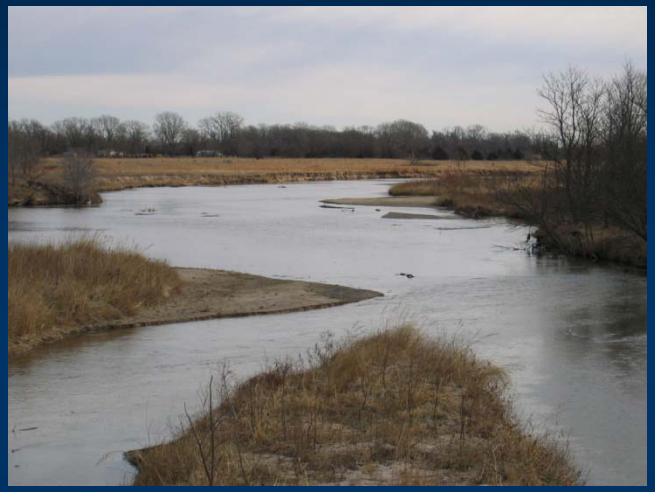
Real-Time Estimation of Taste-and-Odor Occurrences in Cheney Reservoir, Kansas



Jennifer L. Graham[1], Andrew C. Ziegler[1], Trudy J. Bennett[1] and Gerald T. Blain[2]
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[2]City of Wichita Water and Sewer Department

Houston, Texas
February 11, 2009

USGS

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Overview

- Cyanobacterial Harmful Algal Blooms
- Cheney Reservoir and Watershed
  - Background information
  - Previous USGS studies
- Real-Time Water-Quality Monitoring
- Initial Model Estimating Geosmin Concentrations in Real Time
- Current Research
  - Model re-evaluation
  - Long-term trends
  - New sensor technology

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Cyanobacterial Harmful Algal Blooms

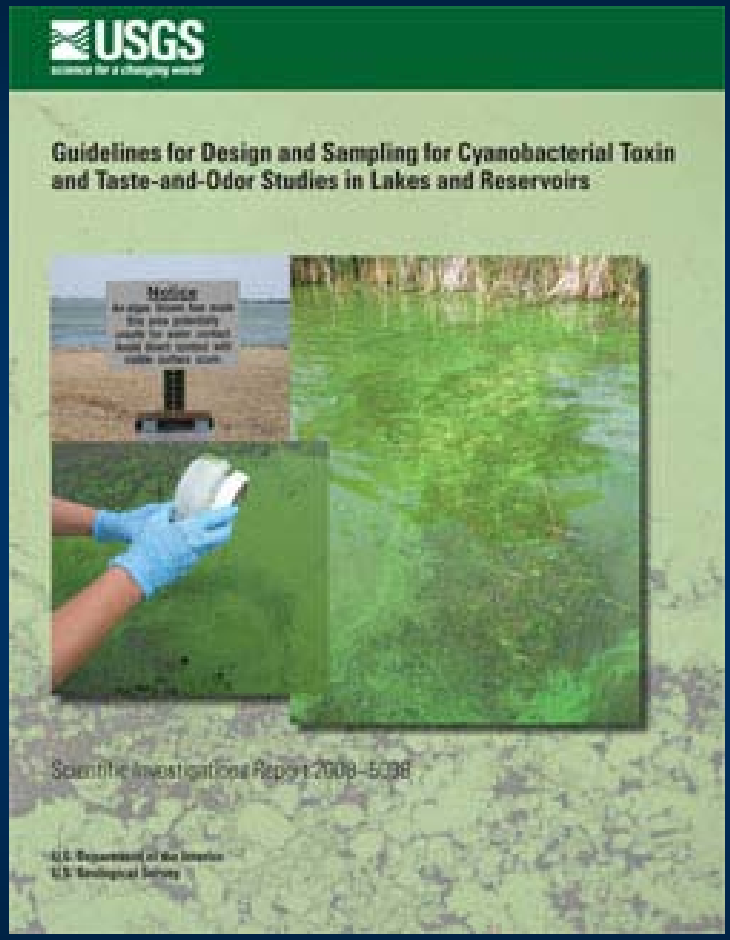
- Health Concerns
  - Toxins
    - Human and animal illness and death
    - Included on EPA Drinking Water Contaminant Candidate List
    - Drinking water – microcystin-LR
      - WHO Guideline – 1 µg/L
      - Drinking-water treatment processes effectively remove most toxins
    - Recreational water – microcystin-LR
      - WHO Guideline – 20 µg/L; beach closures at 10-20 µg/L
    - Known chronic effects
    - Limited data and guidelines for toxins other than microcystin

Cyanobacterial Harmful Algal Blooms

- Ecologic Concerns
  - Low dissolved oxygen
  - Fish kills
  - Losses to bird and mammal populations
  - Zooplankton avoidance or death
  - Accumulation of toxins by mussels
- Economic Concerns
  - Added drinking water treatment costs
    - Olfactory sensitivity to taste-and-odors at low concentrations (5-10 ng/L)
  - Loss of recreational revenue
  - Death of livestock and domestic animals
  - Medical/veterinary expenses

USGS Kansas Water Science Center Algal Toxin Team

- Sampling guidance documents
  - SIR 2008-5038
  - NFM 7.5
- Methods Development
  - Multi-analyte LC/MS/MS for 12 cyanotoxins
  - Standardized sample preparation techniques
- Occurrence
  - Midwest Reconnaissance
  - 2007 EPA National Lake Assessment
  - Culture collection assessment
- Fate and Transport
  - Fort Cobb, OK (USGS CERC)
- Ecology
  - Cheney Reservoir, KS
  - Lake Houston, TX
- Early Warning and Predictive Models
  - Cheney Reservoir, KS
  - Lake Houston, TX



http://ks.water.usgs.gov/Kansas/studies/qw/cyanobacteria

Toxins and Taste-and-Odor Compounds Produced by Cyanobacteria

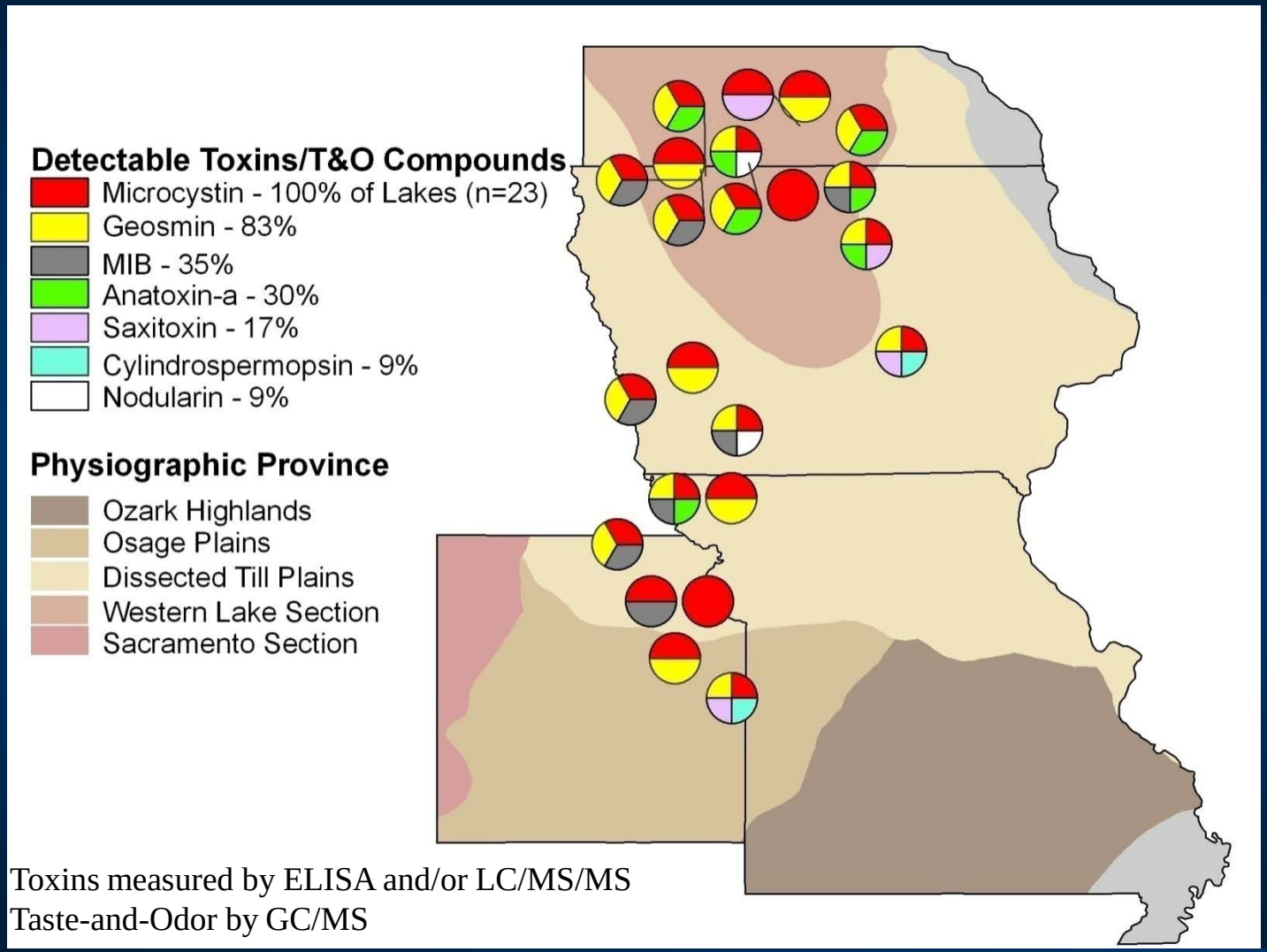
	Dermatoxins	Hepatotoxins		Neurotoxins		Taste/Odor	
		CYL	MC	ANA	BMAA	GEOS	MIB
Colonial/Filamentous							
Aphanizomenon	X	X		X	X	X	
Anabaena	X	X	X	X	X	X	?
Cylindrospermopsis	X	X			X		
Microcystis	X		X		X		
Oscillatoria/Planktothrix	X		X	X	X	X	X
Unicellular							
Synechococcus	X		X		X	X	X
Synechocystis	X		X		X		

USGS

After Graham and others, 2008

Toxins and Taste-and-Odor Compounds in the Midwest

During August 2006 100% of Blooms Sampled (n=23) Had Detectable Microcystin, 83% Had Detectable Geosmin, and 30% Had Detectable Anatoxin



Toxins measured by ELISA and/or LC/MS/MS
Taste-and-Odor by GC/MS

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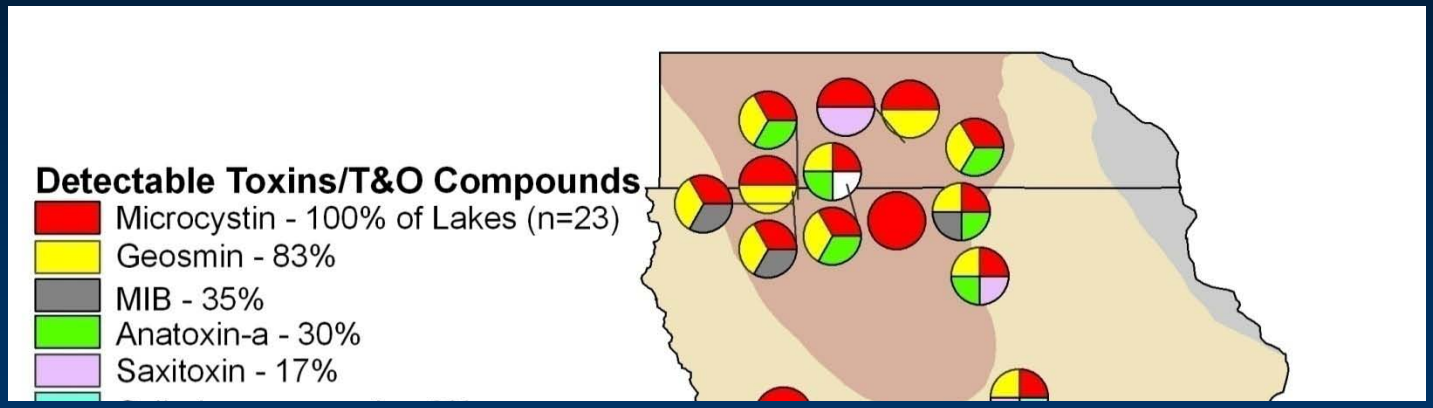
Graham, Loftin, Meyer, and Ziegler, in review

Toxins and Taste-and-Odor Compounds in the Midwest

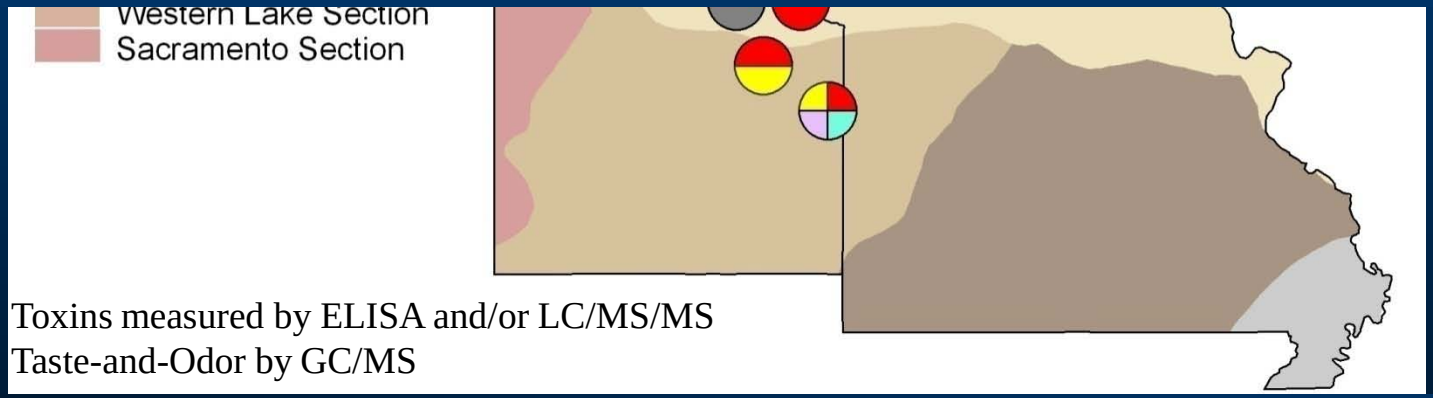
During August 2006 Toxins and Taste-and-Odor Compounds Co-Occurred in 87% of BLOOMS Sampled (n=23) and Anatoxin-a Always Co-Occurred with Geosmin



Disproving statements such as:

"Algae may make for stinky water, but it poses no health risks"

