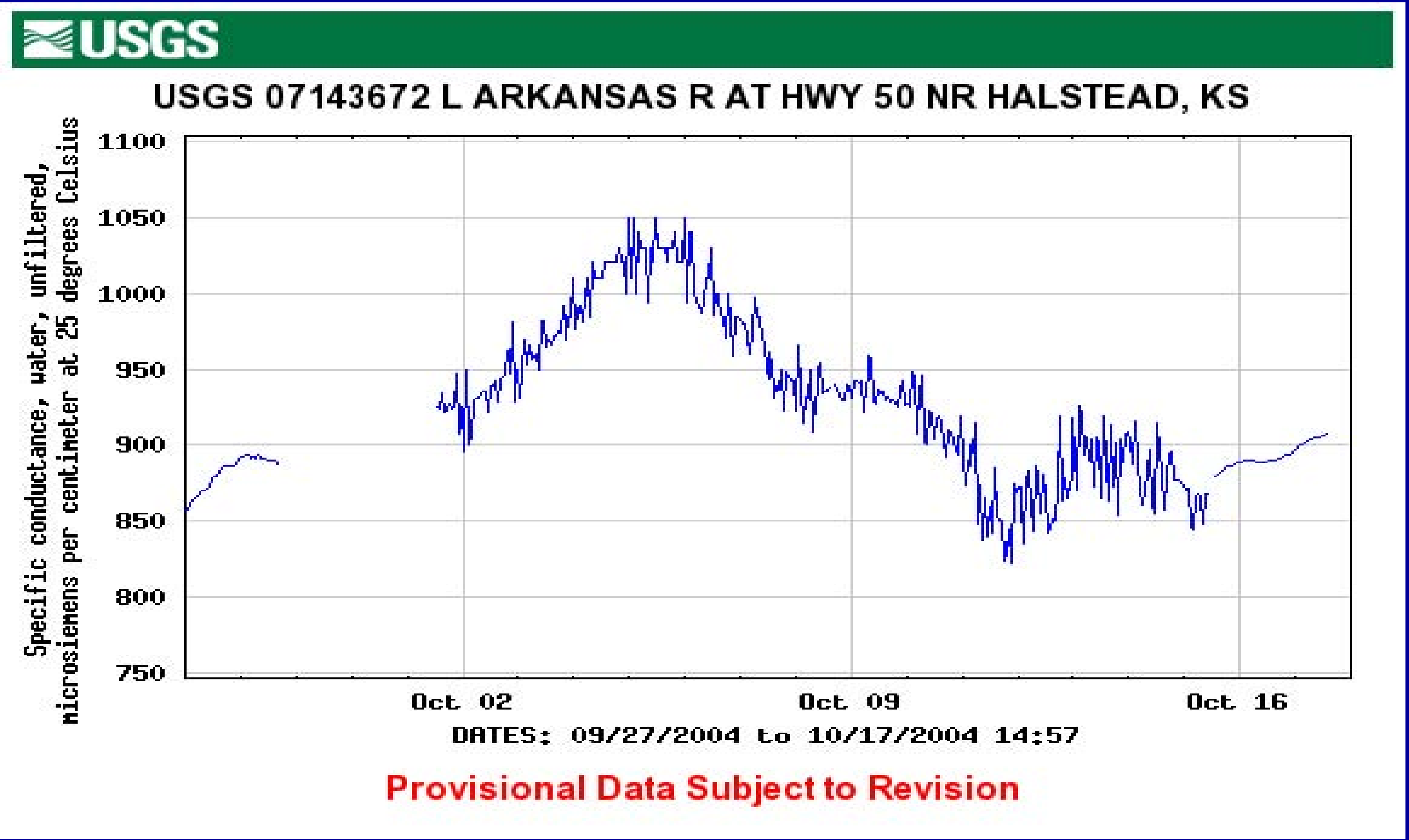
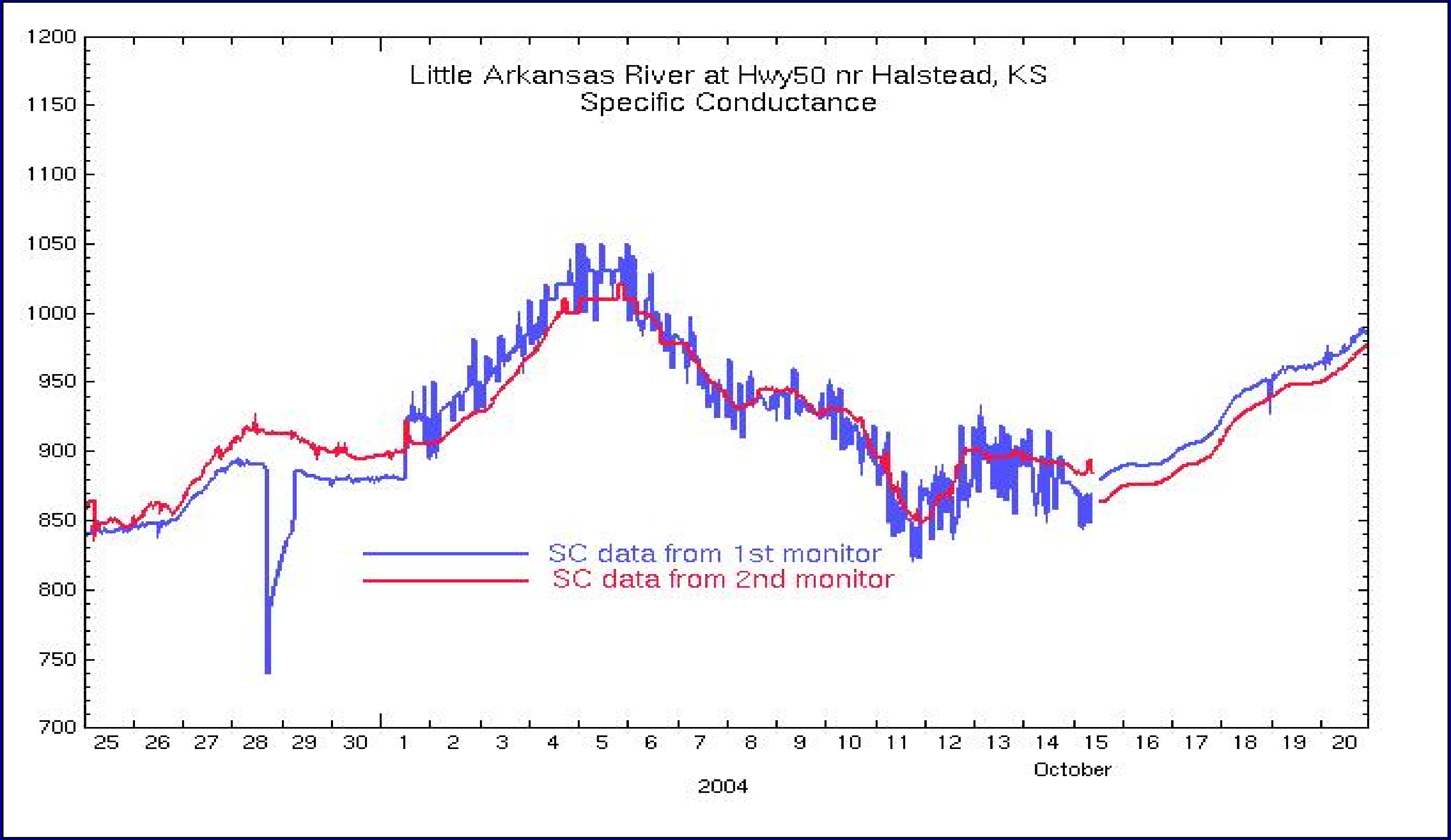
Sensor Noise in Conductivity Sensor



Sensor Noise (cont.)



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Step 1. Office Work (cont.)

1. Daily Review of Transmitted Data
2. Delete Erroneous Data
3. Set Thresholds (recommended)
4. Remove Site or Parameter from Web (last option)

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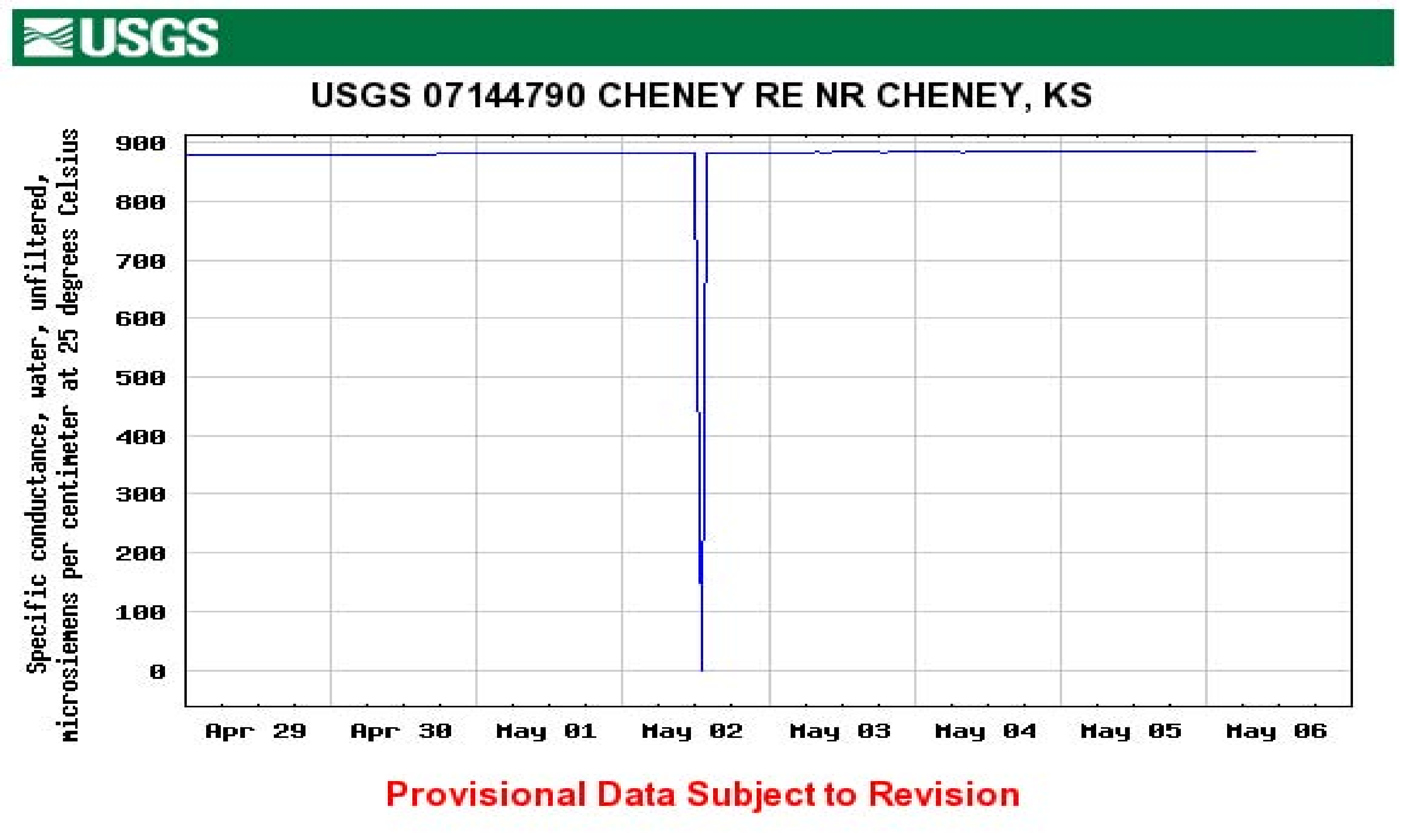
Spike in Transmitted Data



Step 1. Office Work (cont.)

1. Daily Review of Transmitted Data
2. Delete Erroneous Data
3. Set Thresholds (recommended)
4. Remove Site or Parameter from Web (last option)

USGS Program for Setting Thresholds Limits

Terminal

Window Edit Options Help

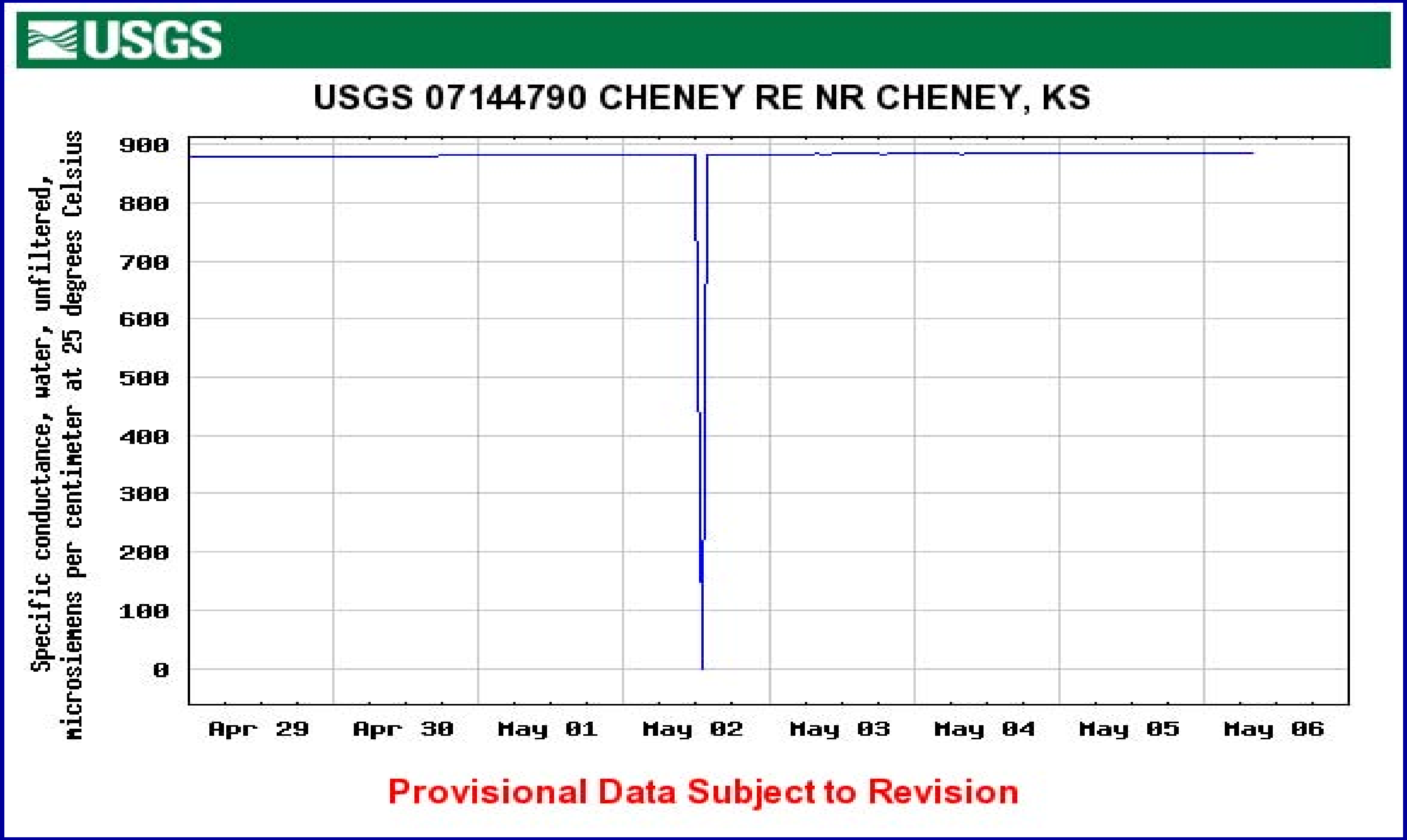
```
          PRIMARY PROCESSING DATA SCREENING AND VERIFICATION INFORMATION
                  Specific cond at 25C FROM DCP, in uS/cm @ 25C

VHI - Very High Condition (units) *            3000 LVH - Label: very high condition
HI  - High Condition (units)                  ---   LHI - Label: high condition thre
LO  - Low Condition (units)                   ---   LLO - Label: low condition thres
VLO - Very Low Condition (units) *                1 LVL - Label: very low condition
SD  - Value To Value Test Difference            300 LSD - Label: standard difference
 * identifies thresholds that are used to screen data from the public for the WEB disy


BK  - Define zone breakpoints (units)
VI  - VERY RAPID INCREASE (UNITS/MINUTE) *       ---
RI  - RAPID INCREASE (UNITS/MINUTES)             ---
RD  - RAPID DECREASE (UNITS/MINUTES)             ---
VD  - VERY RAPID DECREASE (UNITS/MINUTE) *       ---

Enter code of field to change, or [CR] to continue:
```

USGS

Thresholds are Site Specific (example)

	Max.	Min.	ROC
• Temperature	40.0	0.1	0.1
• SC	3000	0.1	15
• pH	10	0.1	0.1
• DO	30	0.1	0.1
• Turbidity	2500	0.1	15

Spike in Transmitted Data



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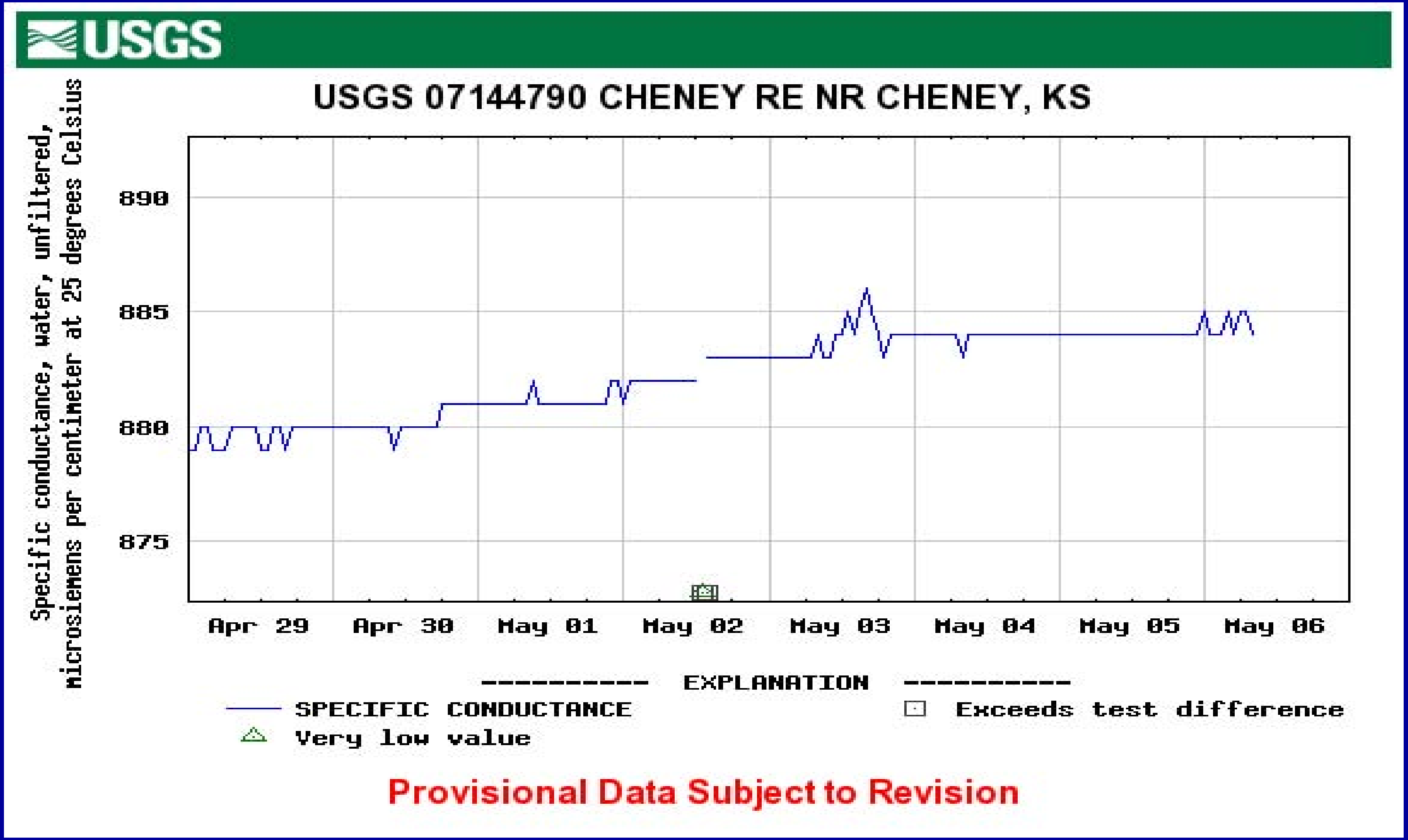
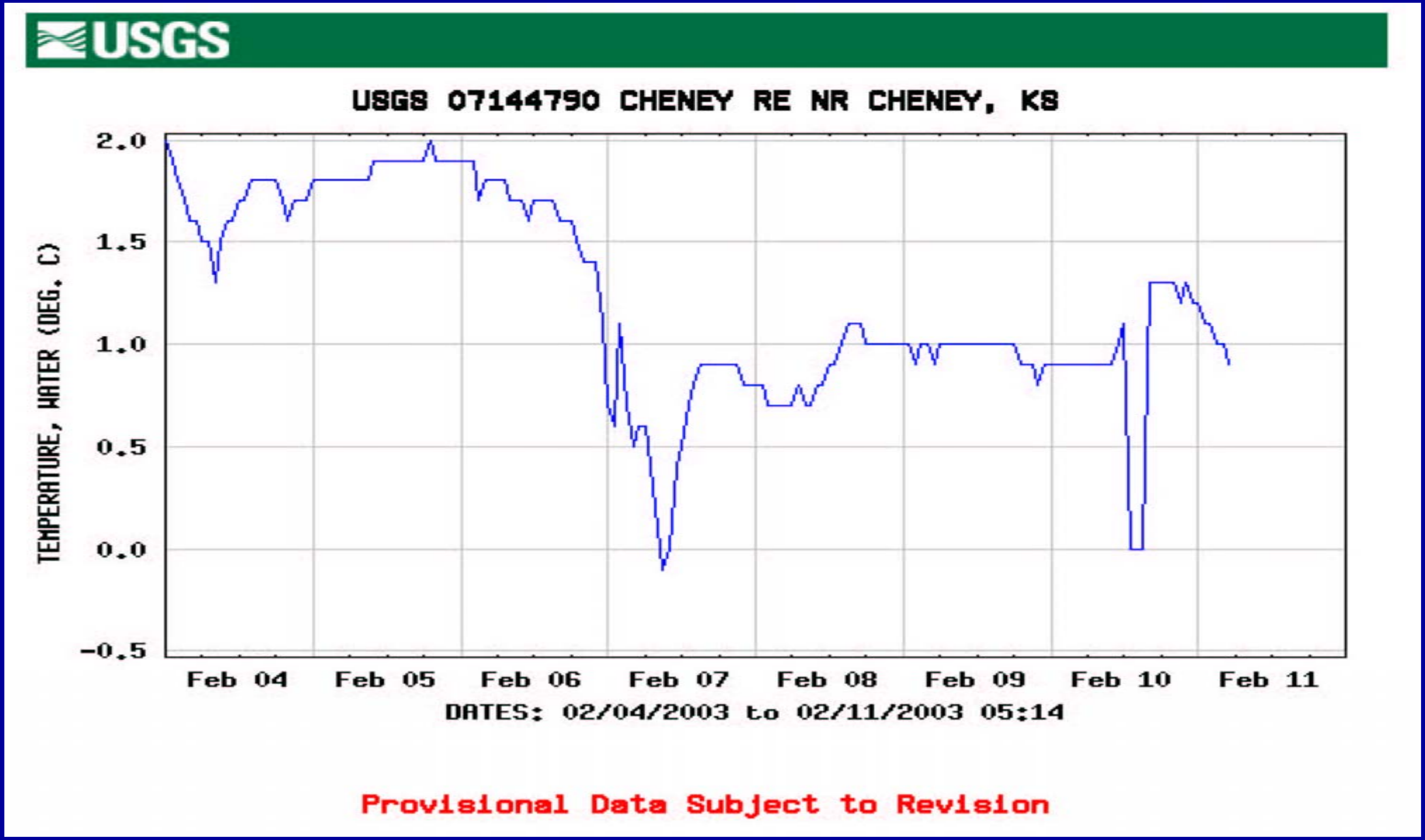
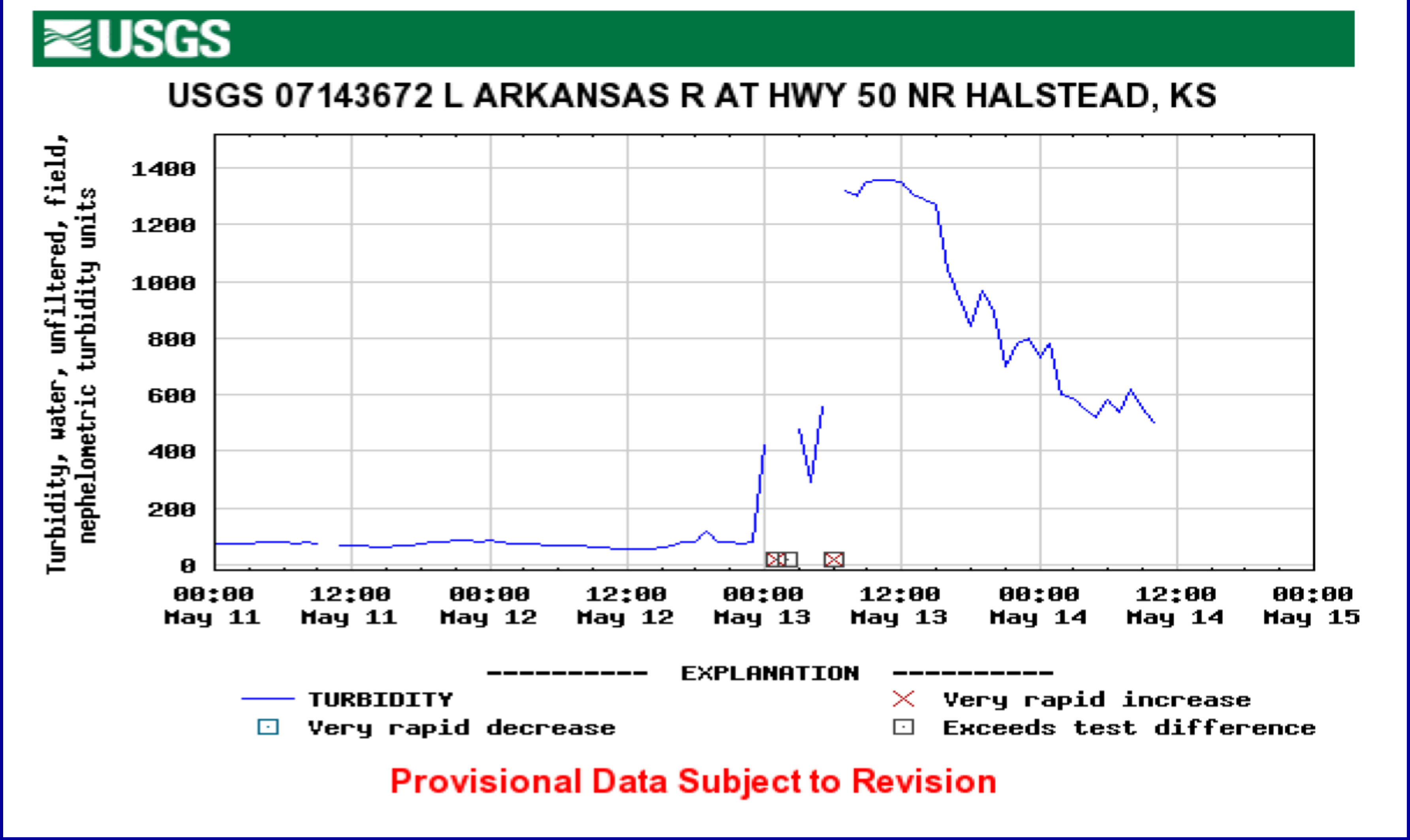
Thresholds Effect on NWIS Web



