Table of Contents

Welcome Message .................................................................................................................. 2
Symposium Purpose & Intent
Dr. Karl Longley Bio ............................................................................................................. 4
Occurrence of Arsenic in San Joaquin Valley Ground Water
Dr. Beth Weinman Bio ........................................................................................................... 7
Occurrence of Arsenic in Groundwater, Hanford, CA
Chris Johnson Bio .................................................................................................................. 23
USGS National Quality Assessment Program & Groundwater Ambient Monitoring
Dr. Miranda Fram .................................................................................................................... 32
USGS Central Valley Hydrolic Model
Dr. Claudia Faunt Bio .......................................................................................................... 39
Key Regulatory Challenges for Arsenic in Drinking Water
State Water Control Board Bios .......................................................................................... 59
Overpumping Leads to California Groundwater Arsenic Threat
Dr. Scott Fendorf Bio ............................................................................................................ 82
Breakout Session .................................................................................................................. 106
Greetings from the California Water Institute at Fresno State.

I want to extend my sincere appreciation to everyone that had an opportunity to attend the Arsenic Symposium at Fresno State on October 11, 2018. The event was a great success thanks in large part to the quality and extensive expertise of the event speakers, and the quality and level of participation and engagement from the symposium attendees. Thanks again to everyone for making this event special and great success for the San Joaquin Valley.

As promised, we are pleased to provide the enclosed Arsenic Symposium Proceedings for everyone that attended, and also for those that were unable to attend. As an introduction to the Arsenic Symposium Proceedings, I would like to highlight a few of the key teaching moments from the event.

- **From Dr. Beth Wienman, Associate Professor, Fresno State, we learned that**:
  - Arsenic is a persistent and pervasive element in the environment, and it is a globally-recognized water quality contaminant of concern.
  - Arsenic results from the natural erosion and sedimentation of mountain ranges like the Himalayas and Sierra Nevadas
  - Long-term exposure to Arsenic can cause a variety of diseases including respiratory, diabetes, skin lesions, and cancer.

- **From Chris Johnson, Fresno State Alumnus, and Owner of Aegis Consulting, we learned that**:
  - Fresno State has been involved in the study of Arsenic in the San Joaquin Valley groundwater for nearly 40 years;
  - Arsenic is not present everywhere in the SJ Valley, and it can be traced to clay and silt deposits with high organic content as may be found in an ancient riverine systems.
  - There are hydrogeologic investigative procedures (bore hole assessments) that can be applied in the field and laboratory to avoid drilling wells in Arsenic prone formations.

- **From Dr. Miranda Fram, Geochemist, United States Geological Survey (USGS), we learned that**:
  - Arsenic has been the subject of USGS studies dating back to the 1970’s, and the USGS has Arsenic data for approximately 3,000 wells for the entire Central Valley, including the San Joaquin Valley.
  - Through extensive study work, the USGS has identified the geochemical conditions that contribute to the release of Arsenic into drinking water wells - Arsenic is more soluble in anoxic water or in high pH oxic water, Arsenic is generally more common in older water, which is generally deeper water.
  - USGS has been working to integrate water quality modeling with hydrologic modeling to predict the probability of the presence of Arsenic, as well as the concentrations of Arsenic, in drinking water wells in the Central Valley.
  - USGS has the capacity to work with public water supply well owners to investigate corrective actions to reduce Arsenic concentrations in drinking water, and that the USGS has conducted research relating Arsenic concentrations with stratigraphy and groundwater pumping rates, and that the rate and degree of Arsenic release can be related to activities that change the flow patterns in an aquifer including groundwater recharge and groundwater pumping rates.