-Concord Monitor, Concord, NH July 7, 2006



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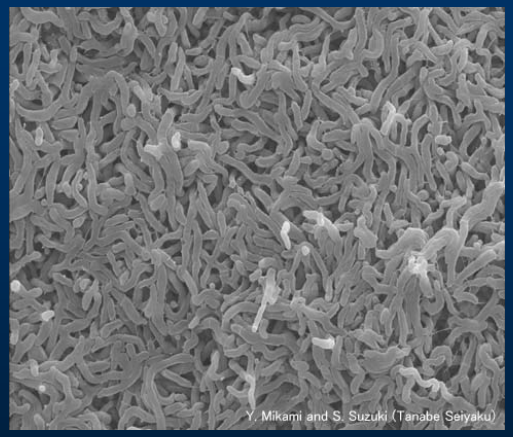
Graham, Loftin, Meyer, and Ziegler, in review

Geosmin and 2-Methylisoborneol (MIB) Commonly Cause Persistent Tastes-and-Odors in Drinking Water

Cyanobacteria (*Anabaena circinalis*)
Image Courtesy of PhycoTech



Actinomycetes Bacteria
SEM Image Courtesy of Chiba Univ, Japan

- Potential Sources of Geosmin and MIB
  - Cyanobacteria
    - i.e. *Anabaena*, *Oscillatoria*
  - Actinomycetes bacteria
- Detectable in Drinking Water at ~10 ng/L

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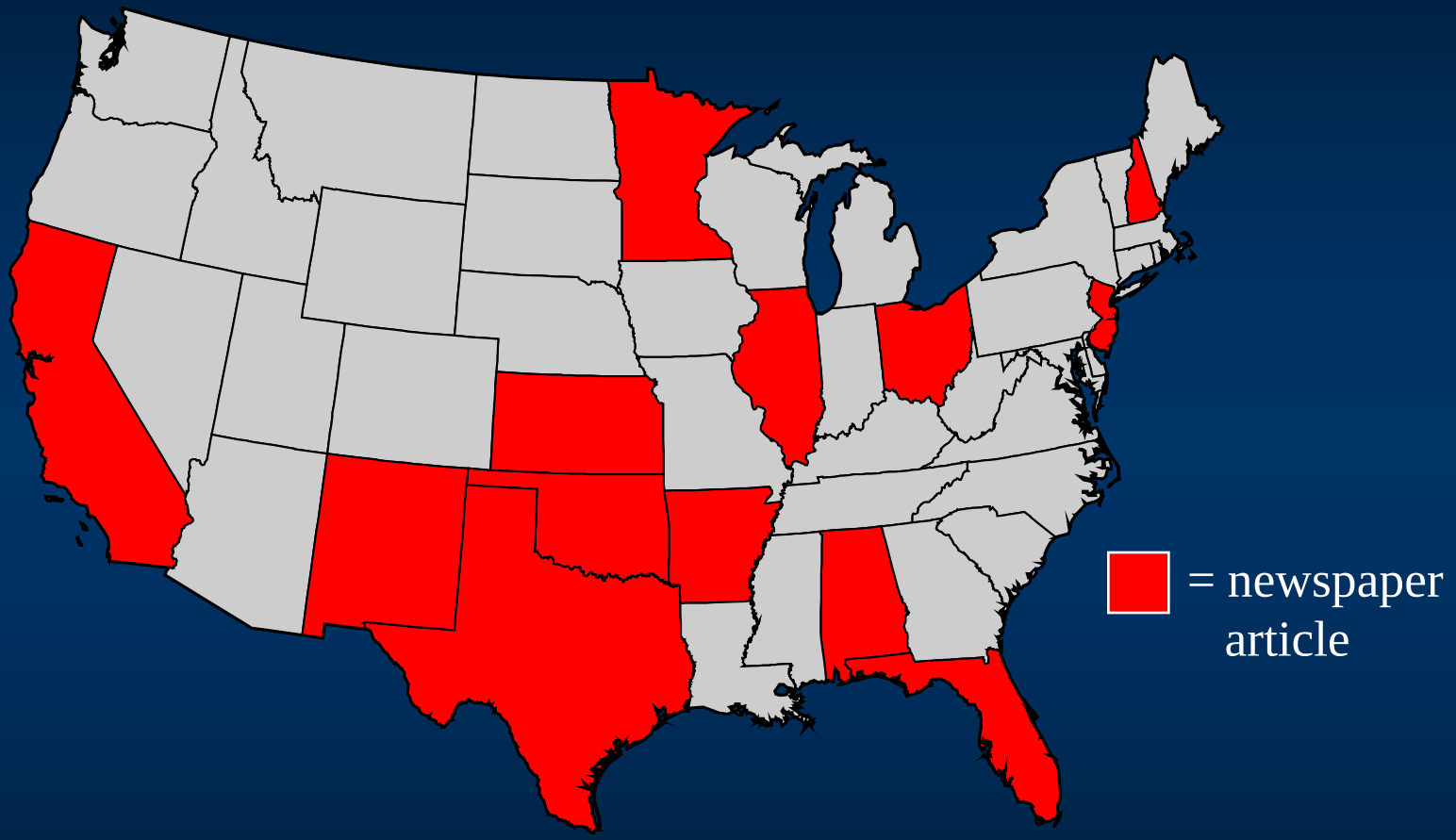
Cyanobacterial Tastes-and-Odors Made the News in at Least 13 U.S. States During May-August 2006



"It's dirty and rank. And you have that smell too. Unfortunately, you can't use bottled water for showers."

-The Dallas Morning News, Dallas, TX Aug 3, 2006

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Taste-and-Odor Events in Cheney Reservoir

- Cheney Reservoir provides about 70% of the City of Wichita's water supply.
- 1990 – first year of taste-and-odor problems.
- City has conducted several watershed and reservoir studies to protect and improve water quality
- Upgraded to ozone treatment in 2006 to control effects of taste-and-odor events
  - A tool to predict cyanobacterial blooms and taste-and-odor events would allow in optimization of ozone dosage, resulting in cost savings

Cheney Reservoir, June 2003
Image Courtesy of KDHE

USGS

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USGS Assessment of Water Quality in the Cheney Watershed and Reservoir, 1996-present

- Concerns
  - Taste-and-odor occurrences related to algal blooms
  - Relation between watershed inputs, reservoir processes, and taste-and-odor causing algal blooms
- Approach
  - Describe current and historical loading inflow to Cheney Reservoir using reservoir and watershed sediment studies and continuous data
  - Describe physical, chemical, and biological processes associated with the proliferation of algae and production of algal by-products using a combination of discrete samples and real-time water-quality monitors

USGS

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USGS Assessment of Water Quality in the Cheney Watershed and Reservoir, 1996-present

- Watershed Studies(1996-2000)
  - Low flow synoptic study
  - Historic loading – reservoir sediment cores
  - Transport – continuous stream-flow data and autosamplers
  - Natural and agricultural sources – graveyard soils

- Watershed and Reservoir Studies (2001-2015)
  - Instantaneous loads and yields – continuous water-quality monitor on main inflow
  - Real-time estimation of geosmin – continuous water-quality monitor in reservoir
  - Regular and event-based samples for physical, chemical, and biological variables that cannot be measured in real time.

http://ks.water.usgs.gov/Kansas/studies/qw/cheney

http://www.wichita.gov/CityOffices/WaterAndSewer/ProductionAndPumping/

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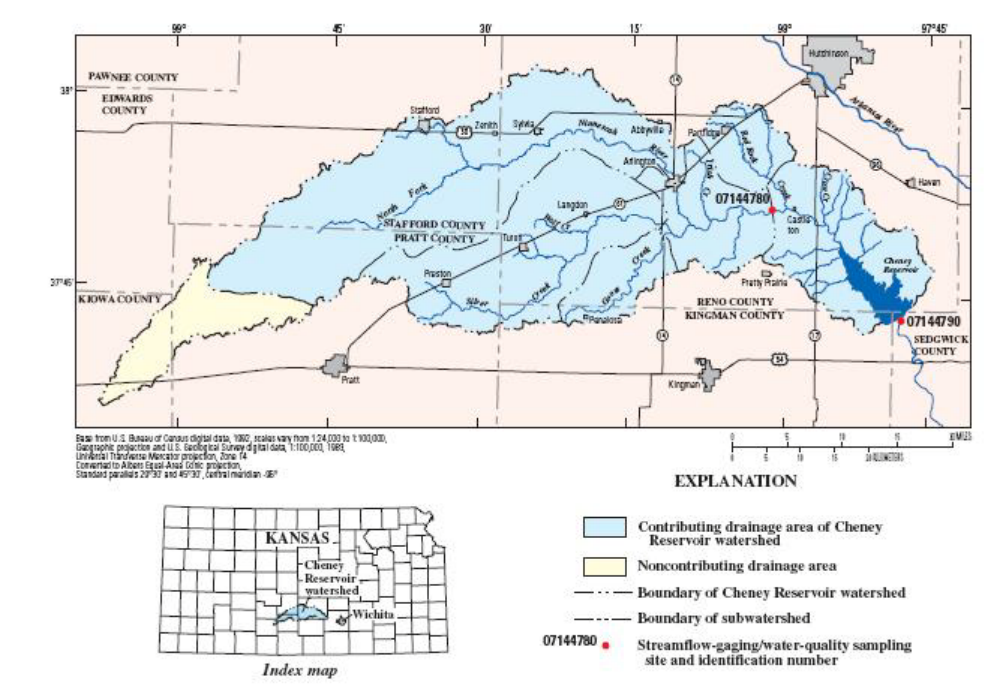
Cheney Reservoir and Watershed

- Watershed
  - Area: 933 mi^2
  - Crop and rangeland
  - Nutrient and Sediment Loads are of Non-point Origin
- Reservoir
  - Constructed 1965
  - Area: 7,663 acres
  - Maximum Depth: 13 m (43 ft)
  - Reservoir does not stratify
  - 303(d) listed for eutrophication and sediment
  - Mesotrophic-Eutrophic



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The City of Wichita is a Partner in Implementing Best Management Practices in the Watershed to Reduce Phosphorus and Sediment Loads to Cheney Reservoir

- Federal and State programs provide 70% to 80% funding for BMP implementation.
- City of Wichita provides missing cost share to minimize producer costs to install practice.
- Accomplishments:
  - 14 livestock waste-control systems
  - Nutrient management plans on 46,500 acres
  - 95 miles of terraces
  - 95 acres of grassed waterways
  - Conservation tillage

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CITY OF WICHITA

USGS Cheney Reservoir Watershed Studies

USGS science for a changing world

Prepared in cooperation with the
KANSAS WATER OFFICE and the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Sediment Deposition and Trends and Transport of Phosphorus and Other Chemical Constituents, Cheney Reservoir Watershed, South-Central Kansas

Water-Resources Investigations Report 01–408

U.S. Department of the Interior
U.S. Geological Survey

USGS science for a changing world

Prepared in cooperation with the
CITY OF WICHITA, KANSAS

Significant Findings of Water-Quality Studies and Implications for Cheney Reservoir Watershed, South-Central Kansas, 1996–2001

—Larry M. Pope

Water-quality issues in the Cheney Reservoir watershed were investigated from 1995 to 2001 as part of a cooperative effort between the U.S. Geological Survey (USGS) and the city of Wichita, Kansas. Water quality in the Cheney Reservoir watershed is important because much of the population of the area, which includes the Wichita metropolitan area, relies on Cheney Reservoir as a drinking-water source and for recreational activities. Water-quality studies conducted during the investigation addressed the transport of important water-quality constituents that included nutrients (nitrogen and phosphorus species), pesticides, bacteria, and suspended solids. Conclusions drawn for most water-quality studies conducted in the Cheney Reservoir watershed were the result of samples collected at six surface-water-quality sampling sites (five upstream and one downstream from Cheney Reservoir) and reservoir-sediment and watershed-soil studies (fig. 1).

The water-quality studies are documented in the reports referenced in this fact sheet. Reports of all of these studies are available on the World Wide Web at http://ks.water.usgs.gov/Kansas/qw/cheney/

Prepared in cooperation with the
CITY OF WICHITA, KANSAS

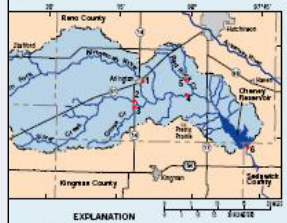
Occurrence of Fecal Coliform Bacteria in the Cheney Reservoir Watershed, South-Central Kansas, 1996–98

—David P. Mau and Larry M. Pope

The sanitary quality of water and its use as a public-water supply and for recreational activities, such as swimming, wading, boating, and fishing, can be evaluated on the basis of fecal coliform bacteria. The presence of fecal coliform bacteria indicates contamination by fecal material of human and (or) animal origin and the possible presence of pathogenic [illegible]

drinking-water supply (Jerry Blain, city of Wichita, Kansas, Water and Sewer Department, oral commun., 1999), the city has a long-term interest in maintaining acceptable water quality in Cheney Reservoir. The city recognizes that the quality of water in the reservoir may be directly linked to the quality of streams in its watershed. The city's interest in Cheney Reservoir watershed includes (1) defining [illegible] conditions in the [illegible] and mass [illegible]uitments) and (2) [illegible]istance to the [illegible]ed for [illegible]age-control [illegible] management [illegible]ity of Wichita, [illegible]r Department, oral [illegible]econd area of [illegible]rough the efforts of the Citizen's Management Committee established to serve as a liaison between the city and landowners and to identify those areas where economic assistance may produce the greatest water-quality benefit (Jerry Blain, city of Wichita, Kansas, Water and Sewer Department, oral commun., 1999).

A lack of historic water-quality data within the watershed led to a cooperative agreement in 1996 between the U.S. Geological Survey and the city of Wichita, with technical assistance provided by the Bureau of Reclamation, U.S. Department of the Interior, to define surface-water quality in the Cheney Reservoir watershed (Pope and Christensen, 1997). Many constituents, including fecal coliform bacteria, were analyzed at six sampling sites (fig. 1, table 1) to evaluate water-quality conditions within the watershed.



USGS Fact Sheet 170–99
December 1999

USGS science for a changing world

Prepared in cooperation with the
CITY OF WICHITA, KANSAS

Occurrence of Pesticides in Streams of the Cheney Reservoir Watershed, South-Central Kansas, 1997–99

—Chad R. Milligan and Larry M. Pope

The quality of water in the Cheney Reservoir watershed in south-central Kansas is important to about 300,000 people in the Wichita area that rely on the reservoir as a source of drinking water. About 52 percent of the watershed is used for the production of grain crops, which generally rely on the use of pesticides for efficient production. Some pesticides subsequently may be transported in runoff water to Cheney Reservoir. The potential exposure to pesticides is of concern. The purpose of this fact sheet is to describe the occurrence of pesticides in streams within the Cheney Reservoir watershed. Pesticide concentrations are compared with Federal water-quality criteria for pesticides such that public and private organizations can evaluate the potential risks from pesticide exposure.