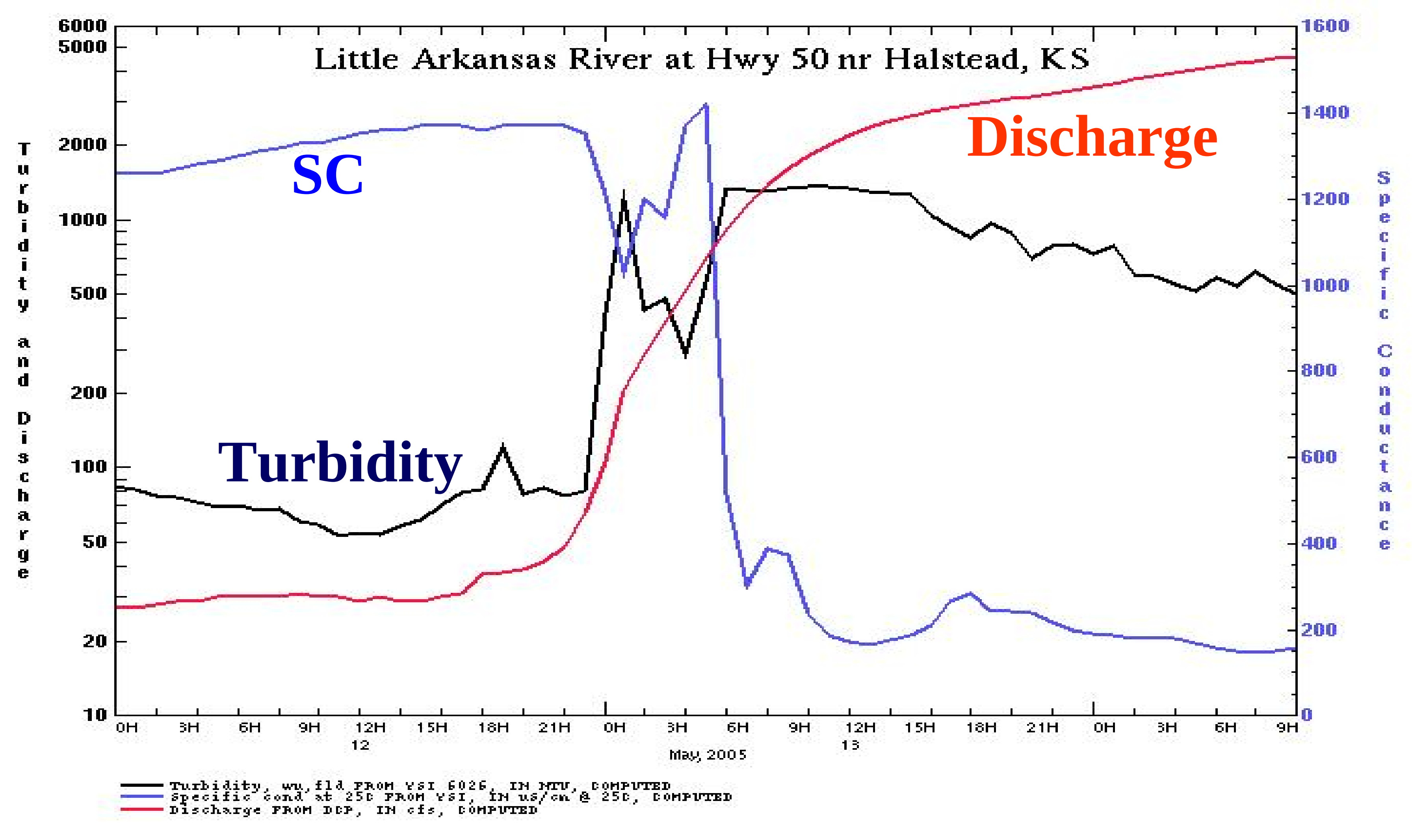
Caution in Setting Thresholds Limits



Thresholds Settings May Need to be Adjusted



Plot Data with Other Parameters



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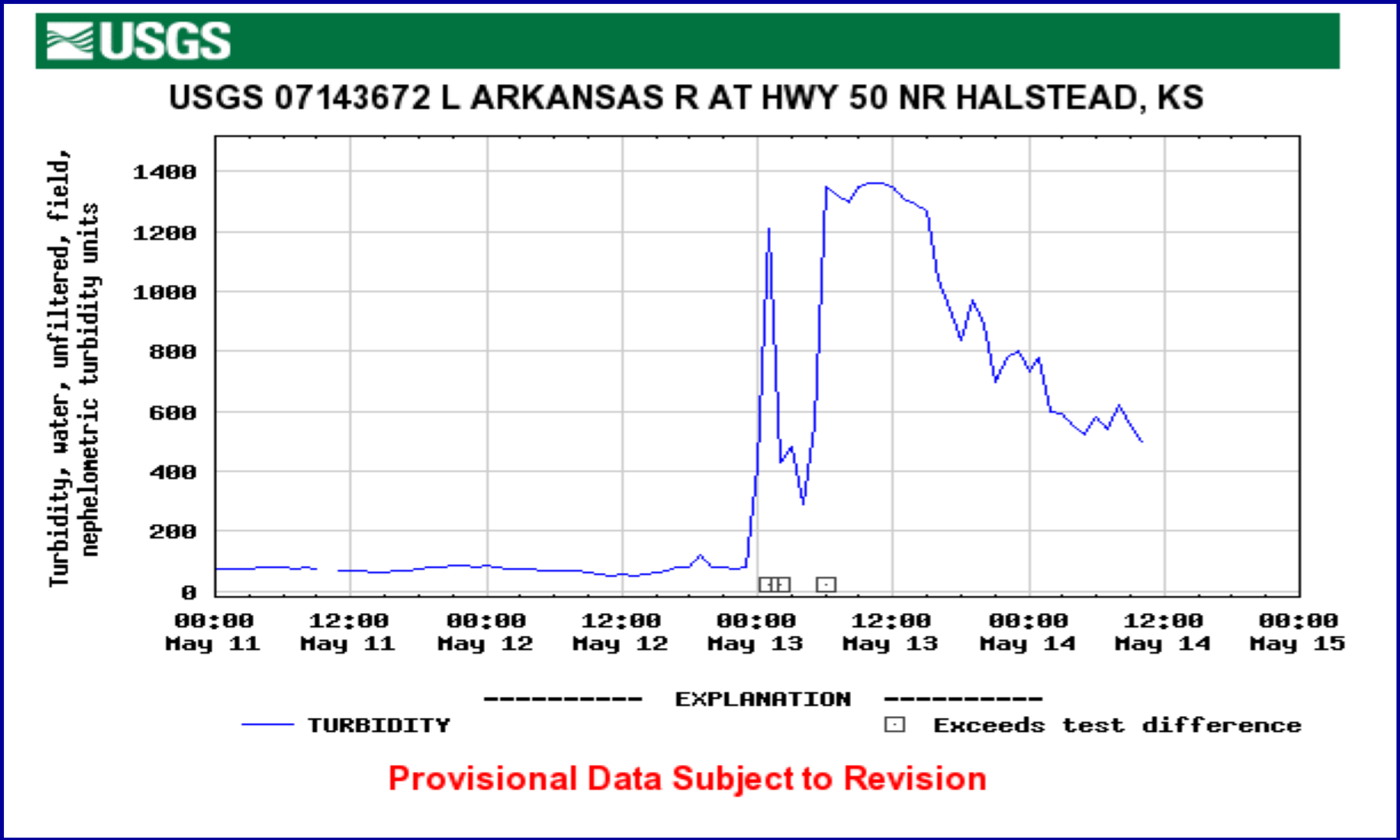
NWIS Web after Resetting Thresholds



Step 1. Office Work (cont.)

1. Daily Review
2. Delete Invalid Data
3. Set Thresholds (recommended)
4. Temporarily Remove Site or Parameter from Web until problem is fixed (last option)

USGS

Step 2. Field Work Protocols

Standard Protocols for Servicing a Monitor

1. Before cleaning readings ***
2. After cleaning readings ***
3. Calibration checks
4. Re-calibration if necessary
5. Final readings ***
6. *** Obtain side-by-side readings from field monitor ***

USGS

Step 2. Field Work Protocols

Protocols were developed to

DEFINE

and

QUANTIFY

why data changed after servicing the water-quality monitor and to understand why changes occurred

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Reasons for data to change

1. Cleaned the sensors
2. Recalibration of sensors
3. Normal environmental changes

Fouling on PVC Pipe

Fouling on Monitor

Fouling on Sensors

USGS

Calibration Checks

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USGS Calibration Criteria for Recalibrating Sensors

Sensor	Variability of Sensors
Water Temperature	+/- 0.2 ºC
Specific Conductance	greater of +/- 5 µS/cm or +/- 3%
pH	+/- 0.2 pH unit
Dissolved Oxygen	+/- 0.3 mg/L
Turbidity	greater of +/- 0.5 turbidity units or +/- 5%

Step 3. Record Working Process

1. Delete Erroneous Data
2. Evaluate and Apply
   Correction for Fouling
3. Evaluate and Apply
   Correction for Calibration Drift
4. Update Web

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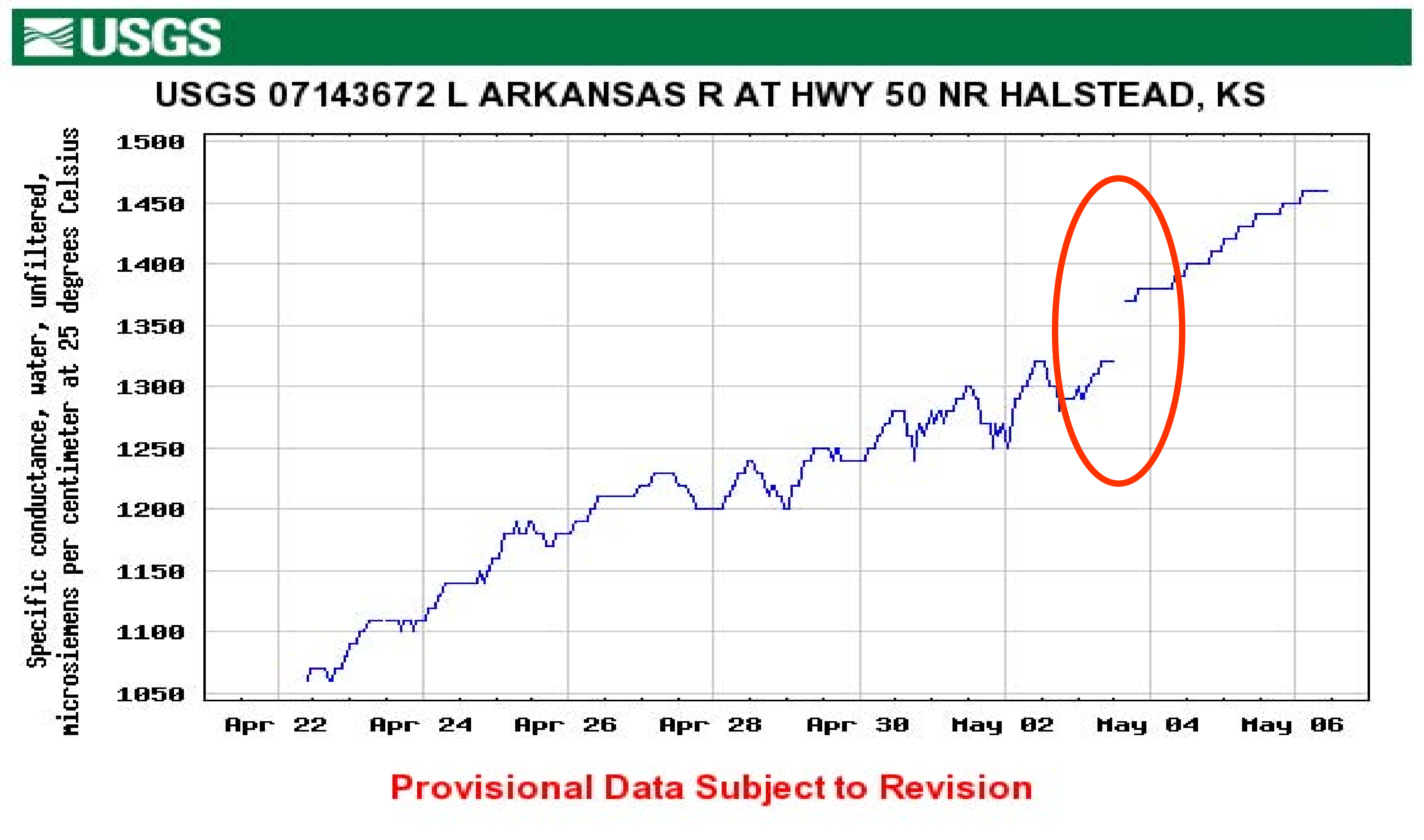
NWIS Web Before Applying any Correction



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Fouling Corrections

1. Determined by steps 1 and 2 of field work protocols.
2. After cleaning (AC) – Before cleaning (BC).
3. Subtract for environmental changes.
4. $(AC\text{-}BC)_{\text{continuous monitor}} - (AC\text{-}BC)_{\text{field monitor}}$
5. % value: $[(AC\text{-}BC)_{\text{continuous monitor}} - (AC\text{-}BC)_{\text{field monitor}}] / BC_{\text{continuous monitor}}$

USGS

Computed SC Fouling Correction using developed spreadsheets

Date	Time arrived	Time left	Fouling Correction				Computed Fouling Correction (%)	Applied Fouling Correction	
			Site Monitor Dirty	Site Monitor Clean	Field Probe Before	Field Probe After		Input	Corr.
5/3/05	1300	1515	1326	1376	1368	1368	3.77	100	4
								2000	75

$$[(1376 - 1326) - (1368 - 1368)] / 1326 = 3.77\%$$

Fouling Correction Applied in ADAPS

Terminal

Window Edit Options Help

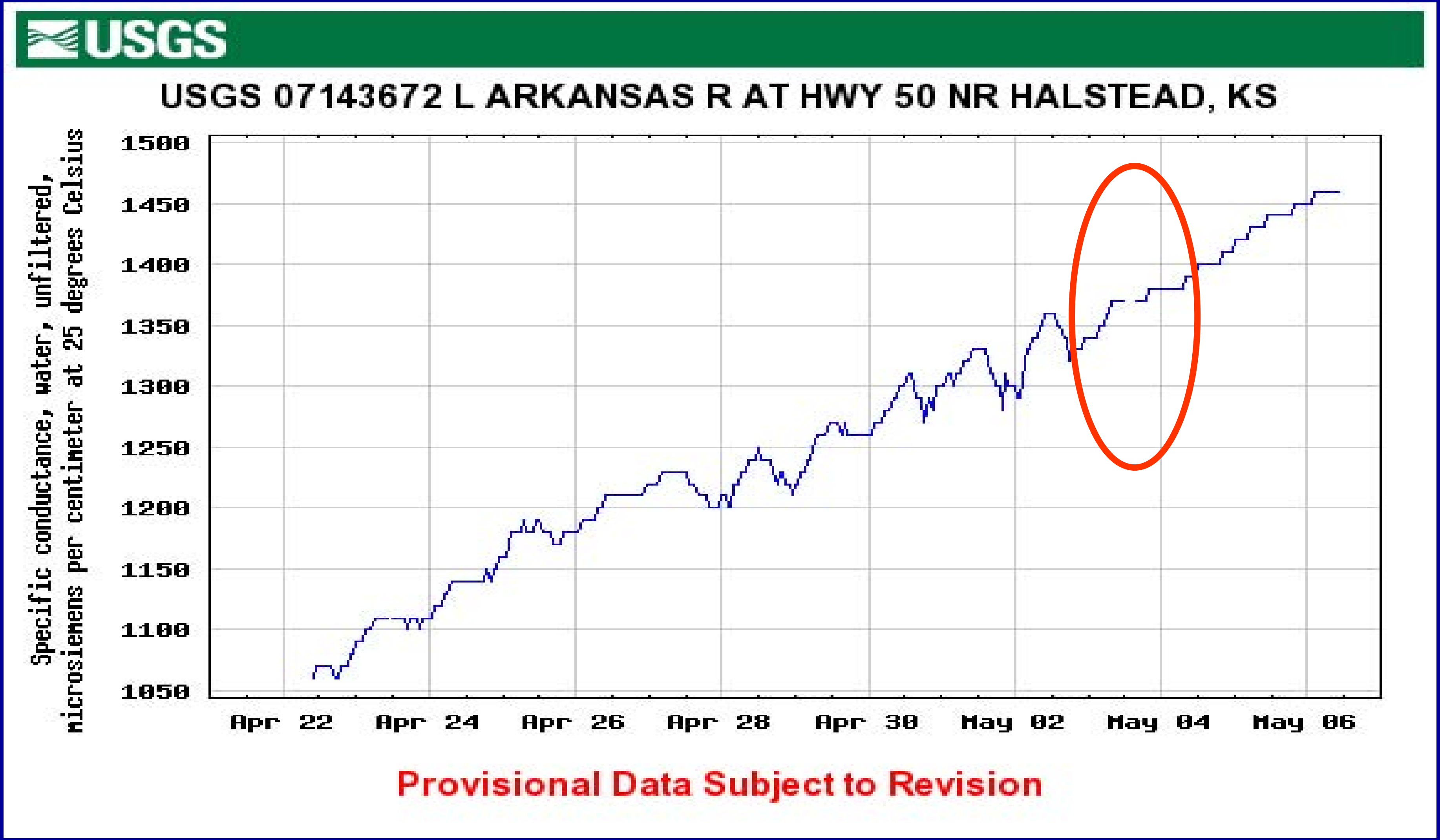
```
                                                      1
    USGS 07143672         L ARKANSAS R AT HWY 50 NR HALSTEAD, KSR YEAR:
    Specific cond at 25C FROM DCP, IN uS/cm @ 25C                       2005
             DATES VALID FROM: 10/01/2004 00:00 TO 09/30/2005 23:59
  Enter one of the commands from the menu
    START DATE TIME DATUM    INPUT     CORR     INPUT     CORR     INPUT     CORR
    END   DATE TIME DATUM   COMMENT

PRV:2004/08/06 1100 CDT          100       0.0      2000       0.0

--------------------------------------------------------------------------------
  4:2005/03/29 1040 CST          100       0.0      1000       0.0 ________ ________
        /__/__ ____ ______ ______________________________________________________
  5:2005/04/27 0900 CDT          100       0.0      2000       0.0 ________ ________
        /__/__ ____ ______ ______________________________________________________
  6:2005/05/03 1200 CDT          100         4      2000        76 ________ ________
        /__/__ ____ ______ ______________________________________________________
--------------------------------------------------------------------------------
NXT: None
 "Q"= enter menu       "E"= exit program    "A"= add to end of list
 "F"= forward 1 page   "M"= down 1 line     "D"= delete line  "C"= change line
 "B"= backward 1 page  "U"= up 1 line       "I"= insert line  "S"= save and quit
```

