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
• 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
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

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...

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

<table>
<thead>
<tr>
<th>Starting records</th>
<th>Affected records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter name</td>
<td>Filtration status</td>
</tr>
<tr>
<td>25,125,379</td>
<td>3,557,821</td>
</tr>
</tbody>
</table>

NAWQA Trend Analysis

  - 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

Surface water interactive trends mapper

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

Chloride trends 1992-2012

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
Potential corrosivity of surface water

Urban waters have become more corrosive over the past 20 years

Corrosion can be difficult to control

Increased potential to cause corrosion

Agricultural  Mixed  Undeveloped  Urban

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
Link Pb Action Level Exceedances to CSMR

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
Severe Harmful Algal Blooms Have Been Reported in Large Rivers

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

Real-Time Chlorophyll, in µg/l

March 30, 2017 18:31ET

Explaination

- 3 - 11.9
- 12 - 24.9
- 25 - 49.9
- 50 - 99.9
- 100 - 199
- >200
- No Data

Temp Cond pH D.O. Turb Nitrate Disch Chlorophyll

http://waterwatch.usgs.gov/wqwatch
Early-warning systems: Cyanotoxins

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

Toxin=f(Chlorophyll)

Stone, Graham, & Gatotho, 2013
Cyanobacteria Assessment Network (CyAN) Project

Remotely sensed data + 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

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

SPARROW modeling: Estimating contaminant transport

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 contaminant 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 available in the Mississippi Basin and large sub-basins within or adjoining it, and new Mappers are being developed for other regions of the U.S. To 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 contaminant

Overview | Science | Data and Tools | Publications

Access SPARROW mappers and data bases used to develop SPARROW.

SPARROW Mappers: Web-Based Interactive Water-Quality

These interactive tools allow the user to explore river nutrient loads and particular river basins. Data can be visualized using maps and interactive HUC, and catchment. Modeling results can be exported as an Excel spreadsheet of nutrient loads and phosphorus concentrations for the Mississippi Basin and large sub-basins within or adjoining it, and then replace the SPARROW Decision Support System (Booth et al., 2011).

- Great Lakes, Ohio, Upper Mississippi, Red River Basins (MRF)
- Mississippi/Atchafalaya River Basin (MARB) SPARROW Mapper
- Red-Assiniboine River Basin (RARB) SPARROW Mapper, 200
- Great Lakes SPARROW Mapper, 2002
- Yellowstone River SPARROW Mapper, 2002

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Models predict nutrient loads in streams & rivers and identify sources.

SPARROW modeling: Estimating contain

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Databases

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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/
**Water Quality Data Discovery…**

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https://www.waterqualitydata.us/
Updated human-health benchmark tool

Norman, Toccalino, and Morman (expected 2018)
http://water.usgs.gov/nawqa/HBSL
Water Quality Data Discovery...


USGS Sediment Data Portal

National Atmospheric Deposition Program Animated Maps

BioData – Aquatic Bioassessment Data

Estimated Annual Agricultural Pesticide Use
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
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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
• Water quality constituents with benchmarks
  o Geologic sources: trace elements, radionuclides, (nitrate)
  o Human sources: nutrients, volatile organic compounds, pesticides and pesticide degradates, microbiological constituents
  o Nuisance constituents: iron, manganese, dissolved solids, hardness, ...

• Water quality constituents without benchmarks

• New analytes ("emerging" concern)
  o Pharmaceuticals, Hormones, Polonium, Enterococci ...
• Geochemical indicators
  o Major ions, redox, pH, DO, T

• Tracers of groundwater age
  o Tritium, SF₆, CFCs, carbon-14, noble gases

• Low-level detection methods
  o VOCs and pesticides, < parts per billion (PPB)
  o Indicator of human “fingerprint”
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**: Conc. < 1/10 of benchmark for organic
  Conc. < 1/2 of benchmark for inorganic
- **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?

Inorganic

Organic

Trace elements

Radioactivity

Nitrate

VOCs

Pesticides

Constituent concentrations

- **High**
- **Moderate**
- **Low or not detected**

Basin and Range
WHICH CONTAMINANTS ARE MOST PREVALENT AT HIGH CONCENTRATIONS?