Background

The use of pesticides in agriculture has existed for much of the 20th century. In particular, the past 50 years has been a period of ever-increasing reliance on pesticides in an integrated system of pest management, nutrient supplementation, and irrigation in agricultural production.

Pesticide application (mainly herbicides and insecticides) creates the potential for chemical transport into environmental settings for which pesticides were not originally intended. Runoff from agricultural fields can move pesticides into surface-water systems where they may have adverse effects on aquatic life or contaminate drinking-water supplies. The movement of pesticides into and through shallow ground-water systems may contaminate those systems and affect their use as a drinking-water supply or ultimately may be discharged into surface-water systems.

In 1996, the U.S. Geological Survey (USGS) entered into a cooperative study with the city of Wichita, Kansas, with technical assistance from the Bureau of Reclamation, U.S. Department of the Interior, to define surface-water-quality characteristics of the Cheney Reservoir watershed. The purposes of the study are to:

- Describe spatial variations in concentration and load characteristics for selected water-quality constituents;
- Evaluate annual loading of selected constituents into and out of Cheney Reservoir;
- Determine the occurrence of pesticides in surface water within the Cheney Reservoir watershed.

This information will be used by the city of Wichita, which obtains 40 to 60 percent of its daily water supply from Cheney Reservoir (Jerry Blain, city of Wichita Water and Sewer Department, oral commun., 1997), to evaluate the water-quality characteristics of this valuable resource for current (2000) and future suitability as a water supply. The information also will be used by the Citizen's Management Committee, a committee of landowners within the Cheney Reservoir watershed, to evaluate the effectiveness of implemented watershed-management practices in mitigating surface-water contamination by agricultural chemicals. This fact sheet relates to the third study purpose listed; it describes the occurrence of pesticides in streams within the Cheney Reservoir watershed during 1997–99 in relation to Federal water-quality criteria.

Methods of Study

A network of six streamflow-gaging/water-quality sampling sites was

Rod Rock Creek near Pretty Prairie, Kansas, 1998. Photograph by Chad Milligan.

U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 096–00
July 2000

USGS science for a changing world

Prepared in cooperation with the
CITY OF WICHITA, KANSAS

Sources and Concentrations of Phosphorus in the Cheney Reservoir Watershed, South-Central Kansas

—Larry M. Pope and Chad R. Milligan

Significant Findings

- *Human-related activities in the predominantly agricultural watershed of Cheney Reservoir have substantial effects on the quality of water in the reservoir.*
- *Agricultural activities have accounted for 65 percent of the phosphorus transported by streams to Cheney Reservoir, and most of that phosphorus was transported when streamflow consisted predominantly of runoff from agricultural fields.*
- *On a long-term basis, surface water from five water-quality sampling sites in the watershed exceeded the established goal for phosphorus by about two to five times.*
- *Substantial reductions in phosphorus concentrations in streams could involve a combination of approaches such as reducing the application of phosphorus in the watershed and more extensive implementation of land-management and agricultural practices to limit its movement to streams.*

Introduction

Phosphorus is a nutrient required by plants for growth and reproduction and often is added to agricultural soils to increase crop yields. However, the agricultural application of phosphorus historically has been greater than crop requirements and has led to a buildup of soil phosphorus (Carpenter and others, 1998). The buildup of soil phosphorus has increased the potential for phosphorus transport to surface water in runoff from agricultural fields (Sharpley and others, 1999).

Excess phosphorus in surface water may contribute to eutrophication (nutrient enrichment) of surface water, particularly lakes and reservoirs. Nutrient enrichment can overstimulate algal production creating algal blooms that may reduce the aesthetic and recreational value of the water, create taste-and-odor problems in drinking water, and, in severe cases, stress or kill aquatic organisms as a result of dissolved oxygen depletion or the release of toxins when algal blooms die (Sharpley, 1995).

The Cheney Reservoir watershed is a 933-square-mile contributing drainage area of Cheney Reservoir located on the North Fork Ninnescah River in an agricultural area of south-central Kansas (fig. 1). The watershed is used almost exclusively for crop and livestock production. Since 1965 when Cheney Reservoir was constructed, the percentage of the watershed used for crop production has averaged about 52 percent annually. Cattle inventories have averaged about 64,000 animals since 1965. Crop production and cattle inventories were estimated from county data presented in Kansas State Board of Agriculture and U.S. Department of Agriculture (1964–94) and Kansas Department of Agriculture and U.S. Department of Agriculture (1995–97).

The human population in the Cheney Reservoir watershed is less than 4,000, many of whom are associated with the approximately 1,000 farms in the watershed (Cheney

Holmesmoss Point at Cheney Reservoir, April 2001.

U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 016–02
March 2002

USGS

http://ks.water.usgs.gov/Kansas/studies/qw/cheney

CITY OF WICHITA

Key Findings from Watershed Studies 1996-2001: Phosphorus Transport from the Watershed Has Been Increasing Over Time

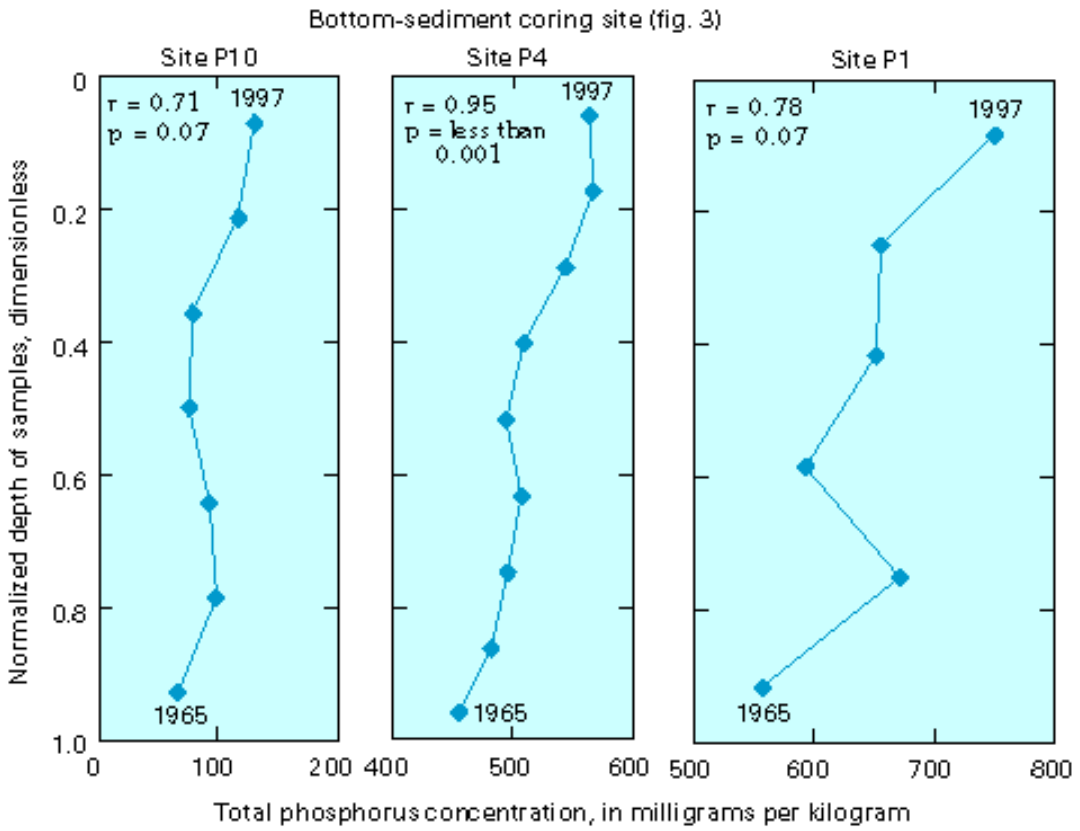


Figure 9. Relation between total phosphorus concentrations in bottom-sediment core samples and normalized depth of samples from selected coring sites in Cheney Reservoir, 1965-97 (modified from Pope, 1998, fig. 10). Sediment cores were collected in August 1997.

From Mau, 2001

Key Findings from Watershed Studies 1996-2001: Agricultural Activities Account for 65% of the Phosphorus Transported to Cheney Reservoir

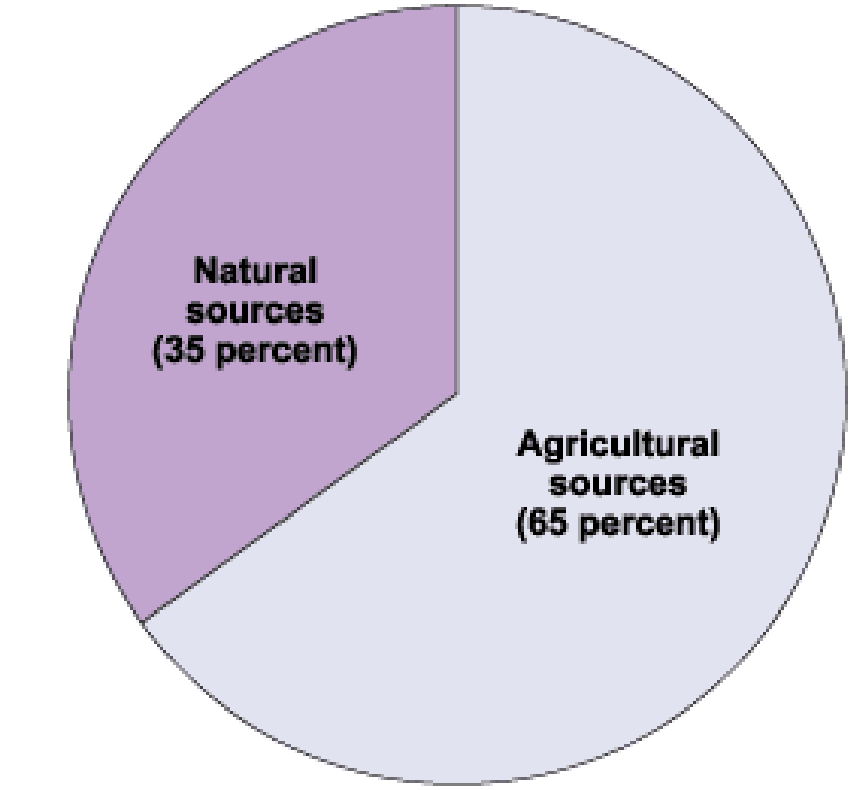


Figure 2. Percentages of phosphorus transported to Cheney Reservoir from natual and agricultural sources, 1965-98.

From Pope and others, 2002

Key Findings from Watershed Studies 1996-2001:Mean Concentrations of Total Phosphorus Exceeded Water-Quality Goals

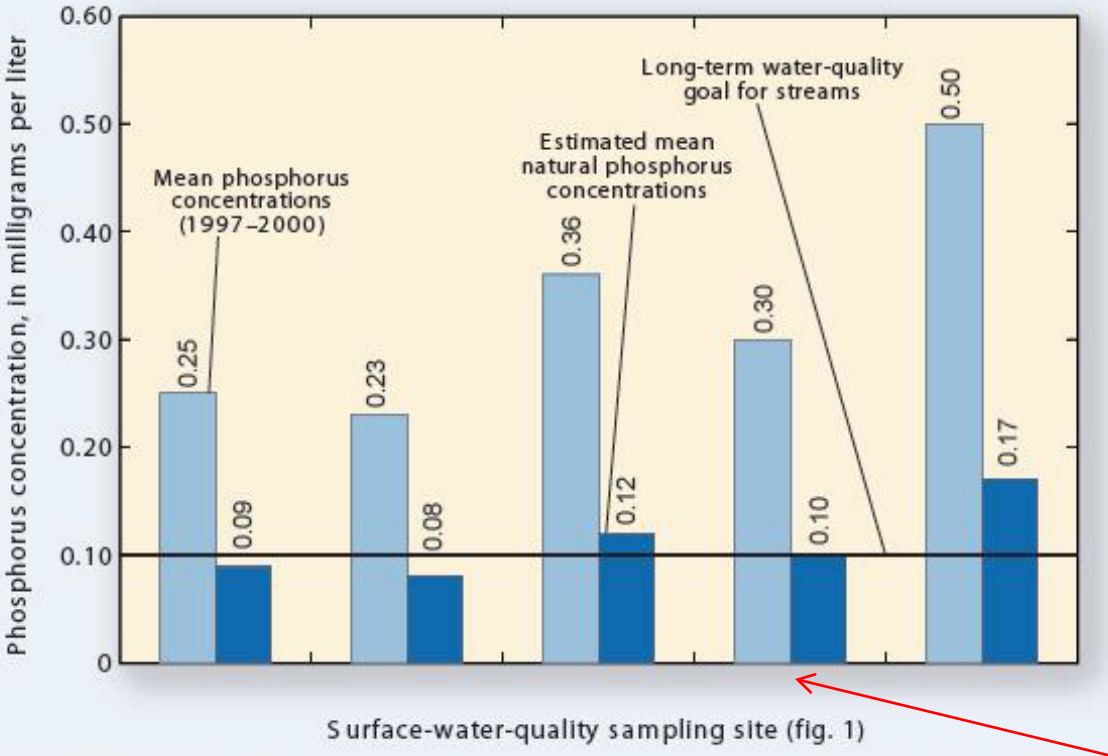


Figure 2. Comparison of mean phosphorus concentrations in water samples from five surface-water-quality sampling sites in Cheney Reservoir watershed to mean concentrations estimated on the basis of an agricultural-enrichment factor of 2.9. The long-term water-quality goal for phosphorus in streams was established by the Cheney Reservoir Watershed Task Force Committee.

