USGS Drinking-Water Related Research, Data, and Tools

Association of State Drinking Water Administrators
Webinar series

Patty Toccalino, Mike Focazio, Neil Dubrovsky, and Ken Belitz
April 24, 2018

USGS drinking water activities

Water Quality & Quantity

National Water Quality Program

- Water-quality assessments at local, state, national scales
- Status & trends
- Understand factors affecting water quality
- Forecasting water quality

Environmental Health

Toxic Substances Hydrology & Contaminant Biology Programs

- Process-oriented exposure and health-related science
- Advanced analytical methods
- Understand transport of chemical & microbial hazards

Current & future environmental health work

- **Exposure-related work**
  - **Quantifying contaminant exposures to the public in drinking water pathways**
- **Effects of infrastructure (treatment, conveyance, plumbing) on tap water chemistry & pathogen content**

- **Work with human-health experts**
  - **Explore associations among drinking water exposures and human-health outcomes**
- ***de facto* water reuse and drinking water**

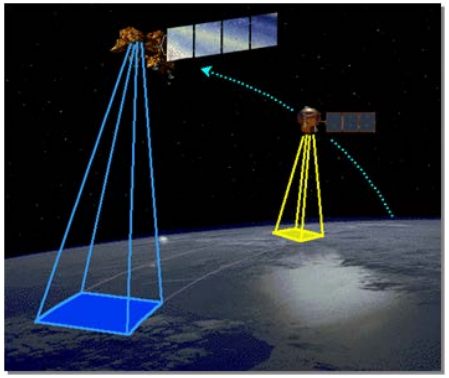
Focus of today's talk: water quality

Recent high-visibility surface water & groundwater efforts related to drinking water

Monitoring & Data	Modeling	Tools	Products

Monitoring approach

- Untreated source water samples
  - Prior to treatment or blending
- Nationally consistent methods
  - For sampling & analysis
- Discrete, continuous, & remotely sensed
- Low detection levels



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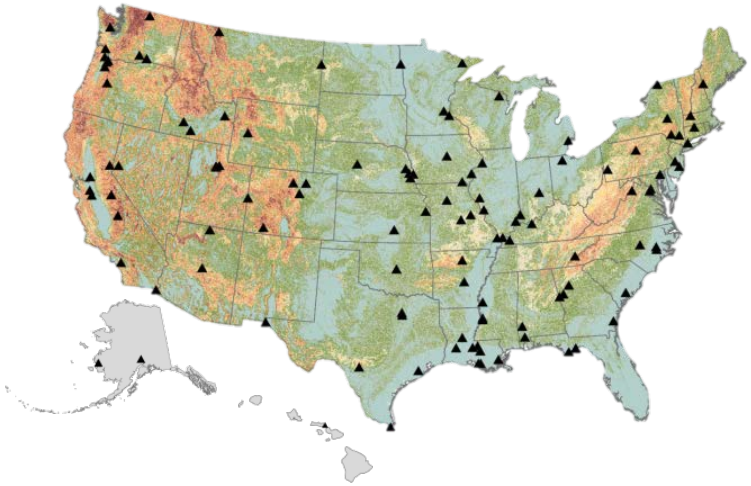
USGS components and goals

Components

- National Water-Quality Assessment (NAWQA) Project
- Cooperative Matching Funds Program



Goals

- Status
- Trends
- Understanding
- Forecasting

Monitoring approach: Surface Water

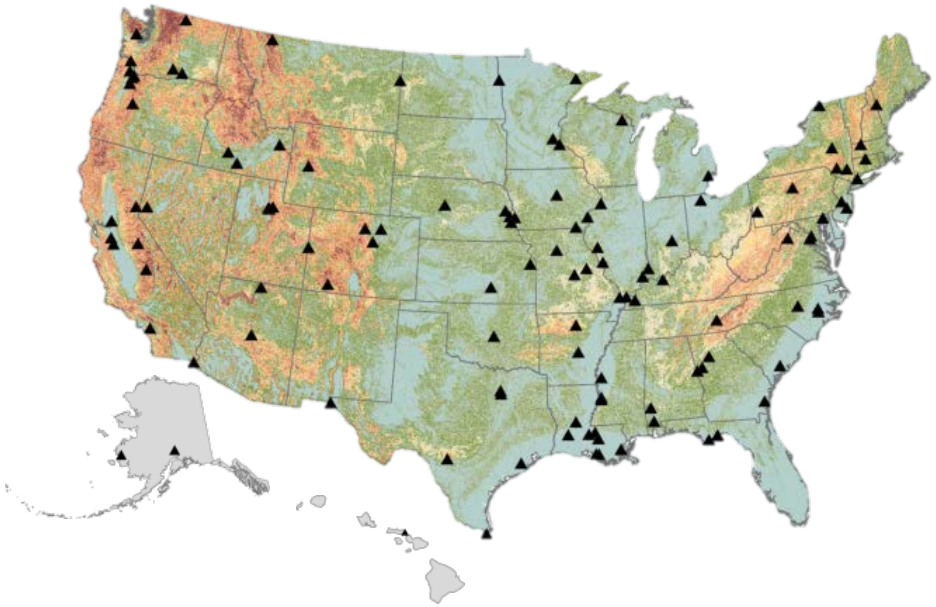
- National Fixed Site Network
  - Discrete sampling throughout year
- Continuous Monitoring – select fixed sites
  - Sensors for select parameters/constituents
- Regional Steam Quality Assessments
  - Contaminant characterization
- Modeling
  - Nutrients, Pesticides

Monitoring & Data | Products | Modeling | Tools

National Fixed Site Network

Discrete samples of surface water analysed for…..

- **Nutrients, major ions**
- **pH, DO, temperature**
- **Dissolved solids, indicators of salinity, hardness, taste**
- **Pesticides & pesticide degradates**
- **Cyanobacteria toxins**



National Water Quality Network: 117 stream & river sites

Water Quality Tracking | Data | Network Information | About

Toggle Header/Footer

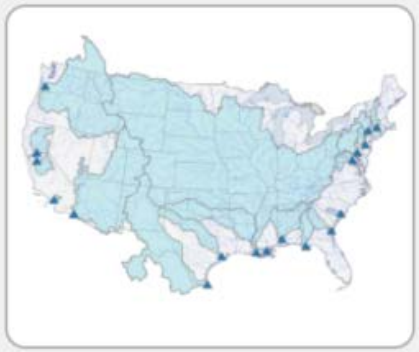
Tracking Water Quality of the Nation's Rivers and Streams

The USGS National Water-Quality Assessment (NAWQA) Project is characterizing the status and trends of the Nation's surface-water quality through a National Water Quality Network. This website provides data on national ambient water-quality conditions. The data are reported systematically and updated annually. Learn more...

Rivers and Streams Across the United States
Water Quality Summaries

Mississippi River Basin
Relative Nutrient Loading from Tributaries

Coastal Rivers
Nitrate Loads and Yields



https://cida.usgs.gov/quality/rivers/home

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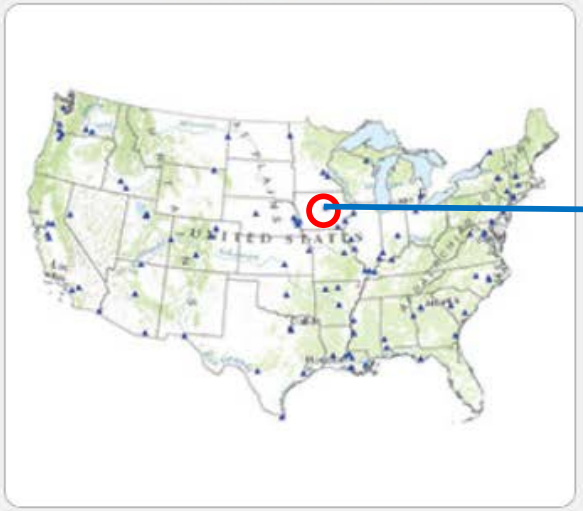
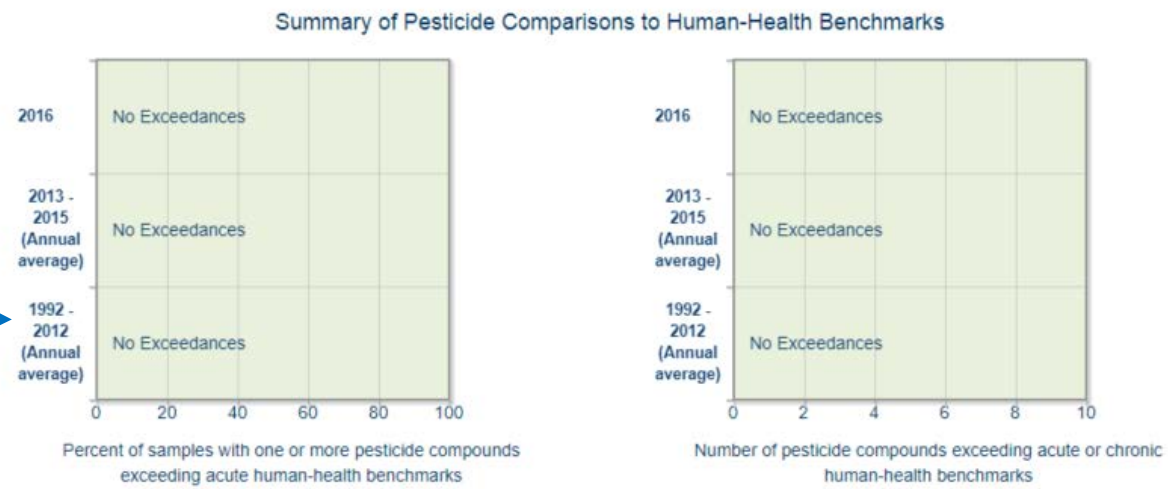
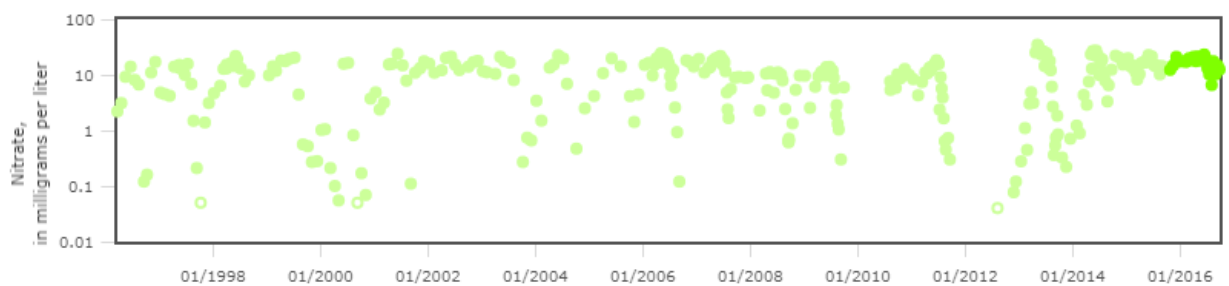






Deacon, Lee, et al (2015)

https://cida.usgs.gov/quality/rivers/home

National Data Aggregation

Evaluation of Multi-source Records for trends: Nutrients

Of the 25,125,379 original nutrient records, 14,453,492 had missing or ambiguous information for one or more of the key metadata elements

Starting records	Affected records					
	Parameter name	Filtration status	Chemical form	Units	Remark codes	Zero, negative, missing
25,125,379	3,557,821	11,946,455	4,265,615	1,311,096	124,523	636,454

Sprague et al., 2017, Challenges with secondary use of multi-source water-quality data in the United States. Water Research, Volume 110, http://dx.doi.org/10.1016/j.watres.2016.12.024

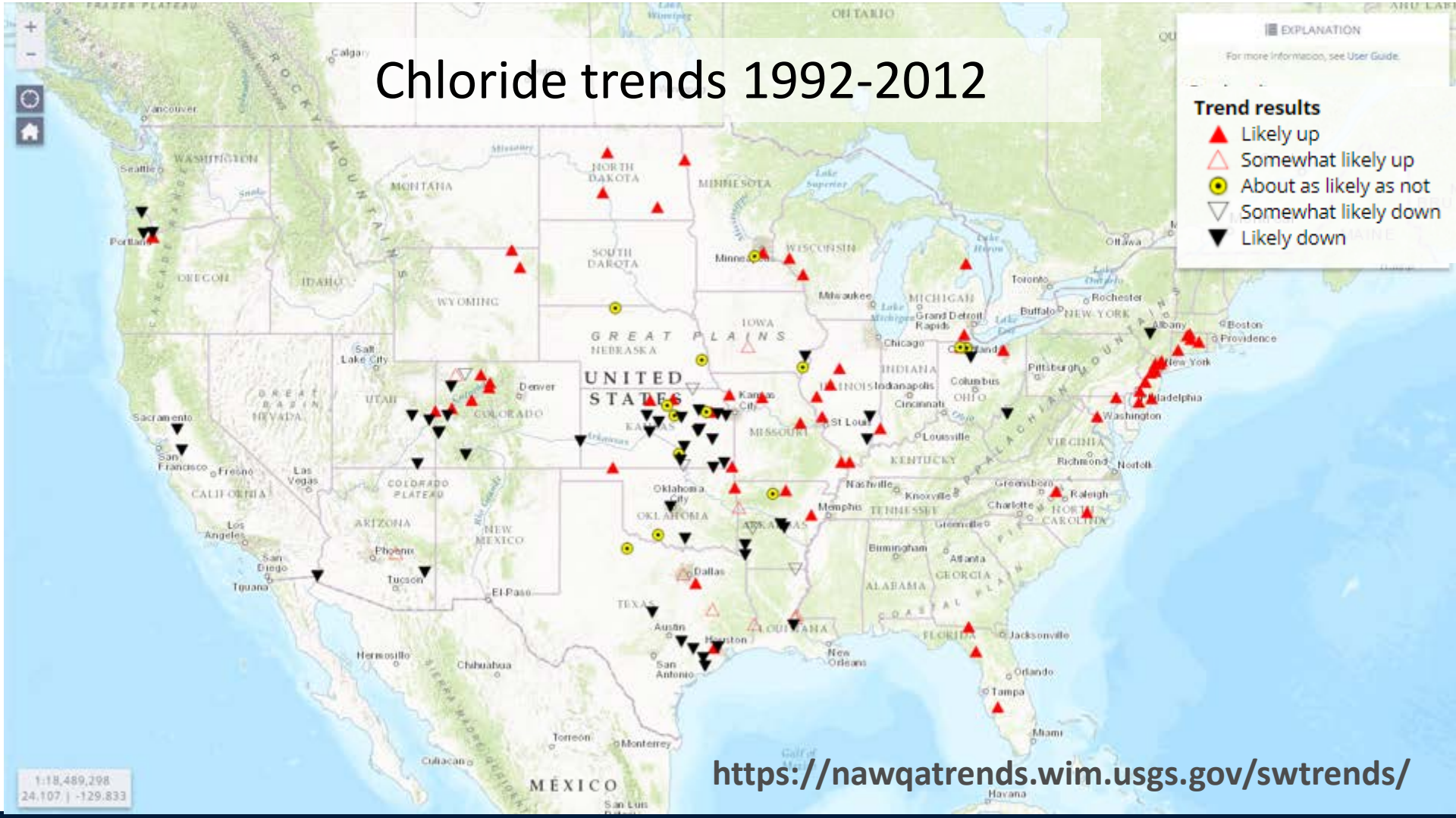
NAWQA Trend Analysis

- **Largest-ever evaluation of trends in U.S. stream quality between 1972 and 2012**
  - **Over 20,000 trend results**
  - **51 chemicals and 38 measures of aquatic life**
    - **nutrients, pesticides, sediment, carbon, salinity, aquatic ecology**
  - **1,400 sites with at least one trend result**
- **Results are the foundation for answering critical questions about the causes and effects of changes in stream quality**
- **On-line interactive map provides easy access to trend results**

Oelsner, G.P., and others, 2017, Water-quality trends in the Nation's rivers and streams, 1972–2012…. USGS SIR 2017–5006, 136 p., https://doi.org/10.3133/sir20175006.

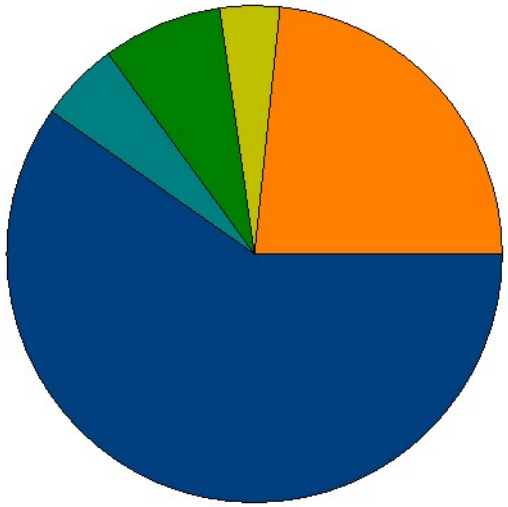
Surface water interactive trends mapper

Trends in surface-water quality over 40 years; 1972-2012



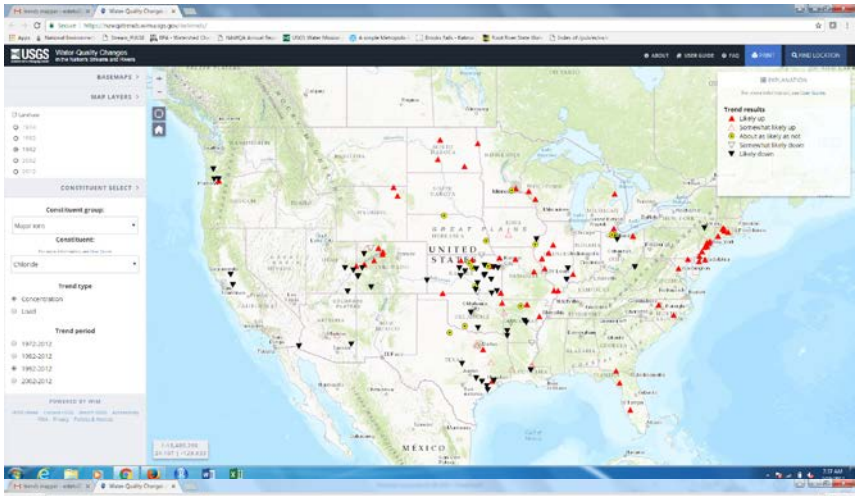
https://nawqatrends.wim.usgs.gov/swtrends/

Chloride-Sulfate ratio 1992-2012: Indicator of Corrosion Potential

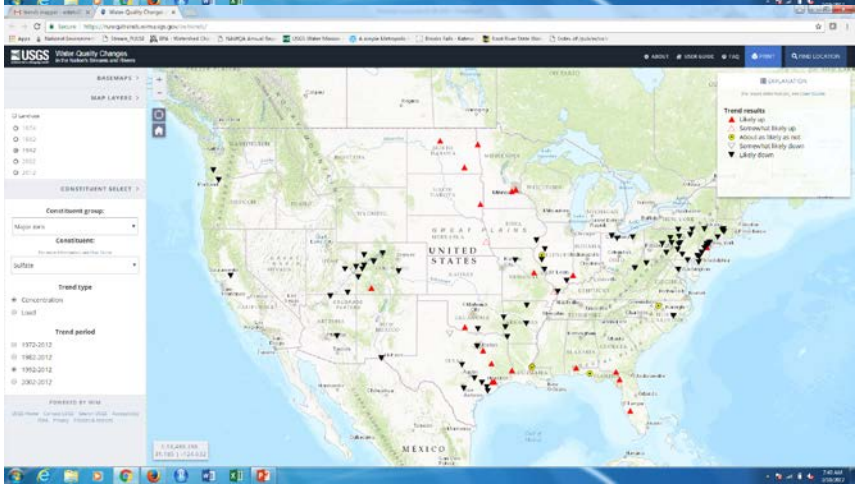


- Decreasing, high confidence
- Decreasing, medium confidence
- No trend
- Increasing, medium confidence
- Increasing, high confidence