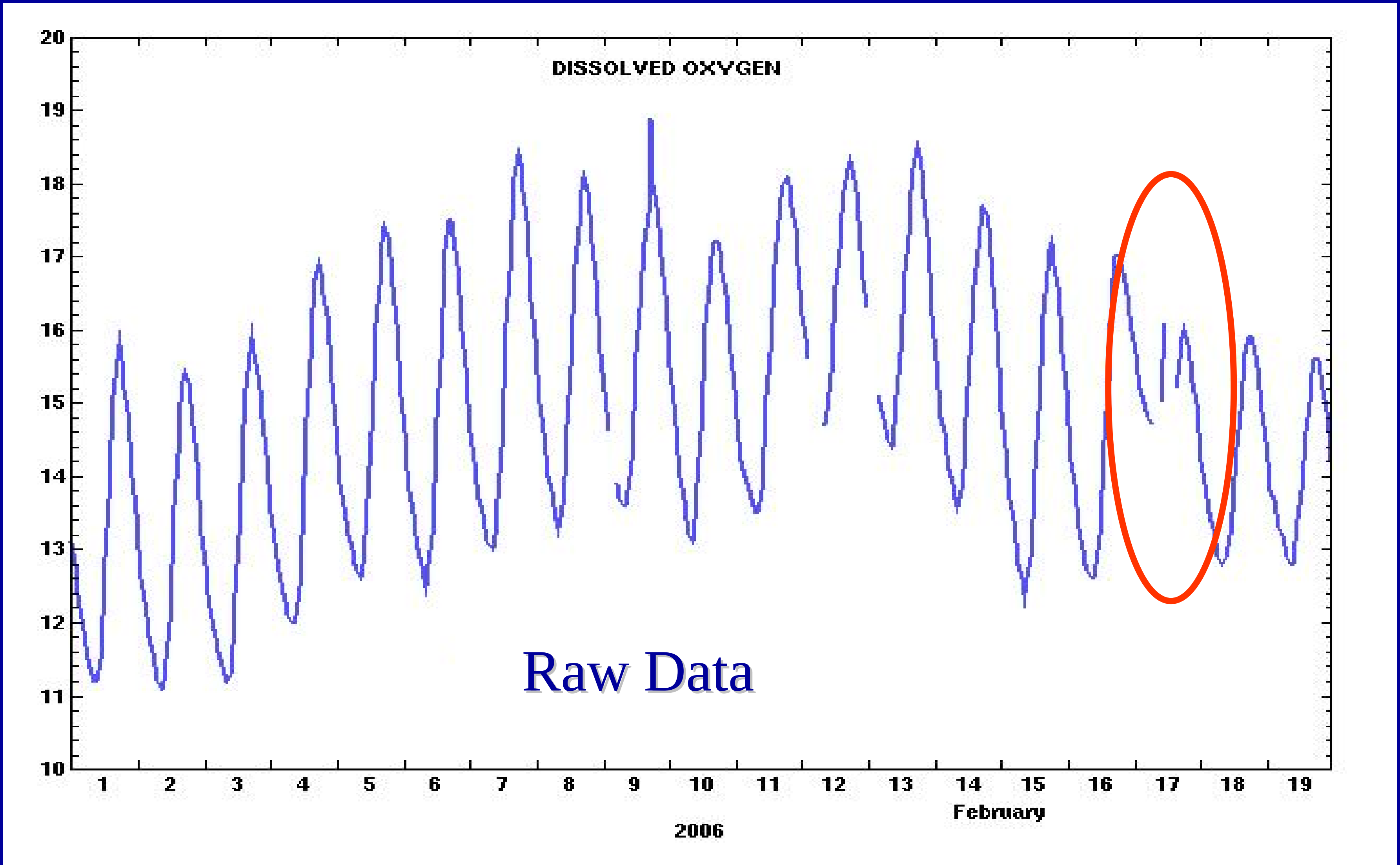
USGS

NWIS Web After Applying a +3.8% Fouling Correction



USGS

DO Data Before Applying any Correction



USGS

Calibration Drift Corrections

1. Determined by step 3 of field work protocols.
2. Standard value – Sensor reading in std.
3. % value: [(Std – Reading) / Reading].

USGS

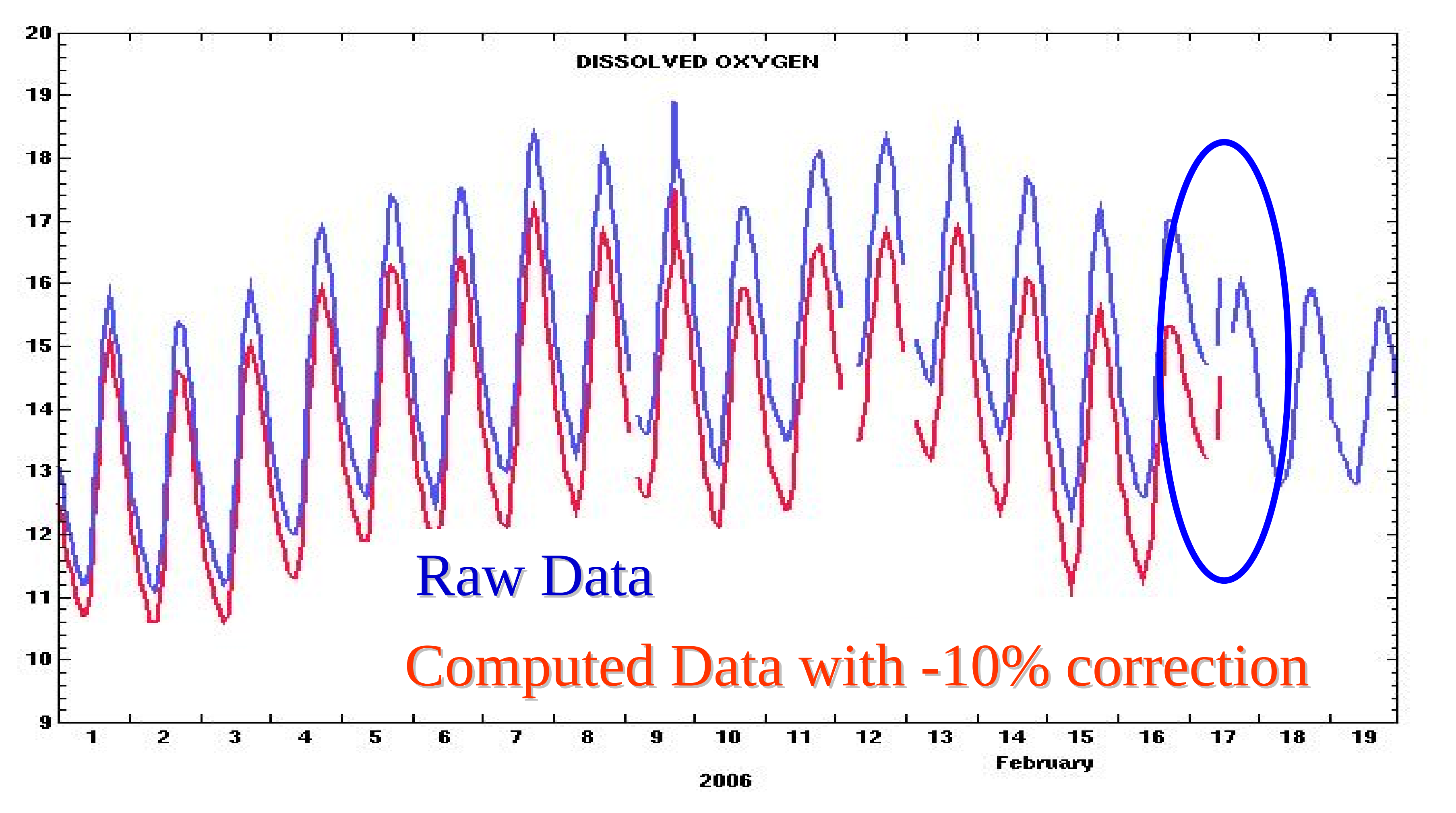
Computed DO Drift Correction using developed spreadsheets

Date	Time arrived	Time left	Calibration Check 100% Air Saturation			Computed Drift Correction			Applied Drift Correction	
			Reading	Chart DO	Adjusted	Reading	Corr.	% Drift	Input	Corr.
2/17/06	1100	1410	10.00	9.00		100%	-1.00	-10.00	2.00	-0.20
			Sensor recalibration						20.00	-2.00
				10.35	10.40					

$$[(9.00 - 10.00) / 10.00] = -10\%$$

USGS

DO Data After Applying a -10% Drift Correction



USGS

USGS Maximum Allowable Limits for Reporting Data

Parameter	Maximum Limit
Water Temperature	+/- 2.0 ºC
Specific Conductance	+/- 30% µS/cm
pH	+/- 2.0 pH unit
Dissolved Oxygen	Greater of +/- 2.0 mg/L or +/- 20%
Turbidity	Greater of 3.0 turbidity units or +/- 30%

USGS

Summary of QA/QC of Real-Time Water-Quality Monitor Records

1. Daily Review of Transmitted Data
2. Delete Erroneous Data
3. Follow Standard Protocols for Servicing the Monitor
4. Apply Corrections to Update Data
5. Update Data on Web (if transmitting)

USGS

For Additional Information

Contact:

Trudy Bennett, trudyben@usgs.gov

Phone 316-773-3225

Publications:

http://pubs.usgs.gov/tm1D3/

http://ks.water.usgs.gov

http://waterdata.usgs/ks/nwis/current

http://ks.water.usgs.gov/Kansas/rtqw

USGS

Statistical Approaches and Data Applications for Continuous Water-Quality Information

Teresa Rasmussen,

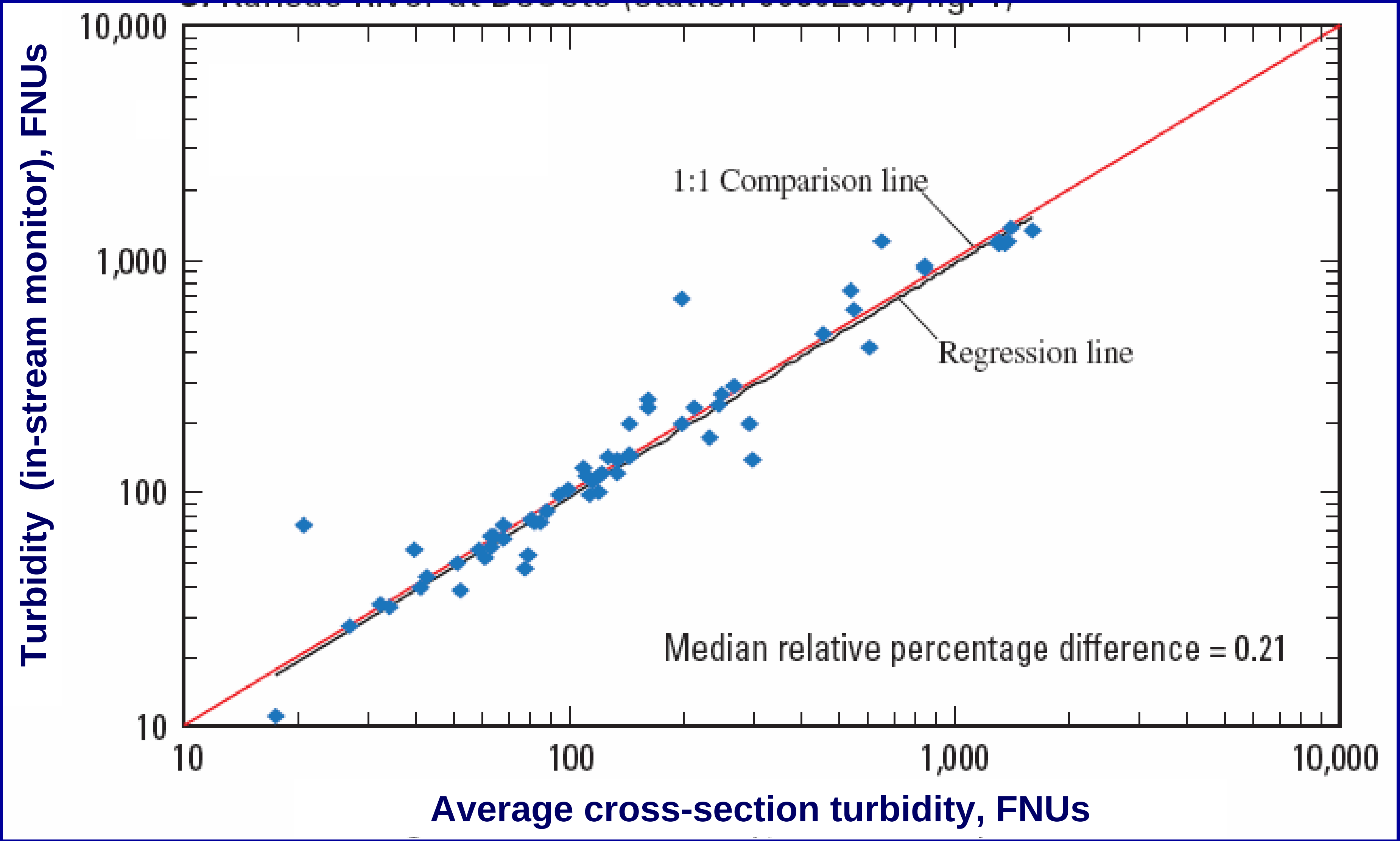
USGS Kansas Water Science Center

USGS

Approach

- **Install stream gages and water-quality monitors**
- Collect discrete samples over range of conditions
- Develop regression models using samples and sensor values
- Estimate concentrations and loads based on regression models and display data on the Web
- Continue sampling to verify relations

Is monitor location representative of stream cross-section?



Kansas River at DeSoto, 1999-2002

Approach

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USGS

Sampling methods

1. Equal Discharge Increment (EDI)

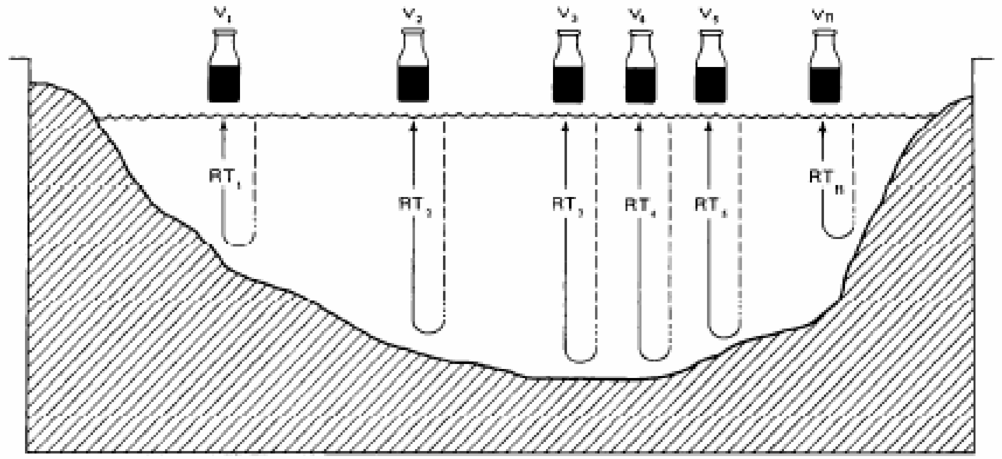


Figure 35. Vertical transit rate relative to sample volume collected at each equal-discharge-increment centroid.

2. Equal Width Increment (EWI)

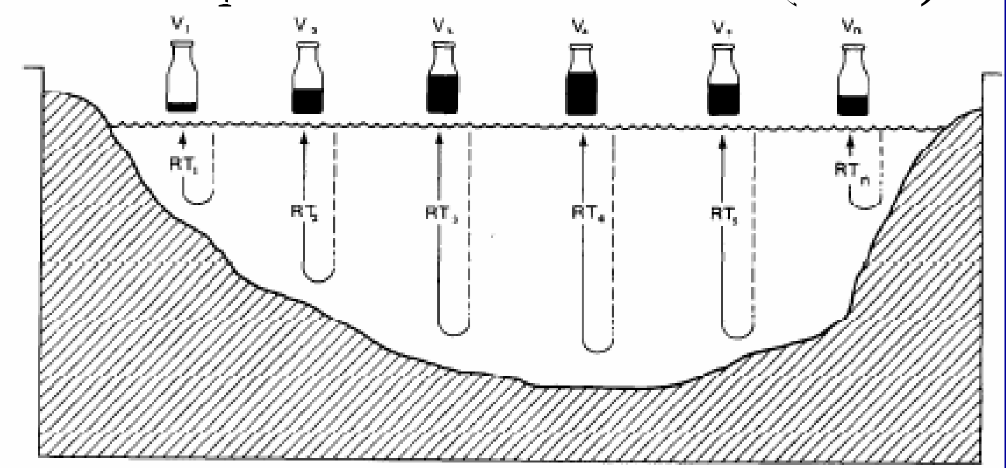


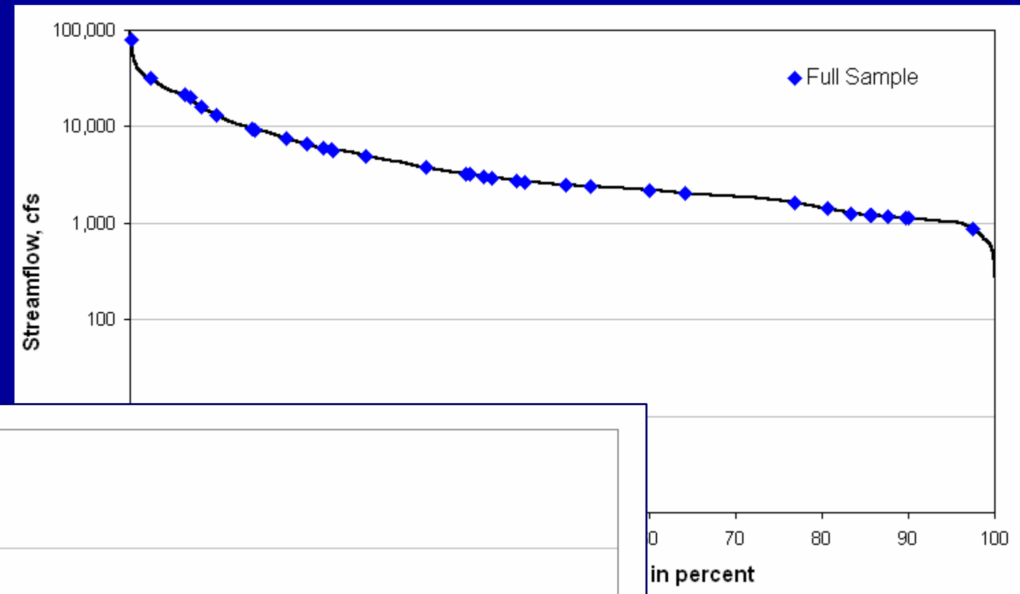
Figure 37. Equal-width-increment vertical transit rate relative to sample volume, which is proportional to water discharge at each vertical.