Cheney Reservoir inflow site

From Pope, 2002

Key Findings from Watershed Studies 1996-2001: 4% of the Original Water Storage Capacity of the Reservoir Has Filled

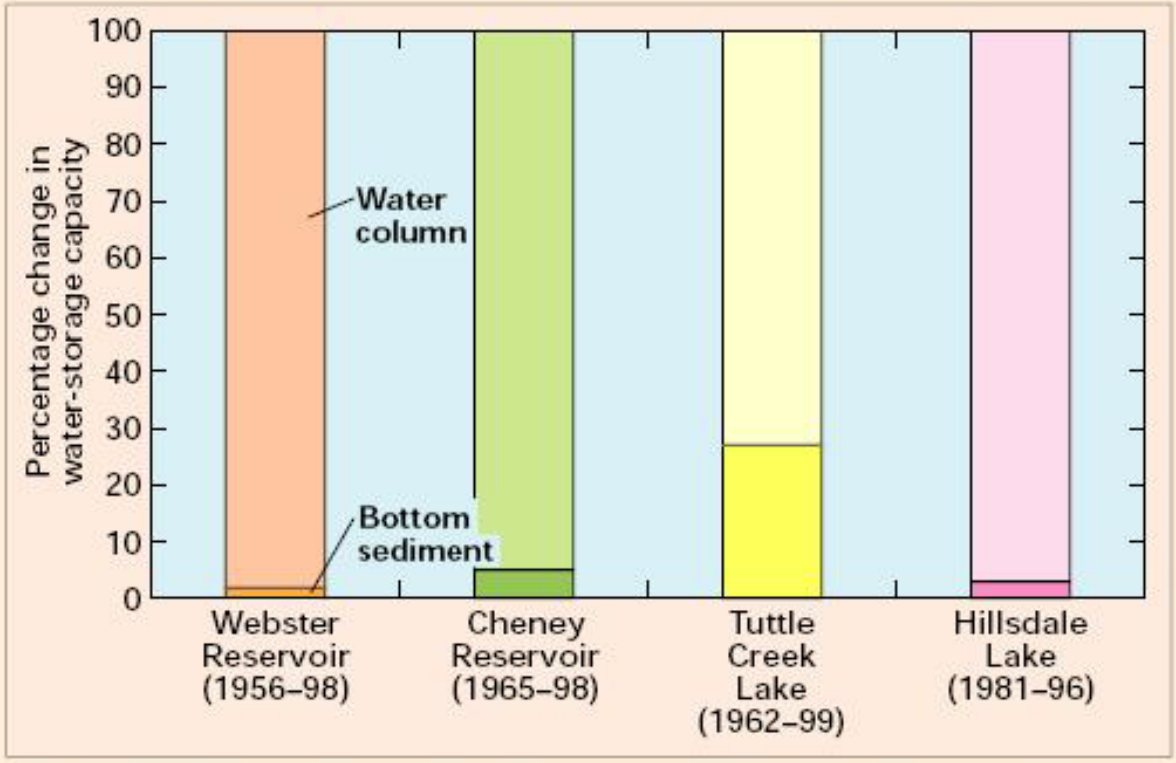


Figure 3. Sediment deposition has caused almost a 27-percent decrease in water-storage capacity in Tuttle Creek Lake, whereas decreases in water-storage capacities in Webster Reservoir, Cheney Reservoir, and Hillsdale Lake were 5 percent or less.

From Mau and Christensen, 2000

Cheney Reservoir Study Objectives
2001-present

- Relate real-time water-quality variables to algal community dynamics and taste-and-odor episodes
- Assess annual and seasonal water-quality conditions in the reservoir and inflow sites as related to cyanobacterial taste-and-odor compounds and other algal-related by-products
- Describe water-quality dynamics in the photic zone to provide an understanding of algal growth and production of taste-and-odor compounds associated with cyanobacteria
- Determine relations between algal community dynamics and the production of taste-and-odor compounds and other algal-related by-products
- Provide a long-term data base with which to verify and refine observed relations between water-quality variables, algal community dynamics, and algal by-products

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Continuous Real-Time Water-Quality Monitoring

- North Fork Ninnescah (Cheney Inflow) - October 1998
  - Specific conductance, pH, water temperature, turbidity, dissolved oxygen
- Cheney Reservoir (near water supply intake) - March 2001
  - Specific conductance, pH, water temperature, turbidity, dissolved oxygen
  - *In situ* fluorescence (chlorophyll)
  - May 2005 – light penetration
  - March 2006 – second monitor near bottom, cyanobacteria, nitrate
  - Spring 2007 – wind speed and direction

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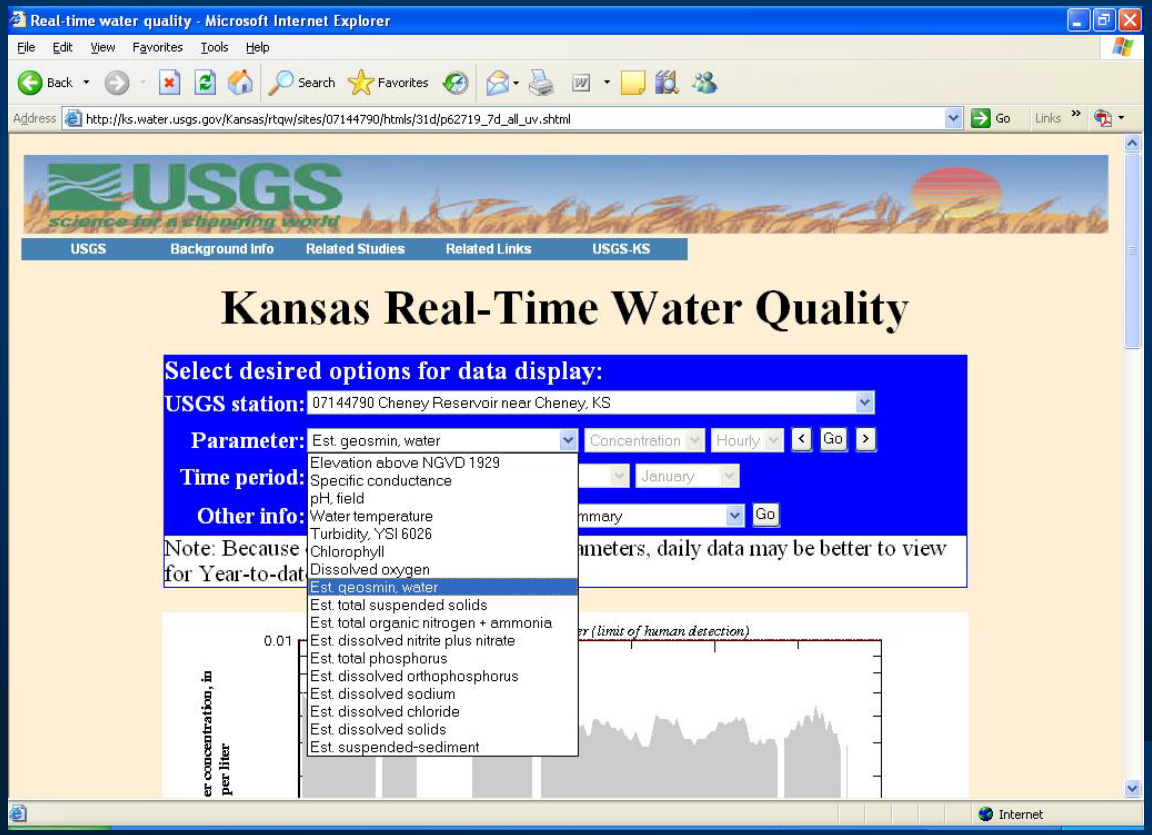
Real-time water-quality data

- Recorded hourly, transmitted every four hours
- Data can be used to develop relations to estimate concentrations of variables that can not be measured in real time
- Site specific models are available on the USGS RTQW web site (http://ks.water.usgs.gov/Kansas/rtqw/index.shtml); a new national RTQW web site will be public this spring (http://nrtwq.usgs.gov)



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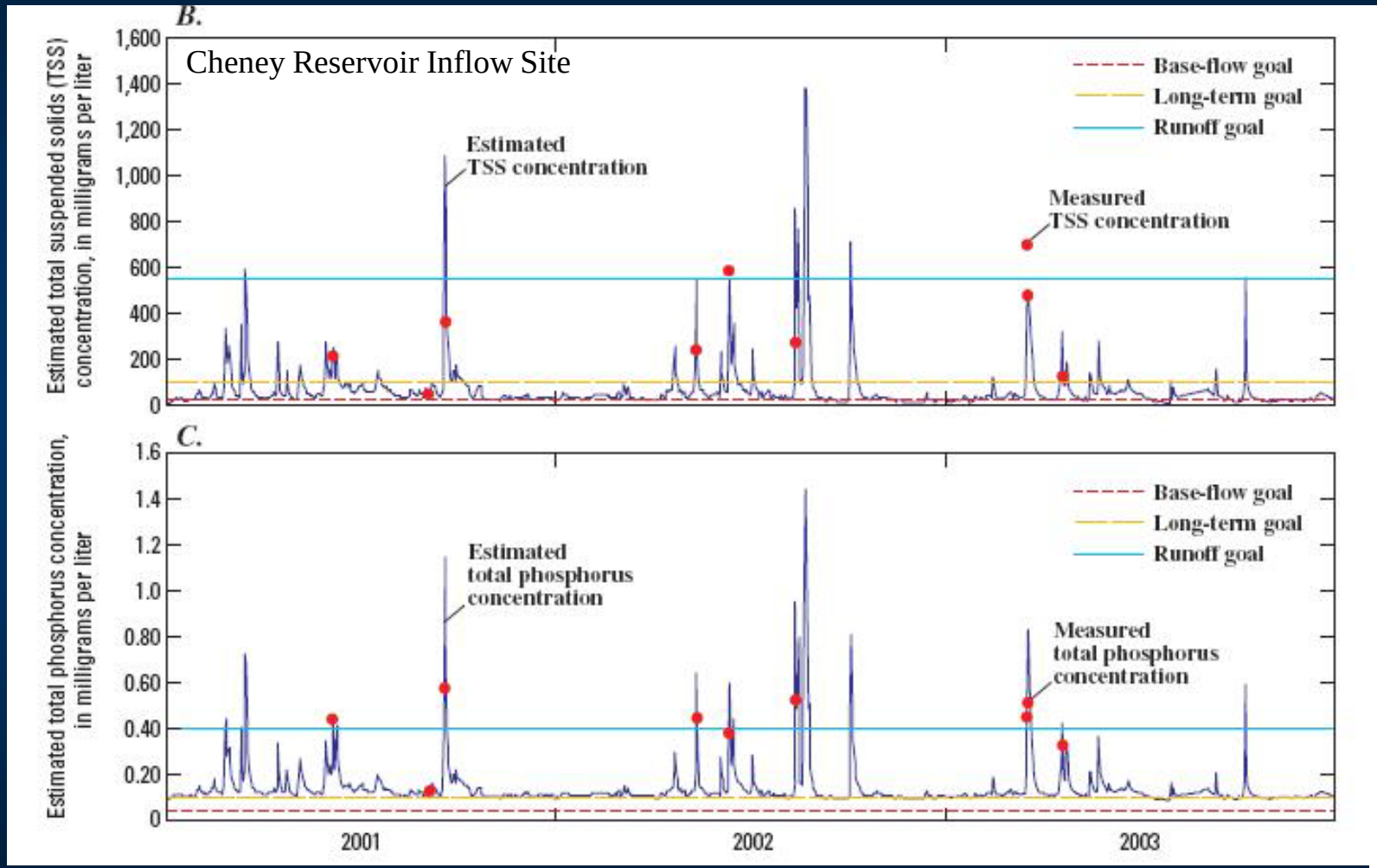
Continuous Estimates of Key Variables Can Be Compared to Water-Quality Goals



USGS

After Christensen and others, 2006

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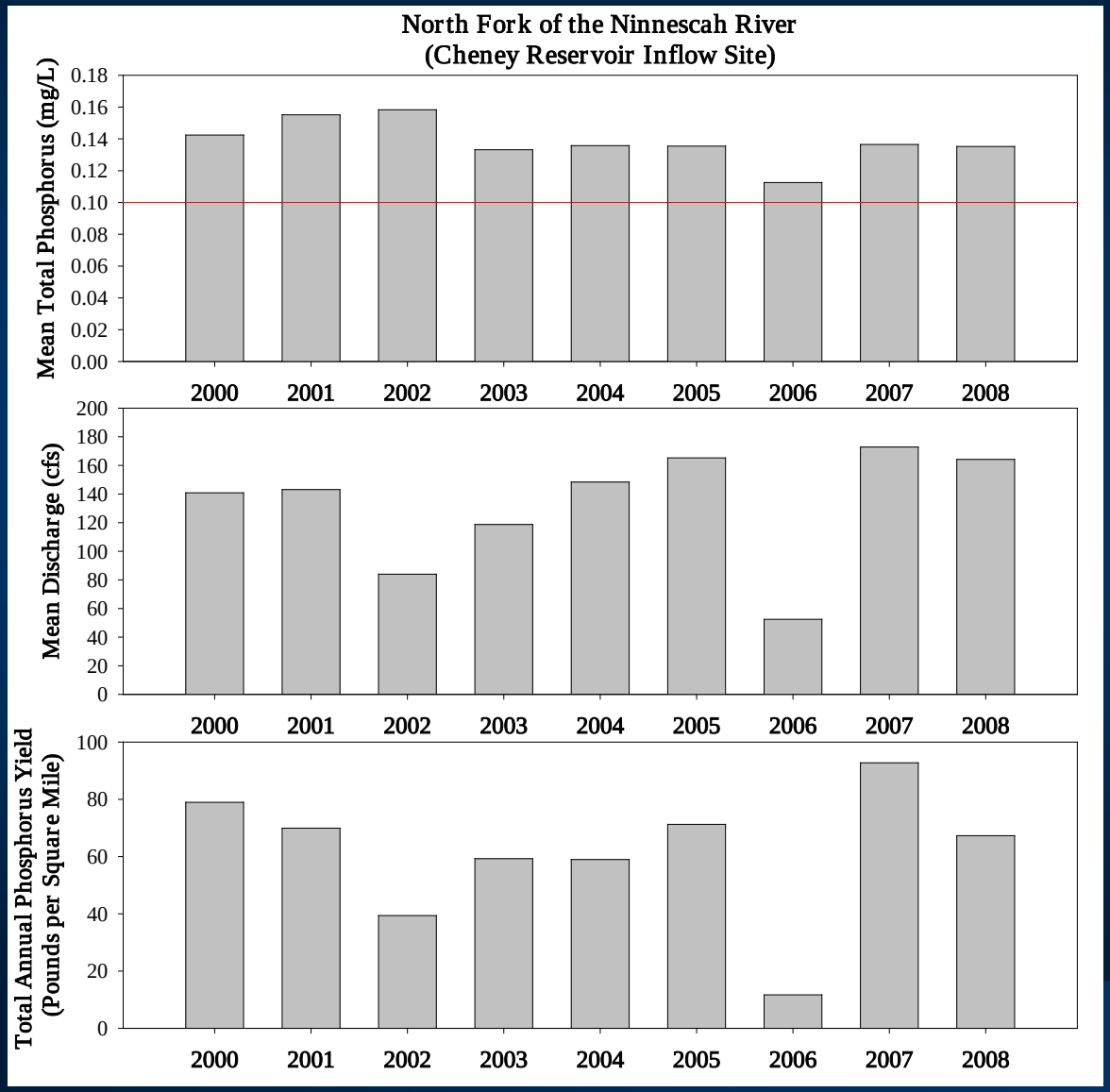
Continuous Estimates Can Be Used to Evaluate Temporal Changes in Concentrations and Loads