Chloride

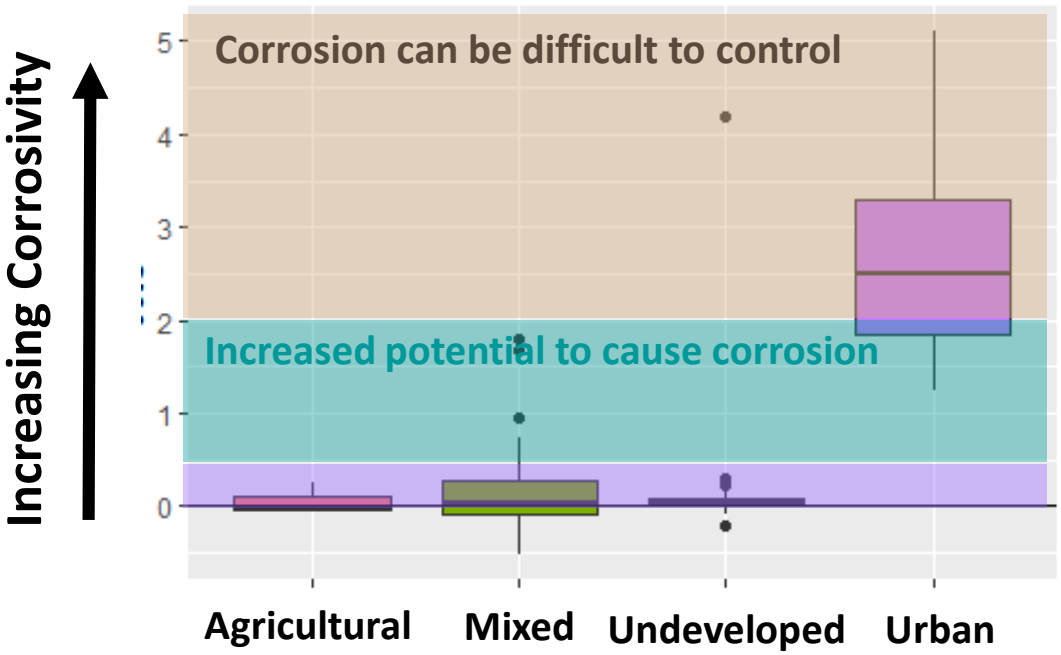


Sulfate

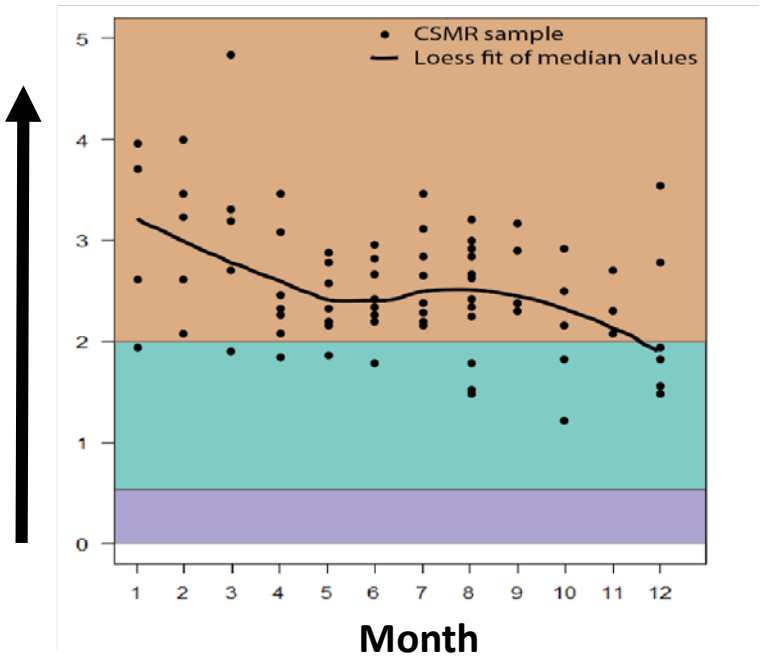


Potential corrosivity of surface water

Urban waters have become more corrosive over the past 20 years

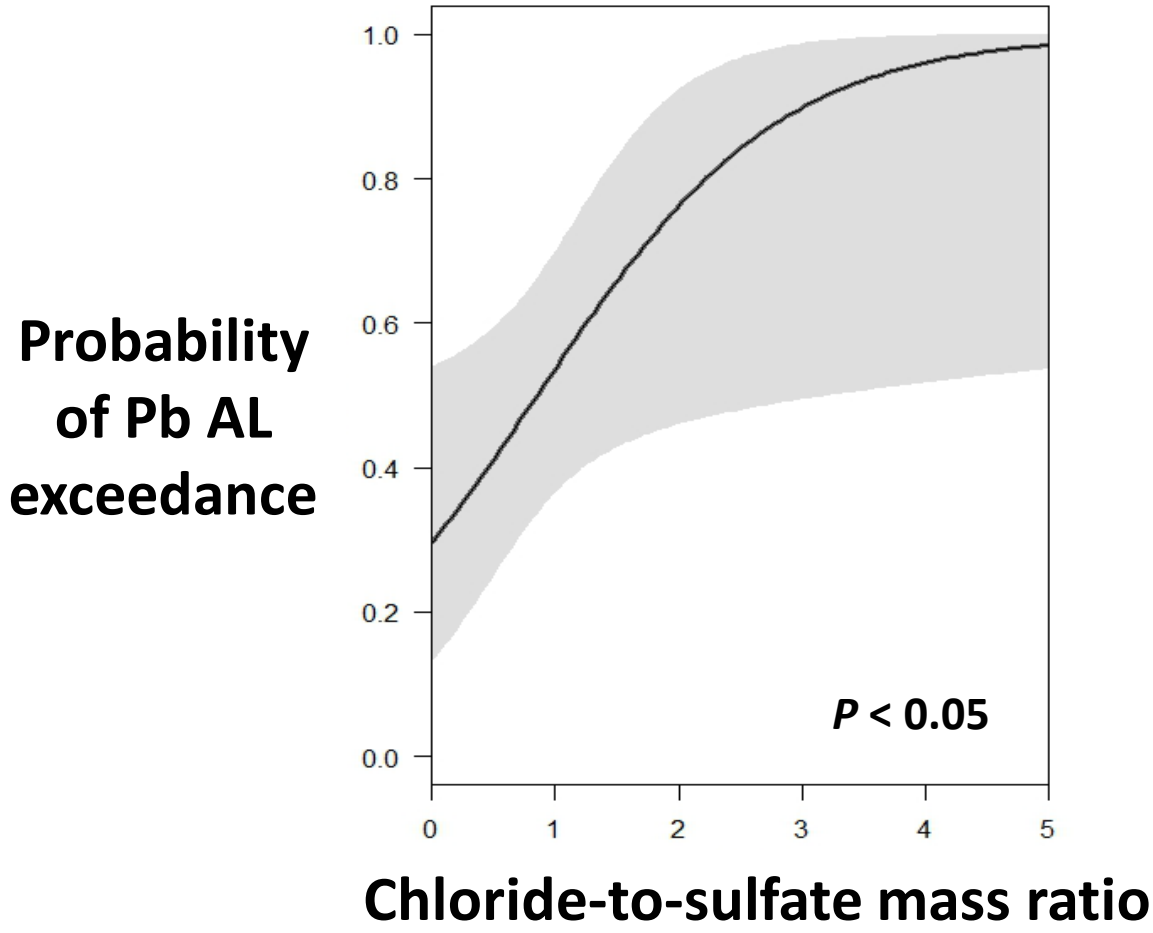


Corrosivity varies seasonally at some stream sites



Stets, Lee, Lytle, and Schock, 2017, Increasing chloride in rivers of the conterminous U.S. and linkages to potential corrosivity and lead action level exceedances in drinking water
http://www.sciencedirect.com/science/article/pii/S0048969717318223?via%3Dihub

Link Pb Action Level Exceedances to CSMR



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Severe Harmful Algal Blooms Have Been Reported in Large Rivers

Courtesy of E. Emory, USACE

Home News Environment

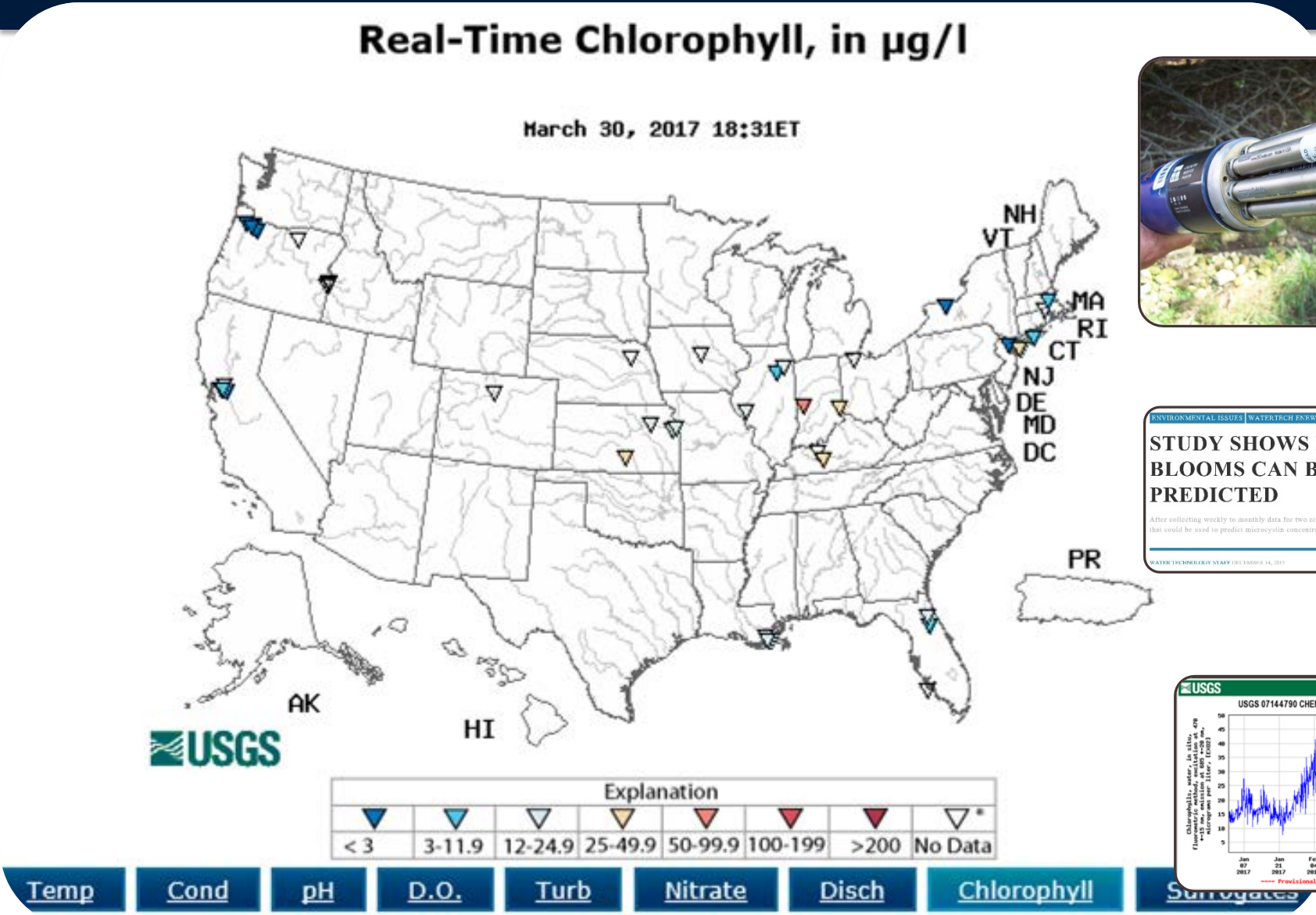
Toxic algae bloom now stretches 650 miles along Ohio river (October 2015)

NAWQA Summer 2017 Large River Harmful Algal Bloom Pilot Study

Pilot Study Objectives:

- **Describe cyanotoxin occurrence in large rivers during summer 2017.**
- **Assess *potential* for harmful algal bloom occurrence in the Nation's large rivers using a combination of traditional and emerging approaches, including algal pigment sensors.**

Water-Quality Sensors Show Promise as Forecasting Tools

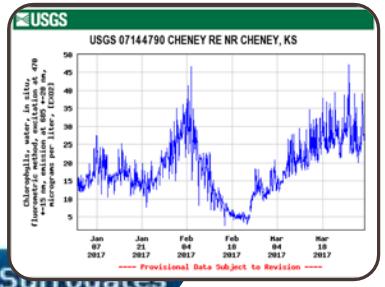


ENVIRONMENTAL ISSUES | WATERTECH ENEWS

STUDY SHOWS HOW ALGAL BLOOMS CAN BE RAPIDLY PREDICTED

After collecting weekly to monthly data for two recreational seasons, the scientists identified factors that could be used to predict microcystin concentrations at a variety of freshwater sites.

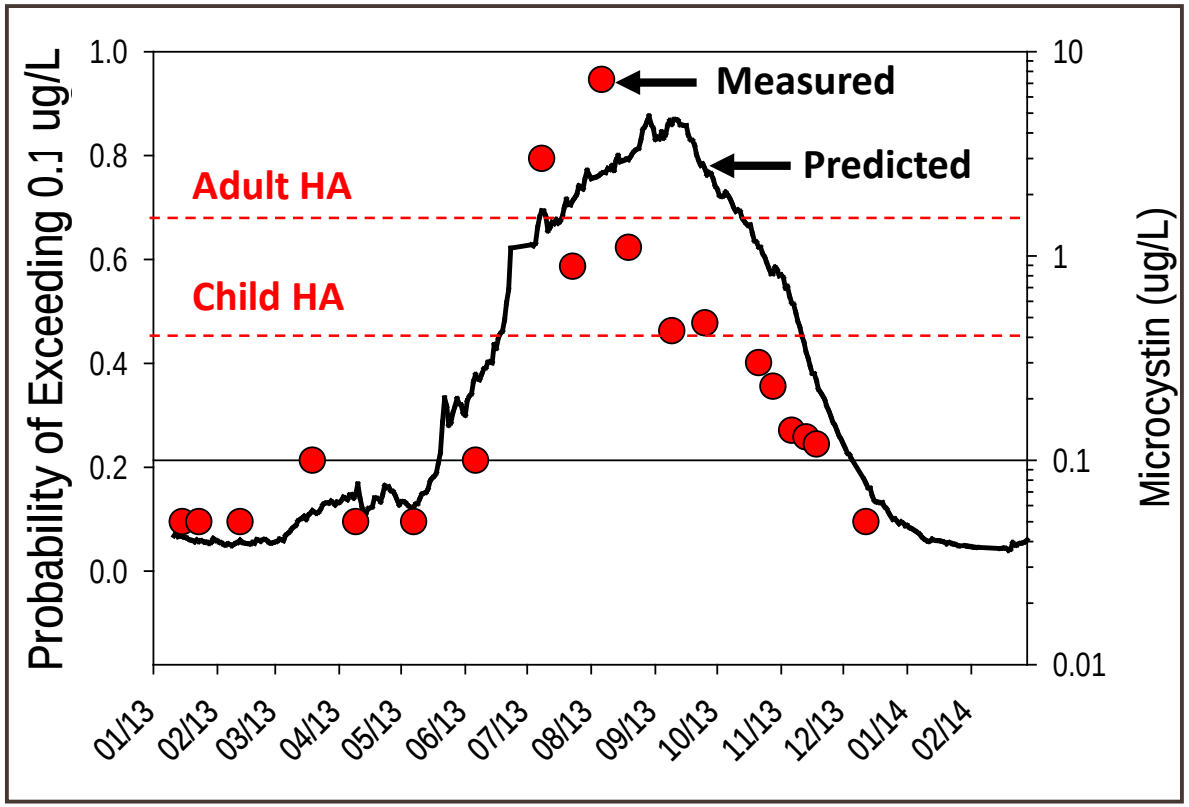
WATERTECHNOLOGY STAFF | DECEMBER 14, 2015 | SHARE ON:



Early-warning systems: Cyanotoxins

- **Compute probability of microcystin >0.1 ug/L in KS drinking-water supply**

Toxin=f(Chlorophyll)

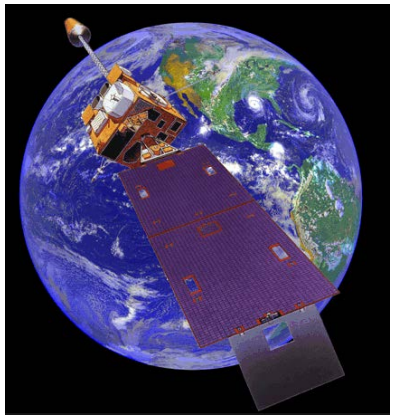


Stone, Graham, & Gatotho, 2013

http://pubs.usgs.gov/of/2013/1123/, http://nrtwq.usgs.gov/ks/

Cyanobacteria Assessment Network (CyAN) Project

Remotely sensed data



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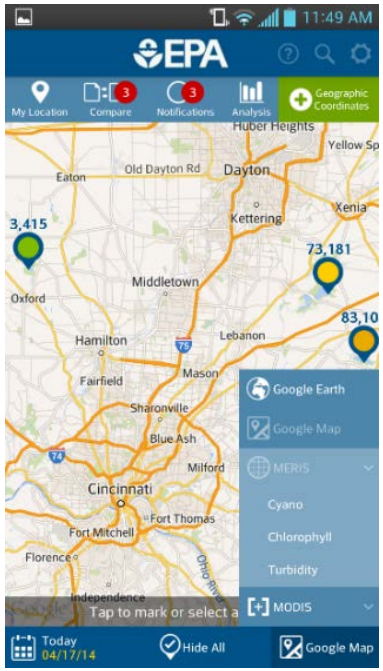
Continuous & discrete data