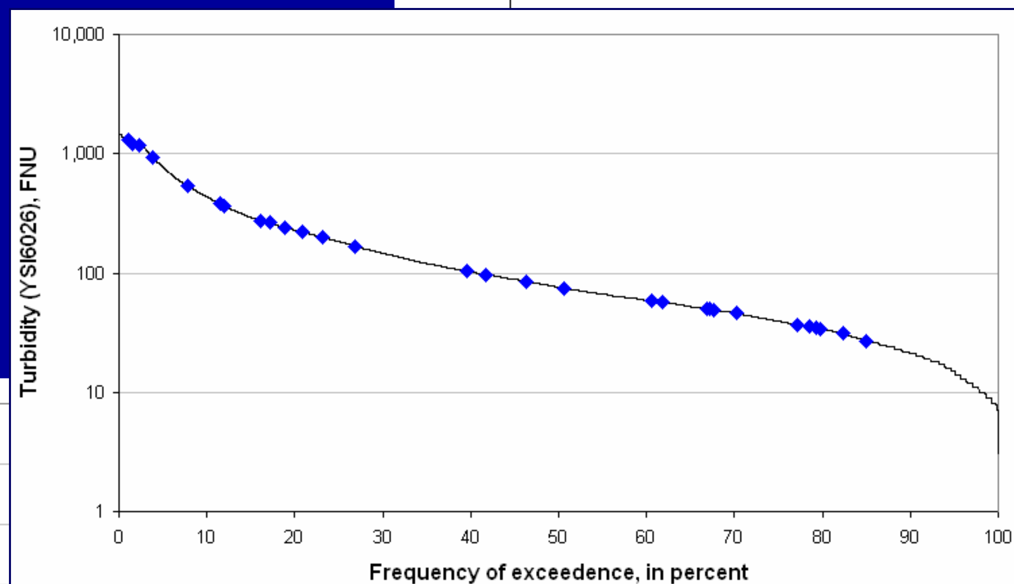
3. Autosampler

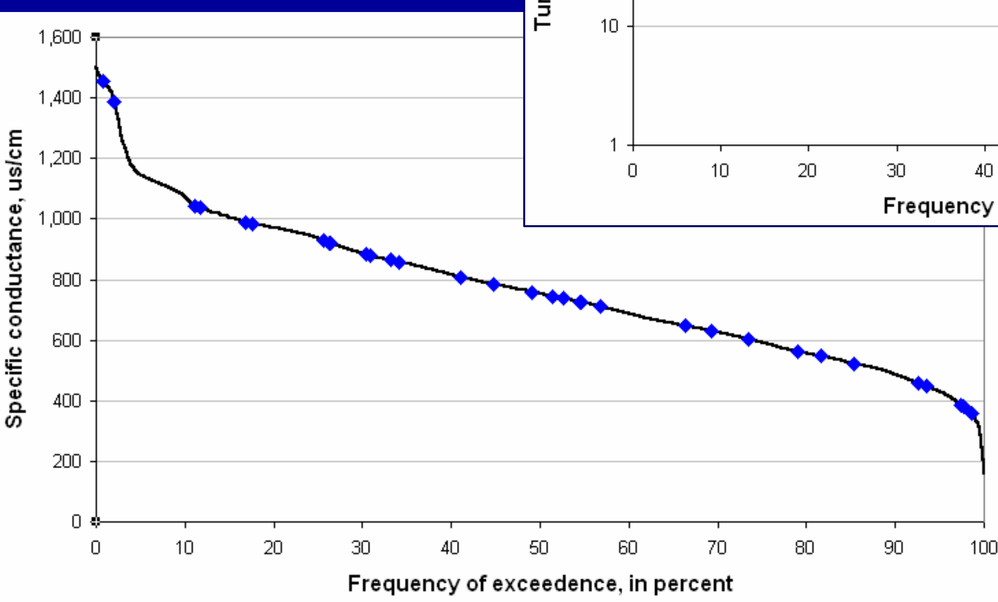
USGS

Edwards and Glysson, 1998

Collect samples over the range of conditions

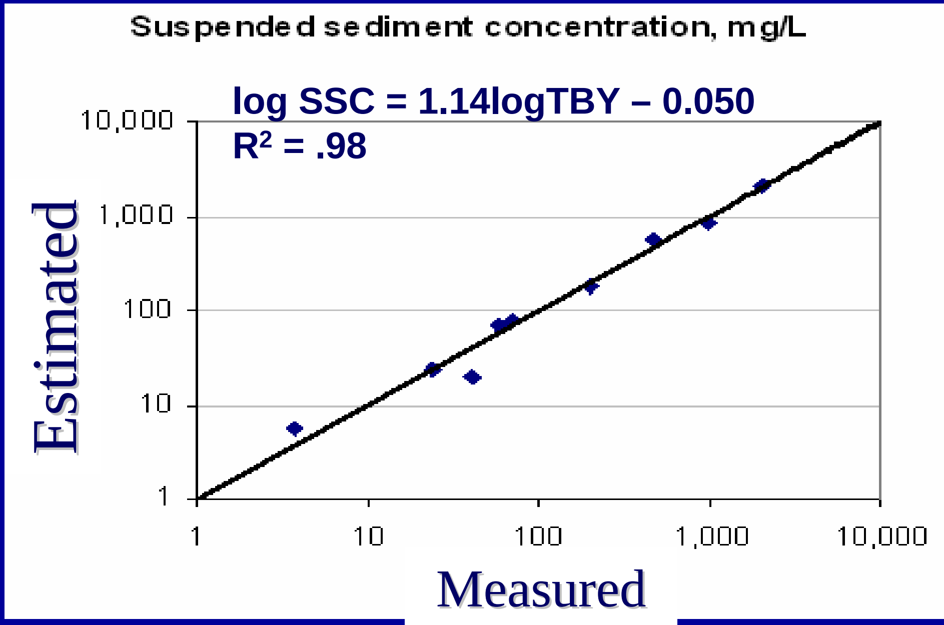


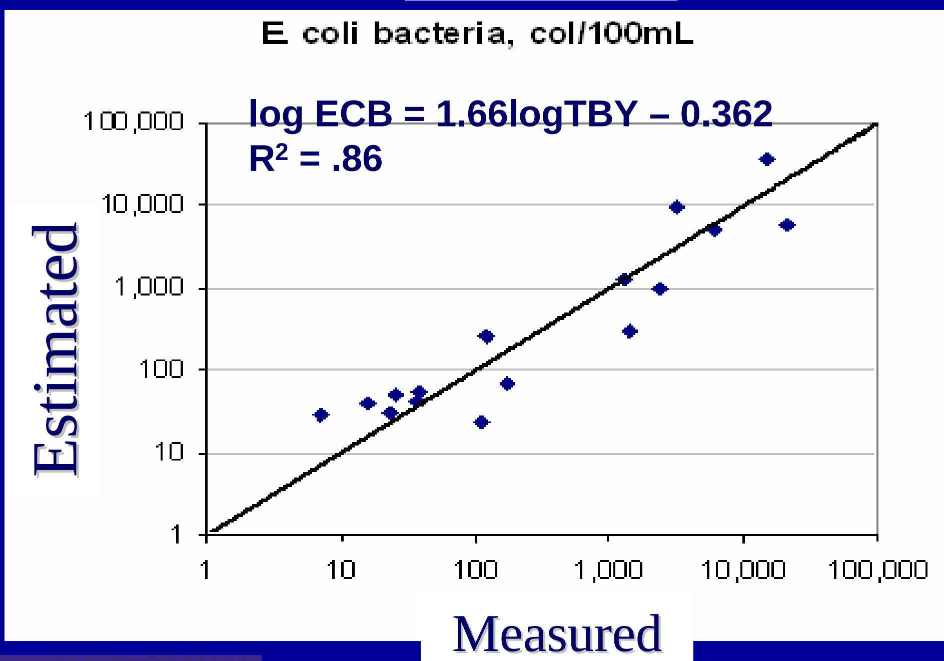




Duration curves for streamflow, turbidity, and specific conductance

Kansas River at DeSoto, 1999-2003



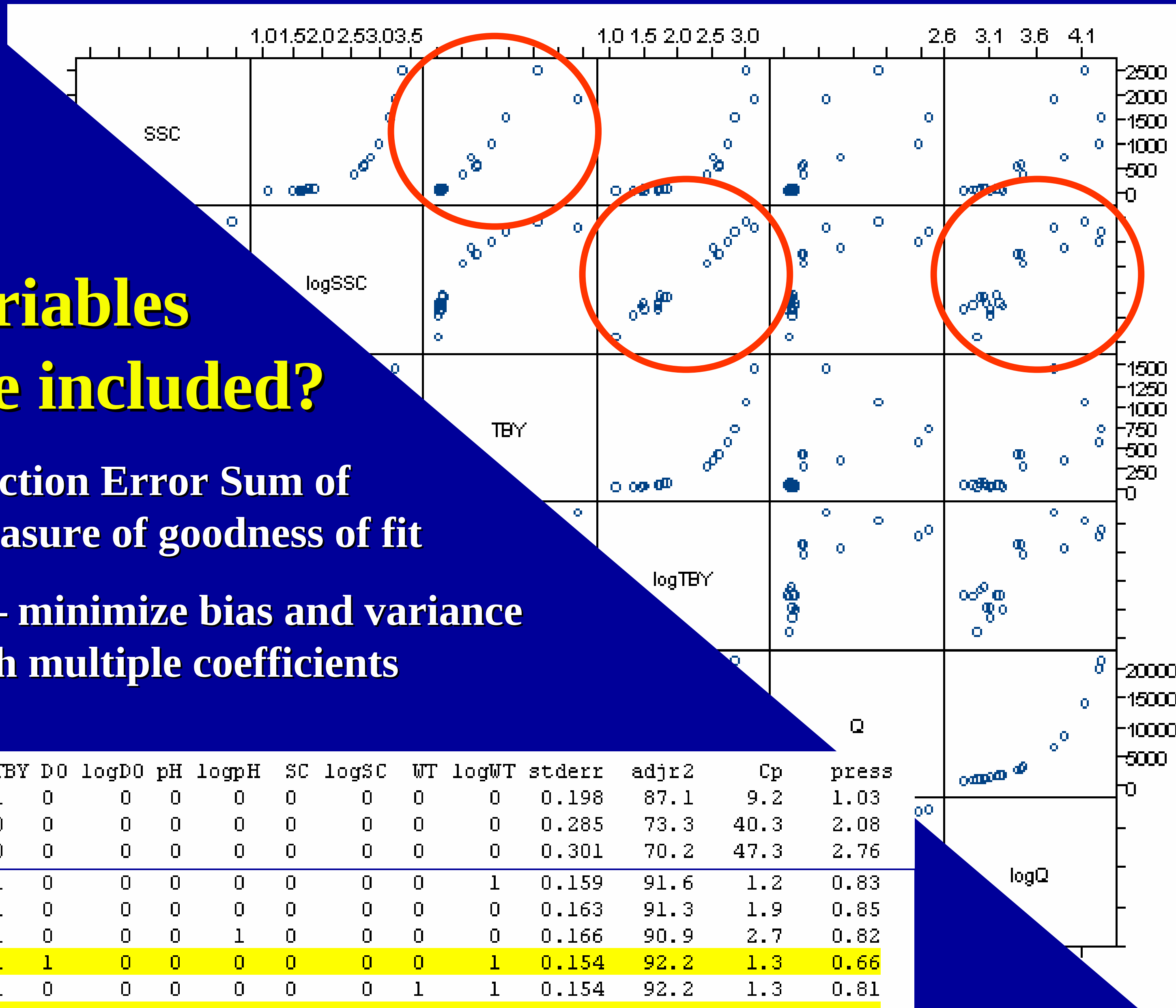


Approach

- Install stream gages and water-quality monitors
- Collect discrete samples over range of conditions
- **Develop regression models using samples and sensor values**
- Estimate concentrations and loads based on regression models and display data on the Web
- Continue sampling to verify relations

USGS

Plot the data



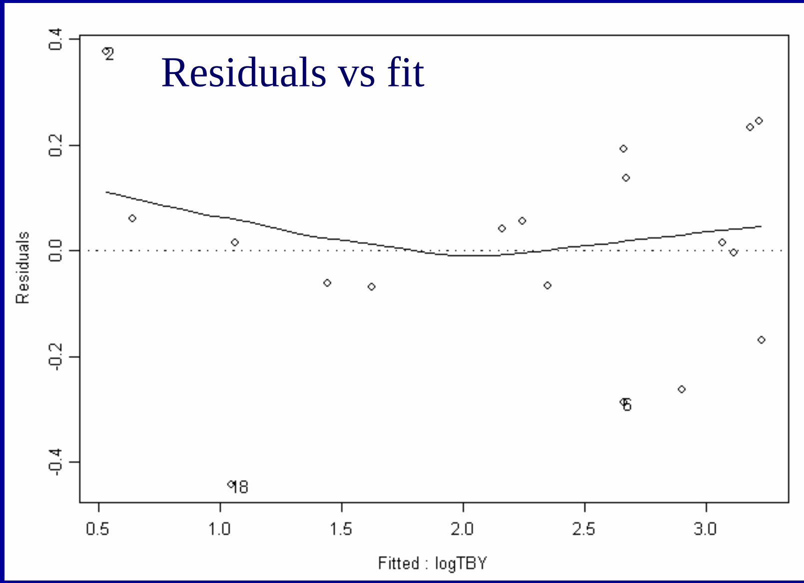
What variables should be included?

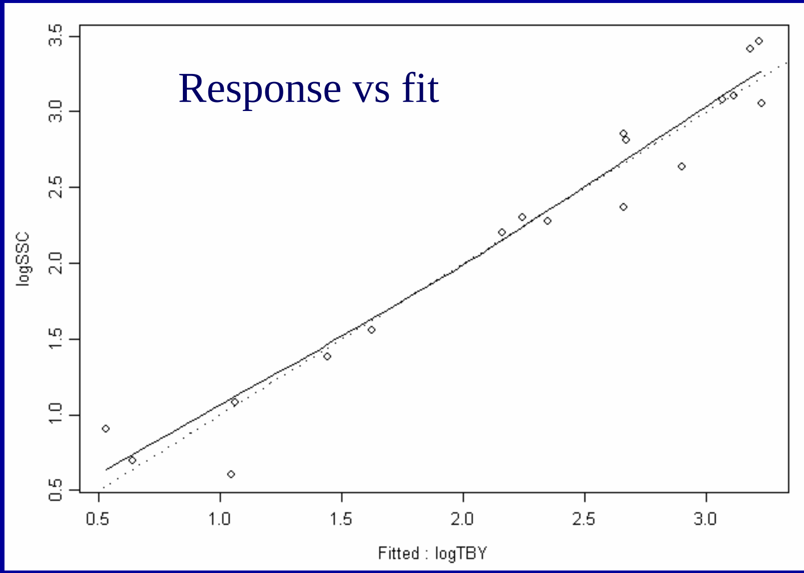
PRESS (Prediction Error Sum of Squares) – measure of goodness of fit

Mallow's Cp – minimize bias and variance associated with multiple coefficients

	Q	logQ	TBY	logTBY	DO	logDO	pH	logpH	SC	logSC	WT	logWT	stderr	adjr2	Cp	press
1(#1)	0	0	0	1	0	0	0	0	0	0	0	0	0.198	87.1	9.2	1.03
1(#2)	0	1	0	0	0	0	0	0	0	0	0	0	0.285	73.3	40.3	2.08
1(#3)	0	0	1	0	0	0	0	0	0	0	0	0	0.301	70.2	47.3	2.76
3(#2)	1	0	0	1	0	0	0	0	0	0	0	1	0.159	91.6	1.2	0.83
3(#3)	0	1	1	1	0	0	0	0	0	0	0	0	0.163	91.3	1.9	0.85
3(#4)	0	1	0	1	0	0	0	1	0	0	0	0	0.166	90.9	2.7	0.82
4(#1)	0	1	0	1	1	0	0	0	0	0	0	1	0.154	92.2	1.3	0.66
4(#2)	0	1	0	1	0	0	0	0	0	0	1	1	0.154	92.2	1.3	0.81
4(#3)	0	1	0	1	0	1	0	0	0	0	0	1	0.155	92.1	1.3	0.67
4(#4)	0	1	1	1	0	0	0	0	0	0	0	1	0.156	92.0	1.7	0.79

Evaluate models






```
     *** Linear Model ***

Call: lm(formula = logSSC ~ logTBY, data = sampledata,
na.action = na.exclude)
Residuals:
     Min       1Q  Median     3Q    Max
 -0.4429 -0.06827 0.01556 0.1178 0.3754

Coefficients:
              Value Std. Error t value Pr(>|t|)
(Intercept)  0.2311  0.1200     1.9258  0.0721
     logTBY  0.9852  0.0544    18.1083  0.0000

Residual standard error: 0.2105 on 16 degrees of
freedom
Multiple R-Squared: 0.9535
F-statistic: 327.9 on 1 and 16 degrees of freedom, the
p-value is 4.402e-012

Correlation of Coefficients:
       (Intercept)
logTBY -0.9105

Analysis of Variance Table

Response: logSSC

Terms added sequentially (first to last)
          Df Sum of Sq  Mean Sq  F Value         Pr(F)
   logTBY  1  14.53088 14.53088 327.9095 4.402256e-012
Residuals 16   0.70902  0.04431
```

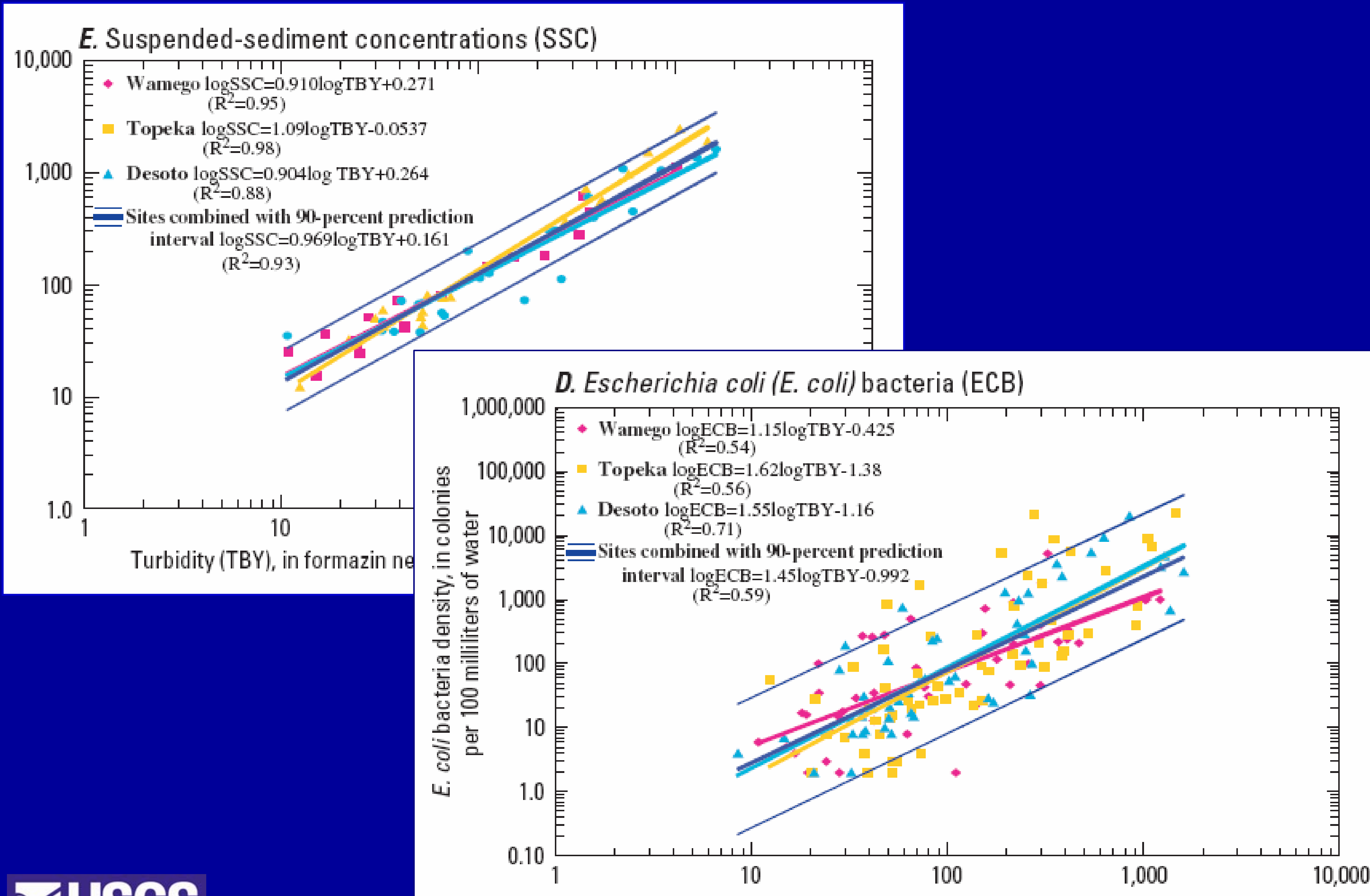
Select the 'best' model

USGS

Other factors to consider in model development

- Should data be transformed? If so, apply a bias correction factor?
- Outliers – how to define and what to do with them?
- Estimate missing data?
- Site specific models or combine sites?
- How many samples are needed? Over what period of time are they collected?
- Changes in sensor technology

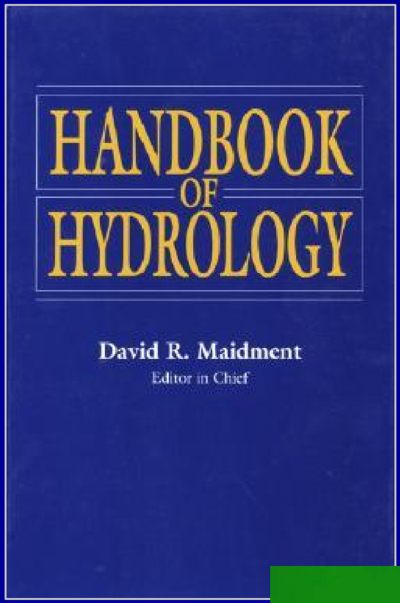
Re-evaluate the final models



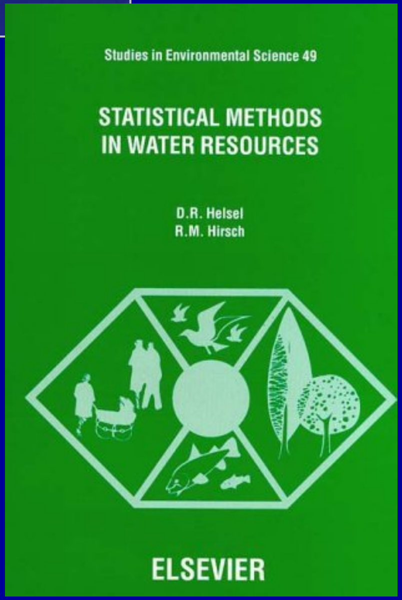
Rasmussen, Ziegler, and Rasmussen 2005

Procedures for developing a regression model

- Plot the data
- Determine which variables to include
- Should the variables be transformed?
- Graphically evaluate homoscedasticity, normality of residuals, and curvature in residuals vs. predicted.
- Select the simplest model that best maximizes R^2 and minimizes PRESS
- Evaluate the model in terms of physical basis, statistics, prediction intervals, probability distributions



Hirsch, Helsel, Cohn, and Gilroy, 1993, Chapter 17



Helsel and Hirsch, 1992

USGS

http://pubs.usgs.gov/twri/twri4a3/

Directly Measured	Estimated
Gage Height/Stage	Streamflow (discharge)
Specific Conductance	Chloride, alkalinity, fluoride, dissolved solids, sodium, sulfate, nitrate, atrazine
Turbidity	Total suspended solids, suspended sediment, fecal coliform, E. coli, total nitrogen, total phosphorus, geosmin