- Valley & Ridge
- Piedmont & Blue Ridge
- Carbonates
- Inorganic
- Organic
- Basin & Range
- Glacial
- North Atlantic Coastal Plain
- Rio Grande
- Coastal Lowlands
- Southeastern Coastal Plain

**Constituent concentrations**
- High
- Moderate
- Low or not detected
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
Data are maintained in Science Base
• 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
Mean Groundwater Age

$^{14}$C indicates young water in regionally unconfined area and water $\geq 30,000$ years in the regionally confined area.

$^4$He indicates residence times $> 100,000$ years in regionally confined area.

Increasing mineralization
Increasingly reduced conditions
• $^{226}\text{Ra}$ is sorbed on Fe-hydroxide coatings under “oxic” conditions
• Mobilized under reducing, mineralized conditions
  ◦ Decreased sorption capacity
  ◦ Increased competitive exchange

CAMBRIAN-ORDIVICIAN AQUIFER SYSTEM
• $^{226}$Ra is sorbed on Fe-hydroxide coatings under “oxic” conditions
• Mobilized under reducing, mineralized conditions
  o Decreased sorption capacity
  o Increased competitive exchange

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 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
• 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
OVER WHAT TIME SCALES DOES GROUNDWATER QUALITY CHANGE?

HOW DOES NAWQA ASSESS TRENDS?

• DECADAL RESAMPLING OF MAS AND LUS NETWORKS

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

• VERTICAL FLOW PATH – TIMESCALES > 10 YEARS
  o Leverage existing networks (nested)
  o Additional wells
  o Age dating
DECADAL RESAMPLING OF MAS AND LUS NETWORKS

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

Decadal Change in Groundwater Quality

Magnitude of change
- Large increase
- Small increase
- No significant change
- Small decrease
- Large decrease
- Trend data not available

Small change indicates the median of all differences is ≤1% of the benchmark or ≤1.5 μg/L.

Benchmark for uranium is 30 micrograms per liter (μg/L), which is a Maximum Contaminant Level.
DECADAL RESAMPLING OF MAS AND LUS NETWORKS

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/

Networks consist of 20 to 30 wells. A Wilcoxon-Pratt Signed Rank Test is used to identify changes at network scale.

Constituents that exceed a benchmark in >1% of MAS & LUS wells.
Constituents that exceed a benchmark in >1% of MAS & LUS wells
Or five most frequently detected VOCs or pesticide compounds (or degradates)
Decadal Change in Groundwater Quality


MAP LAYERS

Basemaps
- Inorganic
- Organic

EXPLANATION

Magnitude of change
- Large increase
- Small increase
- No significant change
- Small decrease
- Large decrease
- Trend data not available

Small change indicates the median of all differences is ≤1% of the benchmark or ≤1.5 µg/L.

Benchmark for uranium is 30 micrograms per liter (µg/L), which is a Maximum Contaminant Level.
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.
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
  o Constituents of concern
  o Regional and National

• MASTER VARIABLES
  o pH, redox, groundwater age

• MACHINE LEARNING
  o Random Forest, Boosted Regression Tree
  o Capable of handling dozens/scores of potential factors
  o Data intensive
Central Valley, CA

Increasing Probability

DO < 1.0 mg/L

Meters, below land surface

3D CHARACTERIZATION OF ANOXIC GROUNDWATER
Central Valley, CA

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

Celia Z. Rosecrans, Bernard T. Nolan, JoAnn M. Gronberg

http://dx.doi.org/10.1016/j.jhydrol.2017.01.014
DOMESTIC WELLS: ~180 FEET
PUBLIC SUPPLY: ~400 FEET

EXPLANATION
Nitrate - N (mg/L)
- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

CALIFORNIA
East Fans
West Fans
Basin

Domestic wells
~180 feet

Public supply
~400 feet

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

Katherine M. Ransom, Bernard T. Nolan, Jonathan A. Traum, Claudia C. Faunt, Andrew M. Bell, Jo Ann M. Gronberg, David C. Wheeler, Celia Z. Rosecrans, Bryant Jurgens, Gregory E. Schwarz, Kenneth Belitz, Sandra M. Eberts, George Kourakos, Thomas Harter

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
SUMMARY

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

• NAWQA groundwater research focuses on constituents of concern
  o Concentrations above health-based benchmarks
  o Emerging concern
  o 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