- **From Dr. Claudia Faunt, Hydrogeologist, United States Geological Survey (USGS), we learned that**:
  - Compaction predominantly occurs in the fine-grained thin interbeds. Where it exists, most compaction in the San Joaquin Valley occurs below the Corcoran clay layer when groundwater levels decline causing compaction of fine-grained deposits.
  - The USGS has develop a regional groundwater hydrologic model for the San Joaquin Valley that can be used on a regional scale to look at various scenarios (a) predict the location and degree of future land subsidence resulting from groundwater level changes, (b) predict the future impacts on groundwater levels resulting from reduced surface water deliveries and climate change, and (c) predict the general direction of groundwater flow in the San Joaquin Valley under varying water supply and hydrologic conditions.
  - Compaction from groundwater-level declines occurs rapidly and over long periods of time. The compaction, and resulting land subsidence can be minimized if groundwater levels stabilize, but compaction and associated subsidence can escalate again if groundwater levels exceed historic lows. Some compaction will occur for decades and maybe even centuries as think clays drain slowly and reach equilibrium with current conditions.
• From the State Water Resources Control Board, we learned that:
  – On a statewide basis, the State has tested 16,000 public water supply wells for Arsenic, and 1,300 wells (8%) reported Arsenic concentrations above the maximum contaminant level concentration of 10 micrograms per liter (ug/L).
  – The State has tested 1,300 private domestic wells and small community wells for Arsenic, and 60 wells (5%) reported Arsenic concentrations above 10 ug/L.
  – Arsenic has been used in the manufacture of lumber, electronics, glass, and pesticides, and that food is typically the largest source of Arsenic exposure for humans as Arsenic is present in rice, beer, wine, Brussel sprouts, and other food products.
  – There are a number of different treatment options to reduce the concentration of Arsenic in groundwater, including activated alumina, ion exchange, reverse osmosis, oxidation and filtration, and blending.
  – The SWRCB will allow small water systems to install point of use and point of entry treatment devices to remove Arsenic for limited duration (3 years maximum) until a permanent solution can be implemented, and the point of use devices and point of entry devices must be certified by the State.

• From Dr. Scott Fendorf, Soil Chemist and Biogeochemist, Stanford University, we learned that
  – Arsenic is pervasive on the planet, and is a groundwater contaminant of concern across the globe.
  – Arsenic generally exists in two forms in an aquifer: a particulate form known as As(V), or arsenate, HAsO4²⁻, and an aqueous form known As(III), or arsenite, H₃AsO₃. Arsenite is the form of Arsenic that is a health concern for drinking water.
  – Arsenic, in the arsenate form, binds to soils and sediments, and is retained within the soil matrix; however, under certain conditions the arsenate can be converted to arsenite and be released in aqueous form to the surrounding groundwater.
  – Extensive research has demonstrated that the conditions that contribute to converting arsenate to arsenite in a groundwater aquifer include persistent anaerobic conditions caused by microbial activity, elevated pH (>8.5), changes in ionic composition, and aquifer compression (subsidence) caused by groundwater pumping.
  – In the case of Arsenic release from aquifer compression, when other contributing factors exist (pH, anaerobic environment, etc.) in the aquifer to convert arsenate to arsenite, the compression action releases arsenite from the compressed layer to the surrounding groundwater, just as squeezing a wet sponge releases water from the sponge.
  – Research conducted by Dr. Fendorf with the Orange County Water District, demonstrates that it is possible to control the conversion of arsenate to arsenite through controlled manipulation of the biochemical conditions in the aquifer. This has important implications in the SJ Valley as agencies are moving quickly to increase groundwater recharge programs which may inadvertently change the biochemical conditions of the aquifer.
  – Dr. Fendorf suggests that water agencies working to implement more aggressive groundwater recharge programs should also consider implementing groundwater surveillance systems to monitor the biochemical conditions of the aquifer to detect for early indicators of possible adverse impacts.

After Dr. Fendorf’s presentation, the symposium attendees were invited to provide responses to five questions related to Arsenic in San Joaquin Valley drinking water. The questions and responses to are included as the last section of these Arsenic Symposium Proceedings.

As you can see, the event served as a great learning opportunity for everyone, and we are again grateful to the wonderful speakers and the attendees that participated in the event. We, at Fresno State, look forward to additional opportunities to make such events available to the community to review and discuss critical water resources management issues in the San Joaquin Valley and the State of California. For a list of future events, please visit www.fresnostate.edu/water.

Sincerely,

Thomas C Esqueda, Fresno State
Associate Vice President for Water and Sustainability
Executive Director, California Water Institute
Email:
karll@csufresno.edu

Phone:
559.278.2066

About:
Dr. Longley’s expertise includes serving over 25 years as a Central California Regional Water Quality Control Board (CVRWQCB) member of which eight years were as the Board’s chair; serving as the Dean of the College of Engineering and Computer Science, California State University, Fresno, during the period of 1996 through 2004 with responsibility for a number of programs including the MESA/MEP program; serving three years on the Board of Scientific Counselors, Agency for Toxic Substances and Disease Registry (ATSDR); and having over 45 years of experience directly supervising or conducting studies of water quality, industrial waste control, hazardous waste management, and water and wastewater treatment plant design and as a civil engineering faculty member and academic administrator. Dr. Longley’s responsibilities with the CVRWQCB, MESA/MEP and ATSDR involved extensive interaction with DACs seeking solutions to educational, institutional and infrastructure problems with which DACs and their residents must continually face.
Robin Meadows (Water Deeply), “Living in California’s Central Valley may harm your health,” U.S. News, July 6, 2017