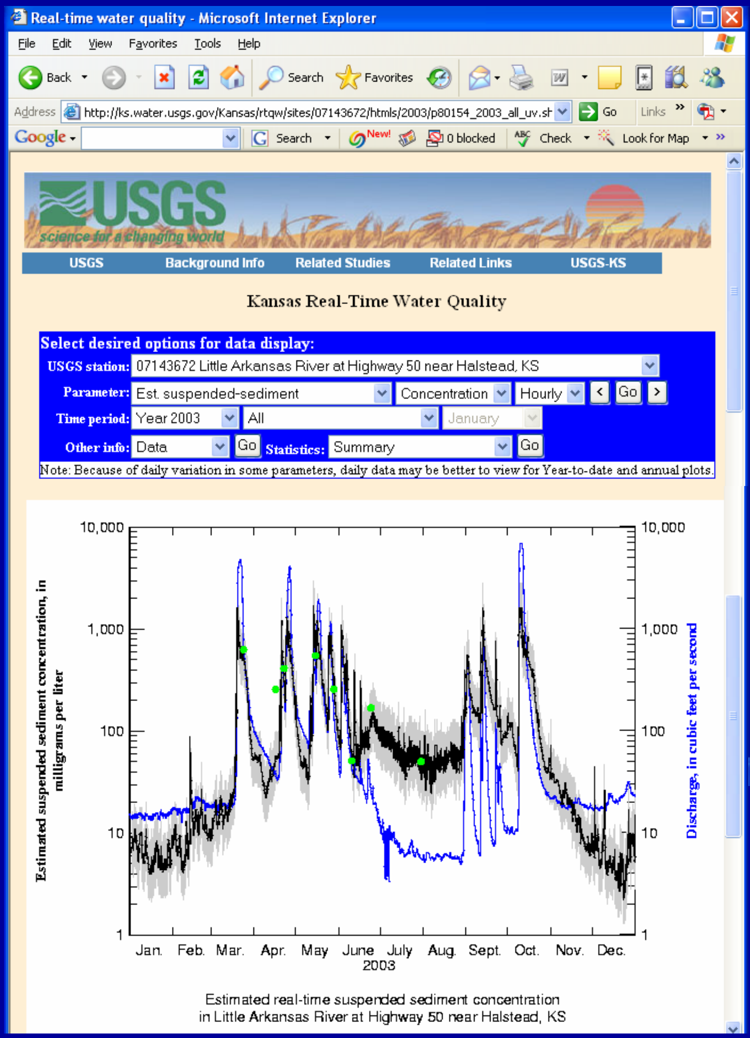
USGS

Nutrients and bacteria are physically (and statistically) related to sediment

Constituent	Model	R^2	MSE
Total nitrogen	$\log_{10} TN = 0.469 \log_{10} SSC - 0.743$	**0.796**	**0.0226**
Total organic nitrogen	$TON = 0.00188\, SSC + 1.05$	**0.817**	**0.3300**
Total phosphorus	$TP = 0.000673 SSC + 0.404$	**0.928**	**0.0148**
Fecal coliform	$\log_{10} FCB = 1.36 \log_{10} SSC - 0.228$	**0.753**	**0.235**
Escherichia coli	$\log_{10} EC = 1.15 \log_{10} SSC + 0.207$	**0.701**	**0.190**

USGS

Approach



- Install stream gages and water-quality monitors
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- **Estimate concentrations and loads based on regression models and display data on the Web**
- Continue sampling to verify relations

Display data on the Web

USGS
science for a changing world

USGS | Background Info | Related Studies | Related Links | USGS-KS

Kansas Real-Time Water Quality

Select desired options for data display:

USGS station: 07143672 Little Arkansas River at Highway 50 near Halstead, KS

Parameter: Est. dissolved chloride | Concentration | Hourly

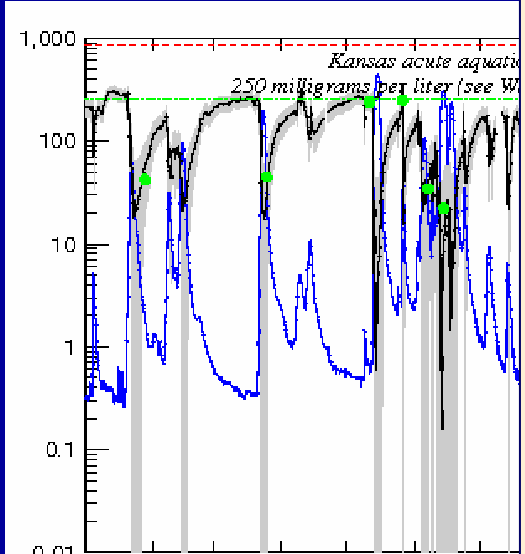
Time period: Year 2005 | All | January

Other info: Data | Go | Summary | Go

Note: Because of daily varia

Summary Statistics of dissolved chloride in Little Arkansas River at Highway 50 near Halstead, KS (January 1, 2005 - December 31, 2005)

Statistics	Cl mg/L	Cl (lower) mg/L	Cl (upper) mg/L	Cl (load) tons/day	Cl (lower load) tons/day	Cl (upper load) tons/day
No. of values	8642	8642	8642	8642	8642	8642
Mean	137.1	99.69	176.4	21.85	10.71	42.39
			69.13	33.39	19.9	84.54
			39.5	0	0	2.39
			43	2.339	0	3.54
			62.4	2.94	0	4.23
			79.7	3.61	0.3541	4.91
			132	4.54	2.48	5.9
			169	11.5	5.74	14.4
			219	24	13	34.8
						98.16
						199.4
						494
						711



Summary of Regression Analysis for Dissolved chloride at Little Arkansas River at Highway 50 near Halstead, KS

Cl = -33.7 + 0.209 SC

where:

Cl -- Dissolved chloride in milligrams per liter .

SC -- Specific conductance in microsiemens per centimeter at 25 degrees Celsius.

Basic information:

No. of measurements: 156
Mean squared error (MSE): 557.90
Multiple R-squared: 0.9572

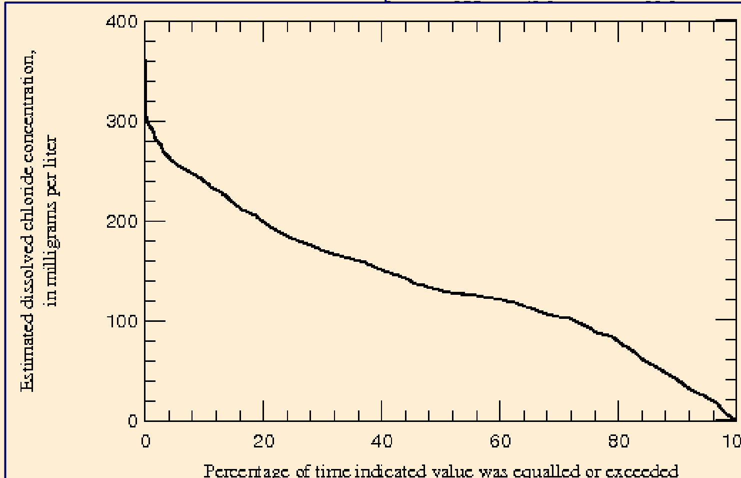
Coefficients:

	Value	Std. Error
(Intercept)	-33.7	3.8775
SC	0.209	0.0036

Correlation matrix of coefficients:

	(Intercept)	SC
(Intercept)	1	
SC	-0.873	1

Smearing factor = 1

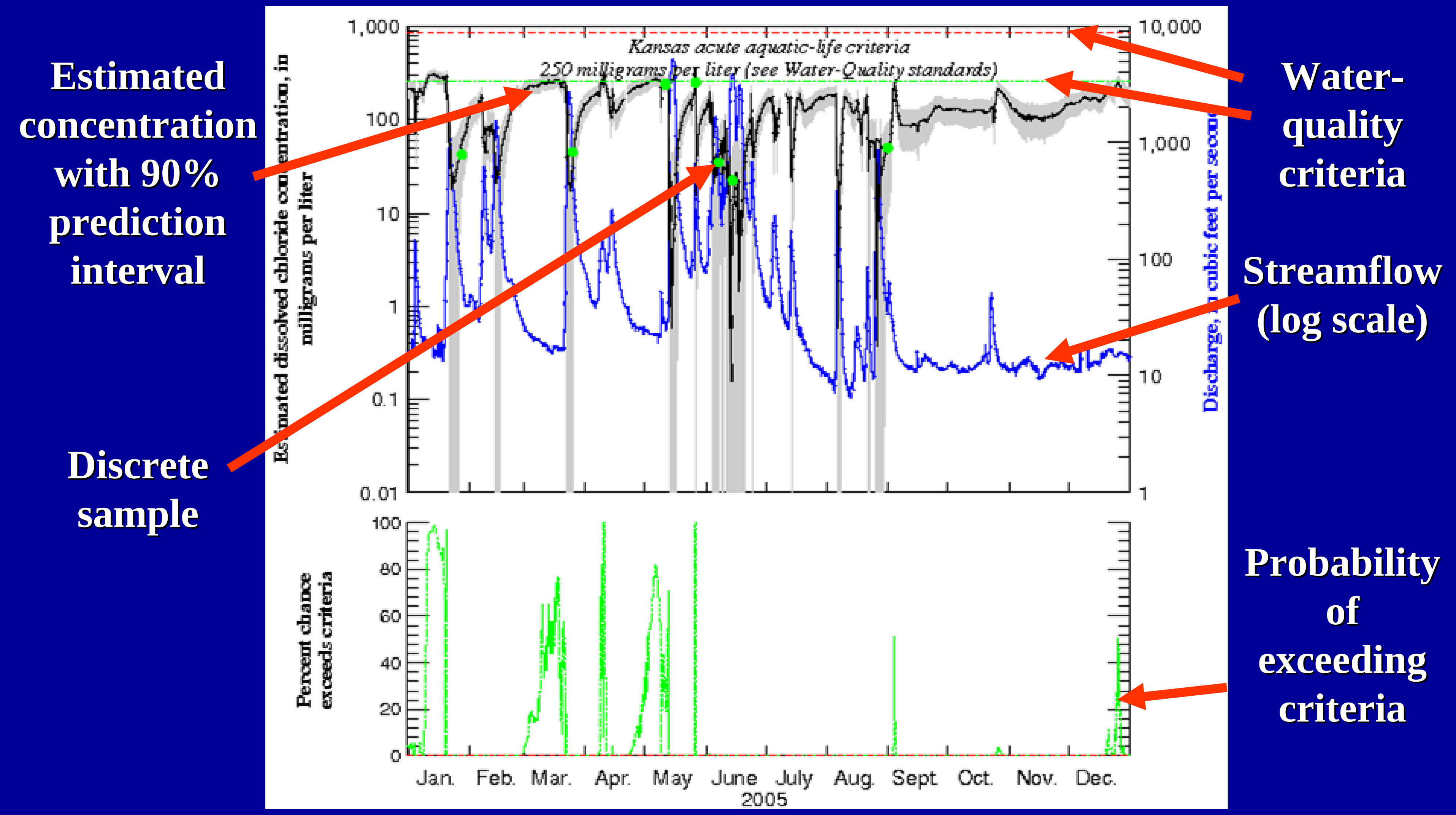


Duration curve of dissolved chloride at 07143672 Little Arkansas River at Highway 50 near Halstead, KS January 1, 2005 - December 31, 2005

USGS

http:// ks.water.usgs.gov/Kansas/rtqw/

Estimated chloride concentration, 2004, Little Arkansas River near Halstead, Kansas



USGS

http:// ks.water.usgs.gov/Kansas/rtqw/

Approach

- Install stream gages and water-quality monitors
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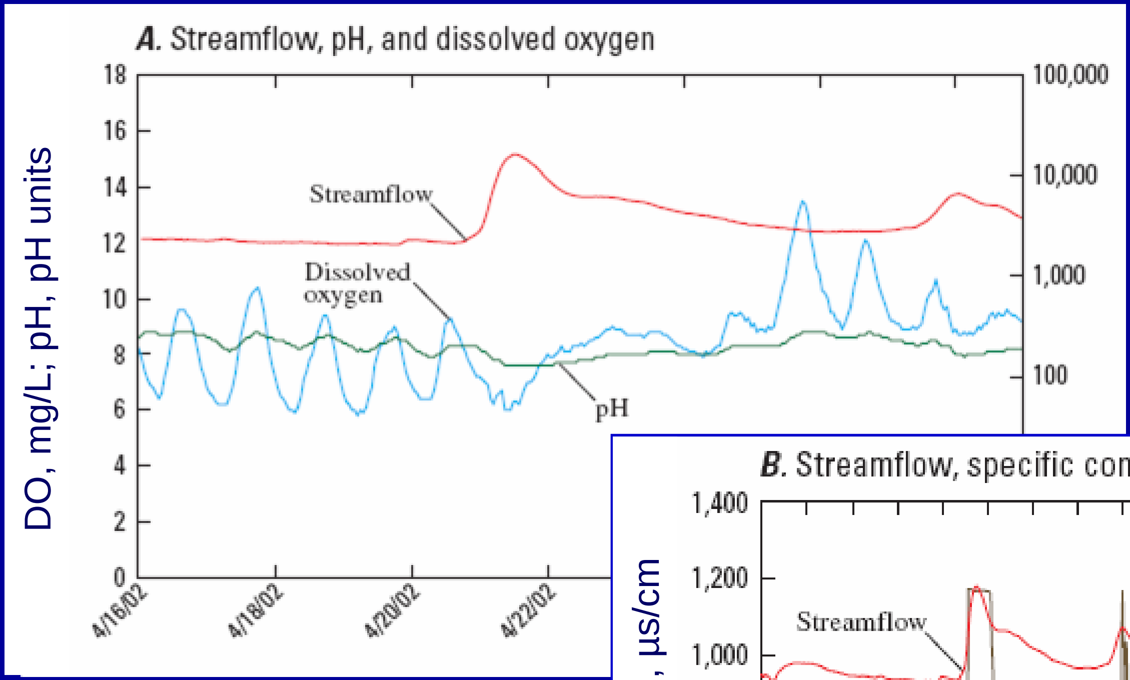
- **Continue sampling to verify relations**

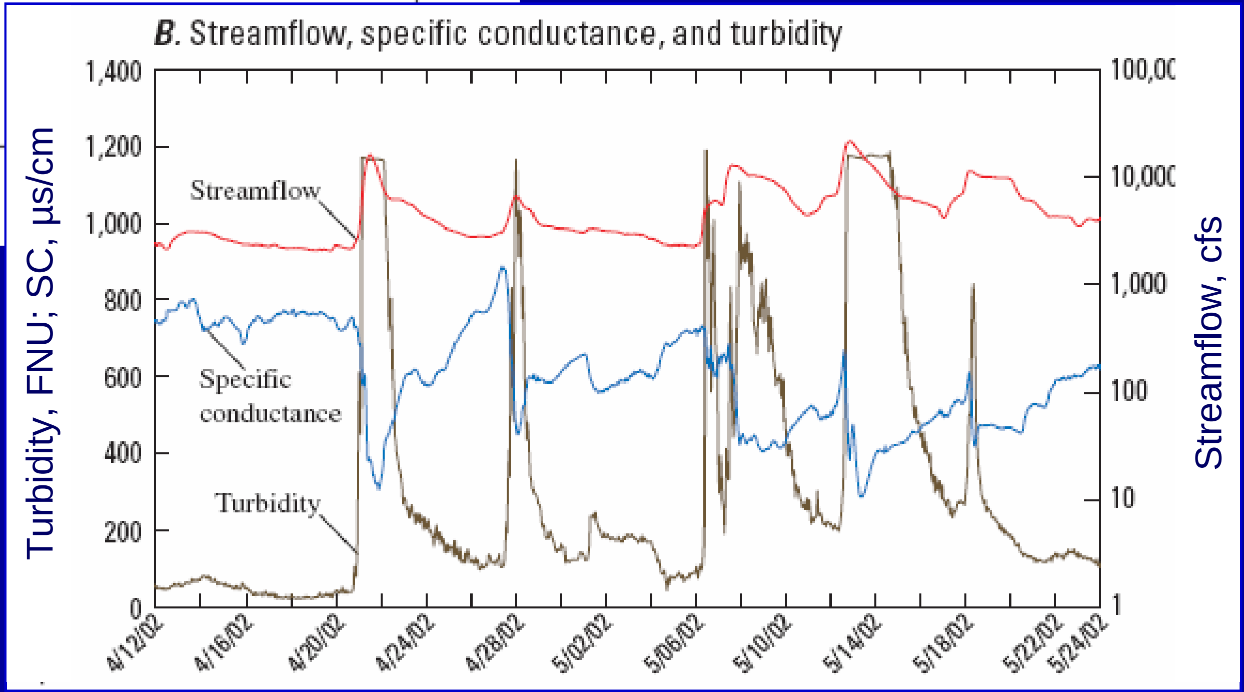
Applications and examples

- Time series data
- Scatter plots
- Duration curves
- Comparisons
- WQ criteria
- TMDLs

USGS

Water-quality varies hourly, daily, monthly, seasonally, and annually

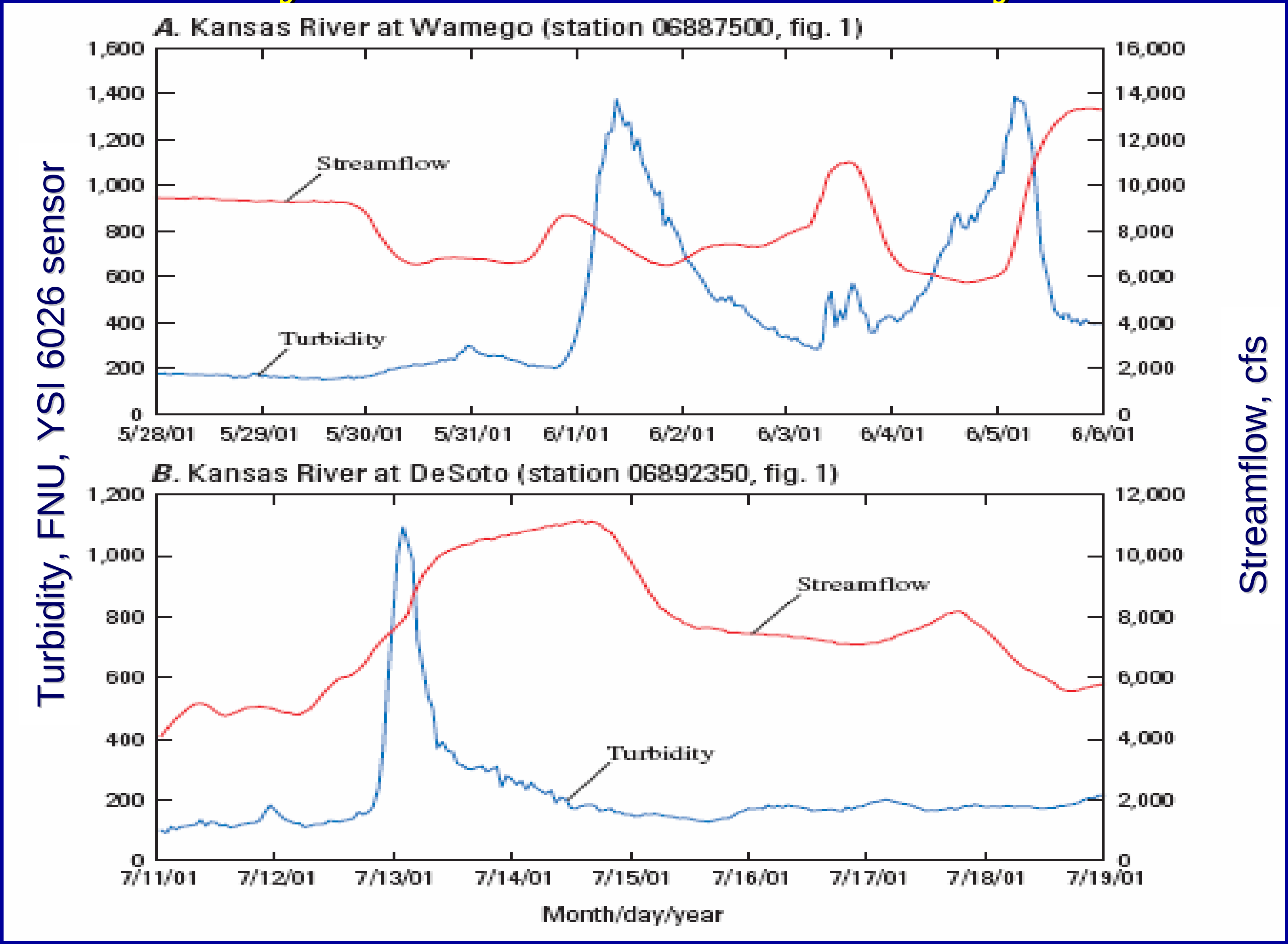




Rasmussen, Ziegler, and Rasmussen 2005

USGS

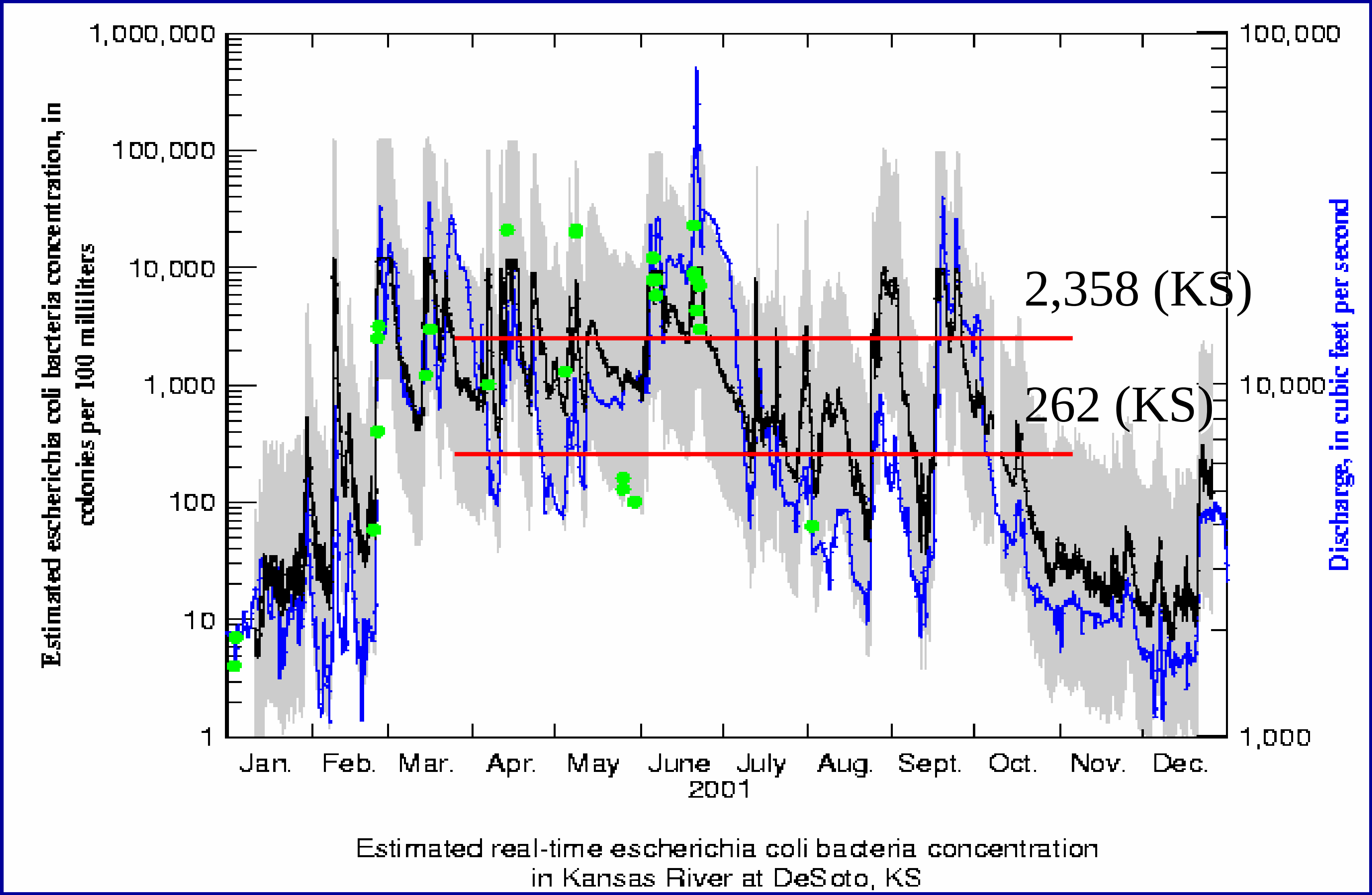
Turbidity and streamflow not directly related