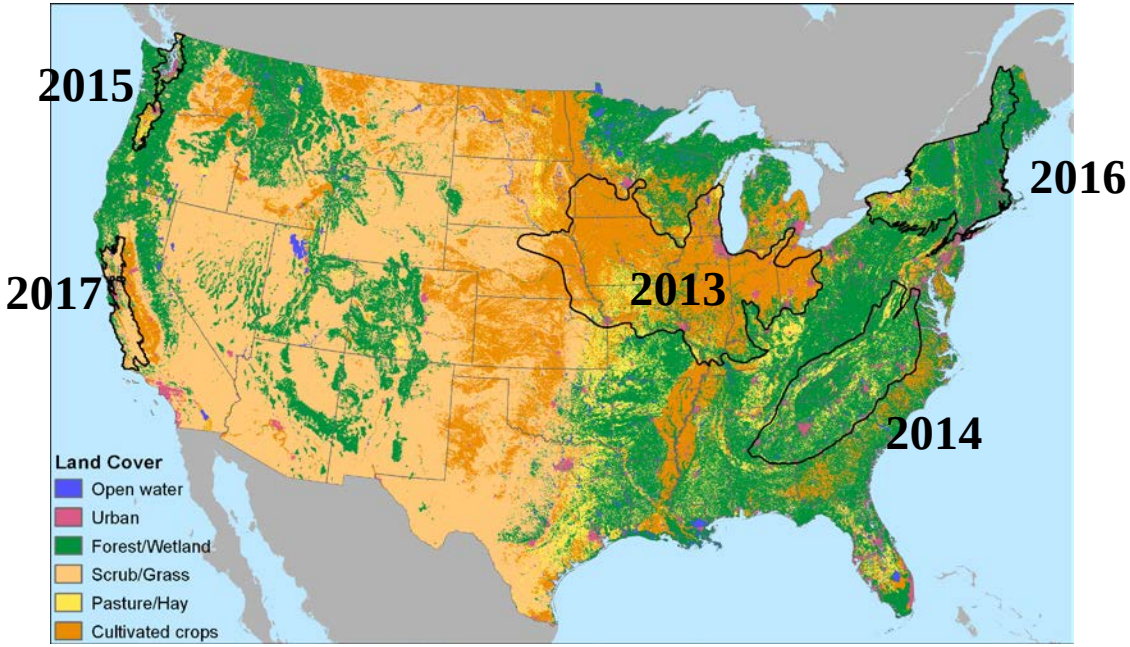
→

Online early warning HABs in inland waters



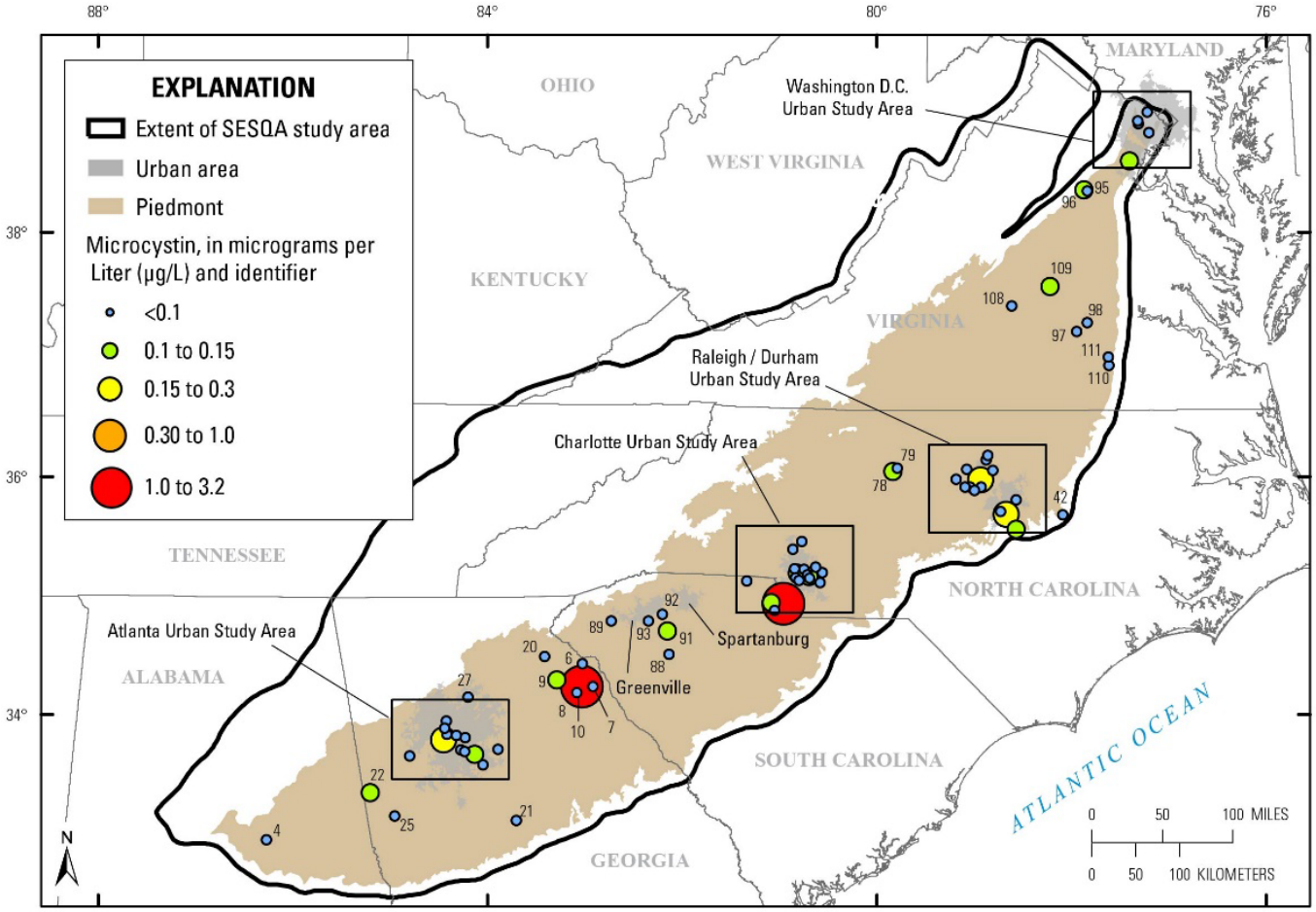
https://www.epa.gov/water-research/cyanobacteria-assessment-network-cyan-project

Regional Stream Quality Assessments



- Intensive studies of small stream chemistry and ecology
- Weekly sampling in Spring/Summer
- **Characterization of the spatial distribution at 85-100 sites of** pesticides, pharmaceuticals, mercury, nutrients, sediment chemistry and stream ecology, **algal toxins**

Microcystins Occurred in 39% of Small Stream Sites Sampled in the Southeastern United States



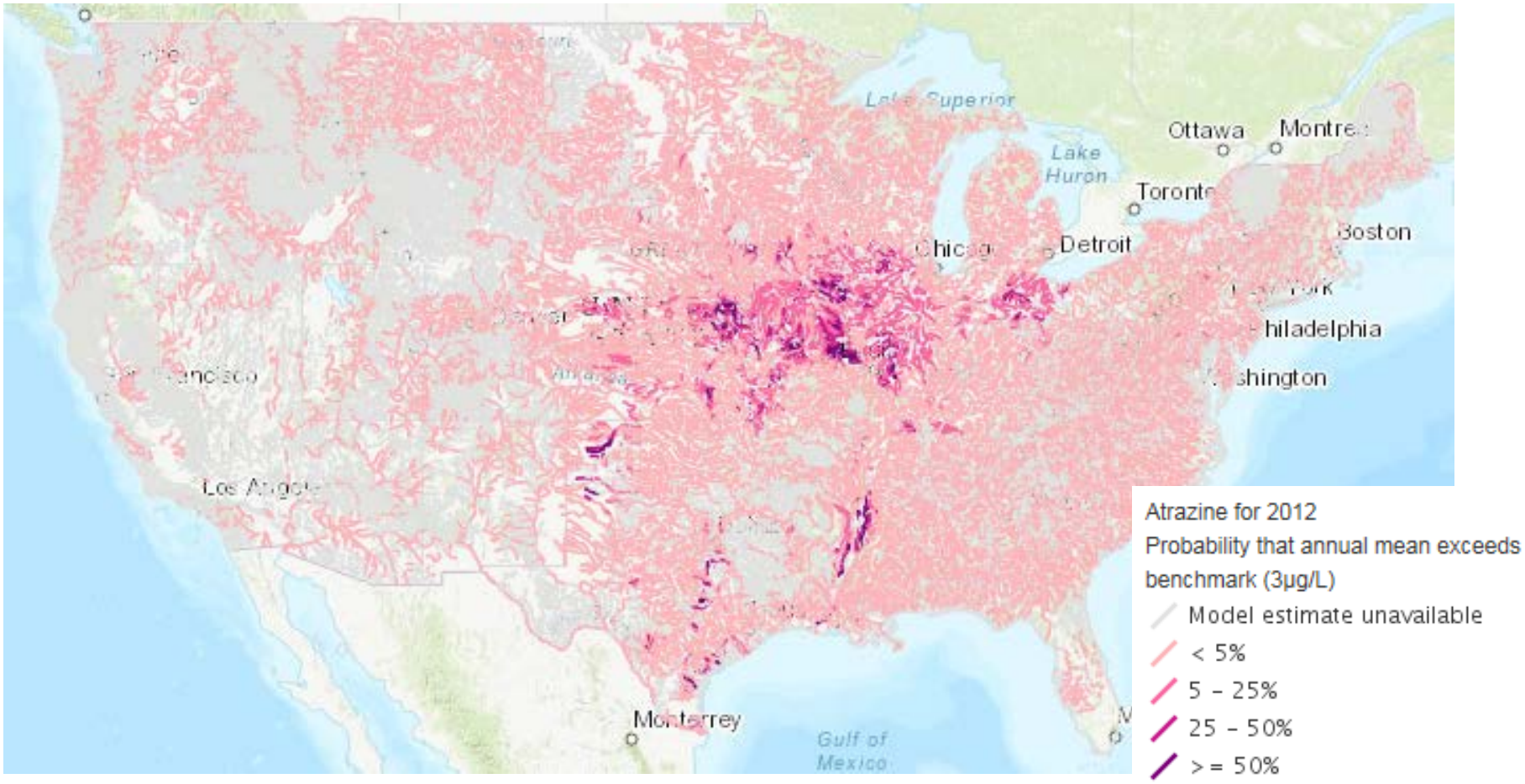
State basemap from the National Map, 1:1,000,000 scale digital data
Piedmont from U.S. Environmental Agency Level III Ecoregions, 2010, 1:250,000
WGS 1984 Web Mercator projection

Loftin and others, 2016, Environmental Toxicology and Chemistry

Pesticides rarely exceed human health benchmarks

- 6 of 445 sites (1.3%) had a mean concentration > HHB
  - 5 of the 6 were atrazine in Midwest
- Individual sample concentrations exceed HHBs 113 times
  - in 107 samples at 50 sites for 8 pesticides (of 119 pesticides with HHBs), out of about 4,000 samples
  - 96 of the 113 were atrazine in Midwest

Models predict benchmark exceedance probabilities in streams & rivers: pesticides



Stone et al: Watershed Regressions for Pesticides (WARP) models

https://cida.usgs.gov/warp/home/

Models predict nutrient loads in streams & rivers and identify sources

National Water-Quality Assessment (NAWQA) Project

Home | Headlines | Featured Studies | Liaison Committee | Informing Decision Makers | Data | Modeling/Software | Publications | Ma

SPARROW modeling: Estimating contaminant transport

Overview | Science | Data and Tools | Publications | Multimedia | Software | FAQs

Access SPARROW mappers and data bases used to develop SPARROW models here.

SPARROW Mappers: Web-Based Interactive Water-Quality Mapping Systems

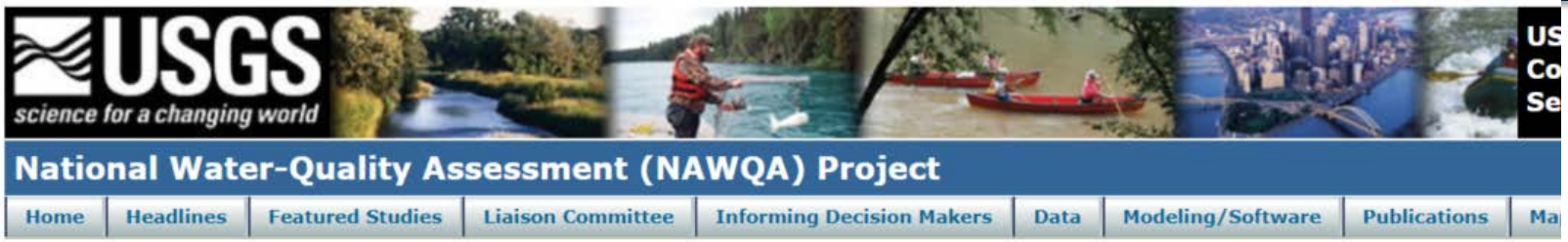
These interactive tools allow the user to explore river nutrient loads and yields and the importance of different sources of contami particular river basin. Data can be visualized using maps and interactive graphs and tables, and rankings can be shown by country HUC, and catchment. Modeling results can be exported as an Excel spreadsheet or a geospatial dataset. Mappers currently are av Mississippi Basin and large sub-basins within or adjoining it, and new Mappers are being developed for other regions of the U.S. T replace the SPARROW Decision Support System (Booth et al., 2011).

- Great Lakes, Ohio, Upper Mississippi, Red River Basins (MRB3) SPARROW Mapper, 2002
- Mississippi/Atchafalaya River Basin (MARB) SPARROW Mapper, 2002
- Red–Assiniboine River Basin (RARB) SPARROW Mapper, 2002
- Great Lakes SPARROW Mapper, 2002
- Yellowstone River SPARROW Mapper, 2002

Databases

The national data bases used in the SPARROW models have value in themselves and can be used for other scientific evaluations.

Models predict nutrient loads in streams & rivers and identify sources



SPARROW modeling: Estimating contam

Overview | Science | Data and Tools | Publications

Access SPARROW mappers and data bases used to develop SPARR

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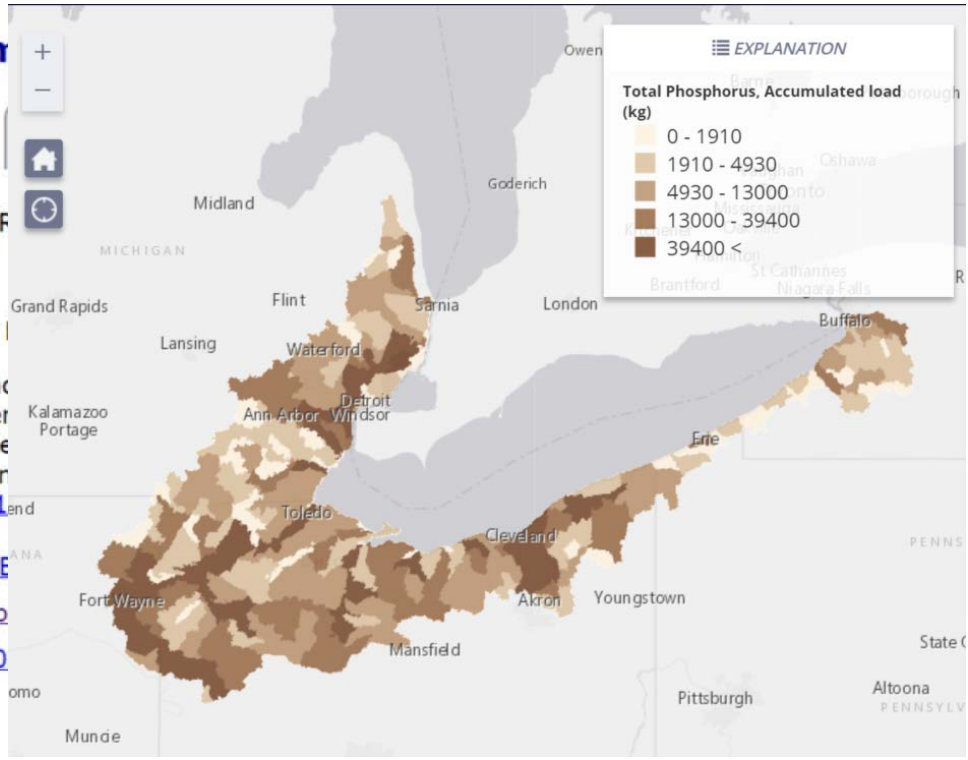
- Great Lakes SPARROW Mapper, 2002
- Yellowstone River SPARROW Mapper, 2002



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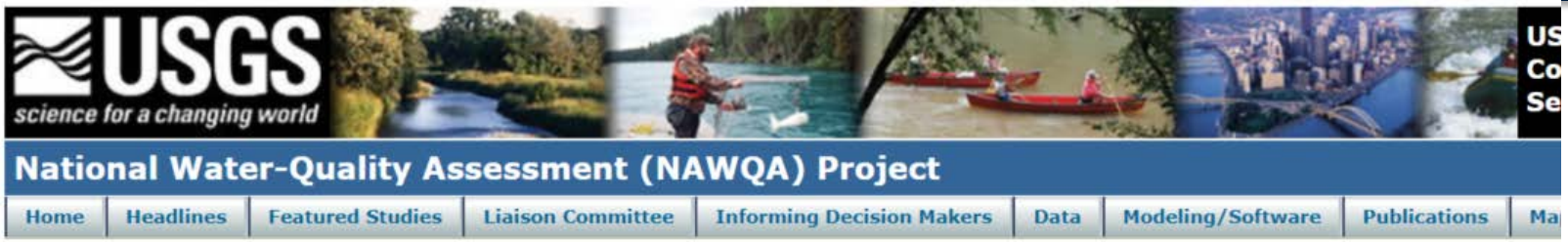

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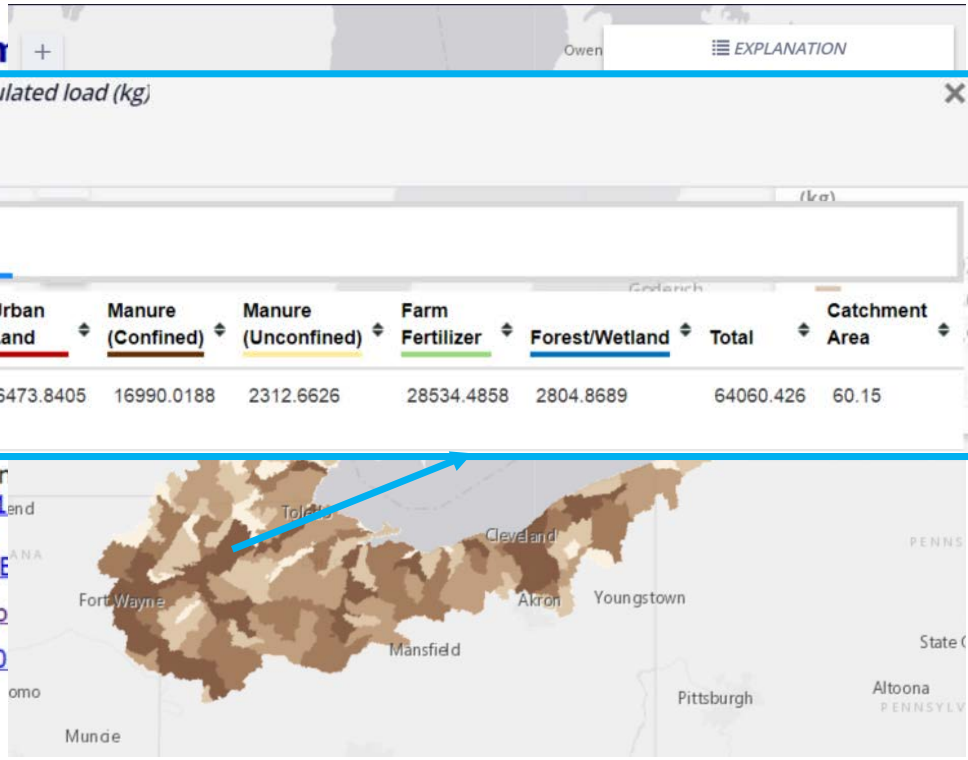
Total Phosphorus Accumulated load (kg)

Show Full Chart

Chart | Table

Catchment ID	Point Sources	Urban Land	Manure (Confined)	Manure (Unconfined)	Farm Fertilizer	Forest/Wetland	Total	Catchment Area
11839-TIFFIN R	6944.5495	6473.8405	16990.0188	2312.6626	28534.4858	2804.8689	64060.426	60.15



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Water Quality Data Discovery…

Water Quality Portal - a cooperative service sponsored by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC).