### Symposium Purpose and Intent

#### TEN MOST FREQUENTLY DETECTED PRINCIPAL CONTAMINANTS IN GROUNDWATER

<table>
<thead>
<tr>
<th>PRINCIPAL CONTAMINANT</th>
<th>NUMBER OF WELLS</th>
<th>NUMBER OF COMMUNITY WATER SYSTEMS</th>
<th>TYPE OF CONTAMINANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>587</td>
<td>287</td>
<td>Naturally occurring</td>
</tr>
<tr>
<td>Nitrate</td>
<td>451</td>
<td>235</td>
<td>Anthropogenic nutrient</td>
</tr>
<tr>
<td>Gross Alpha Activity</td>
<td>333</td>
<td>182</td>
<td>Naturally occurring</td>
</tr>
<tr>
<td>Perchlorate</td>
<td>179</td>
<td>57</td>
<td>Industrial/military use</td>
</tr>
<tr>
<td>Tetrachloroethylene (TCE)</td>
<td>168</td>
<td>60</td>
<td>Solvent</td>
</tr>
<tr>
<td>Trichloroethylene (TCE)</td>
<td>159</td>
<td>44</td>
<td>Solvent</td>
</tr>
<tr>
<td>Uranium</td>
<td>157</td>
<td>69</td>
<td>Naturally occurring</td>
</tr>
<tr>
<td>1,2-Dibromo-3-Chloropropane (DBCP)</td>
<td>118</td>
<td>36</td>
<td>Legacy pesticide</td>
</tr>
<tr>
<td>Fluoride</td>
<td>79</td>
<td>41</td>
<td>Naturally occurring</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>59</td>
<td>17</td>
<td>Solvent</td>
</tr>
</tbody>
</table>

1. Also contains naturally occurring, but typically at levels below the MCL.

Sources: State Water Resources Control Board

#### GAMA Domestic Well Project: Results

<table>
<thead>
<tr>
<th>County Focus Area (No. of Wells Sampled)</th>
<th>Total Coliform</th>
<th>Fecal Coliform</th>
<th>Nitrate at/above MCL</th>
<th>Both Nitrate and Total Coliform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuba (128)</td>
<td>22% (28)</td>
<td>3% (4)</td>
<td>2% (2)</td>
<td>0.8% (1)</td>
</tr>
<tr>
<td>El Dorado (398)</td>
<td>26% (104)</td>
<td>3% (13)</td>
<td>2% (7)</td>
<td>0.7% (3)</td>
</tr>
<tr>
<td>Tehama (223)</td>
<td>25% (56)</td>
<td>1% (3)</td>
<td>1% (2)</td>
<td>0</td>
</tr>
<tr>
<td>Tulare (181)</td>
<td>33% (60)</td>
<td>8% (15)</td>
<td>41% (75)</td>
<td>13% (23)</td>
</tr>
<tr>
<td>Cumulative Project Total (928)</td>
<td>27% (248)</td>
<td>4% (35)</td>
<td>9% (86)</td>
<td>3% (27)</td>
</tr>
</tbody>
</table>
Figure 1 Average arsenic concentration of community water systems (CWS) in study sample, \((n = 464)\), 2005–2007.

Estimate based on average of each point-of-entry source’s average concentration; Sources of data: CDPH Water Quality Monitoring and PICME databases (CDPH 2008a,b); Approximate location of CWSs are depicted, but not true boundaries. Due to close proximity of some CWSs, map partially covers some CWSs.

Today’s Arsenic Symposium Purpose and Intent:

- Informational learning opportunity to really delve into the effects of arsenic in the San Joaquin Valley groundwater.

- An opportunity as a participant to suggest and discuss solutions and a path forward to effectively address the arsenic issue particularly as it pertains to economically disadvantaged communities.