USGS

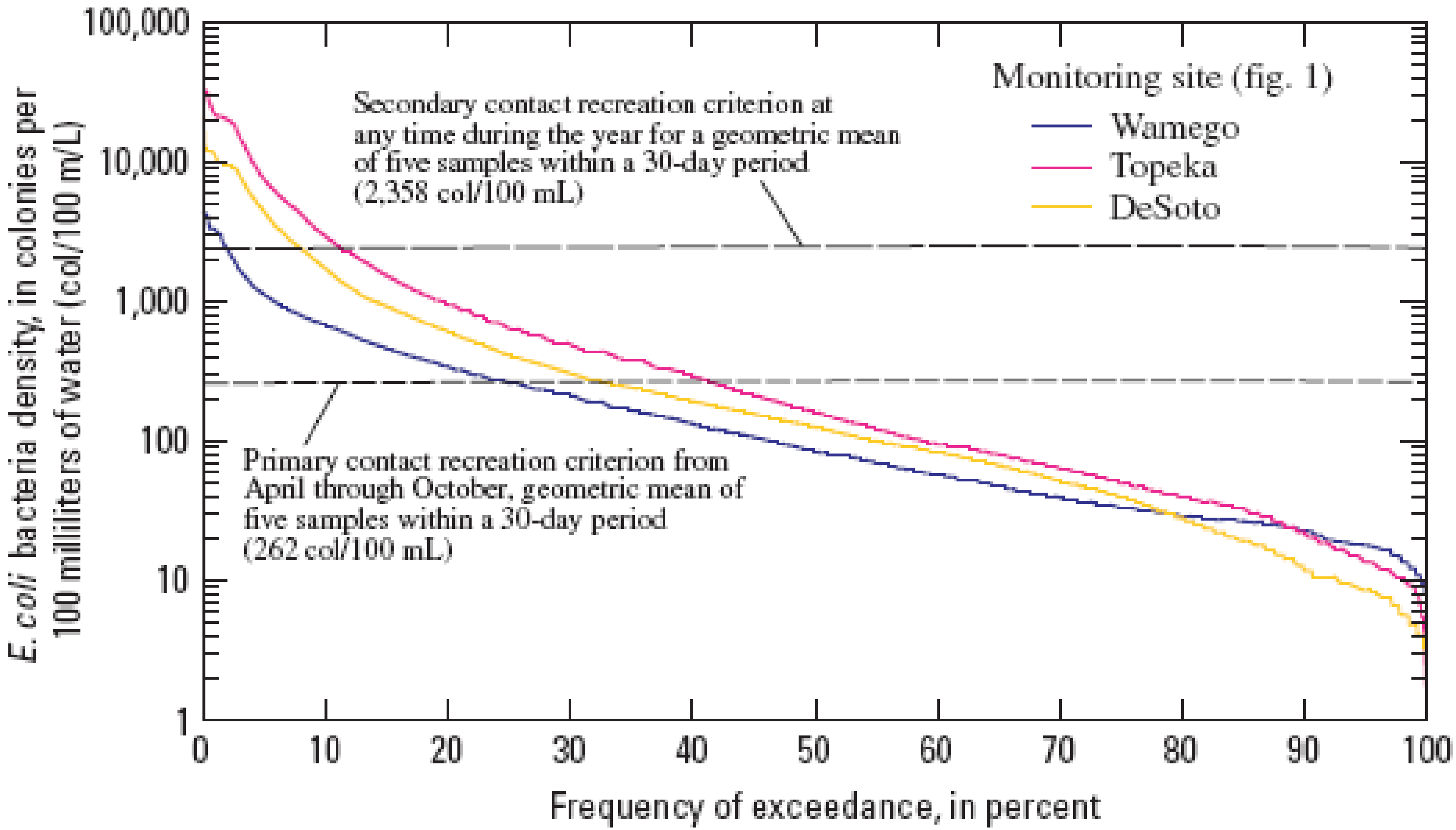
Rasmussen, Ziegler, and Rasmussen 2005

Bacteria frequently exceed water-quality standards



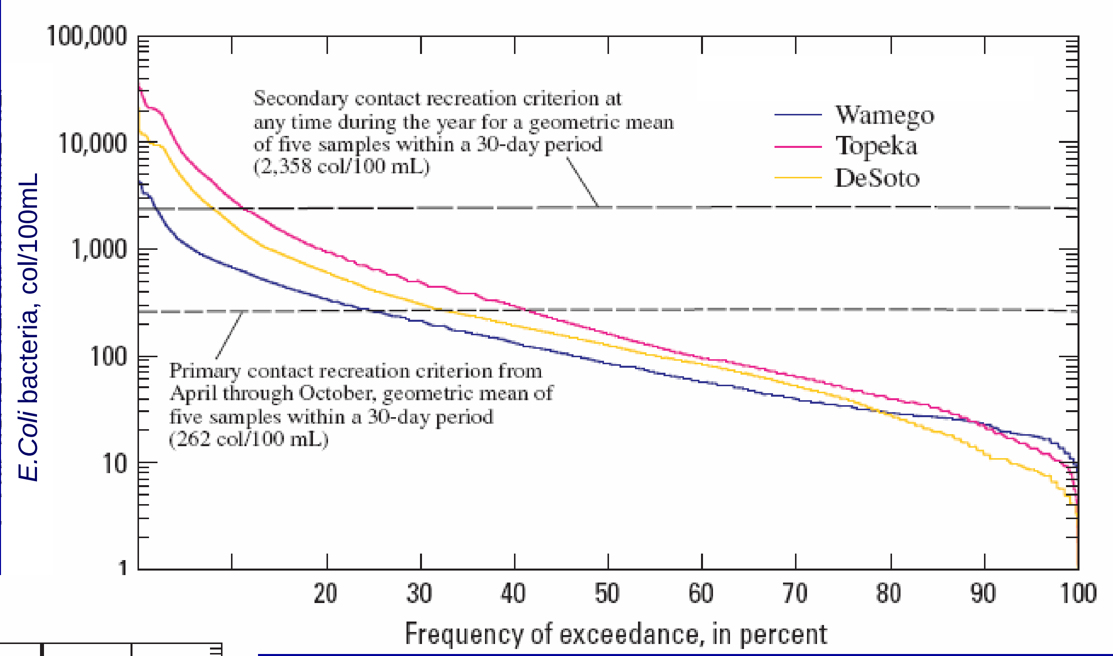
http:// ks.water.usgs.gov/Kansas/rtqw/

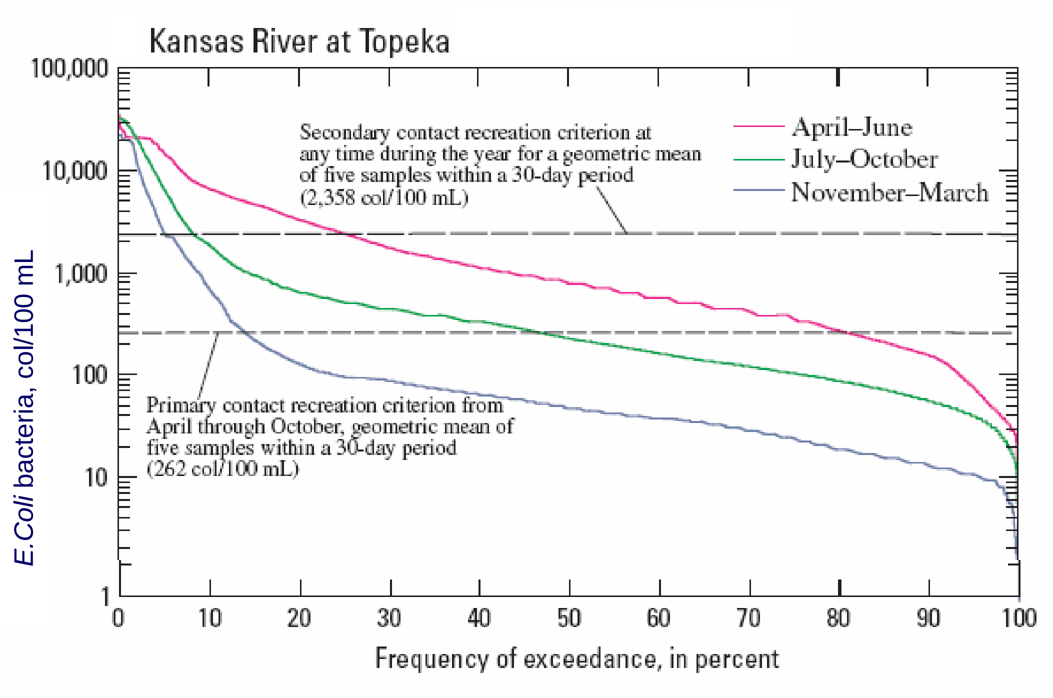
During 2000-03 *E.Coli* bacteria density at Topeka exceeded the primary contact criterion 40% of the time.



Rasmussen, Ziegler, and Rasmussen 2005

E.Coli density generally largest at Topeka



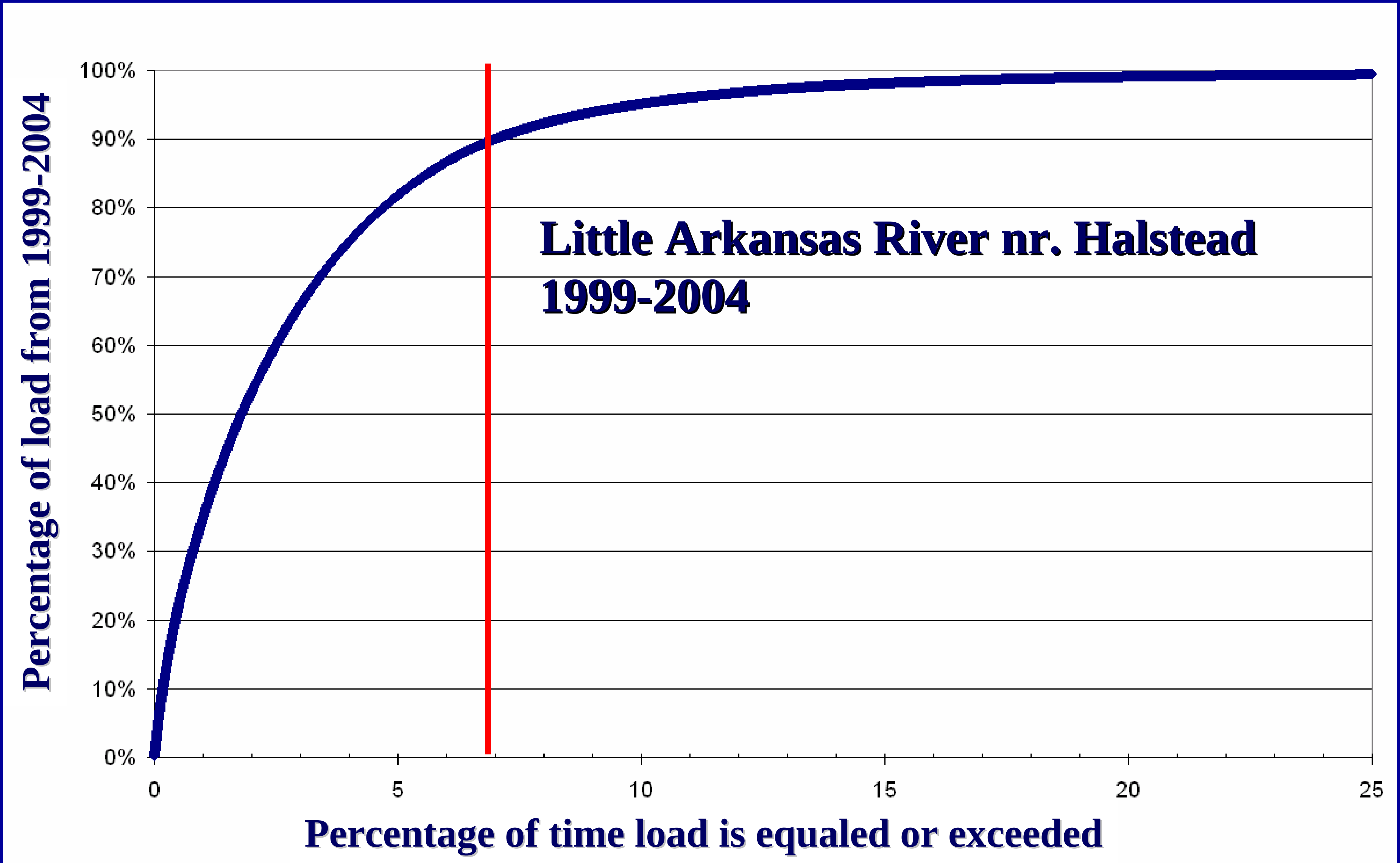


During the spring, the primary contact criterion was exceeded 80% of the time and the secondary contact criterion was exceeded 25% of the time.

USGS

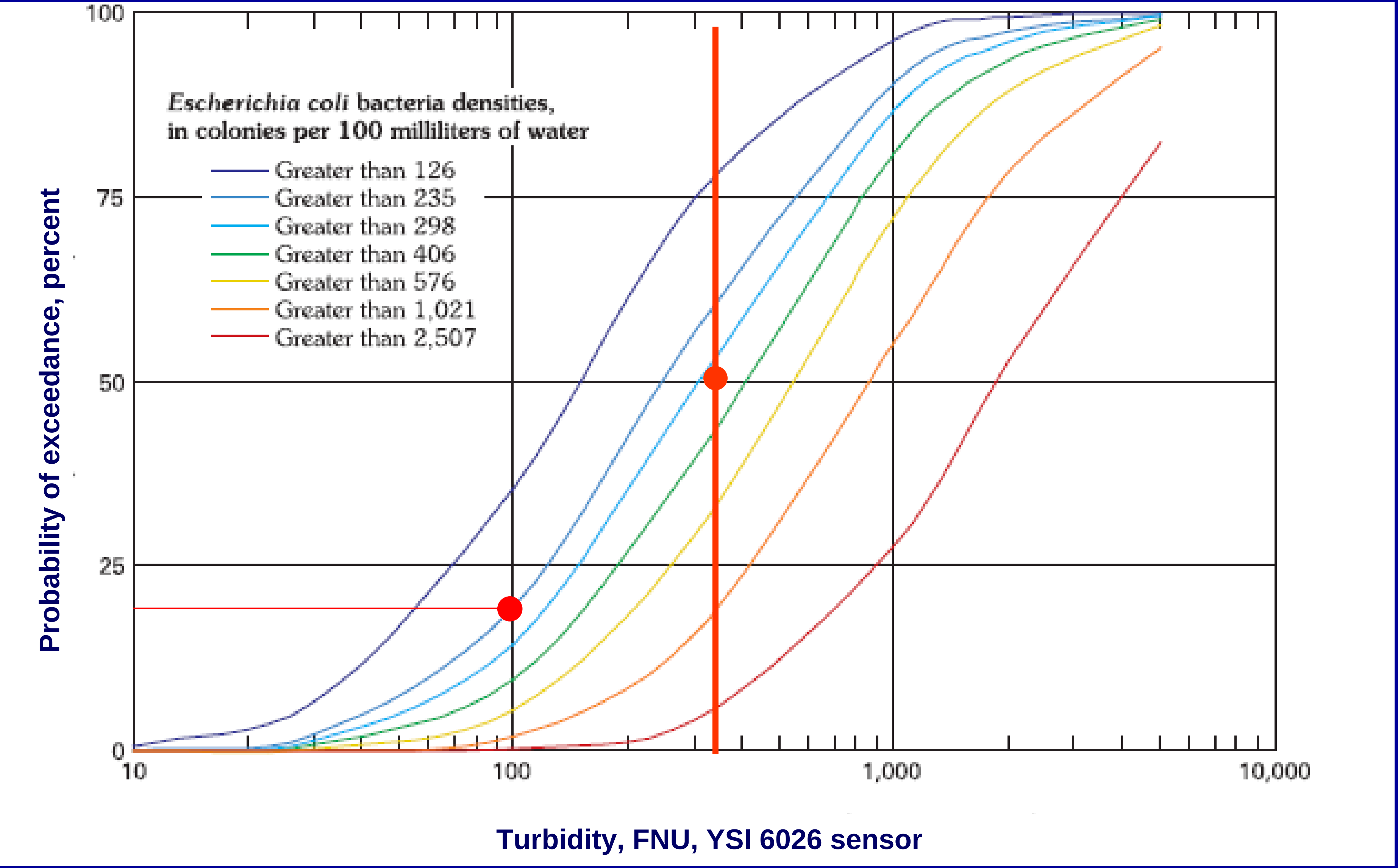
Rasmussen, Ziegler, and Rasmussen 2005

90 percent of the load occurs in 7 percent of the time



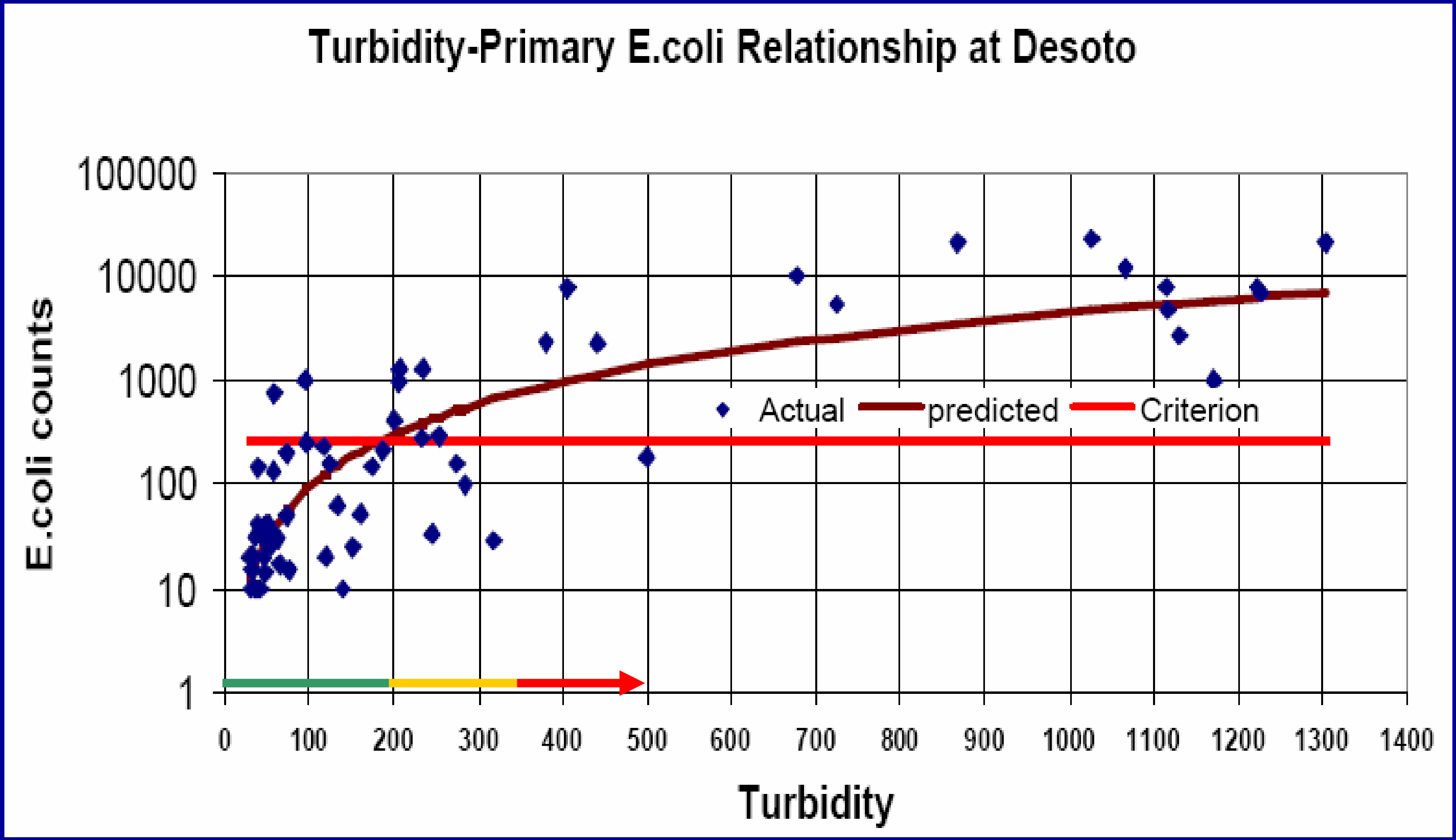
USGS

Turbidity to estimate probability of exceeding E. coli criteria



Rasmussen and Ziegler, 2003

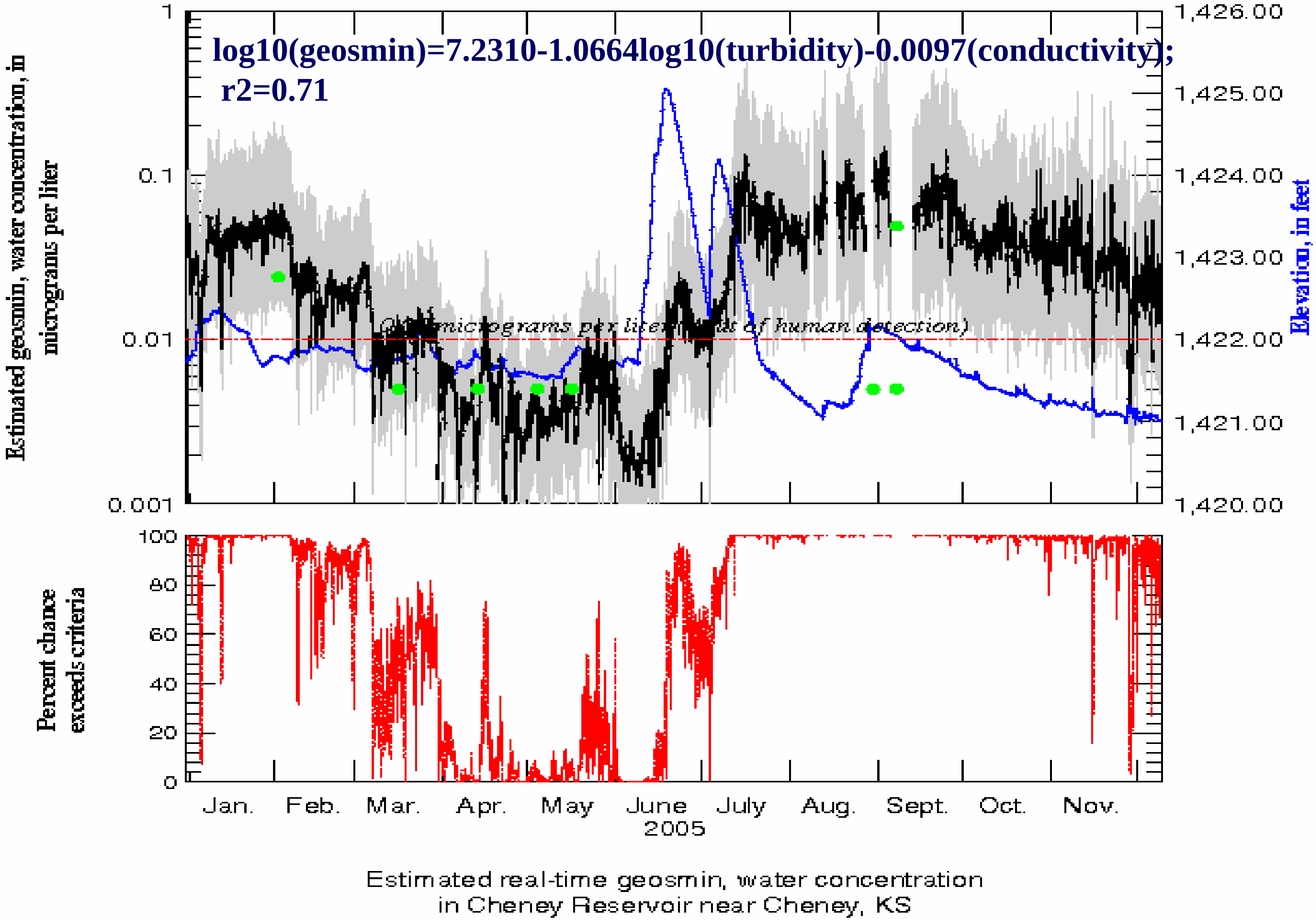
Kansas River TMDL incorporates continuous turbidity data. When turbidity > 350 FNU, *E. coli* criteria likely to be exceeded.