Serves data collected by over 400 state, federal, tribal, and local agencies

Supports other applications including

[EPA Data Discovery Tool]
[EPA Nitrogen and Phosphorus Pollution Data Access Tool]
[Delaware Water Quality Portal]

https://www.waterqualitydata.us/

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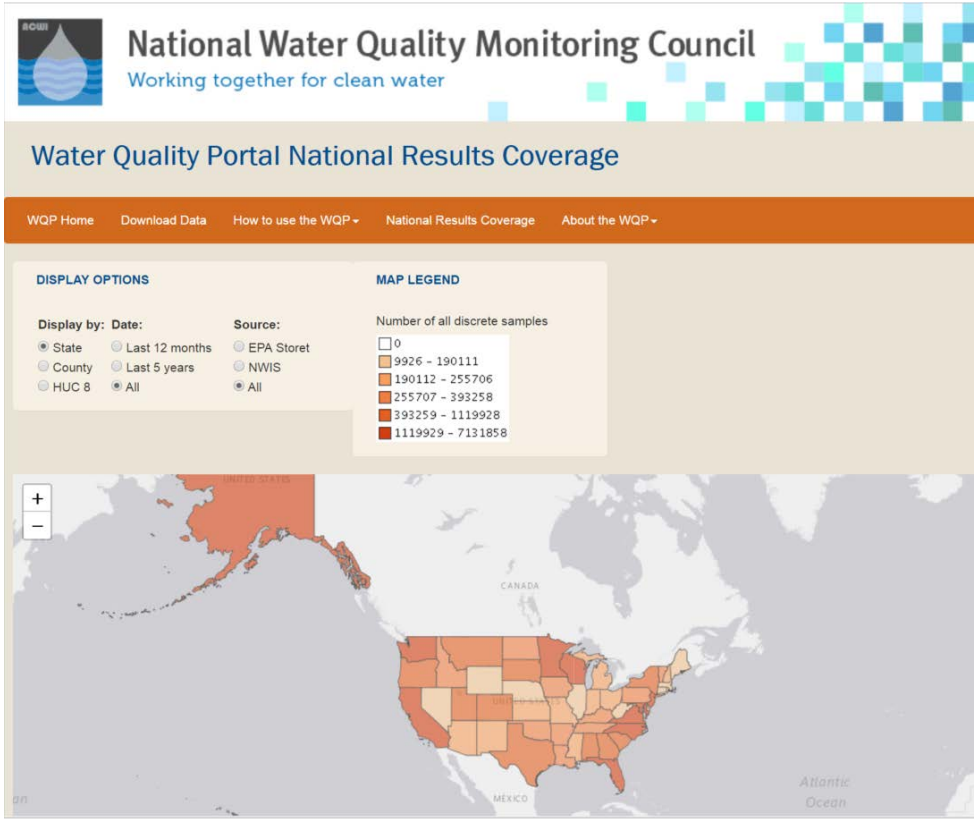


https://www.waterqualitydata.us/

Updated human-health benchmark tool

Health-Based Screening Levels (HBSL)

Home | About | HBSL Methods & Guidance | History of HBSL Revisions | Contacts & Citation

Health-Based Screening Levels for Evaluating Water-Quality Data

Get Glossary + Metadata | Get Documentation for HBSLs

Select column to search: Chemical Class | Select item to search: Pesticide | Rows: 10 | Go | Clear Search | Export Search Results

row(s) 1 - 10 of 208 Next

HBSL values current as of June 30, 2014				USEPA Benchmarks			USGS Benchmarks	
Chemical Name	CAS Registry Number®[a]	USGS Parameter Code(s)	Chemical Class	MCL (µg/L) [b]	Chronic Noncancer HHBP (µg/L) [c,d]	Carcinogenic HHBP (10^{-6} to 10^{-4}) (µg/L) [c,d]	Noncancer HBSL (µg/L) [d,e]	Cancer HBSL (10^{-6} to 10^{-4}) (µg/L) [d,e]
2 (2,4,5-Trichlorophenoxy) Propionic acid	93-72-1	39760, 39762	Pesticide	50	-	-	-	-
2,4,5-T	93-76-5	39740, 39742	Pesticide	-	-	-	70	-
2,4-D	94-75-7	39730, 39732, 68500, 82697	Pesticide	70	-	-	-	-
2,4-D methyl ester	1928-38-7	50470	Pesticide	-	-	-	-	-
2,4-DB	94-82-6	38746	Pesticide	-	210	-	-	-
Acephate	30560-19-1	68519	Pesticide	-	8	-	-	-

Norman, Toccalino, and Morman (expected 2018)

http://water.usgs.gov/nawqa/HBSL

Water Quality Data Discovery…

USGS National Water Quality Program -
https://www.usgs.gov/water-resources/national-water-quality-program?qt-programs_l2_landing_page=2#qt-programs_l2_landing_page).

USGS Sediment Data Portal

National Atmospheric Deposition Program Animated Maps

BioData – Aquatic Bioassessment Data

Estimated Annual Agricultural Pesticide Use

Summary

- USGS develops information relevant to the drinking-water quality of streams and rivers that tracks current water quality concerns while seeking to understand emerging issues
- Discrete, synoptic, continuous, & remotely sensed data for sources of public water supplies
- Models to predict concentrations and identify contaminant sources
- Tools for data discovery, to examine changes over time, to place occurrence in a human-health context, and to display model results are online

Questions? Neil Dubrovsky, nmdubrov@usgs.gov

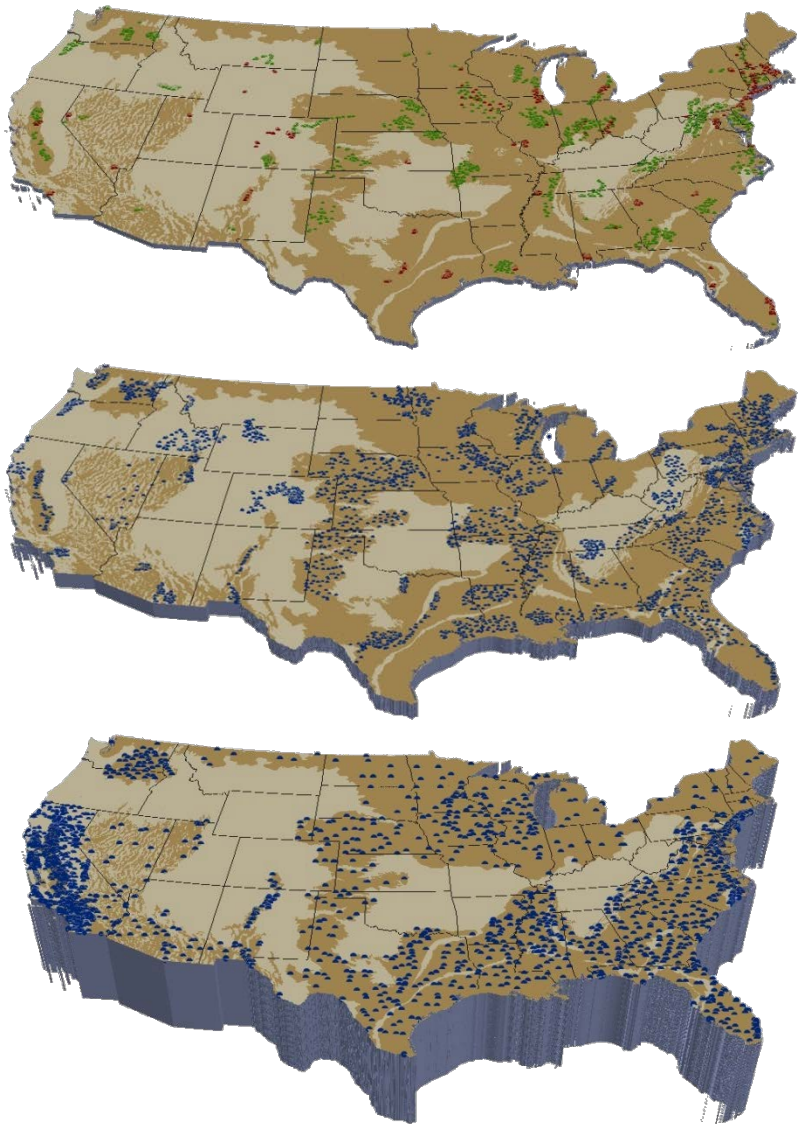
USGS Drinking-Water Related Research, Data, and Tools

Association of State Drinking Water Administrators
Webinar series

Patty Toccalino, Mike Focazio, Neil Dubrovsky, and **Ken Belitz**
April 24, 2018

NAWQA: Status, Trends, Understanding, Forecasting

ASSESSING GROUNDWATER QUALITY IN 3D



Land Use Studies

typically observation wells
~ 20 to 50 feet
~ 1400 wells, 2013-2022

Major Aquifer Studies

typically domestic wells
~ 50 to 150 feet
~ 1200 wells, 2013-2022

Principal Aquifer Studies

typically Public Supply wells
~ 150 to 750 feet deep
~ 1500 wells, new component

NAWQA ANALYTES

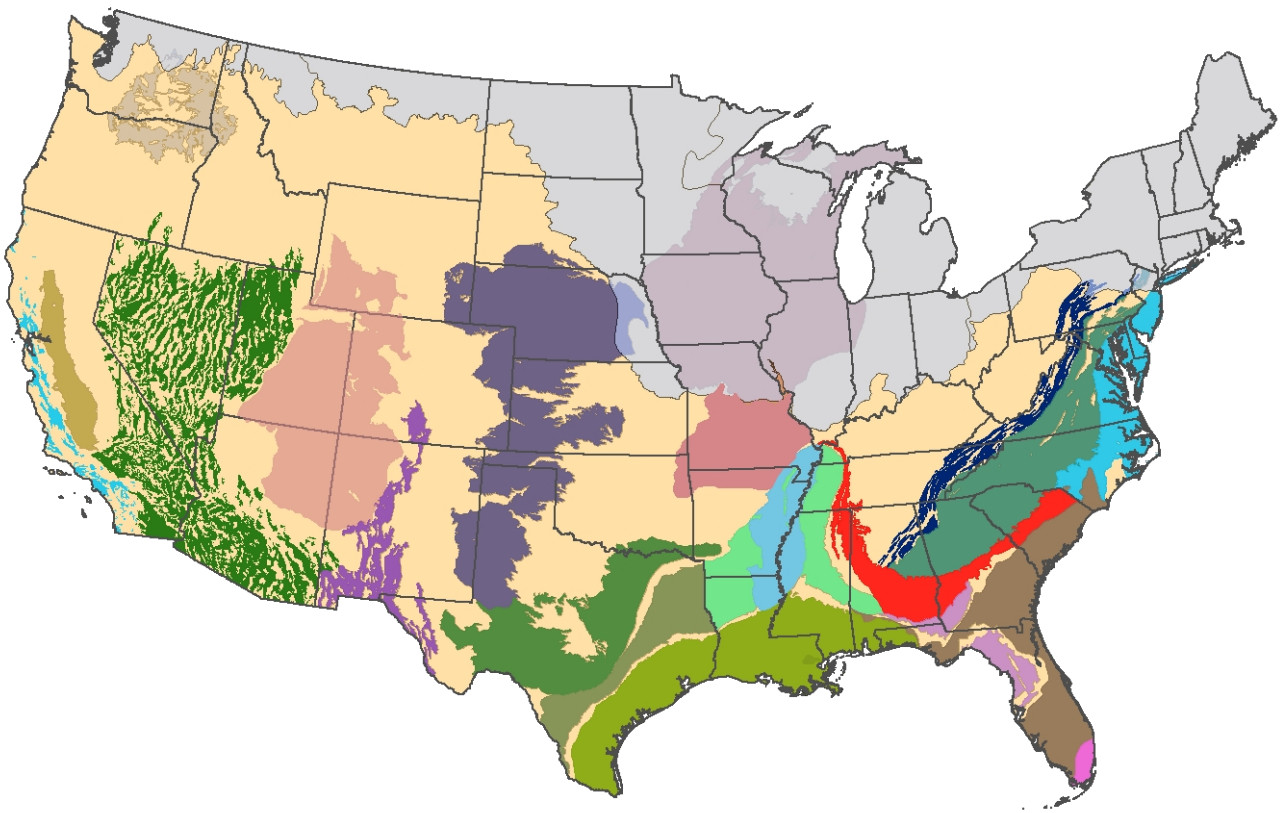
- **Water quality constituents with benchmarks**
  - **Geologic sources: trace elements, radionuclides, (nitrate)**
  - **Human sources: nutrients, volatile organic compounds, pesticides and pesticide degradates, microbiological constituents**
  - **Nuisance constituents: iron, manganese, dissolved solids, hardness, …**
- **Water quality constituents without benchmarks**
- **New analytes ("emerging" concern)**
  - **Pharmaceuticals, Hormones, Polonium, Enteroccocci …**

NAWQA ANALYTES

- **Geochemical indicators**
  - **Major ions, redox, pH, DO, T**
- **Tracers of groundwater age**
  - **Tritium, SF_6, CFCs, carbon-14, noble gases**
- **Low-level detection methods**
  - **VOCs and pesticides, < parts per billion (PPB)**
  - **Indicator of human "fingerprint"**

Untreated water

PRINCIPAL AQUIFERS PROVIDE A FRAMEWORK FOR ASSESSMENT

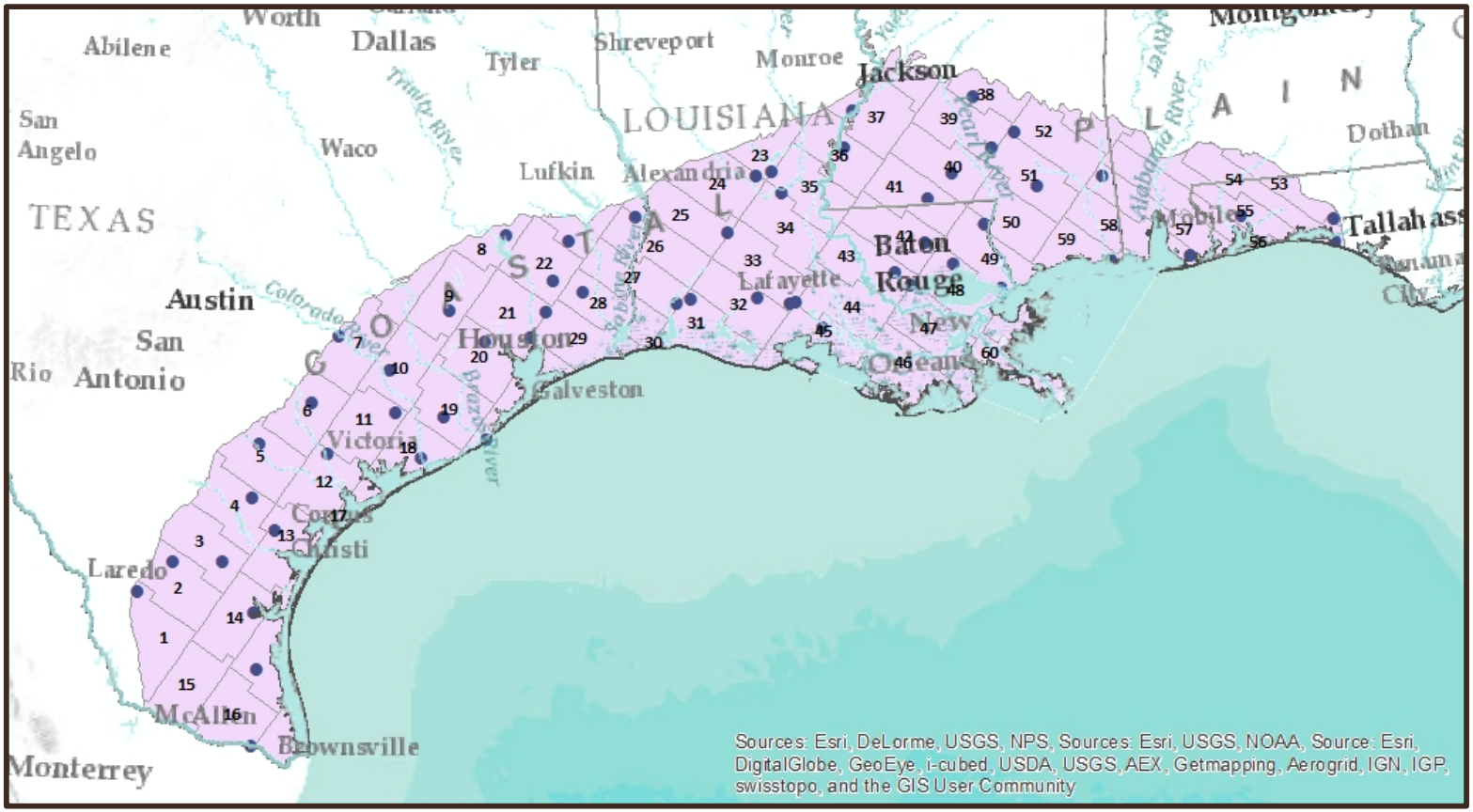


20 Principal Aquifers, 2013-2023

90% of pumping for public supply

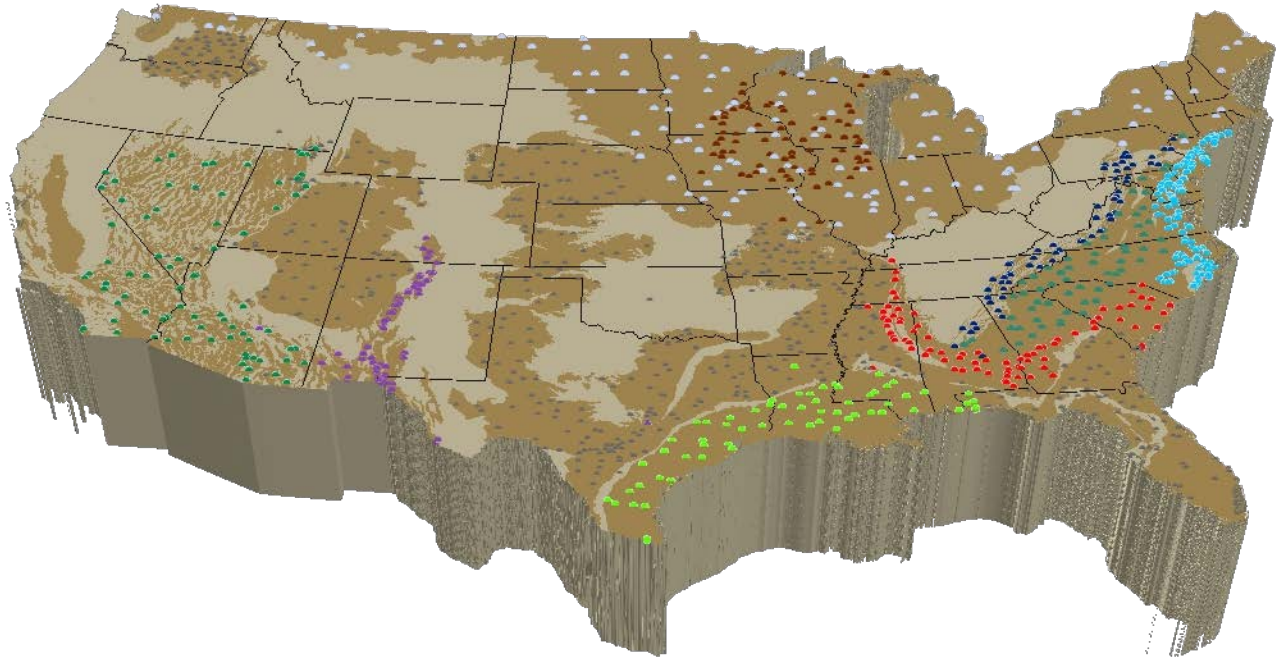
85% of pumping for domestic supply

PRINCIPAL AQUIFER SURVEYS
EQUAL AREA GRID SAMPLING



- Each area of aquifer has equal opportunity to provide a sample
- Spatially distributed, randomized
- Samples are dispersed, not random

PRINCIPAL AQUIFER STUDIES



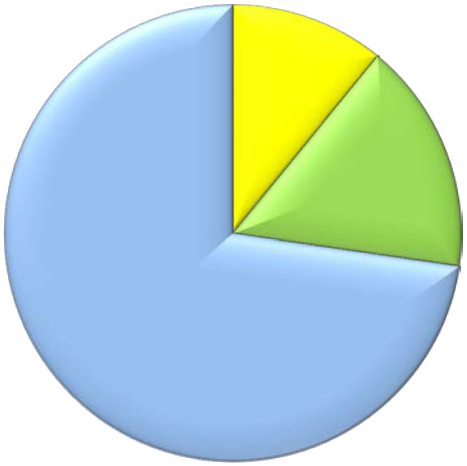
~ 800 wells, 2 Data Series Reports, 9 Fact Sheets, published

~ 700 wells, additional DSR and FS, in progress

HOW DOES NAWQA CHARACTERIZE GROUNDWATER QUALITY AT A REGIONAL SCALE?