- We are looking forward to your comments and recommendations during the last session of today’s symposium.
Dr. Beth Weinman

Email:
bweinman@csufresno.edu

Phone:
559.278.1641

About:
Dr. Weinman has been working on arsenic for over a decade now, starting with undergraduate thesis work with her CUNY Queens College advisor Dr. Yan Zheng. Continued interest in trying to understand the complex patterning of groundwater arsenic seen in sedimentary aquifers in many Asian deltas—Bangladesh, Vietnam, and Cambodia—motivated Dr. Weinman’s graduate work. Building on the geochemical and hydrological understanding of the time, her Master’s Degree in Oceanographic and Atmospheric Science from SUNY Stony Brook, and Ph.D. in Environmental Science from Vanderbilt University, helped yield results showing that complex spatial patterns of groundwater arsenic can be explained and better understood by better understanding of the aquifer’s sedimentology and stratigraphy.
The Occurrence of Arsenic in SJ Valley

Millions - Billions at Risk
Points to Take Home

1. Arsenic is naturally everywhere.
2. Groundwater arsenic here is similar to groundwater arsenic in many other areas.
3. Why it is a problem.
4. New findings suggest that groundwater arsenic here increases with groundwater overdraft.
5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.
Asian Regions with High Concentrations of Groundwater Arsenic
And, aside from their fluvial origins, these areas also share a common problem of arsenic heterogeneity. There are several scales of arsenic heterogeneity, with the most complex and poorly understood occurring over spatial scales 10-1000m.
Points to Take Home

1. Arsenic is naturally everywhere.

2. Groundwater arsenic here is similar to groundwater arsenic in many other areas.

3. Why it is a problem.

4. New findings suggest that groundwater arsenic here increases with groundwater overdraft.

5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.

Arsenic in the US:

*We, too, have arsenic-prone regions*
Occurrence of Arsenic in San Joaquin Valley Groundwater

Figure 2. Spatial distribution of measured arsenic and arsenic concentrations in groundwater samples from north-central California. Arsenic levels in groundwaters were assessed using data from the USGS 2012 study. Arsenic levels were found to be elevated in certain areas, particularly in the San Joaquin Valley region.

UN Report: California County Lacks Clean Water

A report highlights the lack of clean water in certain California counties, emphasizing the need for improved infrastructure and policies to ensure safe and accessible water for all residents.
Occurrence of Arsenic in San Joaquin Valley Groundwater

Governor Brown Signs Human Right to Water Bill

Governor Jerry Brown on September 25 signed historic legislation establishing a state policy that every Californian has a human right to safe, clean, affordable and accessible drinking water.

AB 685, authored by Assemblymember Mina Mello (D-Alhambra), also requires that all relevant state agencies consider the state policy when creating policies and regulations.

"Around 8.5 million people in California repeatedly experience excessive levels of toxicity in their drinking water every year," said Assemblymember Mello. "As the representative of a district

Why Federal Efforts to Ensure Clean Tap Water Fail to Reach Faucets Nationwide

U.S.

The New York Times

World | US | Asia/Pacific | Europe | Business | Education | Science | Health | Sports | Opinion

Why Federal Efforts to Ensure Clean Tap Water Fail to Reach Faucets Nationwide

Article: Why Federal Efforts to Ensure Clean Tap Water Fail to Reach Faucets Nationwide

This article discusses why federal efforts to ensure clean tap water fail to reach faucets nationwide.
Almost 6 years later...

Griswold: Matheny Tract waits on promised water from Tulare

California Town’s Water Tainted With Arsenic For Decades

Opinion

Safe Drinking Water for All  Lanaire, CA
Points to Take Home

1. Arsenic is naturally everywhere.
2. Groundwater arsenic here is similar to groundwater arsenic in many other areas.
3. Why it is a problem.
4. New findings suggest that groundwater arsenic here increases with groundwater overdraft.
5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.

Agricultural Development

Fertilizers and irrigative pumping support a quadrupled population since the 1950’s. However, it remains unclear how human activity affects the groundwater and how arsenic is uptaken in food. With Asia being major exporters of many of the world’s foodstuffs, there are tremendous economic implications.

Rapid Urban Development

The benefits of societal advancement and economic boon must be balanced with the costs of human health and environmental well-being. Consequences of unsewered and industrial wastes infiltrating into the groundwater remain unknown.

Health and Social Impacts: Arsenicosis

Skin lesions, a symptom of arsenic poisoning, can cause severe health and social despair from drinking arsenic-contaminated water. People with lesions suffer not only in health, but from being stigmatized, divorced, unmarried, and unable to go to school. Emerging studies are also showing much lower IQ scores in children living in areas with high groundwater arsenic.