USGS

(Figure from KDHE, *E.Coli* Bacteria TMDL for Kansas-Lower Republican Basin, 2005)

Future: Real-time estimation of geosmin in Cheney Reservoir (2005)



http://ks.water.usgs.gov/Kansas/rtqw/sites/07144790/htmls/ytd/p62719_ytd_all_uv.shtml

What does it cost to operate a site?

Continuous monitoring and developing relations

- Purchase or rent monitor and install
- O&M for 6 sensors and records
- Sampling (15-30 times over 2 years)
- Regression analysis and report
- Put estimates on the web

Subsequent years

- O&M for 6 sensors and records
- Sampling (3-5 times per year)

USGS

Benefits of Real Time Water Quality

- Improve our understanding of the hydrology and water quality of streams
- Continuously measure water quality in real time like streamflow
- Comparison to water-quality criteria
- Provide notification of changes in water-quality conditions for water treatment and recreation in real time
- Better estimate selected constituent concentrations and loads with defined uncertainty
- Identify source areas and evaluate trends for NPDES, BMPs and TMDLs
- Optimize timing of sample collection

USGS

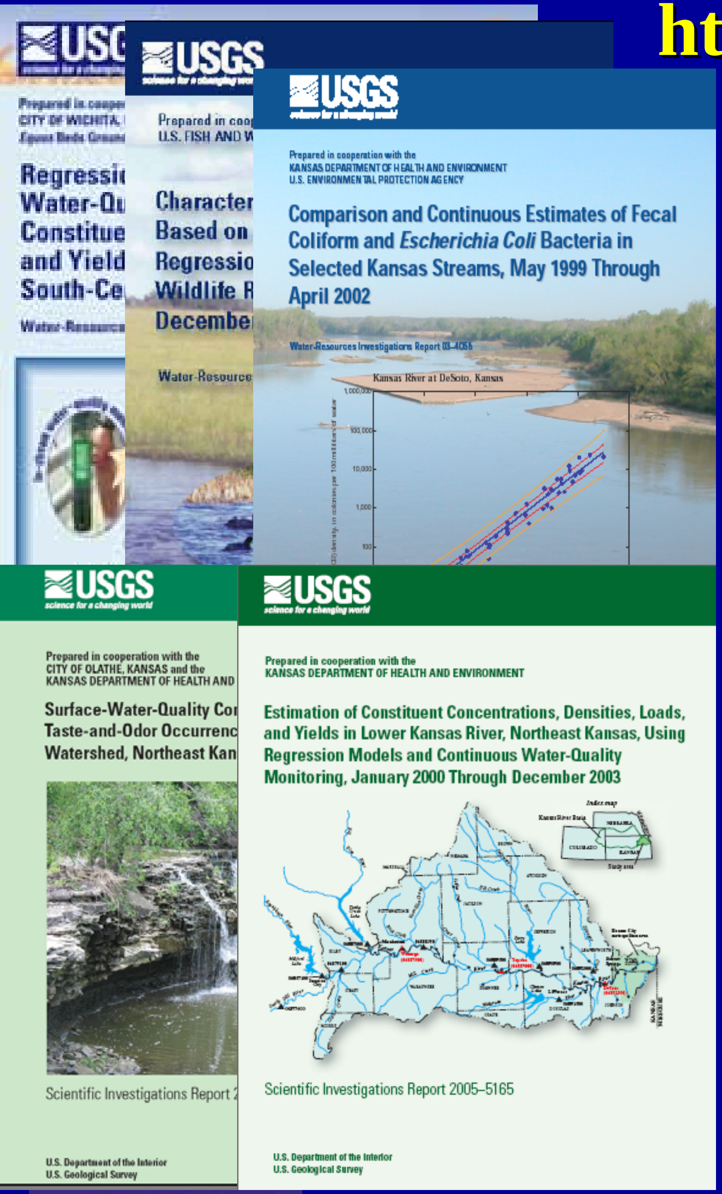
Future Challenges for Continuous Water Quality

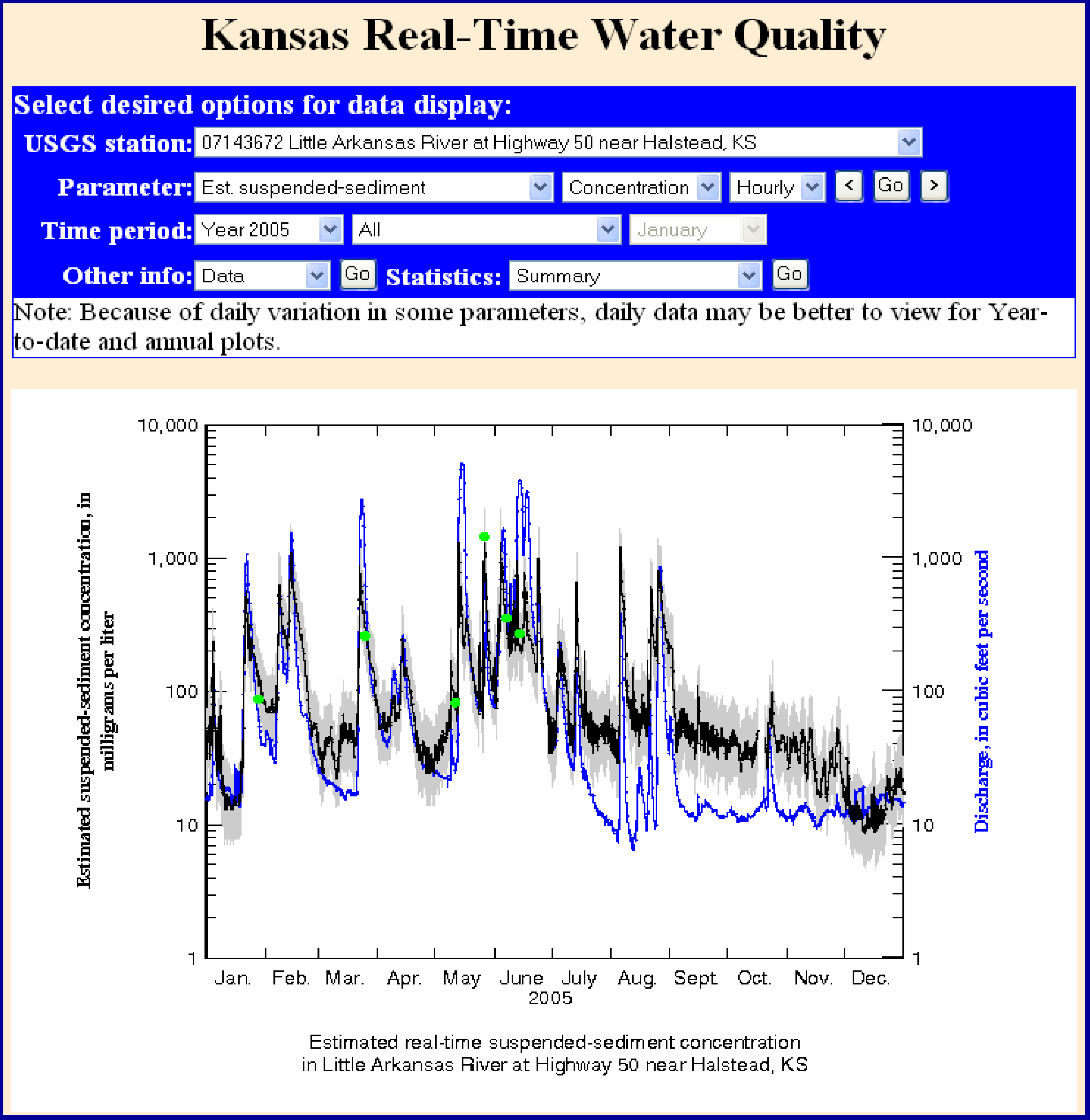
- **Need more and better direct measurement sensors**
- **Reduce O&M costs/time**
- **Ice and shallow water installations**
- **More installations nationwide to better understand variability**
- **Detection of water-quality trends and BMPs effectiveness**
- **Improve ways to estimate and communicate uncertainty**
- **Continued sampling to document that relations remain representative**

USGS

Real-time continuous concentrations and loads on the Web—

http://ks.water.usgs.gov/Kansas/rtqw/





Contact Information

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Trudy Bennett- trudyben@usgs.gov, 316-773-3225

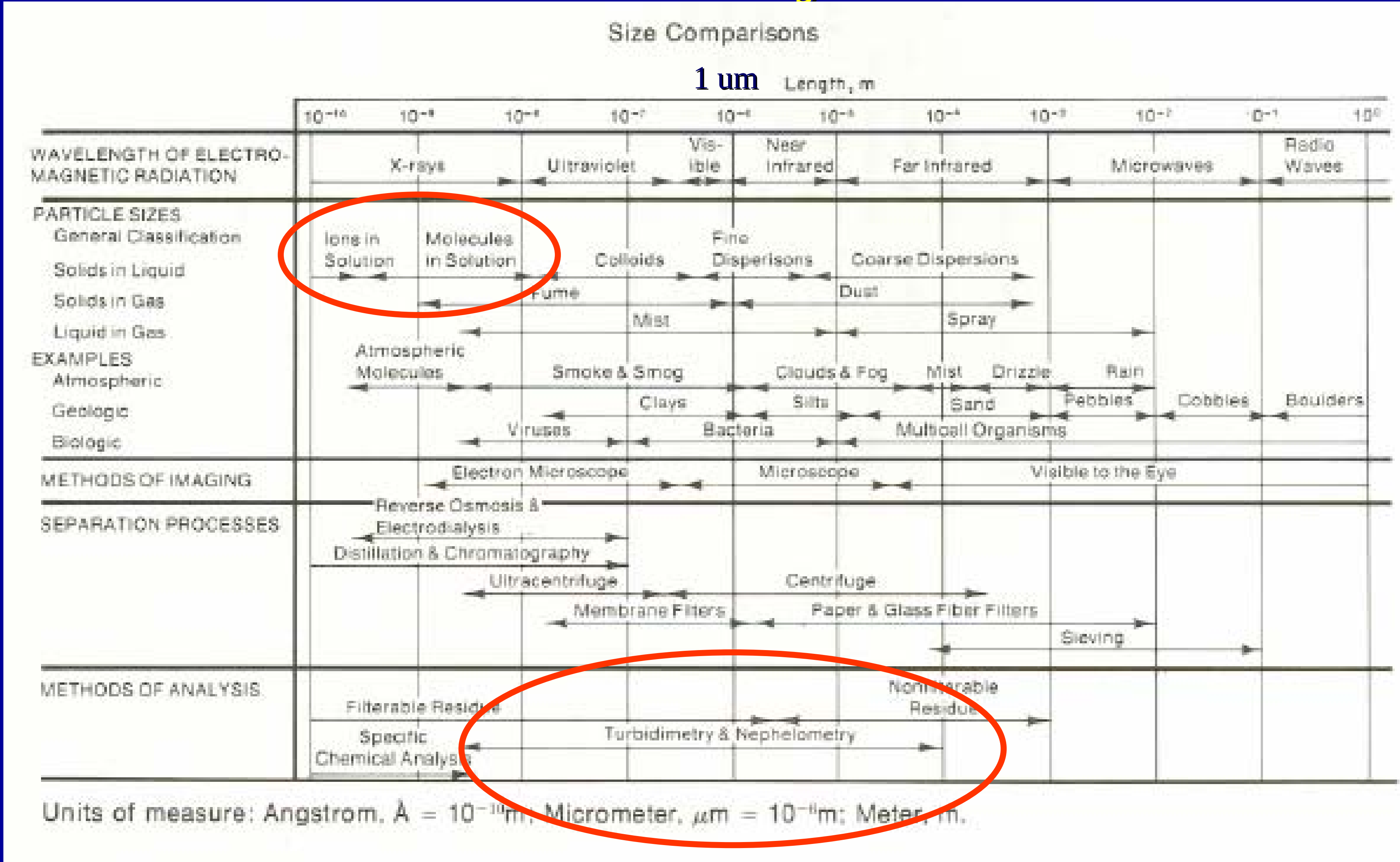
Teresa Rasmussen- rasmuss@usgs.gov, 785-832-3576

Online Resource information:

- http://ks.water.usgs.gov/Kansas/rtqw/
- http://ks.water.usgs.gov/Kansas/pubs/reports/
- http://pubs.water.usgs.gov/tm1D3/--protocols for CWQM
- http://water.usgs.gov/pubs/circ/2003/circ1250/
- http://water.usgs.gov/owq/FieldManual/index.html

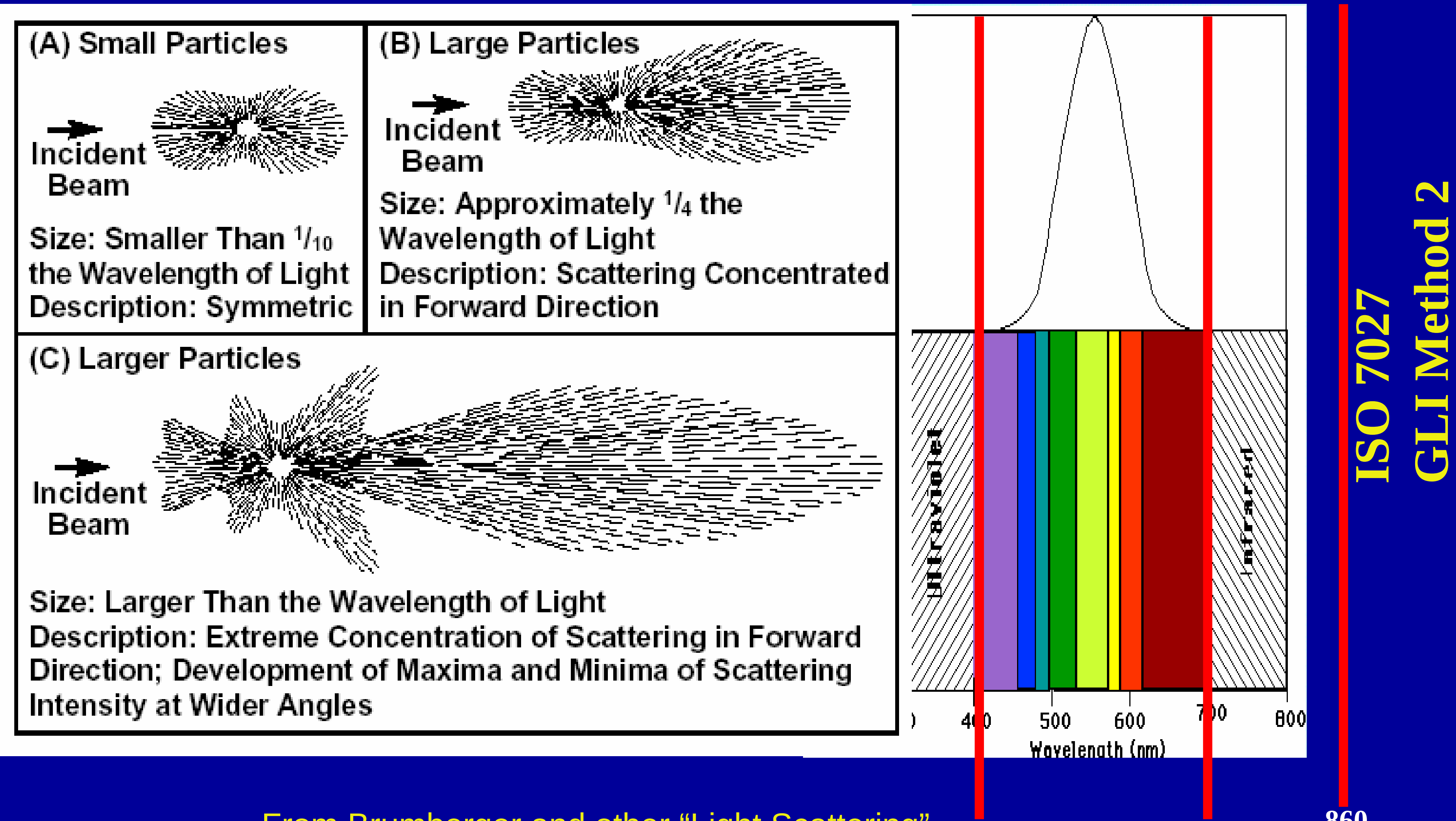
USGS

Grain sizes and turbidity measurement



From Vanous, Larson, and Hach, Water Analysis Volume 1, 1982, Academic Press, Inc

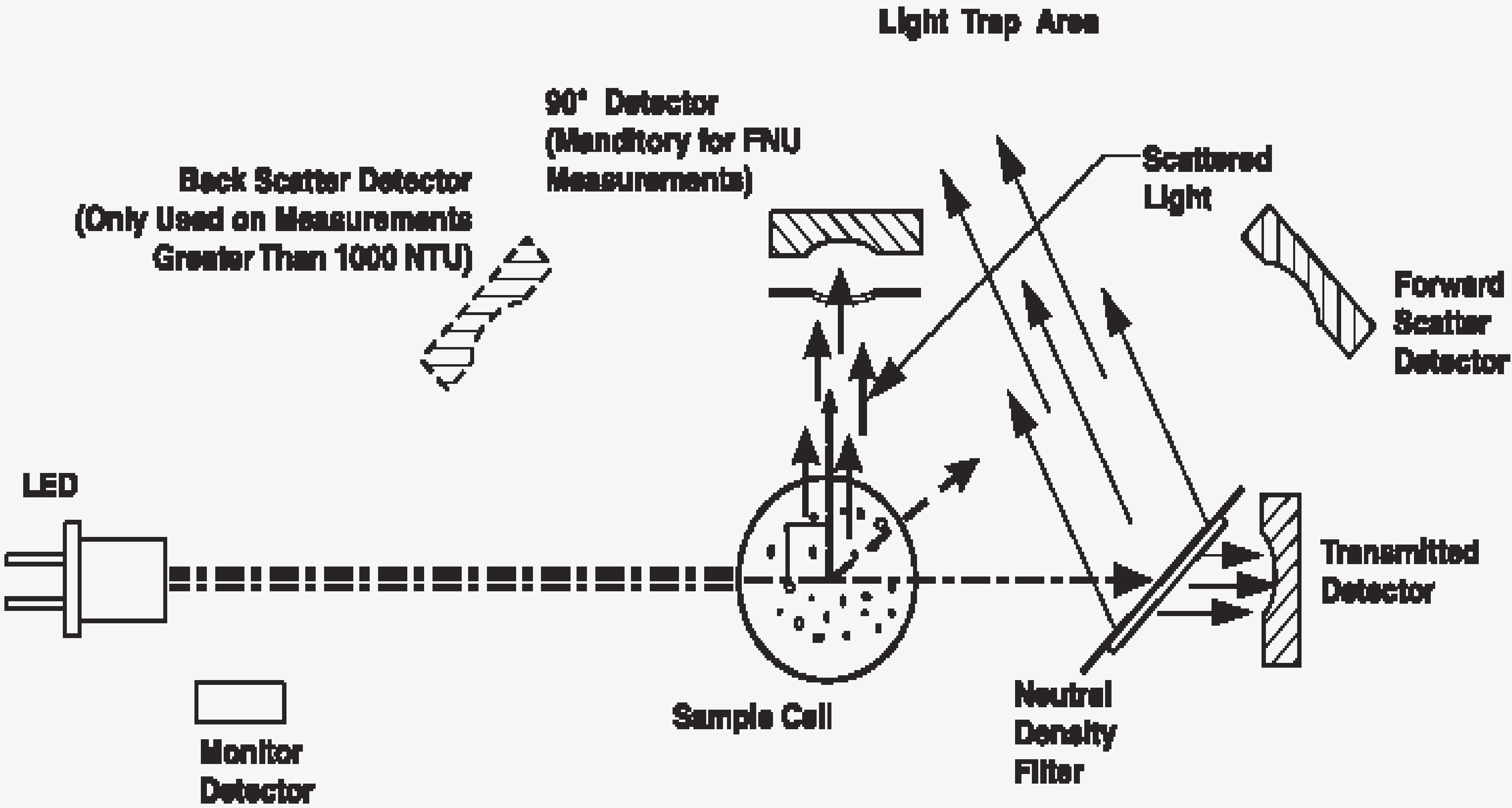
Scattering of light by substances in water



From Brumberger and other "Light Scattering" Science and Technology, 1968
Reproduced from Sadar, 1998

USGS

Figure 4 2100NIS/ANIS Light Path Diagram for Low-Level Measurement



From Mike Sadar, Turbidity Instrument Comparison HACH, 1999 Technical Information Series, 7063

USGS

Color can affect turbidity

Powder activated carbon | Kansas soil | Powdered limestone

400 milligrams per liter

YSI6026; 75FNU
YSI6136; 54 FNU

YSI6026; 124 FNU
YSI6136; 95 FNU

YSI6026; 170 FNU
YSI6136; 114 FNU

YSI6026; 140 FNU
YSI6136; 50 FNU

YSI6026; 500 FNU
YSI6136; 350 FNU

YSI6026; 540 FNU
YSI6136; 410 FNU

1,600 milligrams per liter

Method needs to be stored with the data

Reporting units corresponding to different turbidity instrument designs [nm, nanometers; °, degree]		
Detector geometry	**Light Wavelength**	
	White or broad band (with a peak spectral output of 400-680 nm)	**Monochrome** (spectral output typically near infrared, 780-900 nm)
Single Illumination Beam Light Source		
At 90° to incident beam	Nephelometric Turbidity Unit (NTU)[a]	Formazin Nephelometric Unit (FNU)[b]
At 90° and other angles. An instrument algorithm uses a combination of detector readings, which may differ for values of varying magnitude.	Nephelometric Turbidity Ratio Unit (NTRU)	Formazin Nephelometric Ratio Unit (FNRU)
At 30°± 15° to incident beam (backscatter)	Backscatter Unit (BU)	Formazin Backscatter Unit (FBU)
At 180° to incident beam (attenuation)	Attenuation Unit (AU)	Formazin Attenuation Unit (FAU)
Multiple Illumination Beam Light Source		
At 90° and possibly other angles to each beam. An instrument algorithm uses a combination of detector readings, which can differ for values of varying magnitude.	Nephelometric Turbidity Multibeam Unit (NTMU)	Formazin Nephelometric Multibeam Unit (FNMU)

[a] Use of NTU: limited to instruments that comply with EPA Method 180.1 (U.S. Environmental Protection Agency, 1993).