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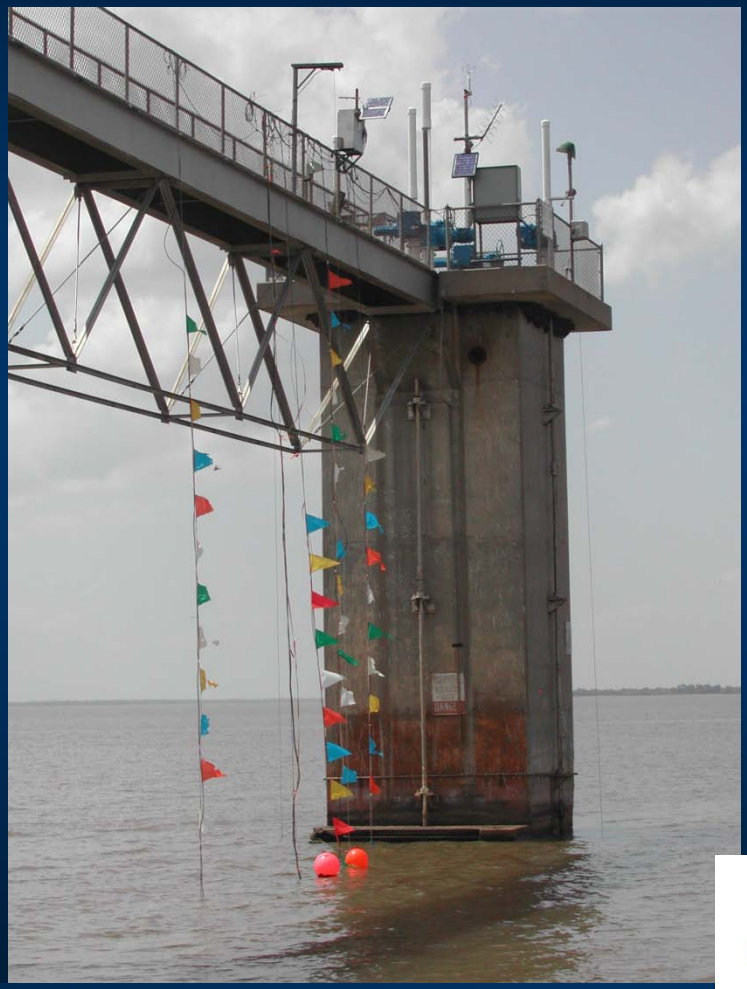
Real-Time Estimation of Geosmin Concentration
Data Collection 2001-2003

- March 2001 – July 2003
- Discrete Samples
  - Monthly May-September During 2001-2002
  - Monthly January-July During 2003
- Samples Analyzed for 38 Environmental Variables
  - Phytoplankton
  - Geosmin/MIB
  - Nutrients
  - Chlorophyll
  - Sediment



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During 2001-2003 Geosmin was Detected in 92% (n=25) of Samples and Concentrations Ranged from <3 to 113 ng/L

Variable	n	Median	Range
Geosmin (ng/L)	25	6	< 3-113
MIB (ng/L)	25	< 5	< 5-11
Total Phosphorus (mg/L)	33	< 0.03	< 0.03-0.15
Total Kjeldahl Nitrogen (mg/L)	19	0.63	0.46-1.40
Chlorophyll (µg/L)	34	6.7	0.5-26

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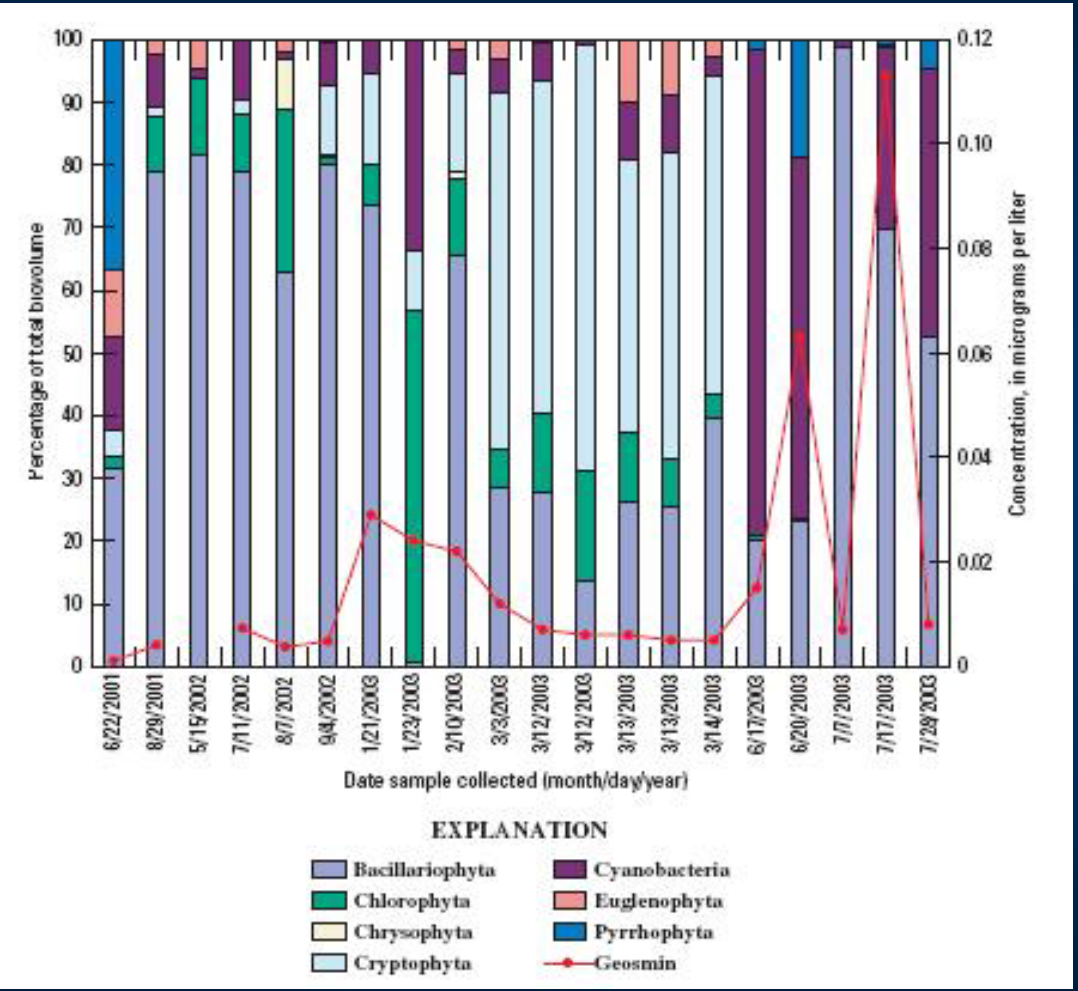
There Was No Clear Association Between Geosmin and Cyanobacterial Abundance



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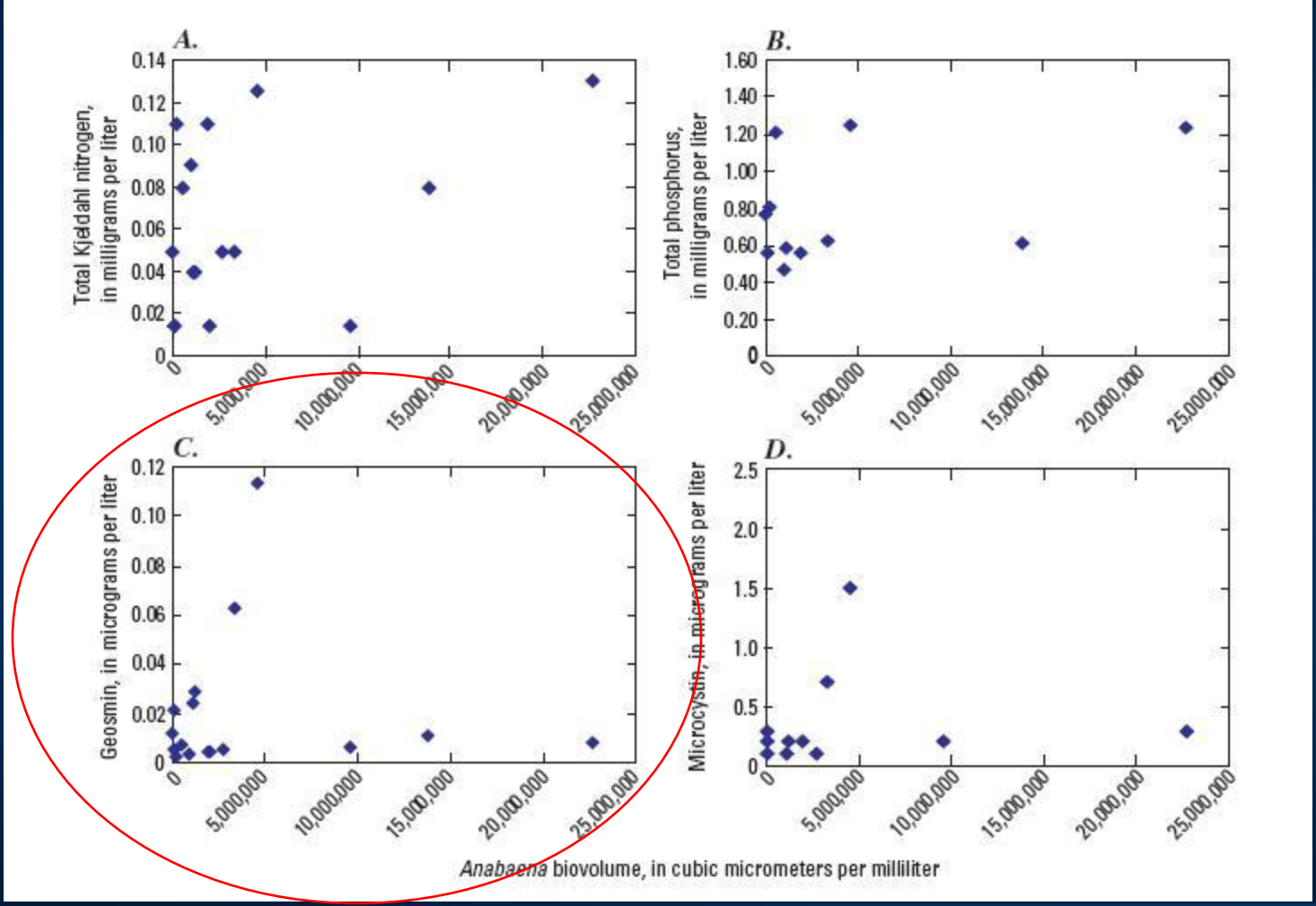
Geosmin was Not Linearly Associated with Anabaena Biovolume



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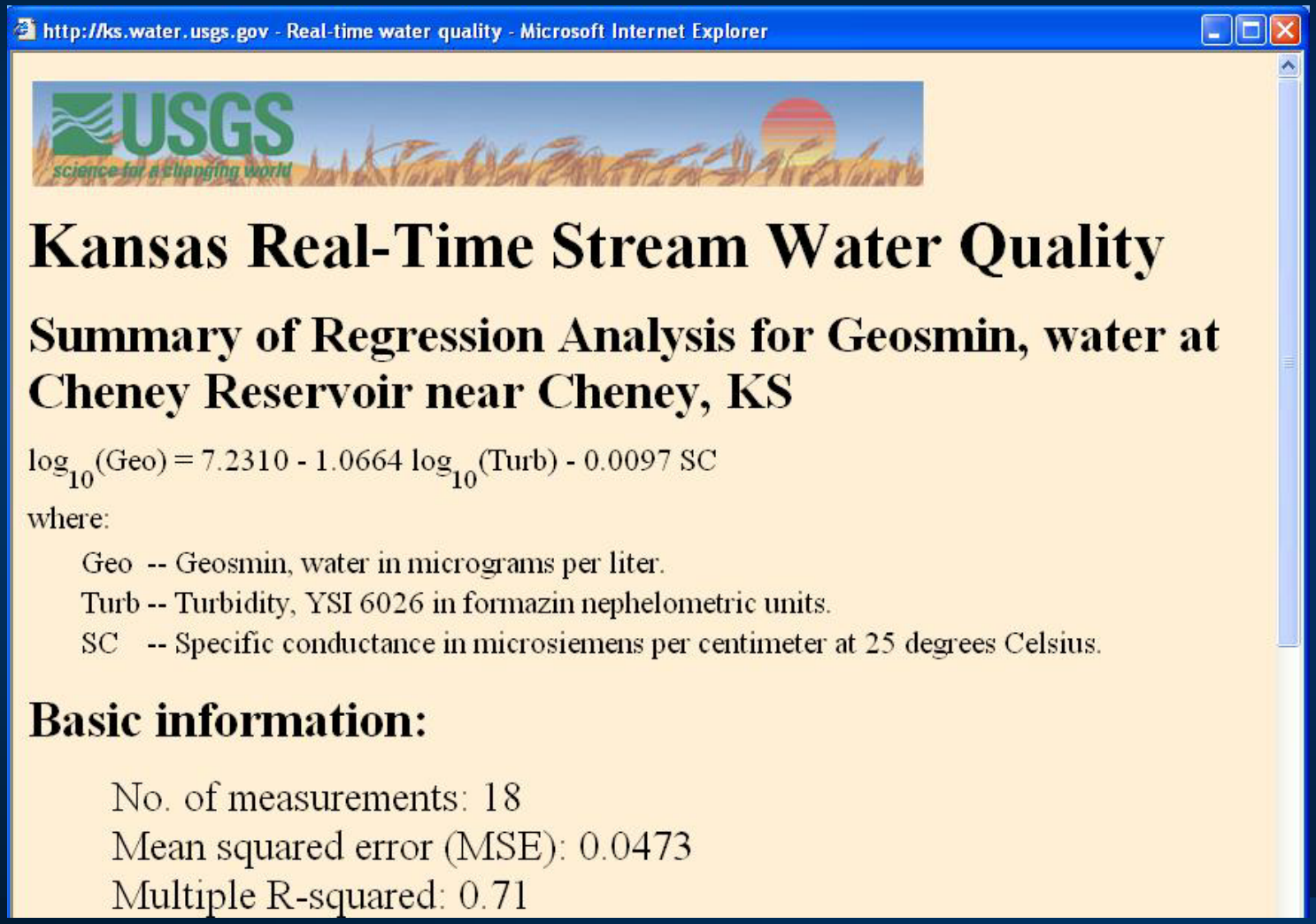
Multiple Regression Using Real-Time Variables Resulted in a Significant Model for Geosmin that Included Turbidity and Specific Conductance