Industrialization

Requires good quality water – right now, we are cleaning our airways at the expense of our water.

Unsanitary Surface Waters

Caused rampant diarrheal diseases (typhoid, cholera, and dysentery) leading to high infant mortality rates prior to the 1970s. Use of groundwater has reduced these deaths and provided a more convenient source of potable water. Women save time and children have more time to go to school. But, WHO still reports up to 1.3 million children under 5 yrs still dying yearly due to diarrhea.

Natural Arsenic

Arsenic Enhanced by Human Activity

Arsenic Enhanced by Human Activity

Mitigation

Unchecked and uncoordinated mitigation has resulted in misuse, ineffective, and sometimes, inadvertently more harmful technologies. Filtering devices fail and are often unmaintained, which can actually release higher doses of arsenic due to microbial activity.

Natural Hazard

Drinking is not the only exposure pathway. A mortar impact in Peru volatilized arsenic from the groundwater, making nearby residents ill.

Susceptibility to Disease and Flu

Dartmouth researchers find suppressed immune response to H1N1 in people exposed to low levels of arsenic.

Different costs of Suffering

In some cases, the economics are such that people can get digital cable in their homes easier than clean water. People exposed to high levels of contaminants in household water suffer tooth and skin erosion from washing and bathing.

Occurrence of Arsenic in San Joaquin Valley Groundwater
Why is arsenic so dangerous?

- Long-term exposure can cause a variety of diseases, ranging from cough and diabetes to skin lesions and cancer
- Carcinogenic at very low concentrations
- Invisible, odorless and relatively expensive to detect
- World Health Organization MCL guideline is 10\(\mu g/L\)
- Impacts water supply, health, education, irrigation, and rural development sectors
- 60 million Asians at risk, 10% CA Water Providers, >300,000 CA residents estimated at risk.
- Each year new arsenic groundwater incidents are being reported in new locations
Points to Take Home
1. Arsenic is naturally everywhere.
2. Groundwater arsenic here is similar to groundwater arsenic in many other areas.
3. Why it is a problem.
4. New findings suggest that groundwater arsenic here increases with groundwater overdraft.
5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.
What Causes Overpumping?

Water Use in CA:
- 50% Environment
- 40% Agriculture
- 10% Urban

Reading About Water

Cohort Projects/Activities
Education
Reading About Water: Campus-wide
- 2016-17: Chasing Water by Brian Richter
- 2017-18: Water 6.0 by David Sedgwick
- 2016-17: Blue Mind by Wallace J. Nichols
- 2015-16: The West Without Water by B. Lynn Ingram
- 2015-16: The Big Thrust by Charles Fishman

Water Foot Print of Humanity – US Net Exports Water

More of a “Water Hook” than a “Water Cycle”

Occurrence of Arsenic in San Joaquin Valley Groundwater
Drought Induced Uplift in Western US

Points to Take Home

1. Arsenic is naturally everywhere.
2. Groundwater arsenic here is similar to groundwater arsenic in many other areas.
3. Why it is a problem.
4. New findings suggest that groundwater arsenic here increases with groundwater overdraft.
5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.
Points to Take Home

5. Like here, overdrafting is occurring all over the world, in other arsenic-prone regions, giving us an opportunity to help find globally relevant water solutions.
Chris Johnson

Email:
aegisgc@gmail.com

Phone:
559.981.2313

About:
Mr. Johnson has over thirty four years of applied industry experience in groundwater assessment, hydrogeology, well design and construction, well rehabilitation, groundwater aquifer testing, geochemistry and hard rock aquifer assessments. Key project experience ranges from being the Project Manager for groundwater monitoring at the Hunters Point Naval Shipyard in San Francisco, to the Technical Lead on the Deep Groundwater Monitoring Well Installation Program for the Los Alamos Nuclear Laboratory in Los Alamos, New Mexico. Mr. Johnson has assessed aquifers for the source of naturally occurring arsenic and uranium, then successfully designed high capacity municipal supply wells with little to no reportable concentrations of these constituent's present. He has been the Principal Hydrogeologist on several large-scale groundwater assessments, that included modeling and testing aquifer performance of deep, high capacity test wells. Knowledgeable of both technical and regulatory requirements, Mr. Johnson has significant experience in conducting cost-benefit analysis for new wells, new well fields, well rehabilitation, and aquifer assessments. He is also well versed in dealing with regulatory requirements related to water quality, production, and basin yield.
SEARCHING FOR ARSENIC

2018 ARSENIC SYMPOSIUM – CALIFORNIA STATE UNIVERSITY, FRESNO
CHRISTOPHER S. JOHNSON, PG, CHG
AEGIS GROUNDWATER CONSULTING, LLC.