[b] Use of FNU: pertains to instruments that comply with ISO 7027, the European drinking-water protocol (International Organization for Standardization, 1999), which includes many of the submersible turbidimeters that are in common use in the USGS for onsite measurements.

REFERENCES

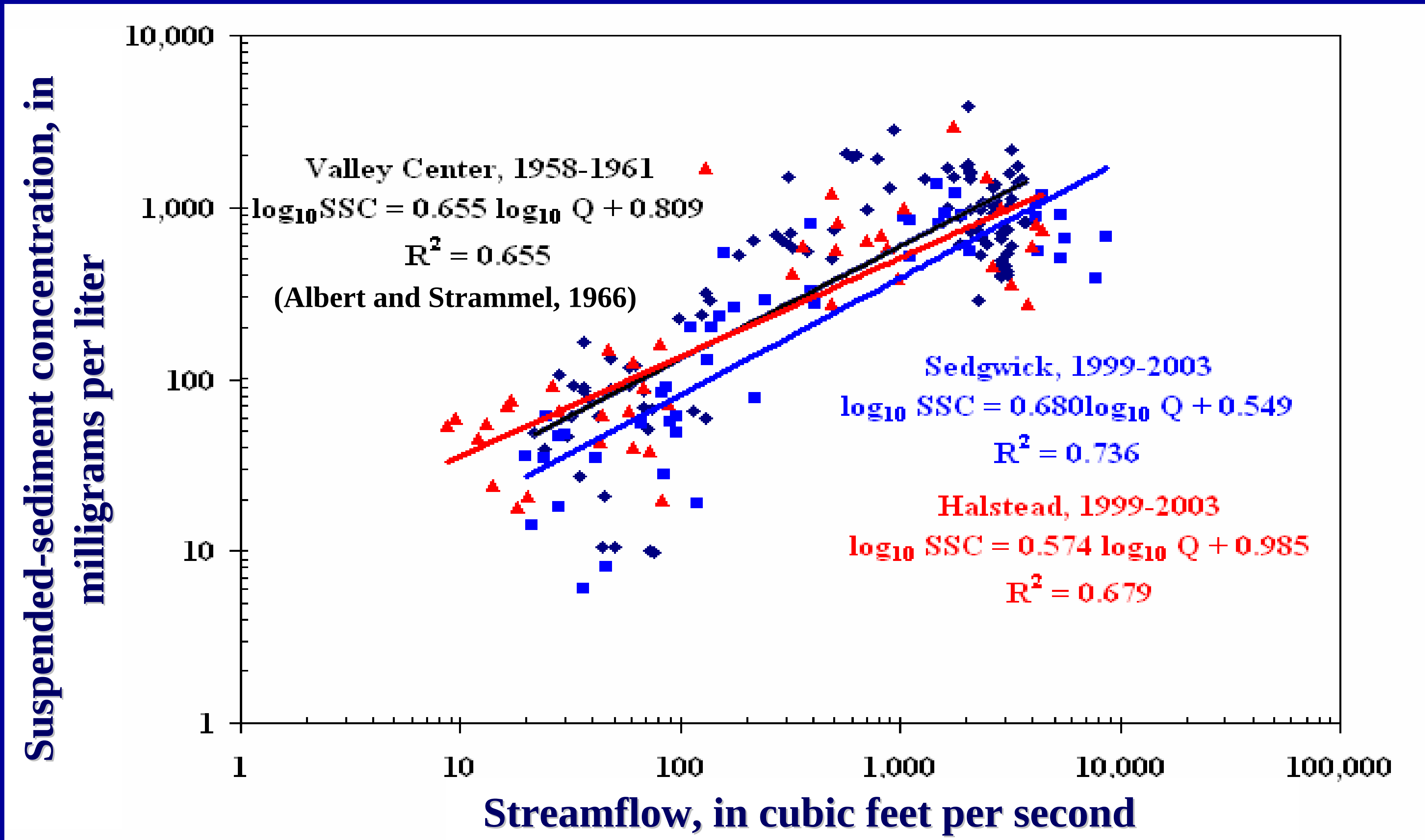
Anderson, C.W., 2004, Turbidity, (version 2): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, section 6.7, accessed September 24, 2004 from http://water.usgs.gov/owq/FieldManual/Chapter6/6.7_contents.html.

USGS

Fouling of sensors increases operational costs

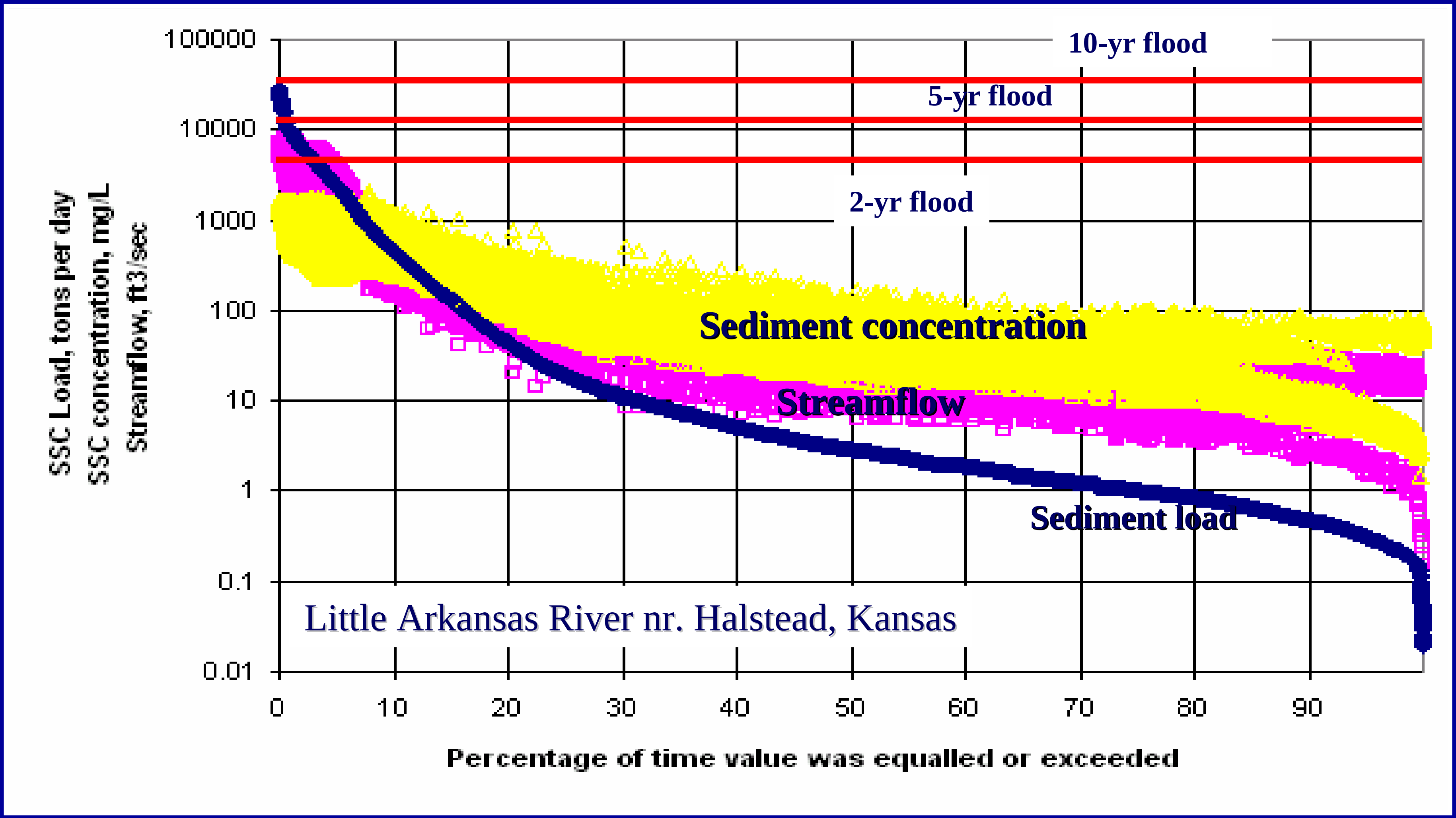
USGS

Streamflow-estimated suspended-sediment concentration



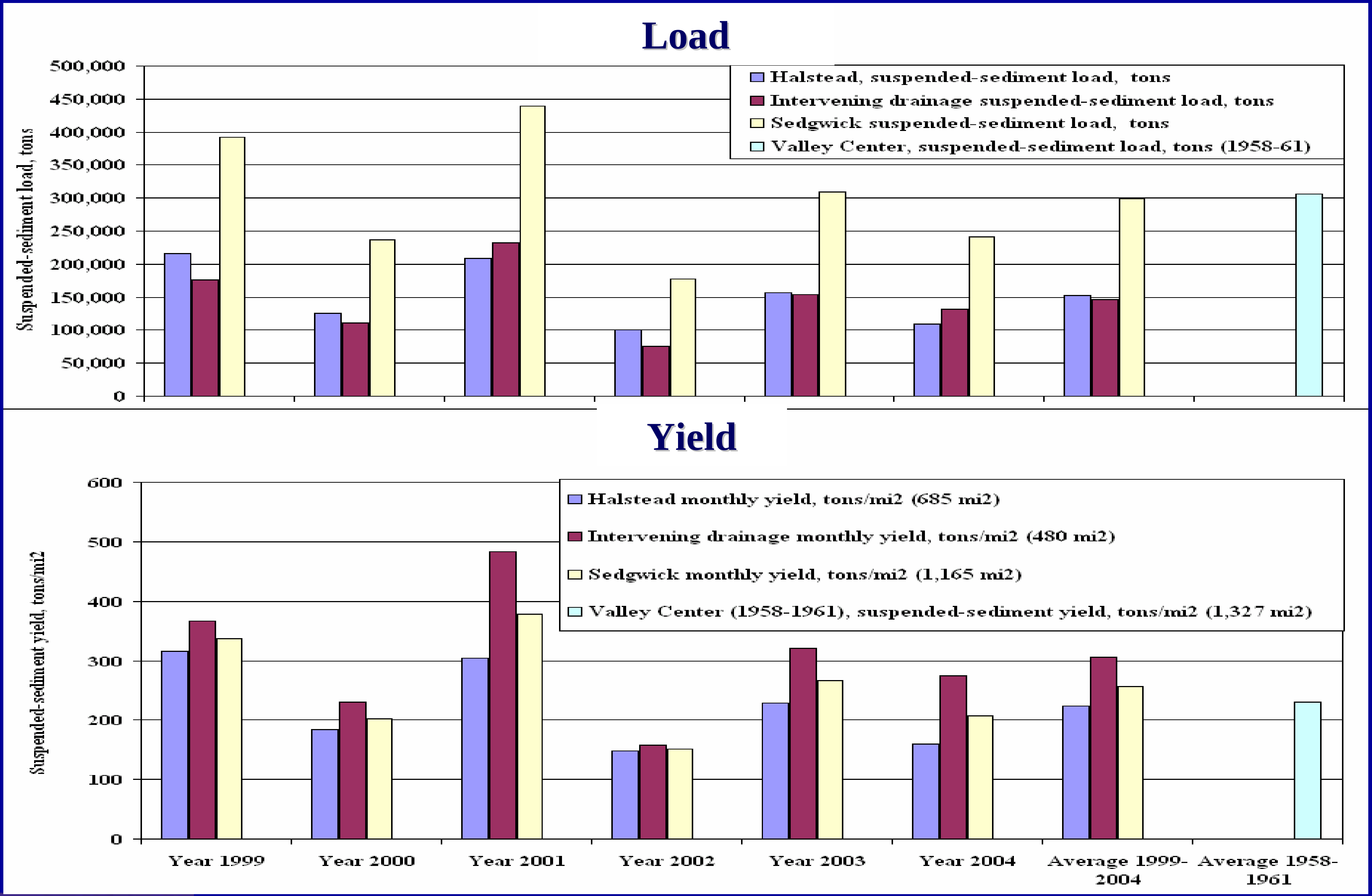
- Q explains only about 70 percent of the variability
- Little change in relation in 40 years

How can changes be documented with factor of 10 variability in concentration and streamflow for the equivalent load?



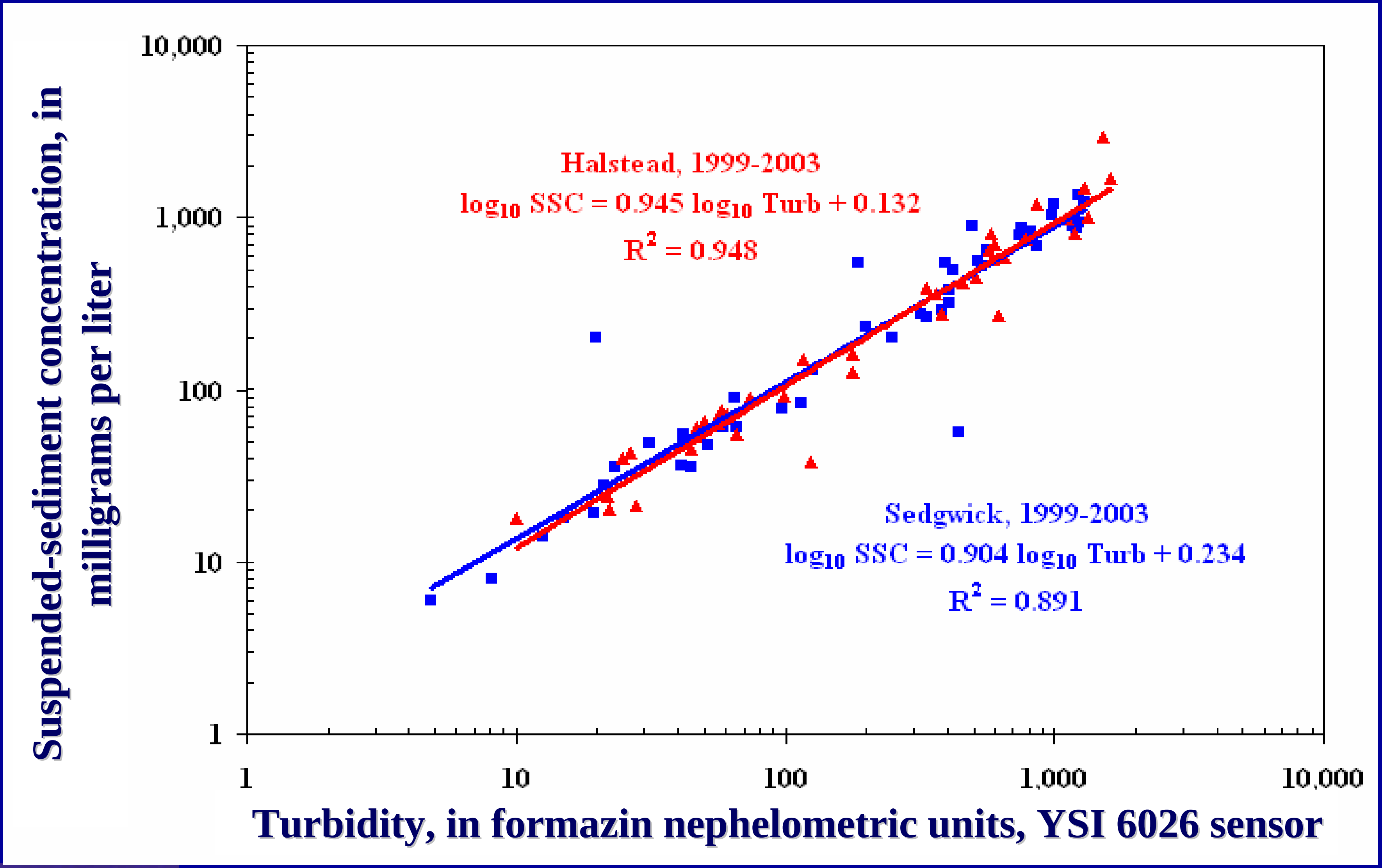
- Capture the variability during the largest streamflows
- Compare the storm yields

Annual loads and yields unchanged in last 40 years



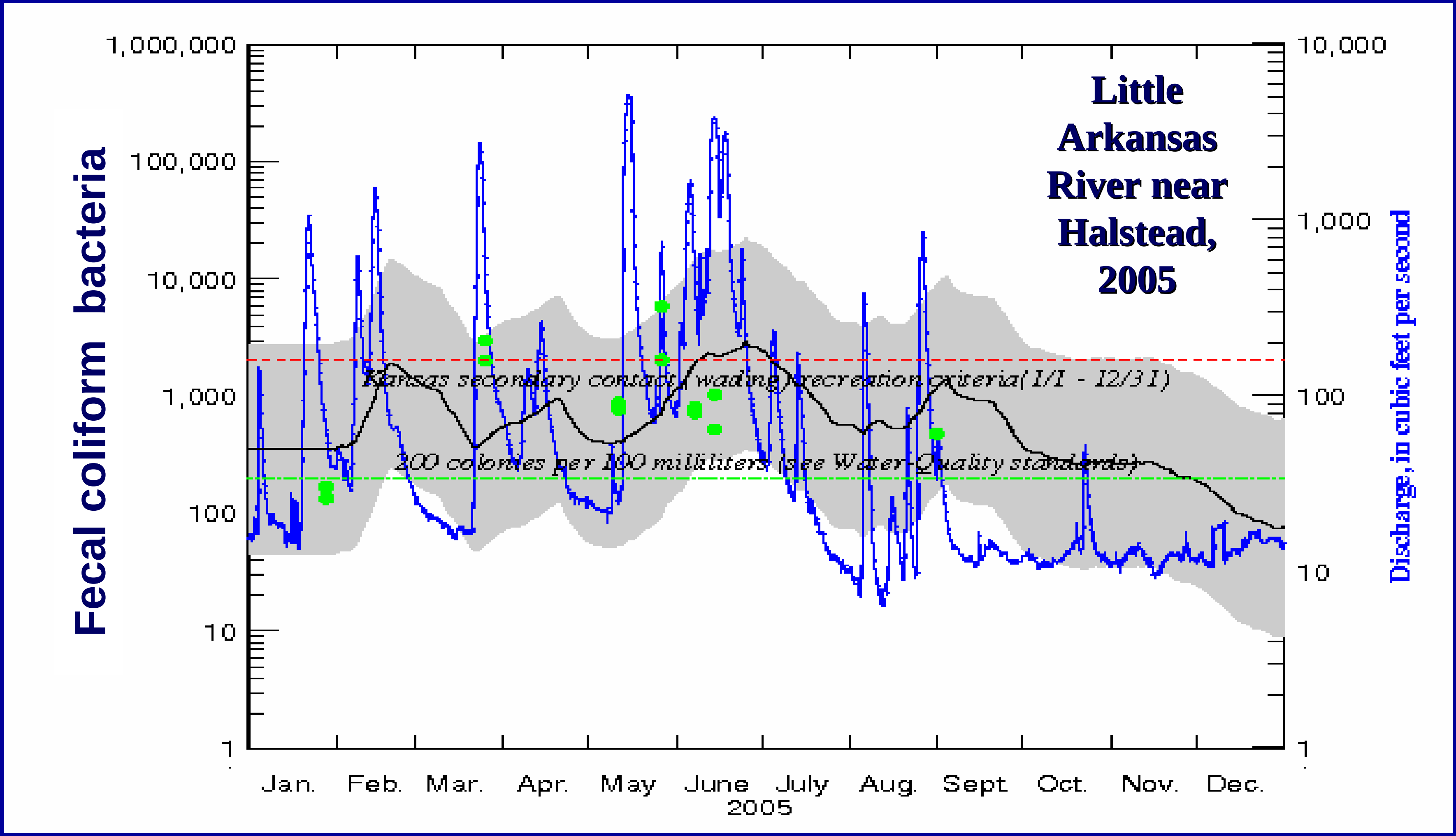
USGS

Turbidity provides an accurate estimate of suspended-sediment concentrations



USGS

Estimated bacteria using 30-day geometric mean



USGS

http:// ks.water.usgs.gov/Kansas/rtqw/