Proportion of the resource with high, moderate, and low concentrations

HIGH Concentration > benchmark



MODERATE

LOW conc. < 1/10 of benchmark for organic
conc. < 1/2 of benchmark for inorganic

Organic constituents are generally introduced by people

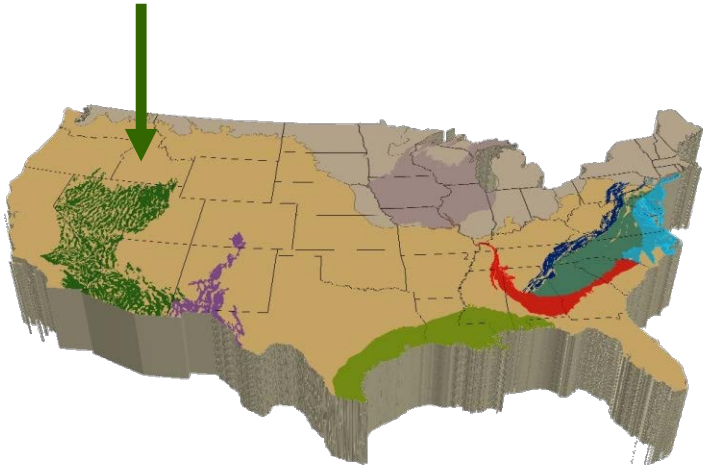
Inorganic constituents occur naturally or can be introduced by people

Proportion scale-invariant

Confidence of estimate depends on the number of samples

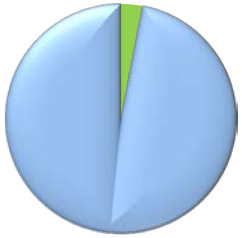
WHICH CONTAMINANTS ARE MOST PREVALENT AT HIGH CONCENTRATIONS?

Basin and Range

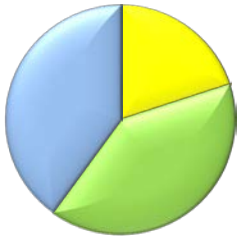


Inorganic

Organic



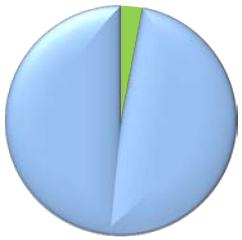
Trace elements



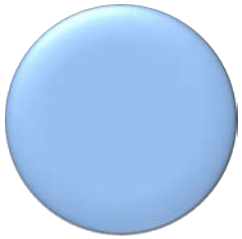
Radioactivity

Nitrate

VOCs



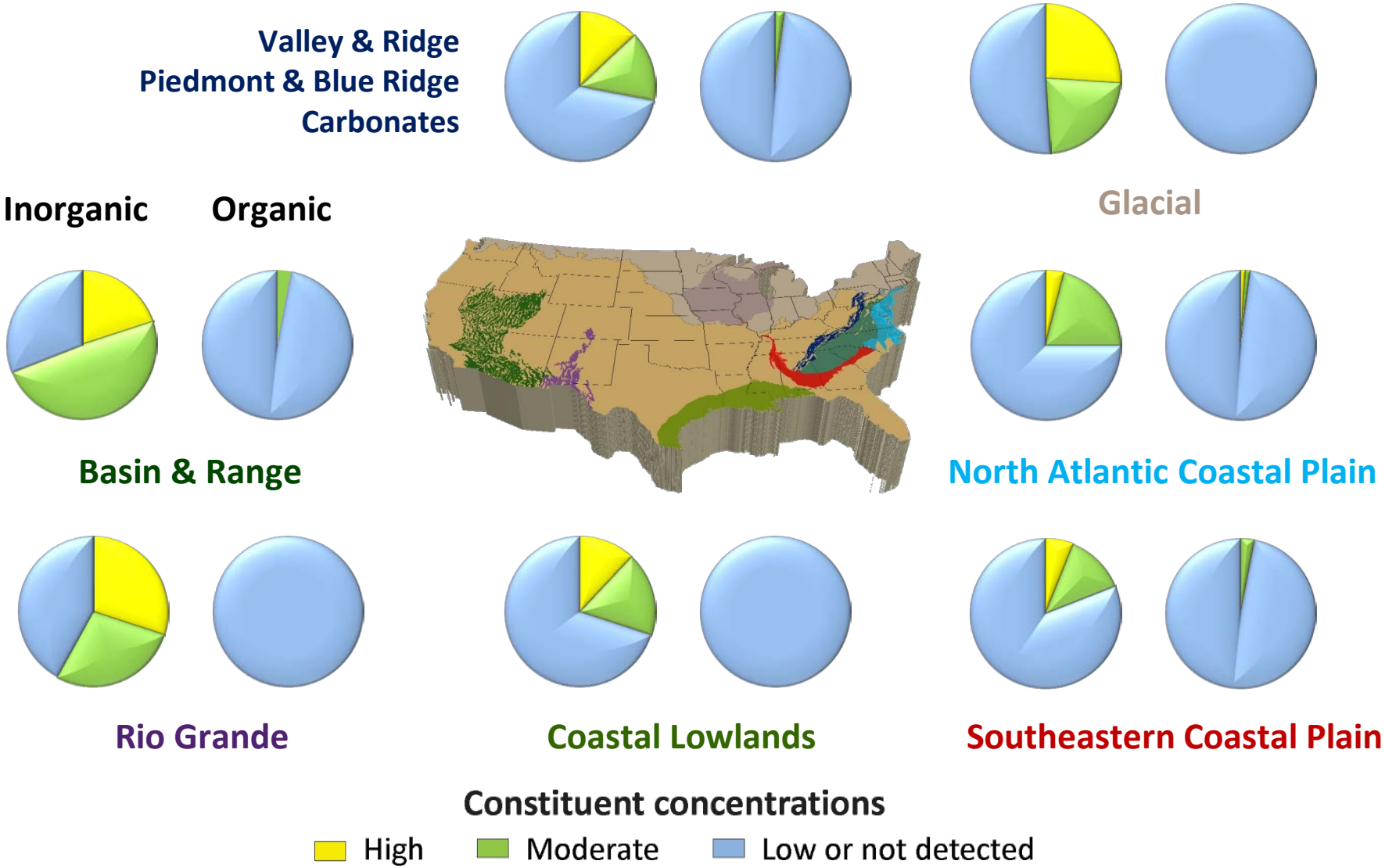
Pesticides



Constituent concentrations

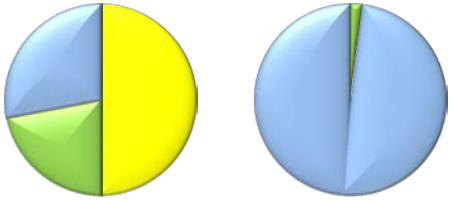
High | Moderate | Low or not detected

WHICH CONTAMINANTS ARE MOST PREVALENT AT HIGH CONCENTRATIONS?

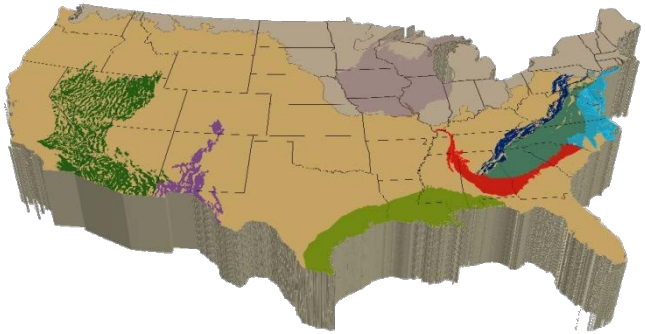


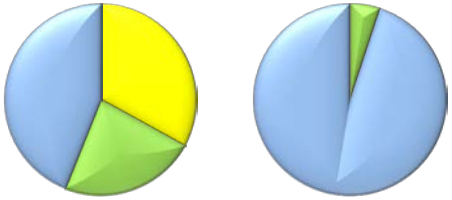
WHICH CONTAMINANTS ARE MOST PREVALENT AT HIGH CONCENTRATIONS?

Inorganic **Organic**



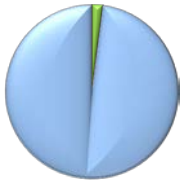
Cambrian-Ordovician

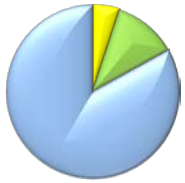


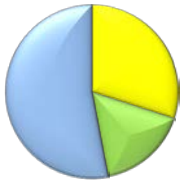


Piedmont – Blue Ridge Crystalline

Trace elements **Radioactivity** **Nitrate**







Constituent concentrations

High Moderate Low or not detected

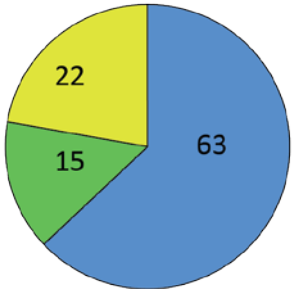
ACCESSING NAWQA DATA & RESULTS

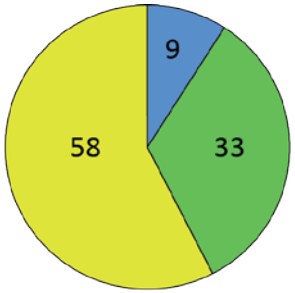
Data are maintained in Science Base

CAMBRIAN-ORDIVICIAN AQUIFER SYSTEM

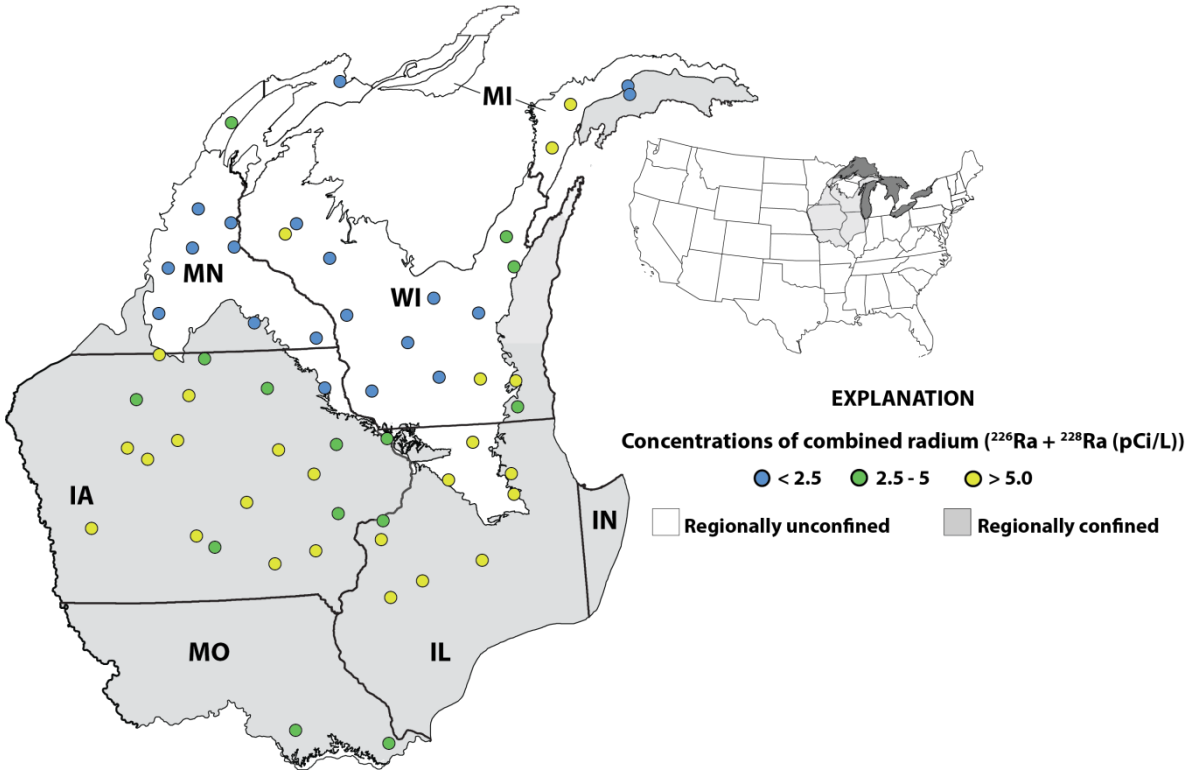
- **60 PSW's selected using a stratified, randomized sampling design**
- **20 PSW's targeted to high Gross Alpha Activity**
- **Collaboration with MN Department of Health and others**

Combined radium, regionally unconfined area



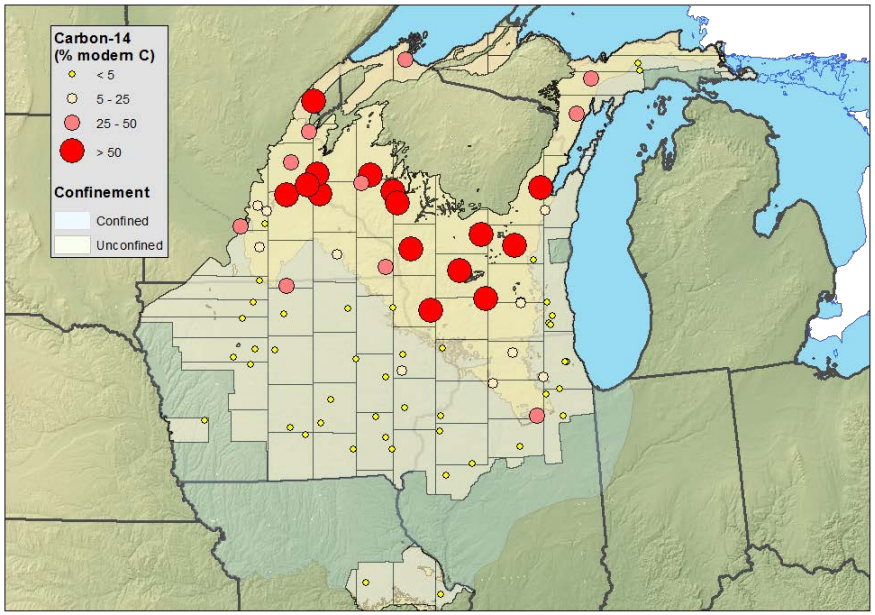


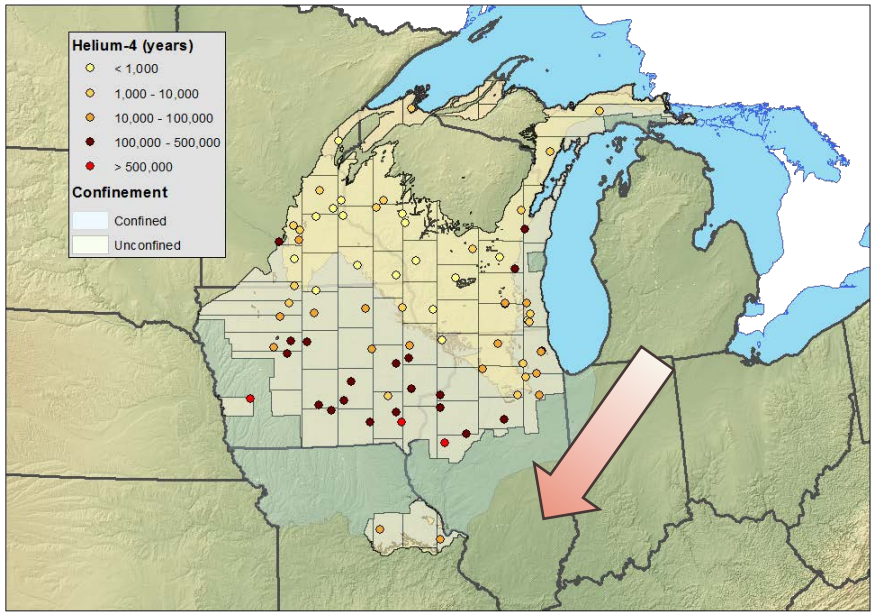
Combined radium, regionally confined area



Mean Groundwater Age

^{14}C indicates young water in regionally unconfined area and water ≥ 30,000 years in the regionally confined area



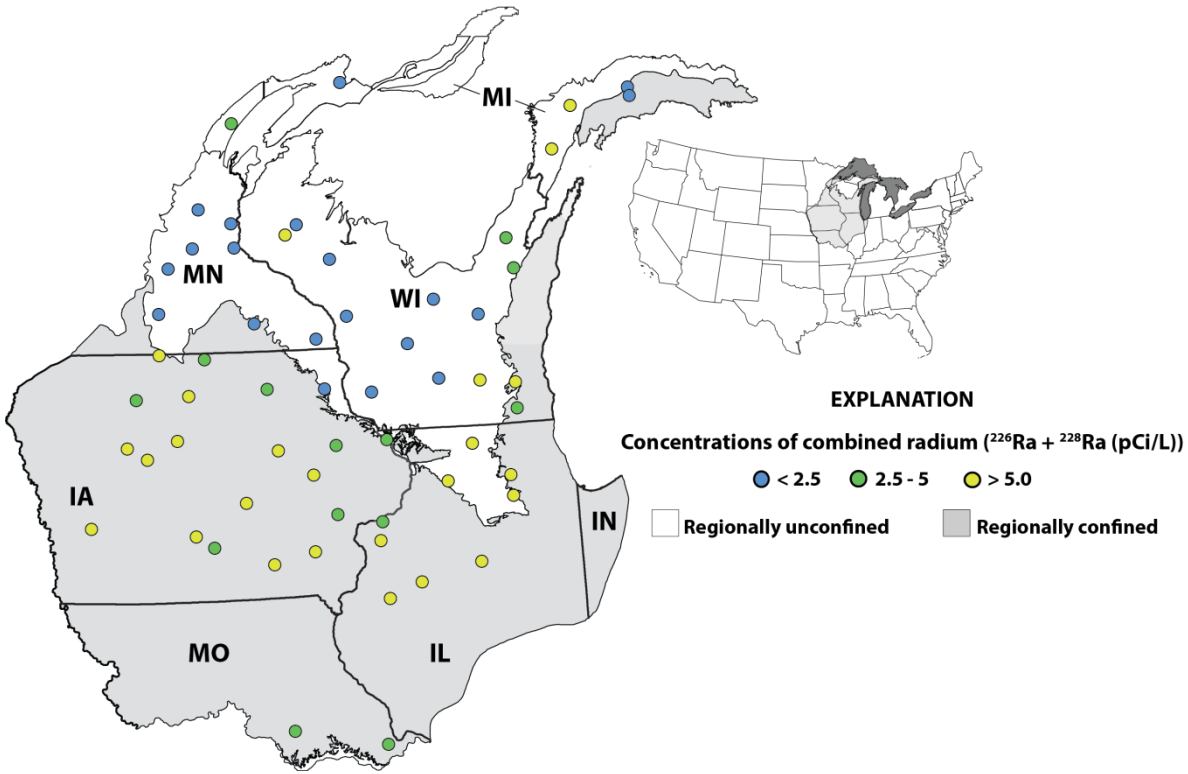


^{4}He indicates residence times > 100,000 years in regionally confined area

Increasing mineralization
Increasingly reduced conditions

CAMBRIAN-ORDIVICIAN AQUIFER SYSTEM

- ^{226}Ra is sorbed on Fe-hydroxide coatings under "oxic" conditions
- Mobilized under reducing, mineralized conditions
  - Decreased sorption capacity
  - increased competitive exchange