INITIAL GRADUATE RESEARCH

• FOCUSED ON GROUNDWATER, AND SPECIFICALLY A WATER QUALITY-RELATED TOPIC.
• HISTORICAL INFORMATION SUGGESTED THAT THE HANFORD-LEMOORE AREA HAD UNUSUALLY HIGH CONCENTRATIONS OF ARSENIC IN GROUNDWATER, RELATIVE TO SURROUNDING AREAS.
• READILY AVAILABLE DATA REPORTEDLY EXISTED REGARDING WELL CONSTRUCTION, PUMPING, WATER LEVELS AND DISSOLVED ARSENIC CONCENTRATIONS IN THE CITY OF HANFORD.
Occurrence of Arsenic in Groundwater, Hanford, CA

GRADUATE RESEARCH QUESTIONS

• IS THERE A RELATIONSHIP BETWEEN SUBSURFACE LITHOLOGIES AND ARSENIC CONCENTRATIONS?
• CAN THE SUBSURFACE GEOCHEMICAL ENVIRONMENT BE ADEQUATELY DESCRIBED?
• IS THERE A RELATIONSHIP BETWEEN WELL CONSTRUCTION AND ARSENIC CONCENTRATIONS?
• WHAT RELATIONSHIP MIGHT EXIST BETWEEN WELL OPERATIONS AND ARSENIC CONCENTRATIONS?

GRADUATE RESEARCH APPROACH

• COMPARE WELL DEPTH & WELL CONSTRUCTION, TO REPORTED DISSOLVED ARSENIC CONCENTRATIONS.
• AS FEASIBLE, COMPARE SUBSURFACE LITHOLOGIES AND ARSENIC CONCENTRATIONS.
• COMPARE WELL OPERATION TO REPORTED DISSOLVED ARSENIC CONCENTRATIONS.
GRADUATE RESEARCH DATA

- 24 CITY WELL CONSTRUCTION RECORDS, INDICATING WELL DEPTH, AND THE LENGTH OF BOTH THE GRAVEL PACK AND INTAKE STRUCTURE. WELLS HAD BEEN CONSTRUCTED BETWEEN 1949 AND 1989, AND RANGED IN DEPTH FROM 405' TO 1500'.
- MONTHLY PUMPING RATES AND WATER LEVELS FOR THE 24 WELLS WAS GENERALLY AVAILABLE AND REVIEWED.

GRADUATE RESEARCH FINDINGS

- SHALLOW WELLS HAVE GREATER DISSOLVED ARSENIC CONCENTRATIONS THEN DEEP WELLS.
- WELLS WITH LONG INTAKE STRUCTURES/GRAVEL PACKS HAVE GREATER DISSOLVED ARSENIC CONCENTRATIONS, ESPECIALLY SHALLOW WELLS.
- WELLS WITH SHORTER INTAKE STRUCTURES, RESTRICTED GRAVEL PACK LENGTHS, AND INTRA-AQUIFER SEALS HAD REDUCED ARSENIC CONCENTRATIONS.
- DEEP WELLS, WITH SHORT INTAKE STRUCTURES, PROPERLY SEALED OFF FROM CLAYS, HAD THE LOWEST CONCENTRATIONS OF DISSOLVED ARSENIC.
- INDICATIONS OF INCREASED ARSENIC CONCENTRATIONS WITH INCREASED DURATION AND SEVERITY OF PUMPING.
GRADUATE RESEARCH CONCLUSIONS

• MORE WELL CONSTRUCTION VS [A.] ASSESSMENT WAS NEEDED. DEEPER WELLS, WITH SHORTER INTAKE STRUCTURES AND GRAVEL PACKS, SHOULD HAVE LESS DISSOLVED ARSENIC PRESENT IN THE WELL WATER SAMPLES.
  • NOT PLACING INTAKE STRUCTURES ADJACENT TO CLAYS, PROBABLY LEADS TO REDUCED DISSOLVED ARSENIC CONCENTRATIONS IN WELL WATER SAMPLES.
• EXTENSIVE ASSESSMENT OF GEOCHEMICAL CONDITIONS WITH DEPTH.
• FLOW RATE VERSUS [A.] SHOULD BE FURTHER ASSESSED. THE DURATION AND INTENSITY OF PUMPING MAY BE AFFECTING THE CONCENTRATION OF DISSOLVED ARSENIC IN THE WELL WATER SAMPLES.