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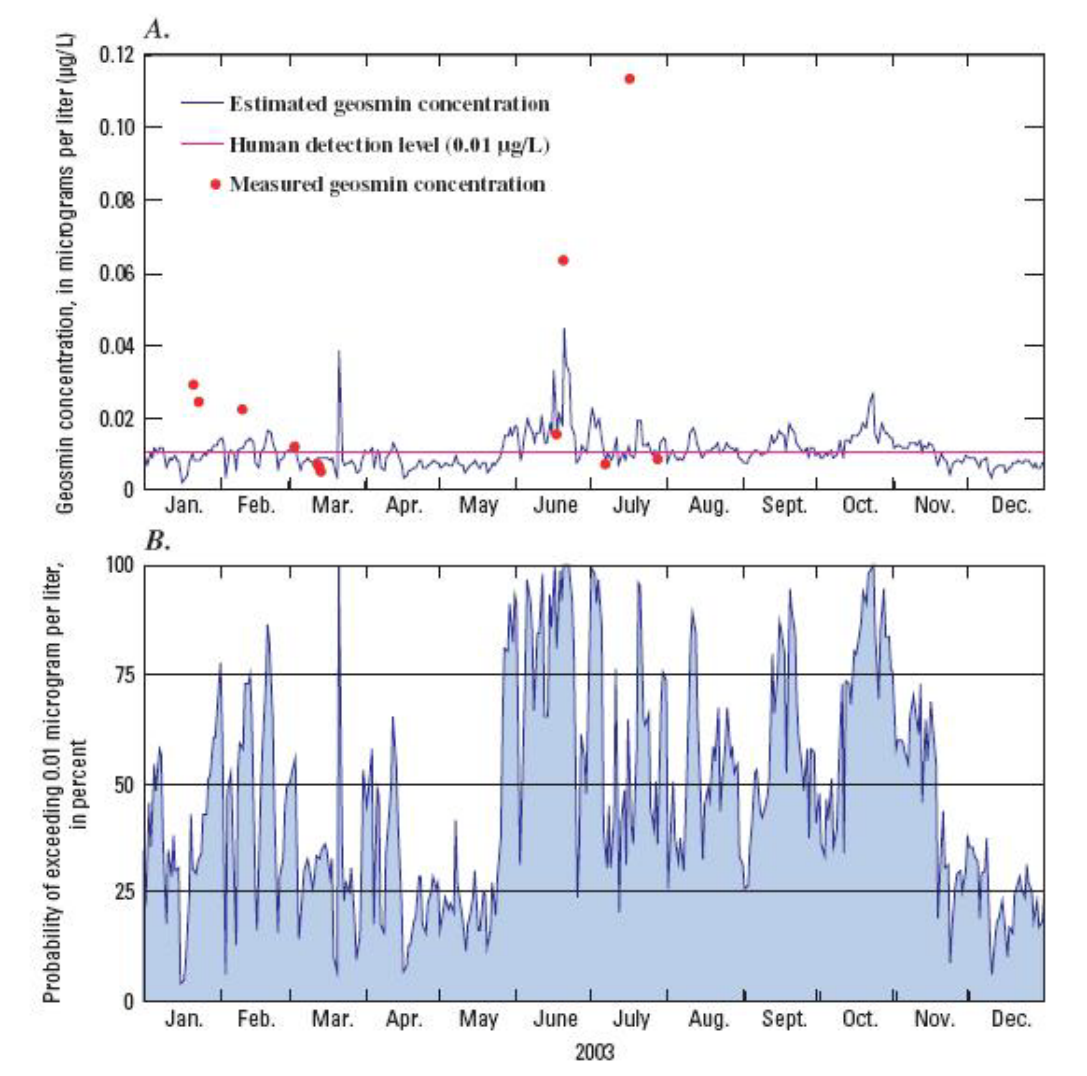
During 2003 Continuous Estimates of Geosmin Consistently Indicated When Geosmin Concentrations Would Exceed the Human Detection Limit of 10 ng/L



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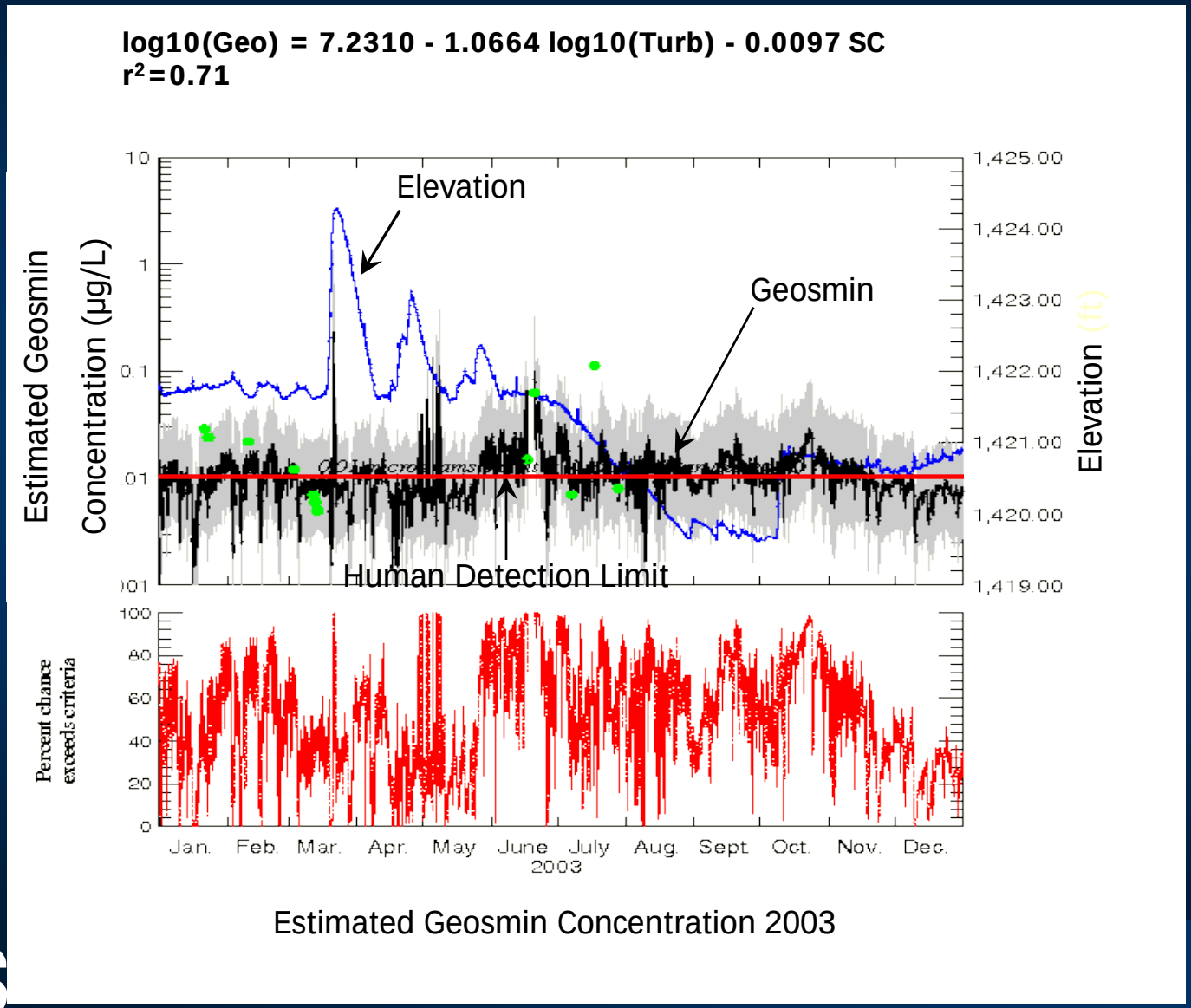
Continuous Estimates are Available in Real Time on the Web (http://ks.water.usgs.gov/Kansas/rtqw/index.shtml)



Estimated Geosmin Concentration 2003

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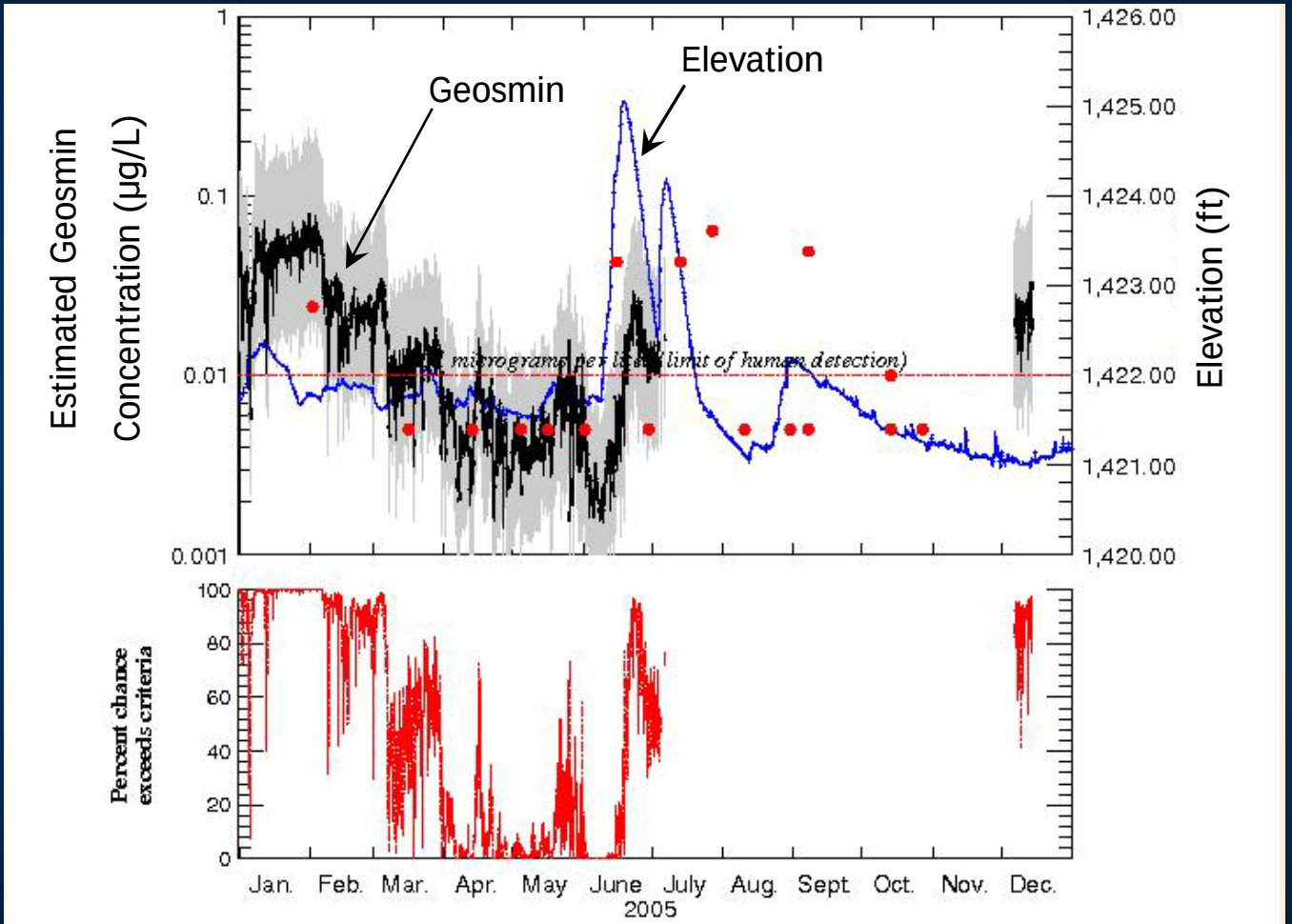
The Model Does Not Perform Well When Predictive Variables Were Outside of the Calibration Range



Estimated real-time geosmin, water concentration
in Cheney Reservoir near Cheney, KS
(No estimates are calculated when predictive variables are outside of the calibration range for the model.)

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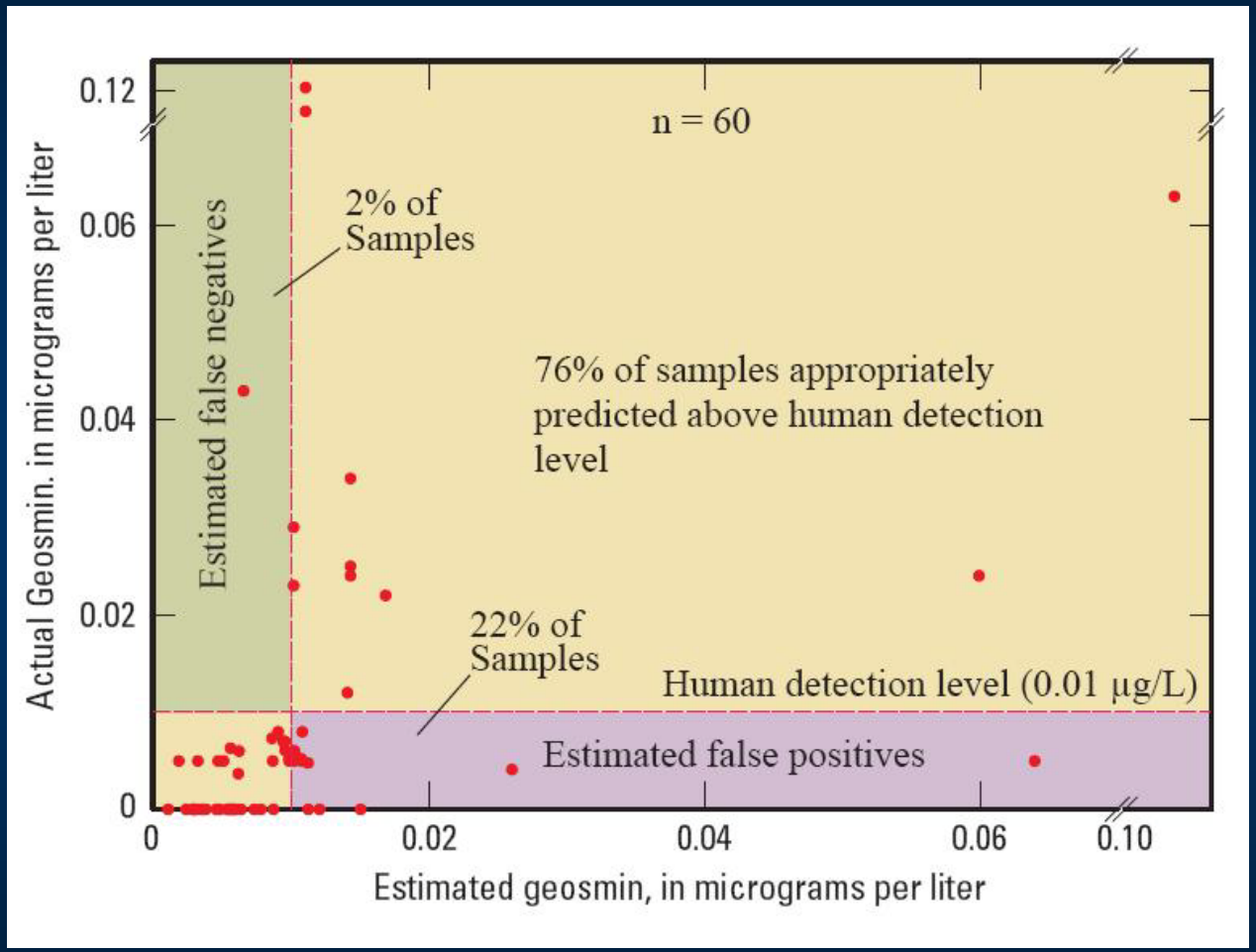
Within Existing Model Limits Geosmin Concentrations Were More Likely to Be Overestimated than Underestimated During 2001-2008