CAMBRIAN-ORDIVICIAN AQUIFER SYSTEM

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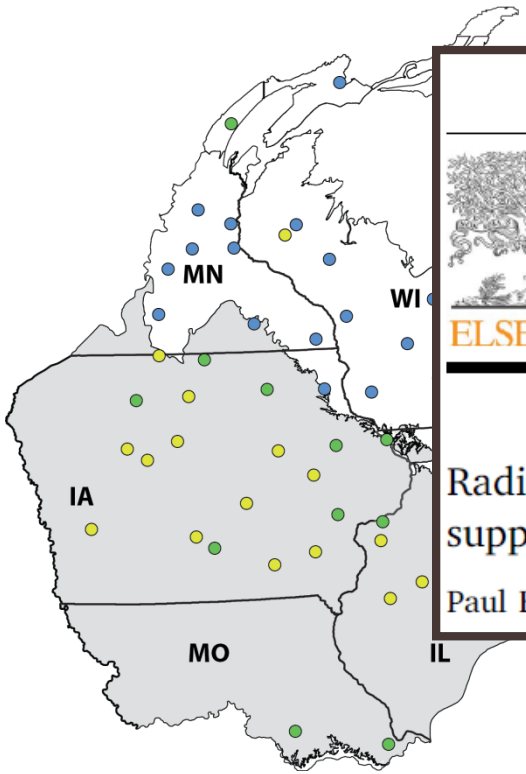


Applied Geochemistry 89 (2018) 34–48

Contents lists available at ScienceDirect

Applied Geochemistry

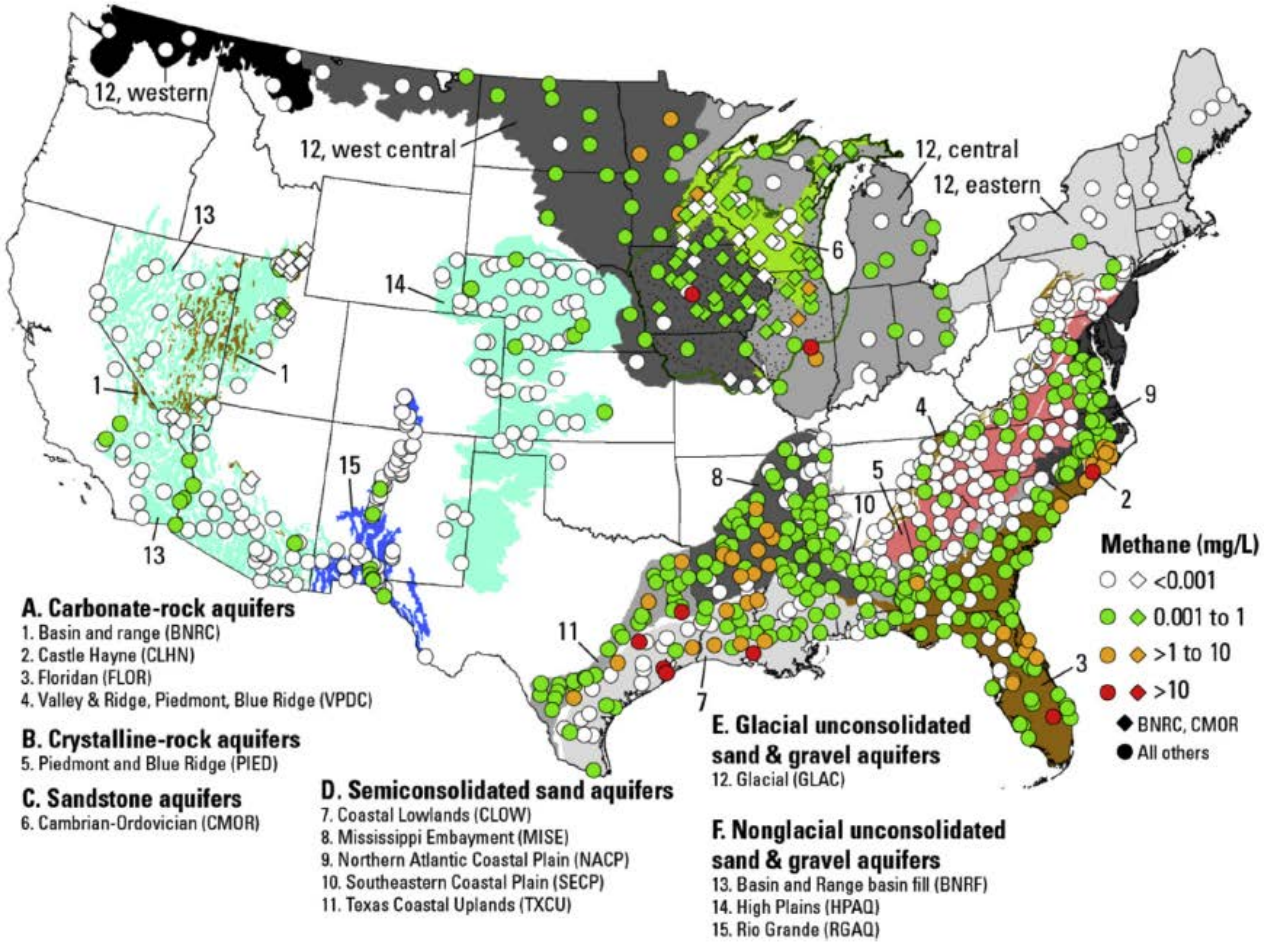
journal homepage: www.elsevier.com/locate/apgeochem

Radium mobility and the age of groundwater in public-drinking-water supplies from the Cambrian-Ordovician aquifer system, north-central USA

Paul E. Stackelberg[a,*], Zoltan Szabo[b], Bryant C. Jurgens[c]

https://doi.org/10.1016/j.apgeochem.2017.11.002

METHANE IN PUBLIC SUPPLY WELLS



METHANE IN PUBLIC SUPPLY WELLS

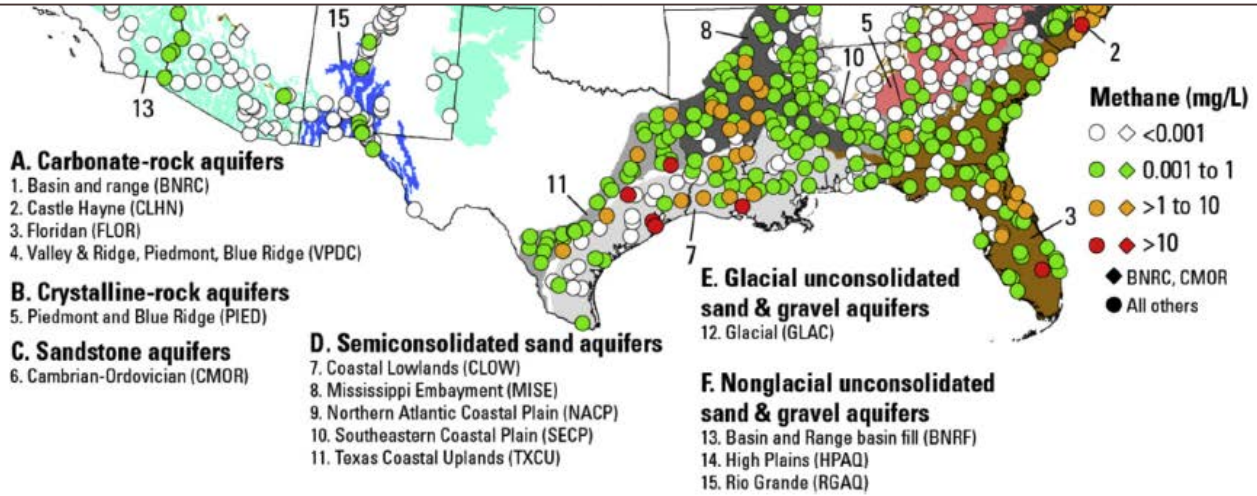
Contents lists available at ScienceDirect

Applied Geochemistry

journal homepage: www.elsevier.com/locate/apgeochem

Methane in aquifers used for public supply in the United States

P.B. McMahon [a,*], K. Belitz [b], J.R.B. Barlow [c], B.C. Jurgens [d]

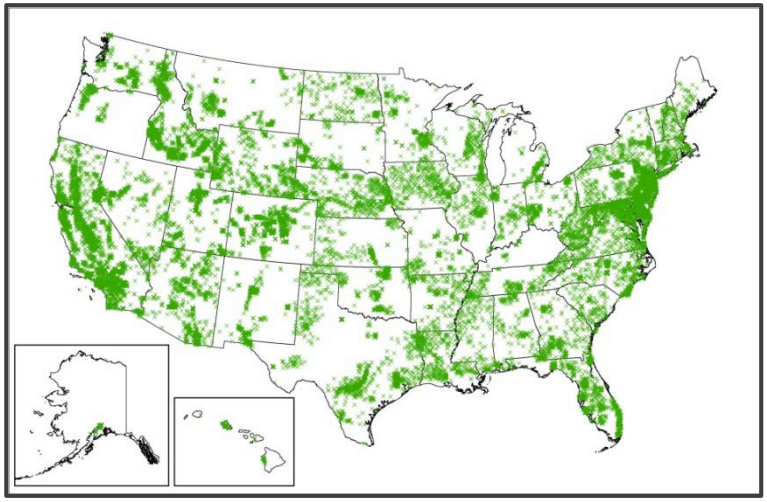


http://dx.doi.org/10.1016/j.apgeochem.2017.07.014

RECENTLY PUBLISHED OR PENDING

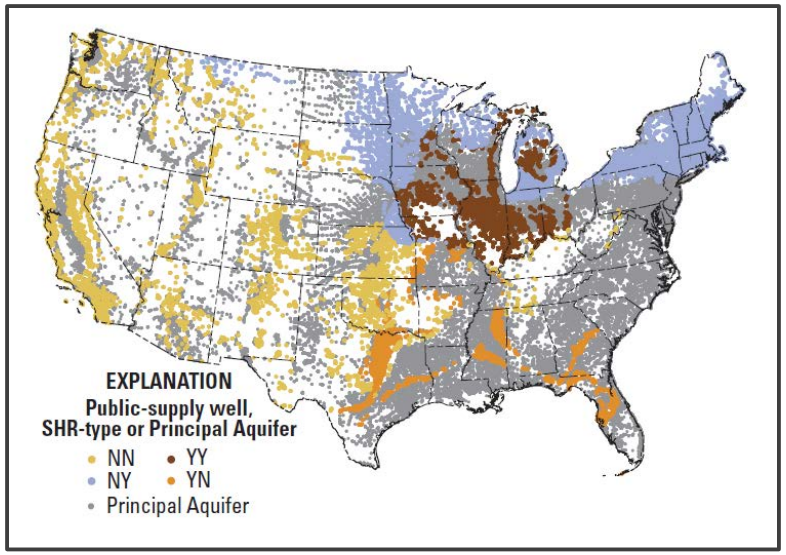
- **Groundwater Quality and Unconventional Oil & Gas Production**
- **Lead Solubility Indices for US Groundwater**
- **Hormones and Pharmaceutical Compounds**
- **Manganese**
- ***+ others***

WHAT ADDITIONAL DATA ARE NAWQA USING?



USGS NWIS
NATIONAL WATER INFORMATION SYSTEM

eg. >22,000 sites used to map GW corrosivity



PUBLIC SUPPLY WELLS
~ 150,000
Secondary Hydrogeologic Regions

Constraints: Locational accuracy / privacy

HOW DOES NAWQA ASSESS TRENDS?

- **DECADAL RESAMPLING OF MAS AND LUS NETWORKS**

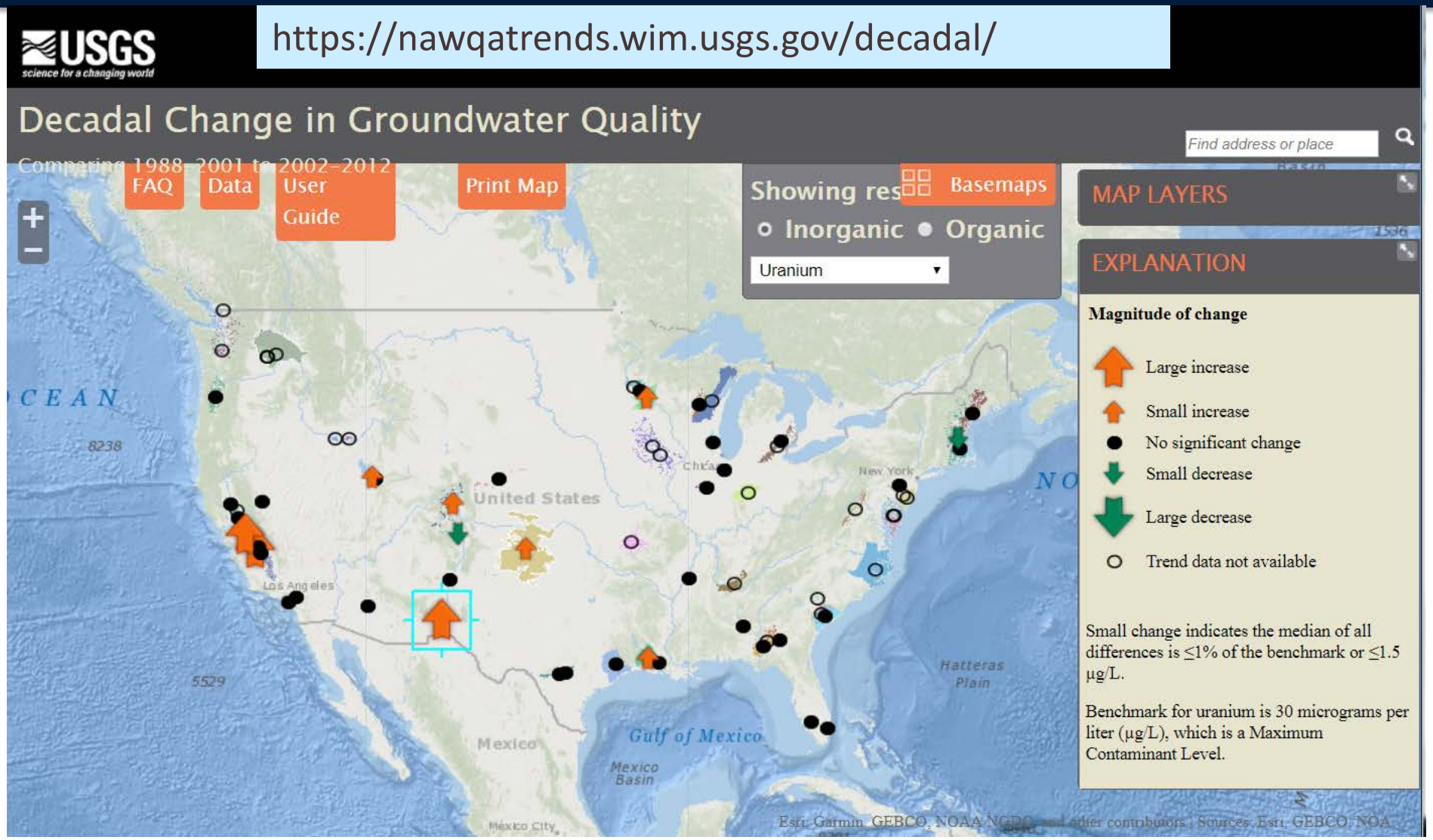
- **ENHANCED TRENDS NETWORKS – TIMESCALES <10 YEARS**
  - Continuous monitoring / daily median
  - Bimonthly sampling 3-4 years, annual 6-7 years
  - Age-dating

- **VERTICAL FLOW PATH – TIMESCALES > 10 YEARS**
  - Leverage existing networks (nested)
  - Additional wells
  - Age dating

OVER WHAT TIME SCALES DOES GROUNDWATER QUALITY CHANGE?