GRADUATE RESEARCH POST-MORTEM

• MORE DETAILED FORMATION SAMPLING AND ANALYSIS, SPECIFICALLY SEARCHING FOR ARSENIC-ENRICHED CLAYS, AND ASSESSING TOTAL VERSUS LEACHABLE ARSENIC CONCENTRATIONS.
• TIME AND FLOW DEPENDENT WATER SAMPLING AND ANALYSIS, TO SEARCH FOR STRONGER INDICATIONS OF THEIR RELATIONSHIP WITH DISSOLVED ARSENIC.
• DESIGN SMARTER WELLS, BUILD BETTER WELLS.
ARSENIC IN OUR PROFESSIONAL PRACTICE

• IN GENERAL, ARSENIC IS NOT EVERYWHERE.
• REPORTED ARSENIC IN GROUNDWATER, OCCURS MOSTLY IN ONE OF TWO PLACES, BEING 1) WITHIN THE DEPOSITIONAL BASIN OF A RIVER SYSTEM, AND 2) IN SPECIFIC FRACTURED BEDROCK AQUIFERS, MOSTLY ASSOCIATED WITH LEUCOCRATIC GRANITES.
• TODAY I WILL FOCUS ON THE ALLUVIAL BASIN AREAS.

WHERE WE SUSPECT ARSENIC IS...

• CLAYS AND SITLS, WITH A HIGHER ORGANIC CONCENTRATION, SUCH AS MIGHT BE FOUND IN ANCIENT MARSH DEPOSITS, ASSOCIATED WITH A RIVERINE DEPOSITIONAL SYSTEM.
• ARSENIC MAY BE BIO-ACCUMULATED IN THE ORGANIC MATTER, IT MAY BE IN MICROCRYSTALLINE OR AMORPHOUS MINERALS, OR IT MAY BE A REPLACEMENT FOR SOME OTHER MINERAL IN THE FINE-GRAINED STRUCTURE OF THESE CLAYS AND SILTS.
• WITHIN GROUNDWATER, THE ARSENIC LIKELY LEACHES OUT (CHEMICALLY, MECHANICALLY, OR BOTH) OF THE CLAYS AND SILTS, AND IF IN A GEOCHEMICALLY CONDUCTIVE GROUNDWATER, REMAINS MOBILE AND AVAILABLE DURING EXTRACTION ASSOCIATED WITH PUMPING.
How we look for Arsenic:

- Collection of formation samples using a side-wall core gun.
- Analysis of formation samples using a modified TCLP extraction method, analyzing for total and leachable arsenic.
- Intentionally bypassing depths/aquifers known to contain arsenic.
- Short-vertical span zone testing focused both on likely aquifers, and avoiding clay layers that might contain leachable arsenic.

Avoidance versus treatment in our practice…

- A properly designed and executed open-borehole assessment can reveal the presence of an arsenic problem, before the construction of a new multi-million dollar well and pumping station…Avoidance.
- A properly designed and constructed well, which includes intra-aquifer seals, along with deep primary well seals, should provide sufficient water with acceptable dissolved arsenic concentrations, such that treatment is avoided.
- Avoidance is generally far less expensive than treatment!
PRACTICE RESULTS…

- Since about 1990, about 25 new deep, high capacity wells constructed with thorough open borehole assessments, and properly designed and constructed, have met historical, and in most cases the current drinking water standard for arsenic in groundwater, in areas known for elevated arsenic concentrations in groundwater.