Model Limits:
Turbidity < 36 FNU
Specific Conductance 790-915 µS/cm

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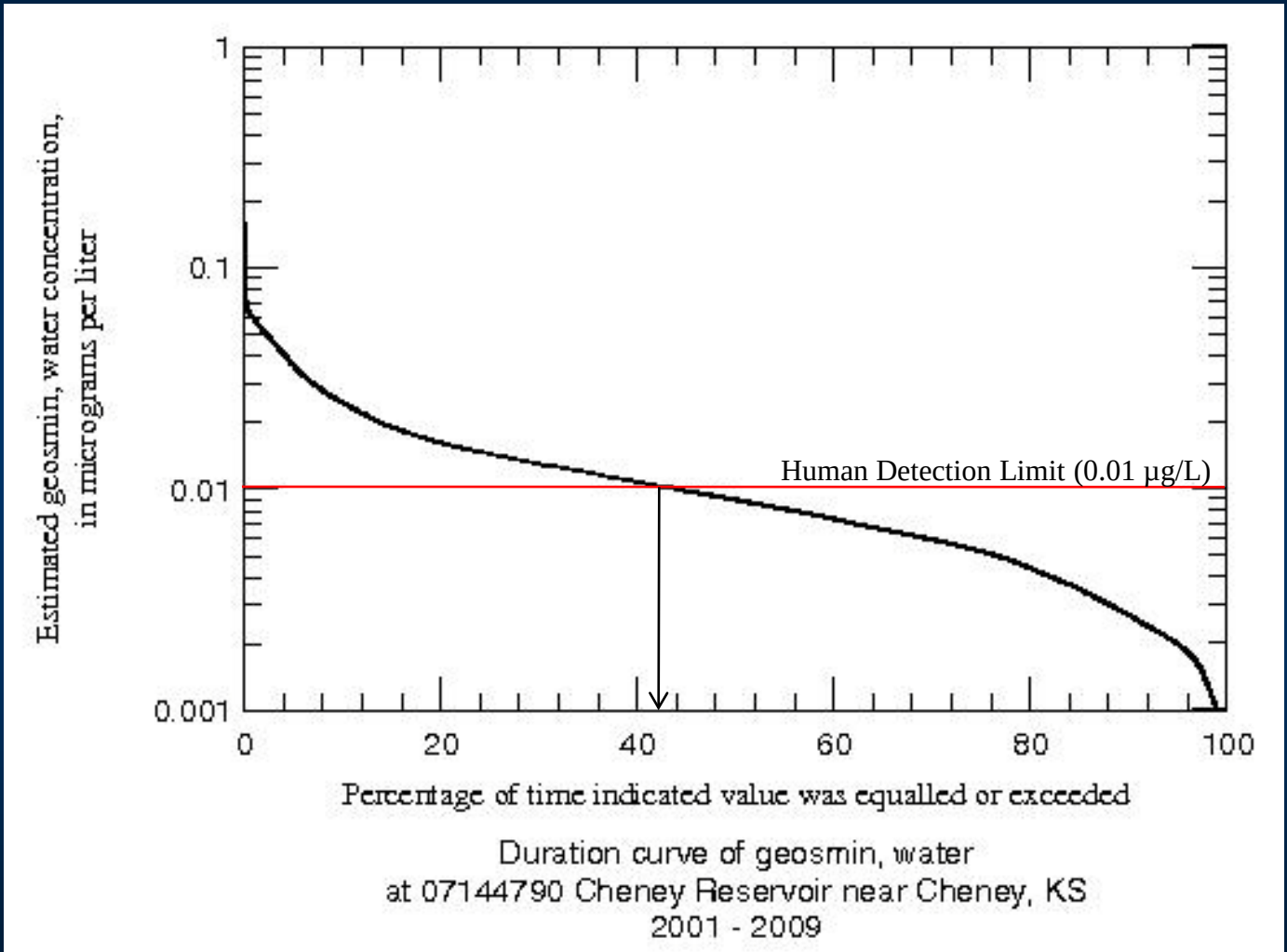
During 2001-2009 the Model Estimated Geosmin Concentration Would Be Above the Human Detection Limit About 40% of the Time



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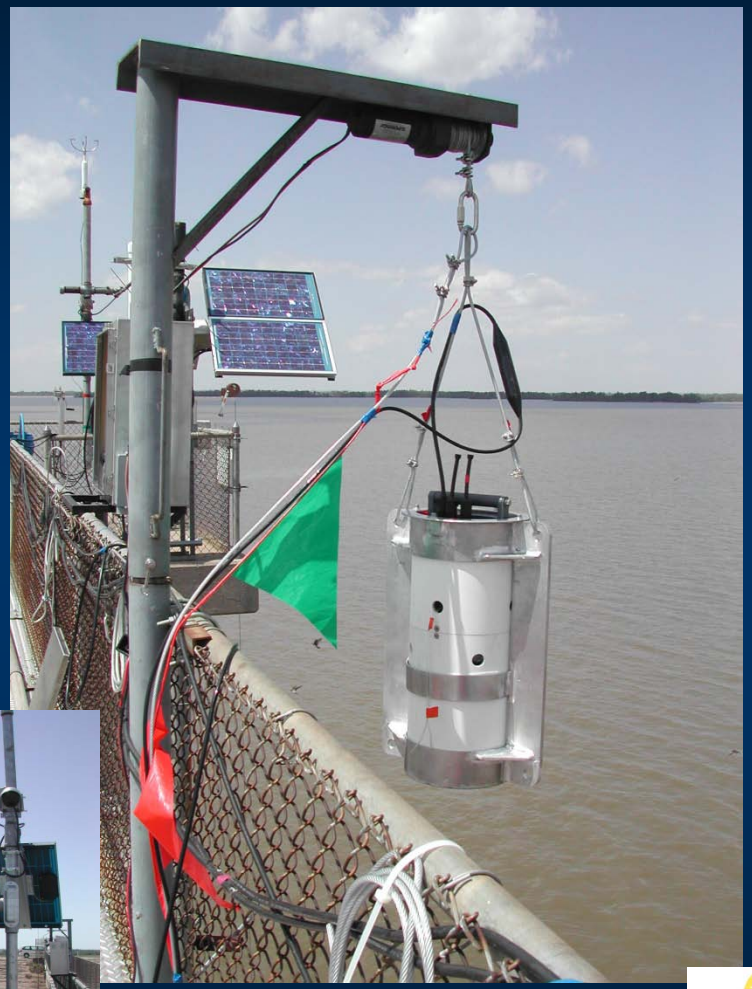
Real-Time Estimation of Geosmin is Promising

- **Refining the Existing Model**
  - Continue Water-Quality Monitoring, Operation of New Water-Quality Sensors
  - Incorporate Hydrologic and Meteorologic Data
  - Develop links between inflow and conditions in the reservoir
  - Actinomycetes Bacteria
  - Increased Sampling



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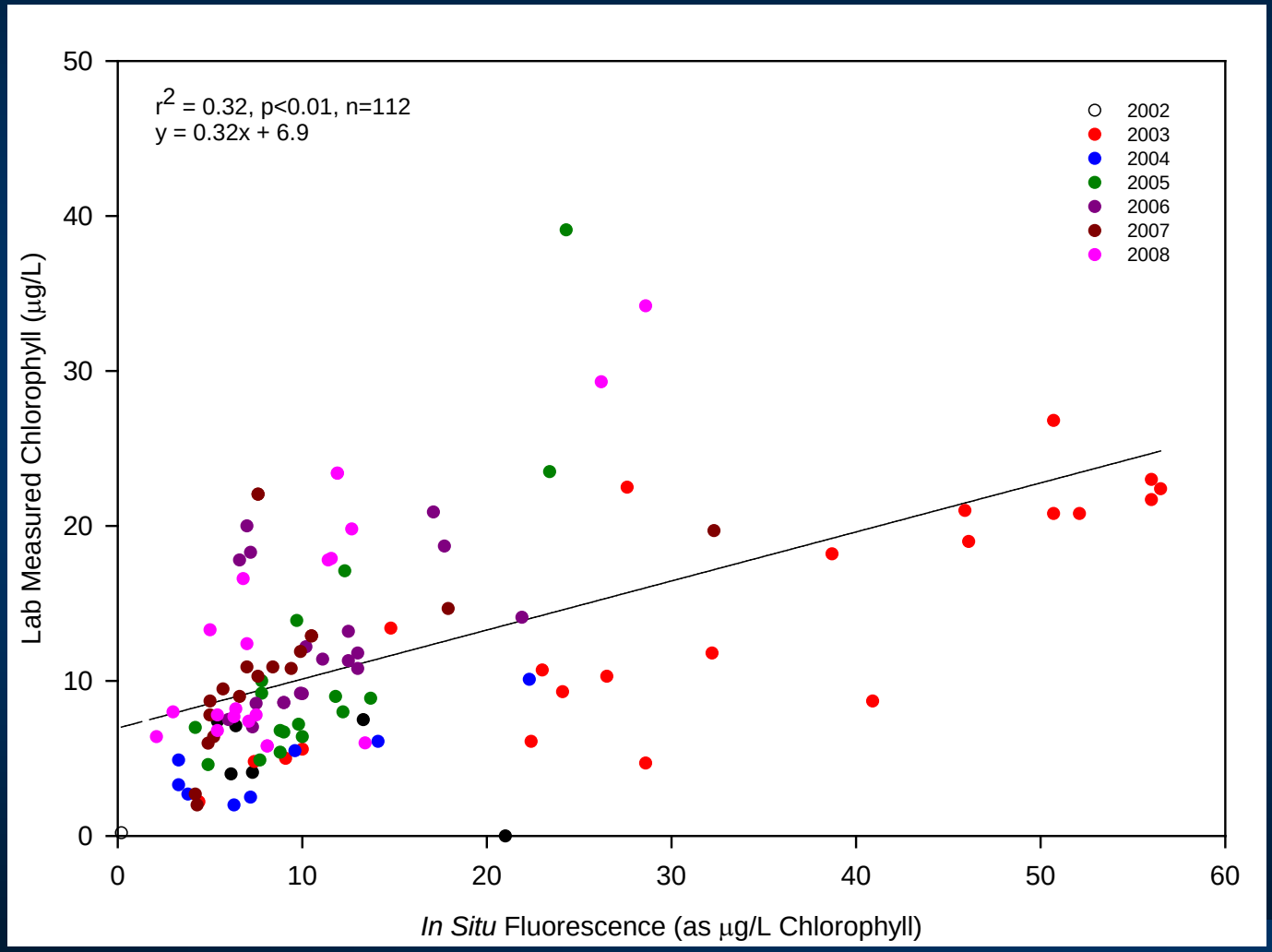
The Relation Between *In Situ* Chlorophyll Fluorescence and Laboratory Measured Chlorophyll May Vary Among Years and *In Situ* Values Do Not Accurately Estimate Laboratory Values



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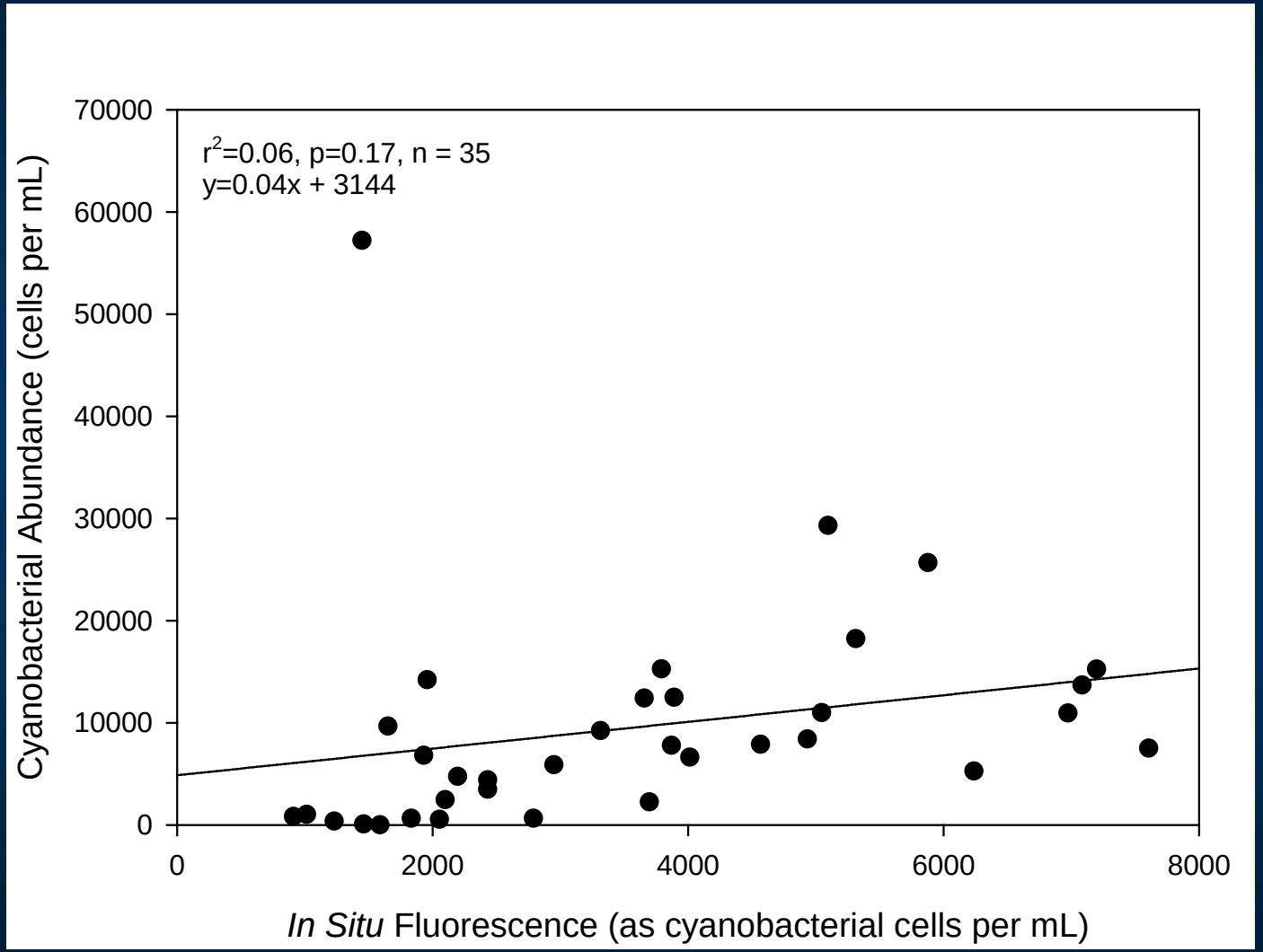
In Situ Cyanobacterial Fluorescence Does Not Accurately Estimate Cyanobacterial Abundance