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

https://nawqatrends.wim.usgs.gov/decadal/



DECADAL RESAMPLING OF MAS AND LUS NETWORKS

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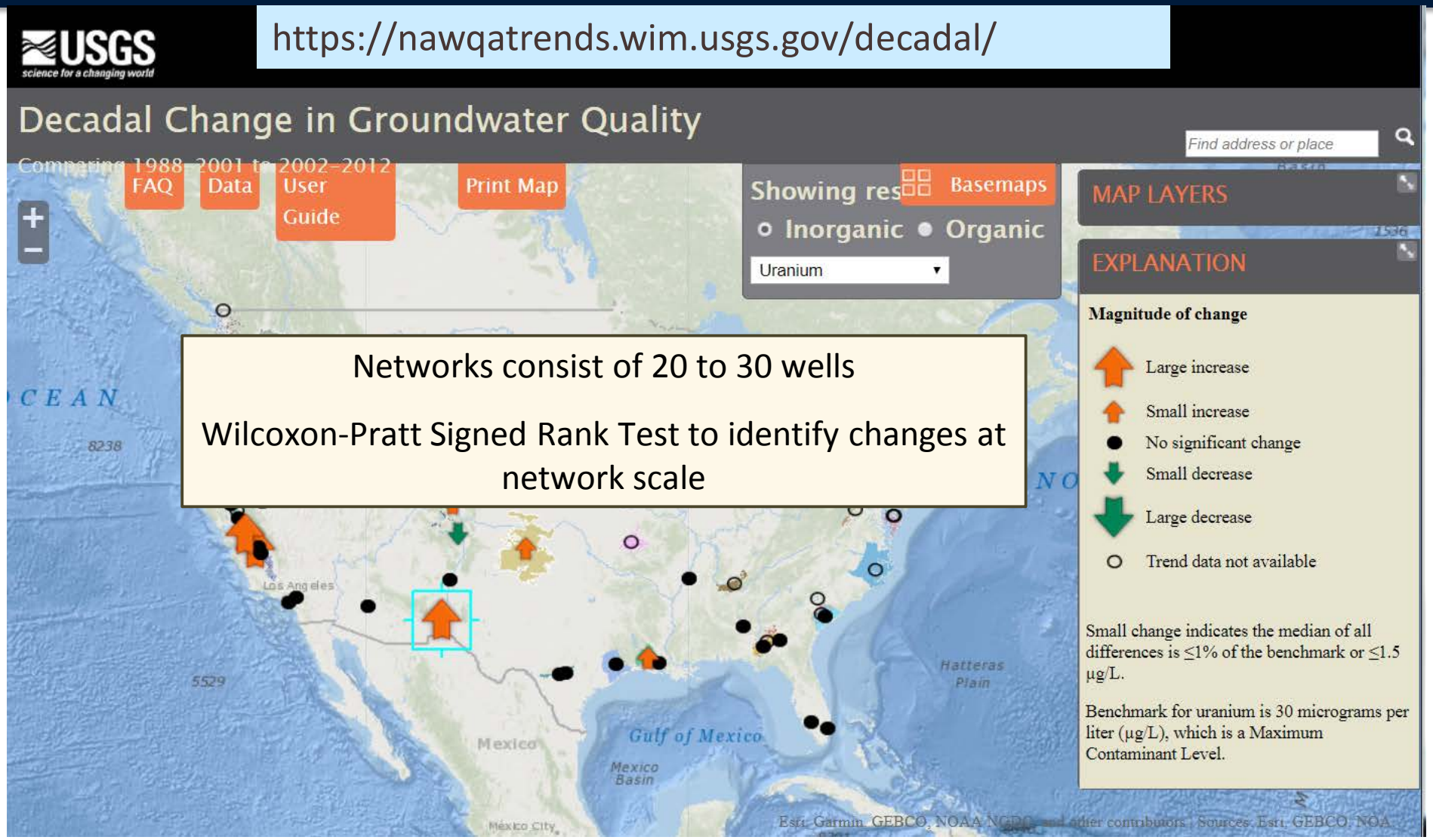
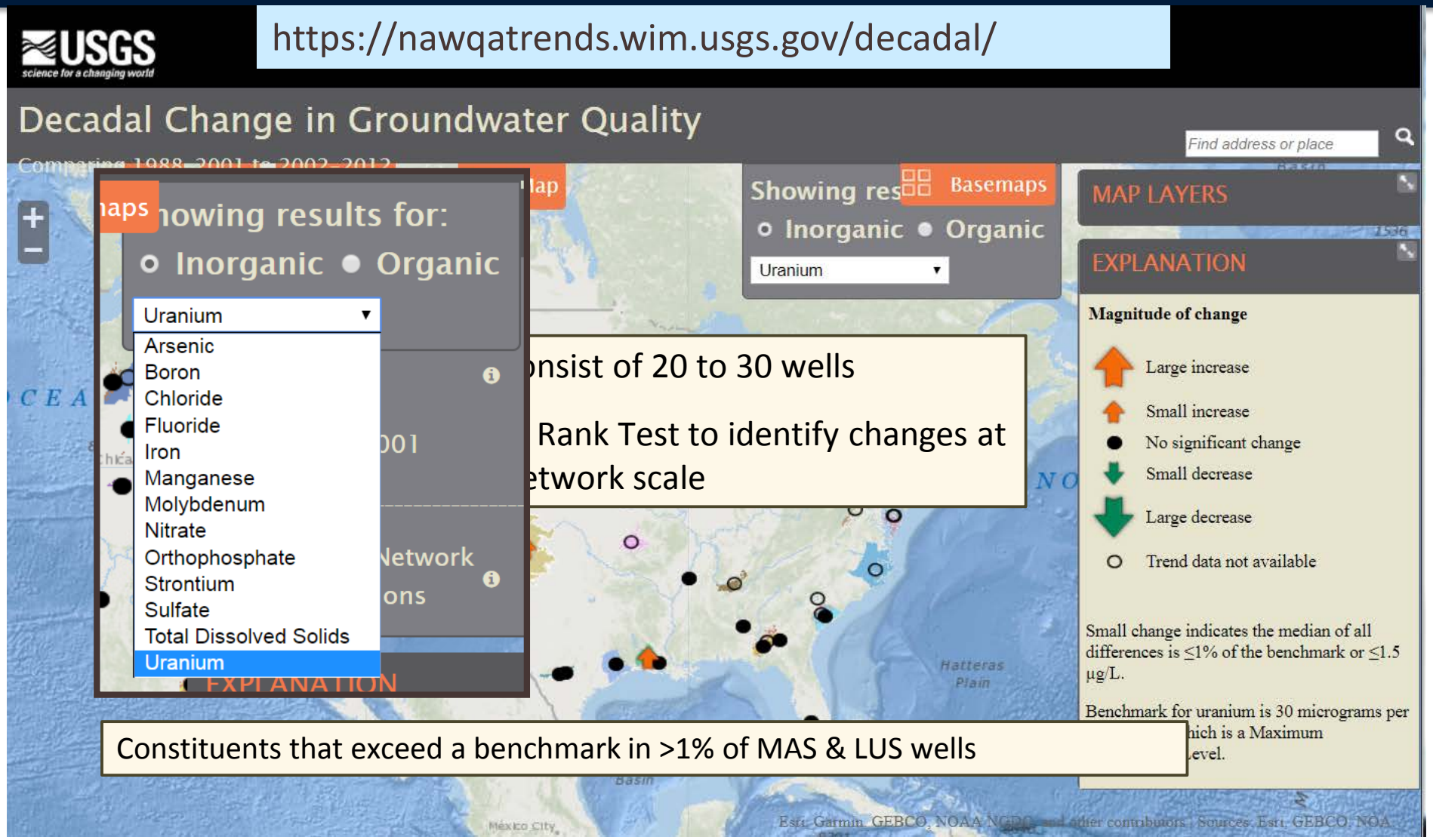


Networks consist of 20 to 30 wells

Wilcoxon-Pratt Signed Rank Test to identify changes at network scale

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

https://nawqatrends.wim.usgs.gov/decadal/



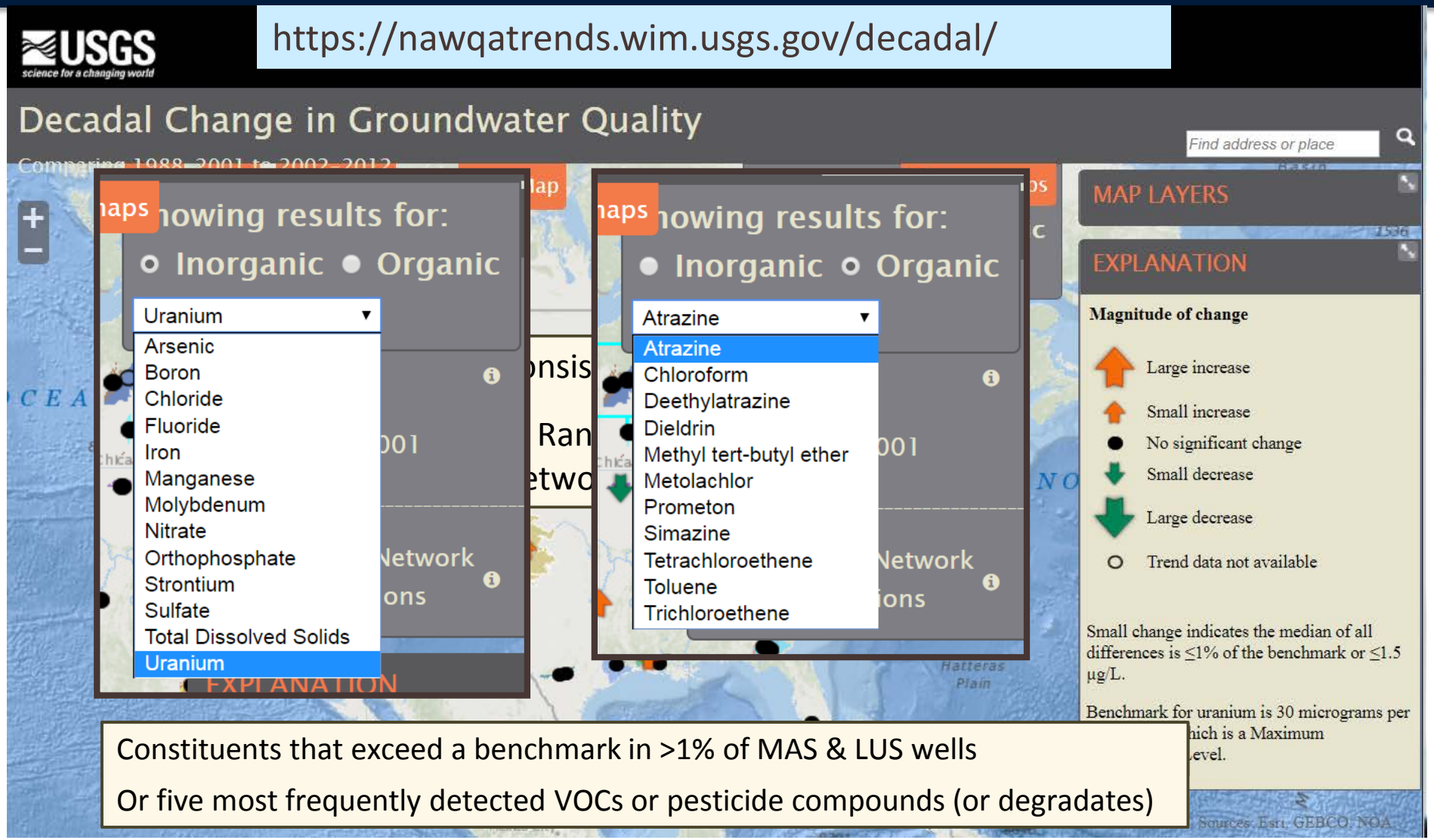
consist of 20 to 30 wells

Rank Test to identify changes at network scale

Constituents that exceed a benchmark in >1% of MAS & LUS wells

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

https://nawqatrends.wim.usgs.gov/decadal/



Constituents that exceed a benchmark in >1% of MAS & LUS wells

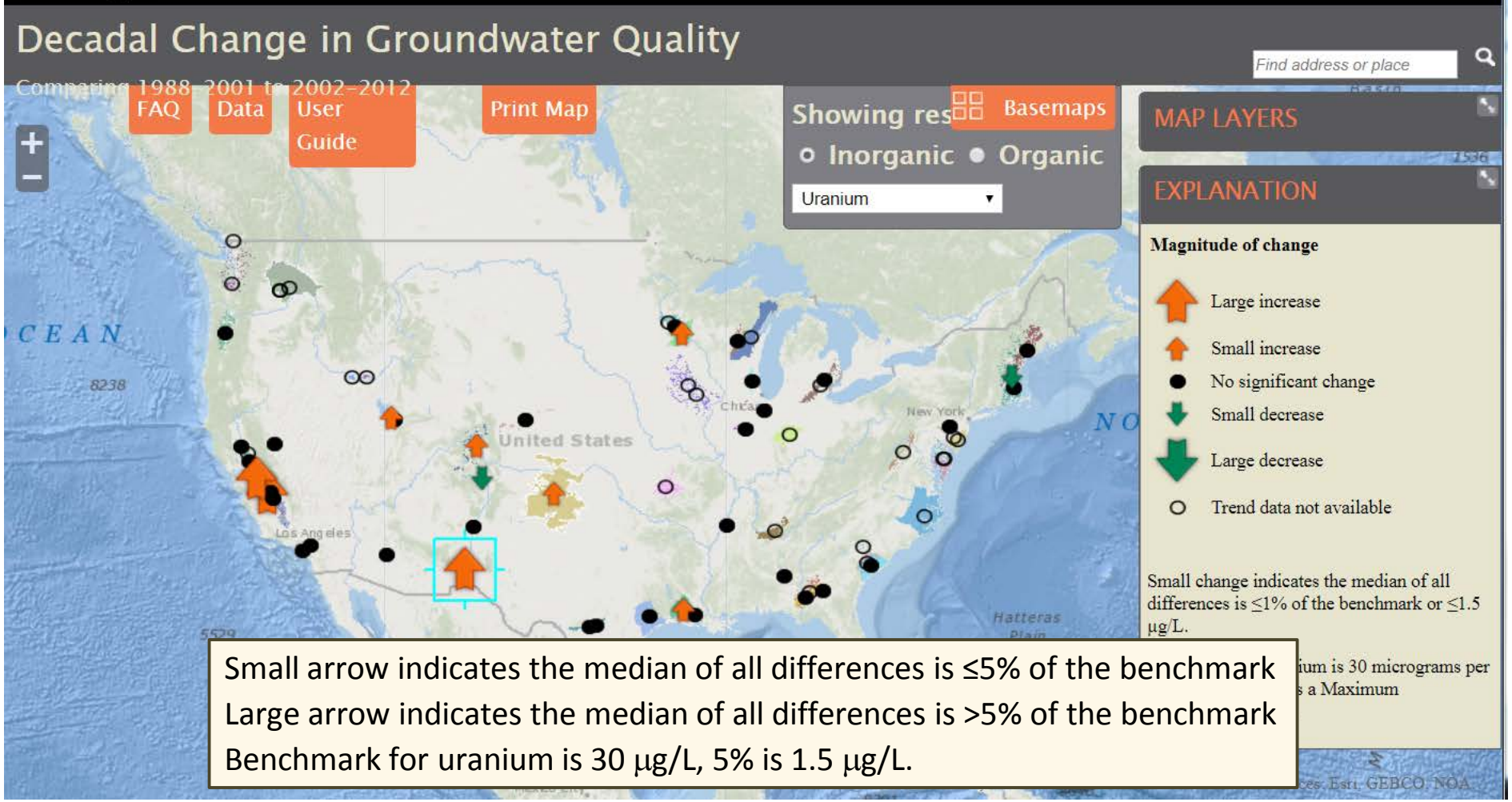
Or five most frequently detected VOCs or pesticide compounds (or degradates)

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

https://nawqatrends.wim.usgs.gov/decadal/

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

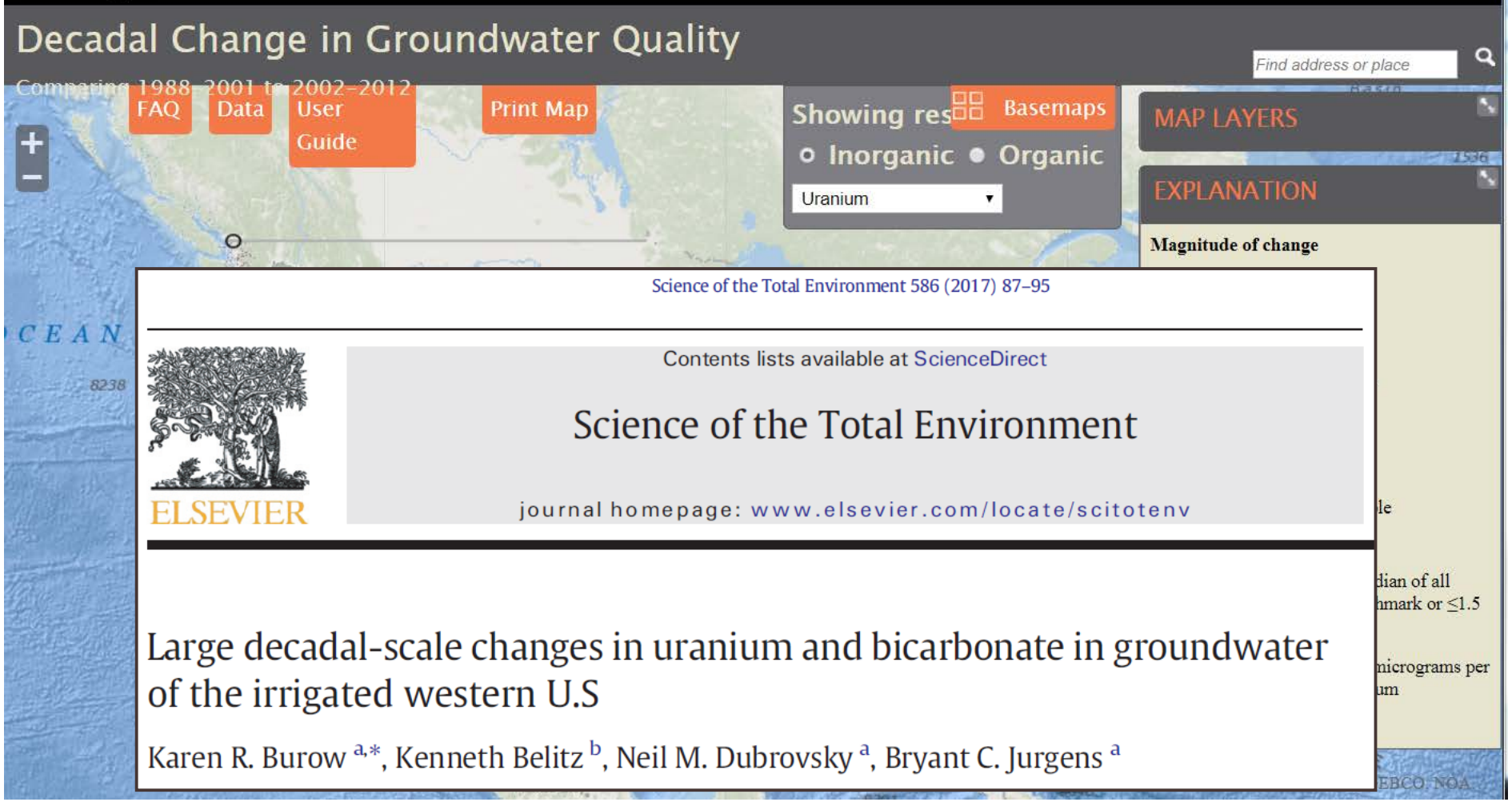
https://nawqatrends.wim.usgs.gov/decadal/



Small arrow indicates the median of all differences is ≤5% of the benchmark
Large arrow indicates the median of all differences is >5% of the benchmark
Benchmark for uranium is 30 µg/L, 5% is 1.5 µg/L.

DECADAL RESAMPLING OF MAS AND LUS NETWORKS

https://nawqatrends.wim.usgs.gov/decadal/



Science of the Total Environment 586 (2017) 87–95

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Large decadal-scale changes in uranium and bicarbonate in groundwater of the irrigated western U.S

Karen R. Burow [a,*], Kenneth Belitz [b], Neil M. Dubrovsky [a], Bryant C. Jurgens [a]

http://dx.doi.org/10.1016/j.scitotenv.2017.01.220

FROM POINTS TO MAPS

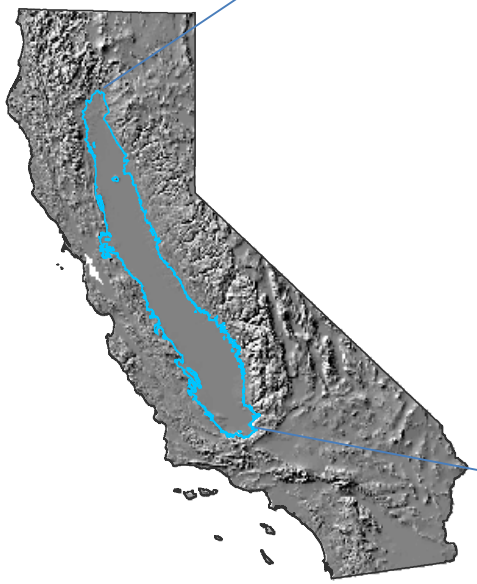
- **WALL-TO-WALL, TOP-TO-BOTTOM COVERAGE**
  - Constituents of concern
  - Regional and National

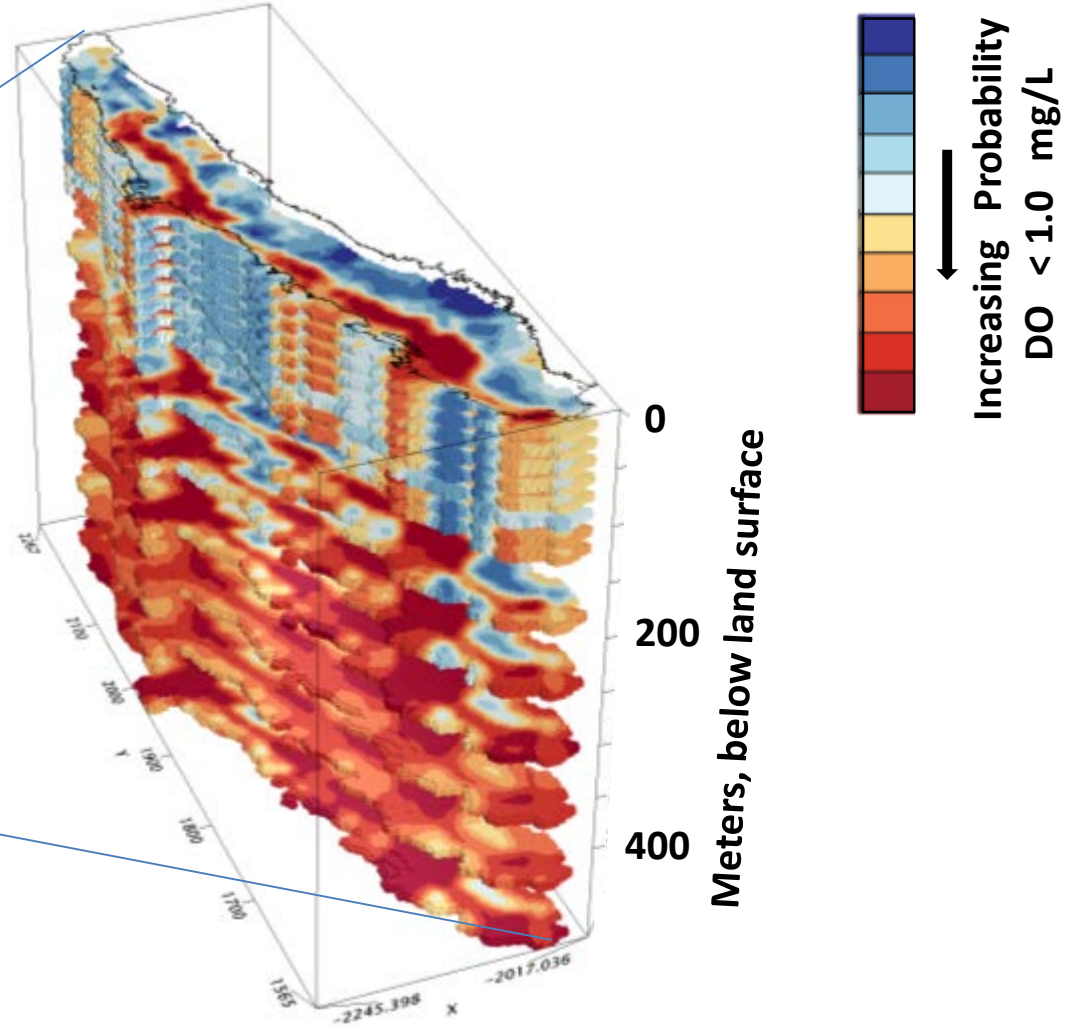
- **MASTER VARIABLES**
  - pH, redox, groundwater age

- **MACHINE LEARNING**
  - Random Forest, Boosted Regression Tree
  - Capable of handling dozens/scores of potential factors
  - Data intensive

3D CHARACTERIZATION OF ANOXIC GROUNDWATER

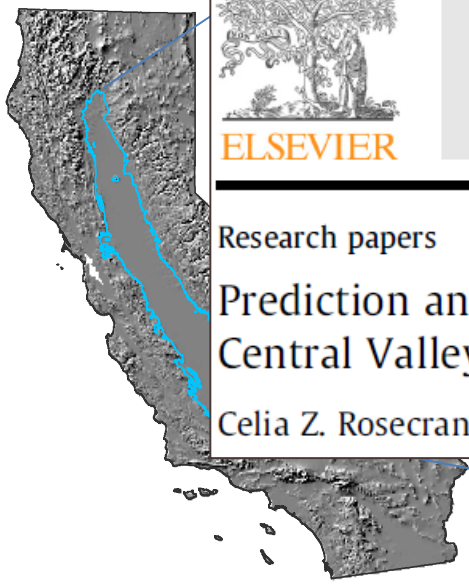
Central Valley, CA

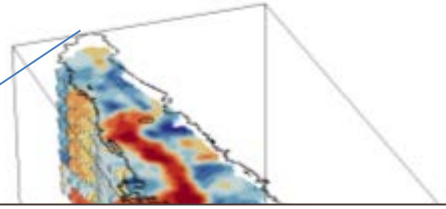




3D CHARACTERIZATION OF ANOXIC GROUNDWATER

Central Valley, CA





Probability

DO < 1.0 mg/L

Journal of Hydrology 546 (2017) 341–356

Contents lists available at ScienceDirect

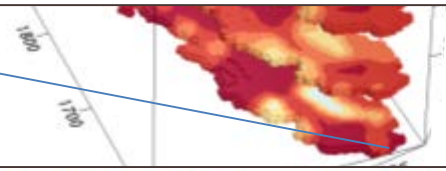
Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Prediction and visualization of redox conditions in the groundwater of Central Valley, California

Celia Z. Rosecrans [a,*], Bernard T. Nolan [b], JoAnn M. Gronberg [c]

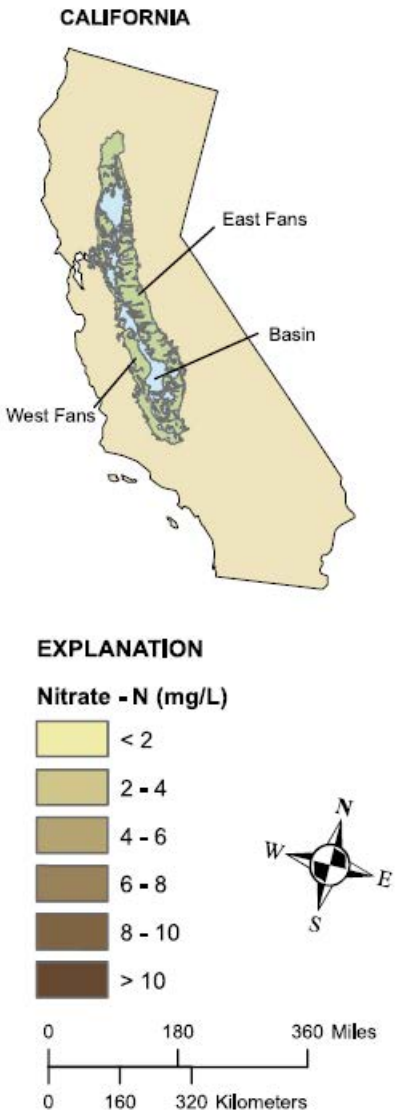


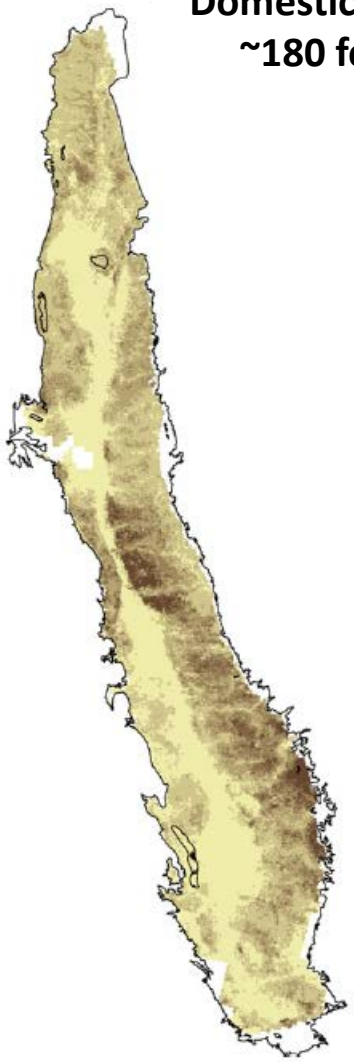
400

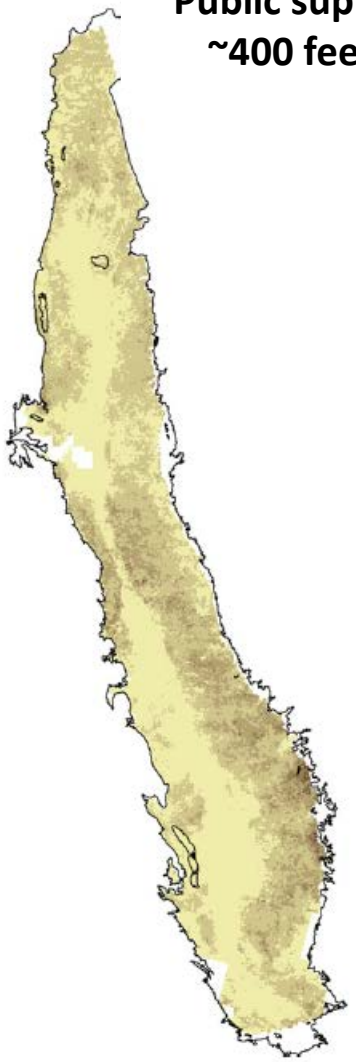
Meter

http://dx.doi.org/10.1016/j.jhydrol.2017.01.014

CENTRAL VALLEY: NITRATE







CENTRAL VALLEY: NITRATE

Domestic wells ~180 feet

Public supply ~400 feet

Science of the Total Environment 601–602 (2017) 1160–1172

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

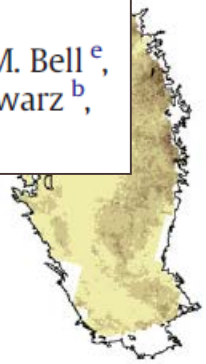
A hybrid machine learning model to predict and visualize nitrate concentration throughout the Central Valley aquifer, California, USA

Katherine M. Ransom [a,*], Bernard T. Nolan [b], Jonathan A. Traum [c], Claudia C. Faunt [d], Andrew M. Bell [e], Jo Ann M. Gronberg [f], David C. Wheeler [g], Celia Z. Rosecrans [c], Bryant Jurgens [c], Gregory E. Schwarz [b], Kenneth Belitz [h], Sandra M. Eberts [i], George Kourakos [a], Thomas Harter [a]

8 - 10

> 10

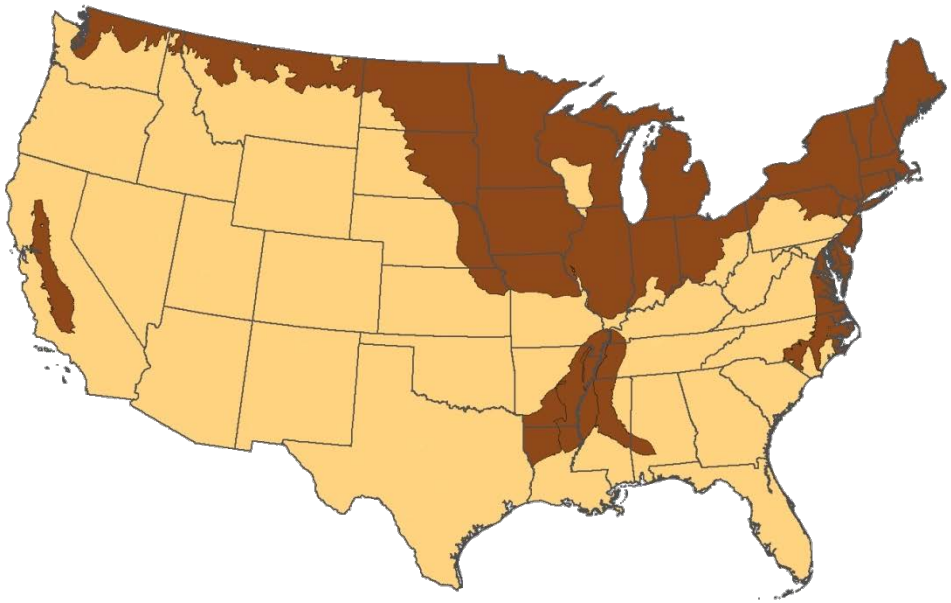
http://dx.doi.org/10.1016/j.scitotenv.2017.05.192



GROUNDWATER MODELING & MAPPING
MULTI-SCALE, MULTI-MODEL STUDIES

Glacial 2014-2019

Central Valley 2013-2018

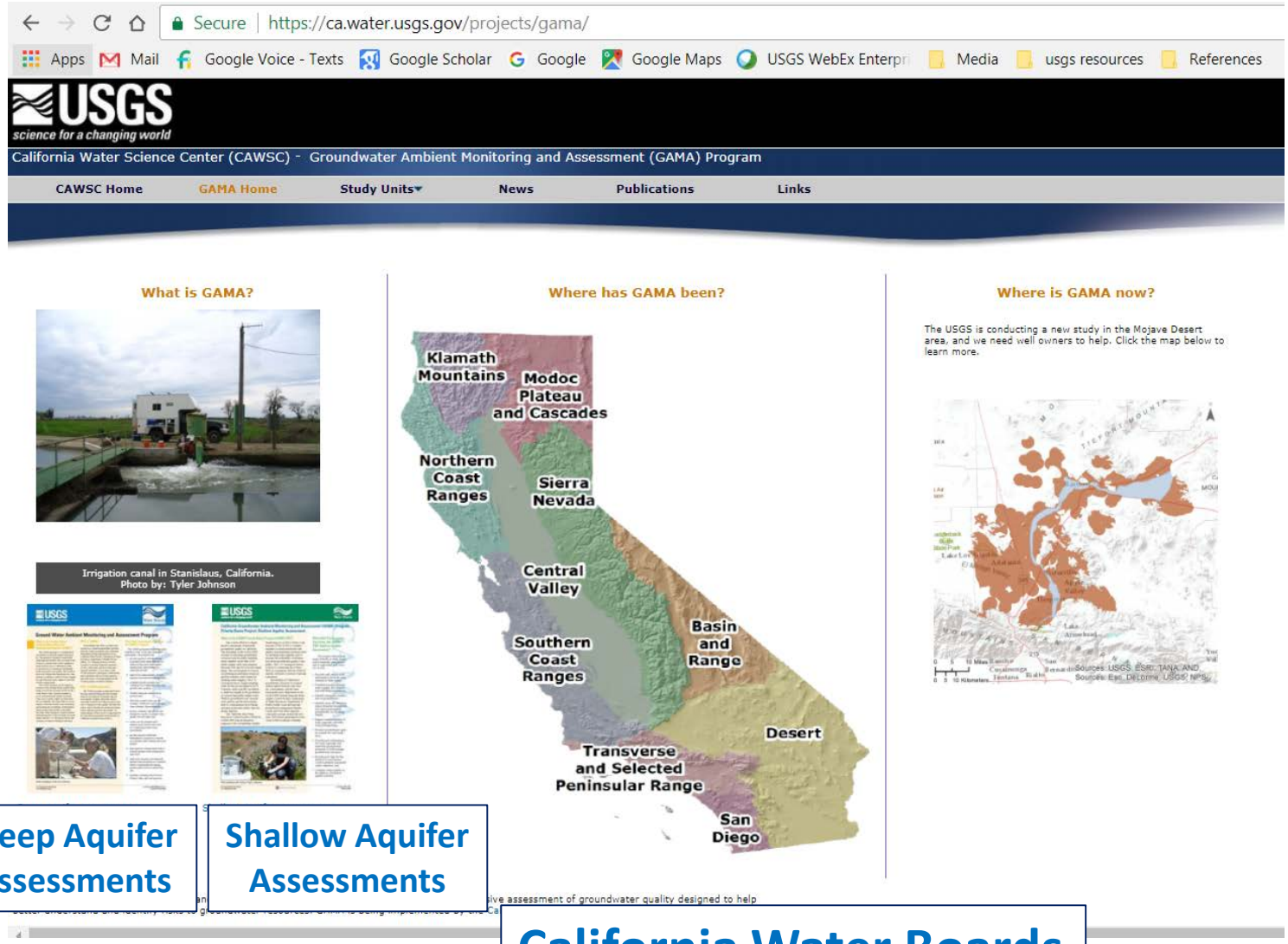


North Atlantic Coastal Plain 2015-2020

Mississippi Embayment 2016-2021

Numerous publications: as shared today + others, pending, planned

COOPERATIVE WATER PROGRAM
GROUNDWATER AMBIENT MONITORING AND ASSESSMENT (GAMA)

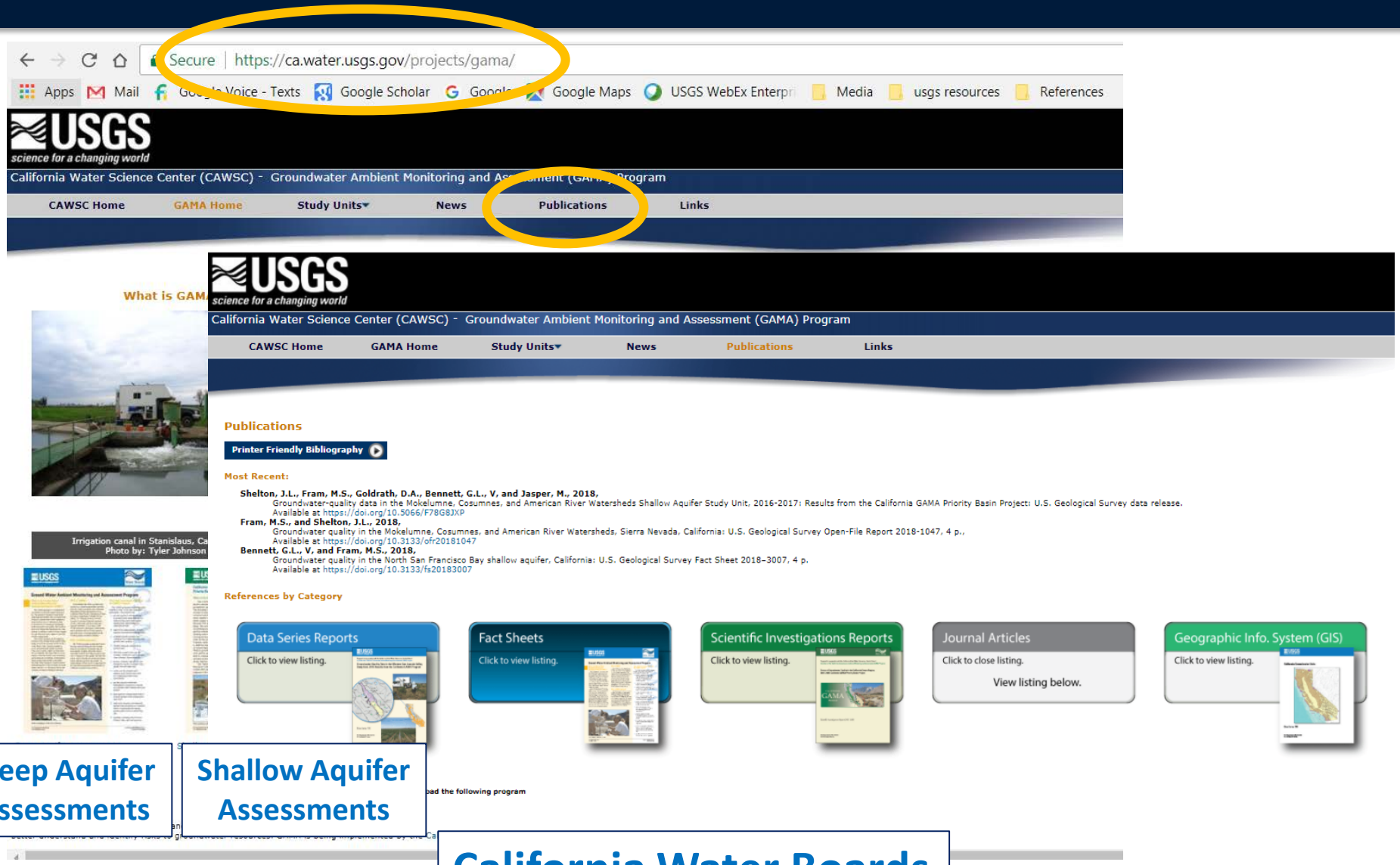


Deep Aquifer Assessments

Shallow Aquifer Assessments

California Water Boards

COOPERATIVE WATER PROGRAM
GROUNDWATER AMBIENT MONITORING AND ASSESSMENT (GAMA)



Deep Aquifer Assessments

Shallow Aquifer Assessments

California Water Boards

SUMMARY

- **NAWQA is assessing groundwater quality used for drinking supply**
  - **Human health benchmarks provide context**
  - **Data from multiple sources (NAWQA, NWIS, SDWIS, other)**
  - **Mapping in three dimensions based on data and modeling**

- **NAWQA groundwater research focuses on constituents of concern**
  - **Concentrations above health-based benchmarks**
  - **Emerging concern**
  - **Master variables (pH, redox, age) and ancillary datasets provide basis for mapping**

- **NAWQA data and information are available on the web**
- **There are additional USGS groundwater quality investigations**