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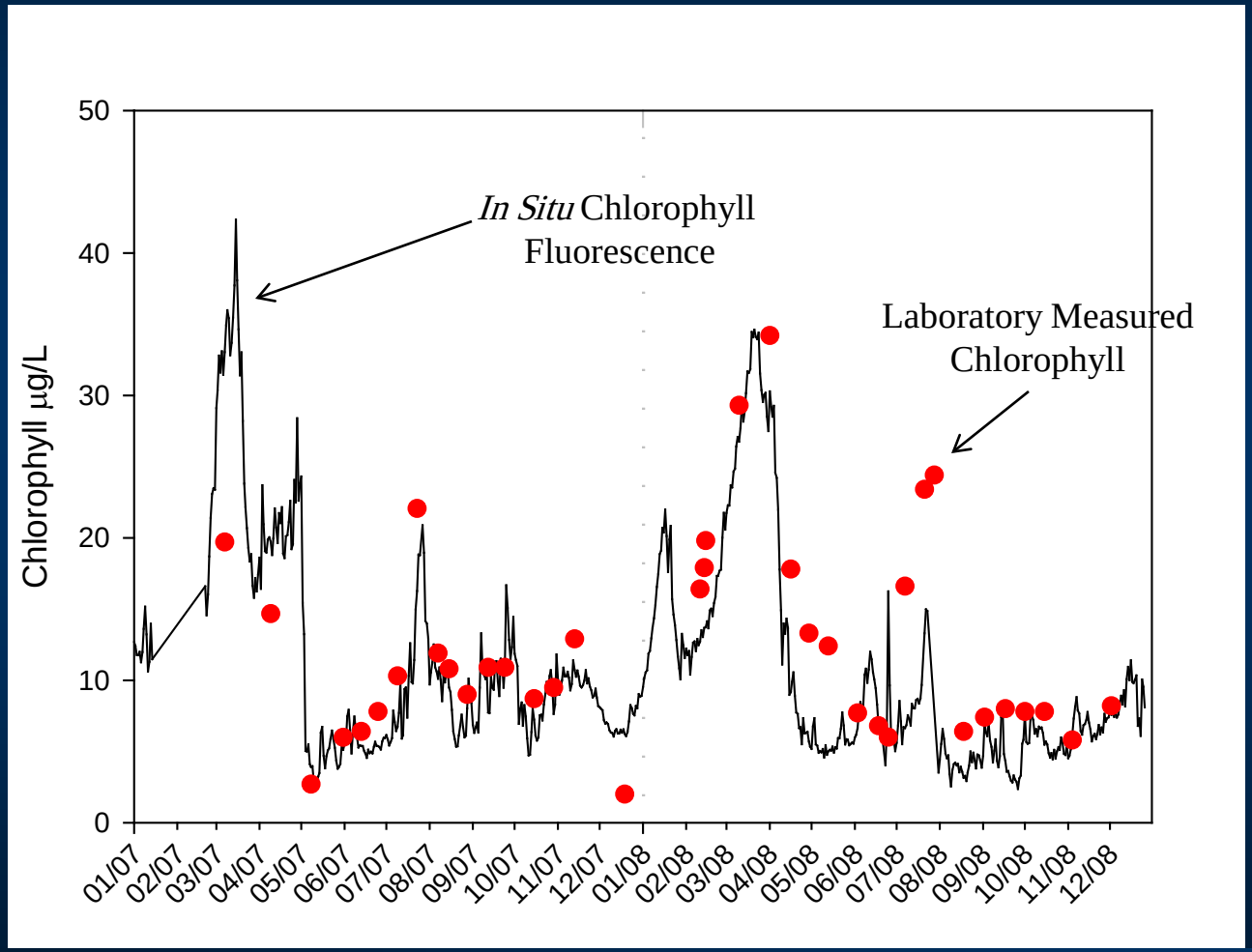
In Situ Chlorophyll Fluorescence Does Reflect Seasonal Patterns in Chlorophyll Concentration



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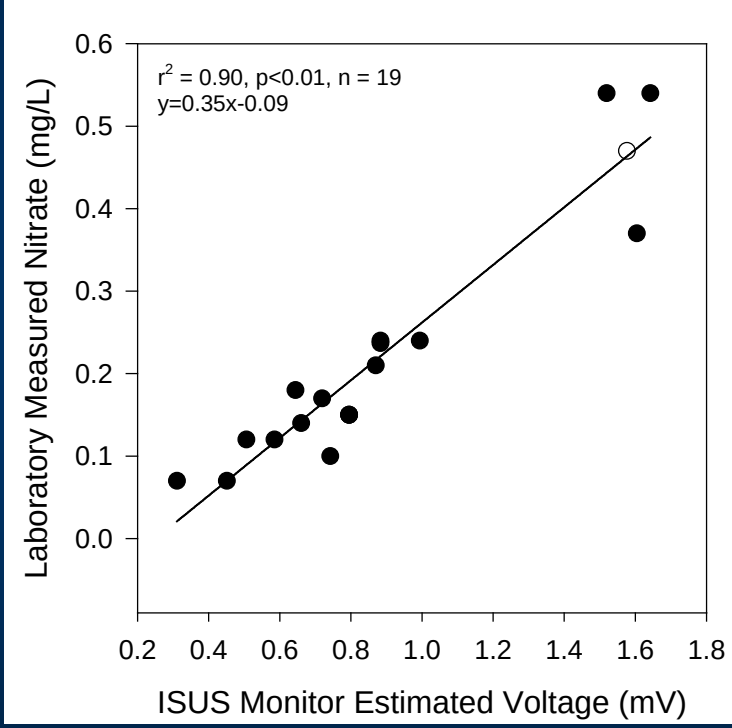
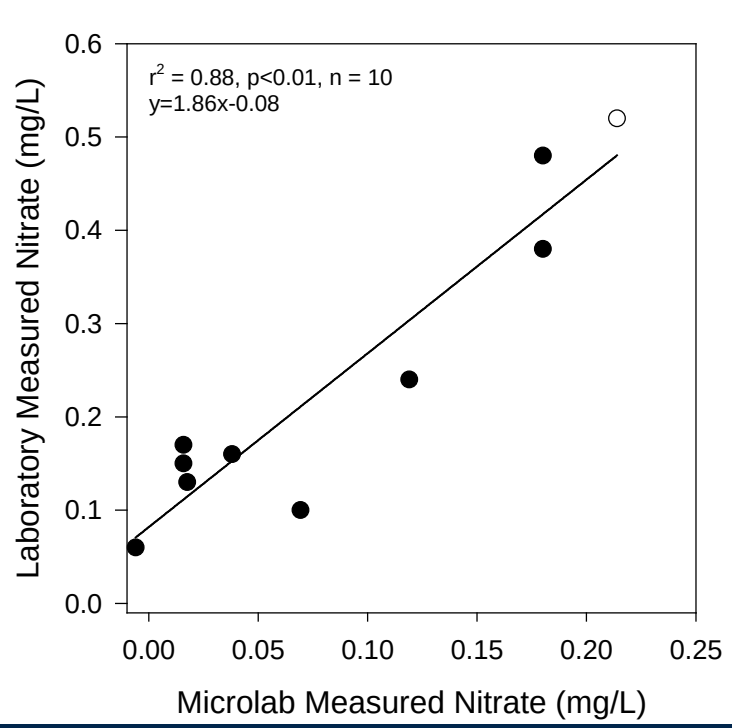
Field Estimated Nitrate Concentrations Are Linearly Related to Laboratory Measured Nitrate Concentrations





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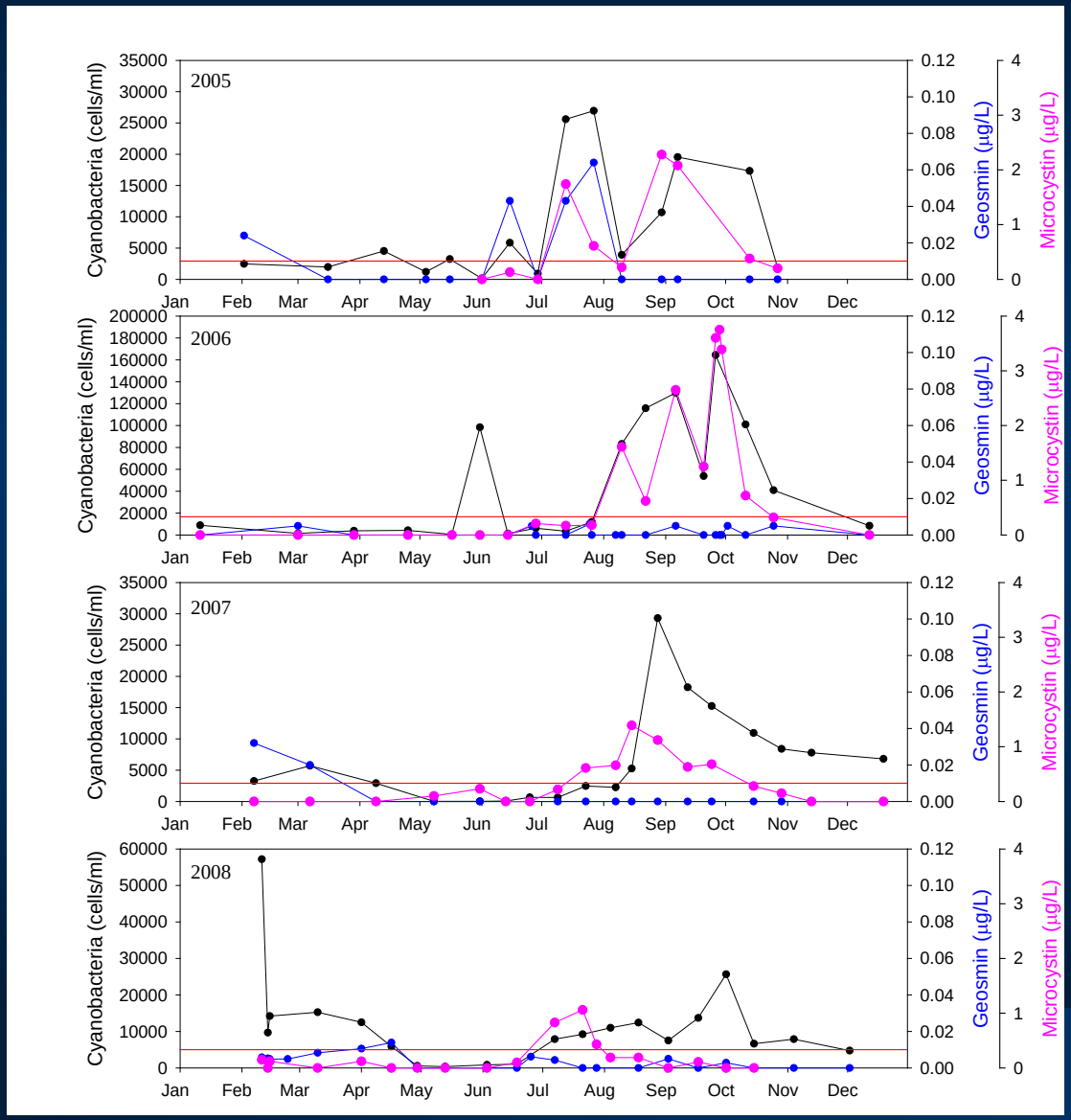
Seasonal Patterns in Occurrence of Cyanobacteria and Associated Toxins and Taste-and-Odor Compounds Vary Among Years



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Ongoing Studies

- Relations between cyanobacteria, toxins, and taste-and-odor compounds are complex and may vary over time.
- Model estimating geosmin concentrations in real time was developed for Cheney Reservoir.
- Continued data collection in the reservoir to refine existing geosmin model and develop models for cyanobacteria and the cyanotoxin microcystin.
- Continued data collection at the inflow site to evaluate changing water quality conditions and link inflow events to reservoir processes.

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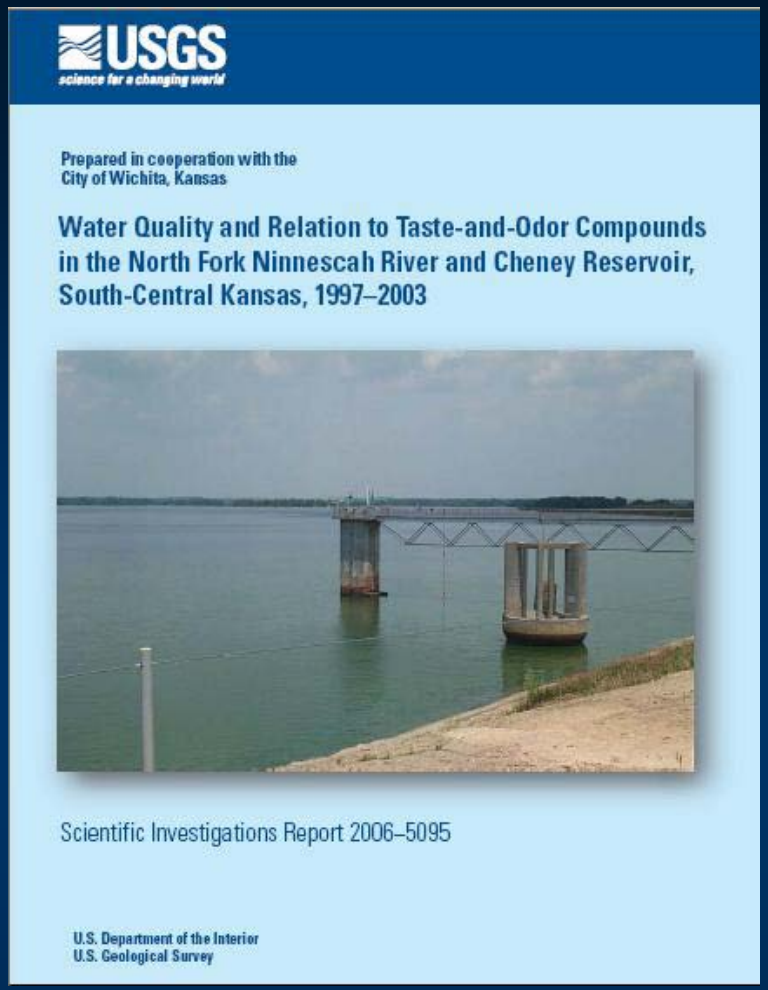

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Debra Ary, City of Wichita: dary@wichita.gov

Additional Information Available on the Web:
Cheney - http://ks.water.usgs.gov/Kansas/studies/qw/cheney
Cyanobacteria - http://ks.water.usgs.gov/Kansas/studies/qw/cyanobacteria
RTQW - http://ks.water.usgs.gov/Kansas/rtqw/index.shtml

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Literature Cited

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