RECOMMENDATIONS AND NEXT STEPS…

- Invest in open-borehole assessments, rather than in treatment.
- Invest in thorough geologic, geophysical and geochemical assessments before committing millions of dollars into the ground.
- Invest in, and insist on, properly constructed wells for both water quantity and water quality.
**CONCLUSIONS AND PERSPECTIVE..**

- **MY INITIAL BELIEF, AND OUR SUBSEQUENT WORK, STRONGLY SUPPORTS RELATIONSHIPS BETWEEN WELL DEPTH AND CONSTRUCTION, AND DISSOLVED ARSENIC IN THE WELL WATER. FURTHERMORE, OUR WORK SUPPORTS SOME MECHANISM BETWEEN ARSENIC CONCENTRATIONS AND PUMPING RATES.**

- **CURRENT WORK STRONGLY SUGGESTS THAT PROPER WELL DESIGN AND CONSTRUCTION, BASED ON IDENTIFICATION AND AVOIDANCE, IS BETTER THAN TREATMENT, AT ACHIEVING WELL WATER WITH ACCEPTABLE ARSENIC CONCENTRATIONS, AND LESS PRONE TO VARIATIONS CAUSED BY PUMPING RATES.**

- **INSUFFICIENT TIME AND MONEY ARE INVESTED IN UNDERSTANDING THE SUBSURFACE CONDITIONS, IN GENERAL, AND AS SUCH WE ARE LEFT WITH THE HOPE THAT TREATMENT WILL OVERCOME WHAT COULD HAVE BEEN AVOIDED.**
Dr. Miranda Fram

Email:
mfram@usgs.gov
Phone:
916.278.3088
About:
Dr. Miranda Fram is a geochemist at the U.S. Geological Survey California Water Science Center. Her work at the USGS for the past 20 years has focused on water quality in groundwater and surface water resources used for drinking water supplies, ranging from investigations of organic matter in Sacramento-San Joaquin Delta waters to comprehensive assessment of water quality in aquifers used for public and domestic supplies throughout California. Since 2012 she has been lead scientist and program chief for the USGS implementation of the California State Water Resources Control Board’s Groundwater Ambient Monitoring and Assessment (GAMA) Program Priority Basin Project. She has a bachelor’s in Geology from Yale University and a master’s and Ph.D. in Geological Sciences from Columbia University.
Lessons from Four Decades of USGS Studies of Arsenic in Central Valley Groundwater

Miranda Fram¹ and Neil Dubrovsky²

¹USGS California Water Science Center
²USGS National Water Quality Program

USGS Central Valley Arsenic Studies

1970’s – 1980’s: Regional Aquifer System Analysis (RASA)

1980’s: San Joaquin Valley Drainage Program (in cooperation with DWR)

1990’s – present: National Water Quality Assessment (NAWQA)

1990’s – present: Cooperative projects with local agencies

2000’s – present: GAMA Priority Basin Project (GAMA-PBP) (in cooperation with SWRCB)

USGS-NWIS Arsenic data
3,000 wells

Arsenic (µg/L)
- > 100
- 10 - 100
- 5 - 10
- < 5

MCL = 10 µg/L
1980’s: RASA and SJVD

- First spatial mapping
- PCA analysis
- Geochemical processes

Hull (1984) Sacramento
Dubrovsky et al. (1991) WSJV
Fujii & Swain (1995) Tulare

1990s: NAWQA

- Systematic assessment
- Regional mapping
- First ‘big data’

Belitz et al. (2003)
2000’s: NAWQA Water-Quality Modeling

- First random forest statistical models
- Landscape predictor variables

Anning et al. (2012) arsenic and nitrate

Studies with Local Agencies

- Water-quality stratigraphy
- Integrate GW flow and water-quality

Izbicki et al. (2008)
2000’s-2010’s GAMA-PBP Public-supply

- Systematic statewide assessment

Belitz et al. (2003)
Belitz et al. (2015)

2010’s: NAWQA Water-Quality Modeling

- Integrate statistical models with CVHM output
- Machine learning, boosted regression tree modeling

Ayotte et al. (2016) arsenic
Ransom et al. (2017) nitrate
Rosecrans et al. (2017) manganese and pH
2000’s-2010’s: GAMA-PBP

Arsenic (ppb)
- > 100
- 10 – 100
- 5 – 10
- < 5

MCL = 10 ppb

Modified from Shelton et al. (2013), Burton et al. (2012), Fram & Shelton (2017), Fram (2017a)
USGS Central Valley Arsenic Studies

1970’s – 1980’s: Regional Aquifer System Analysis (RASA)

1980’s: San Joaquin Valley Drainage Program (in cooperation with DWR)

1990’s – present: National Water Quality Assessment (NAWQA)

1990’s – present: Cooperative projects with local agencies

2000’s – present: GAMA Priority Basin Project (GAMA-PBP) (in cooperation with SWRCB)

USGS-NWIS Arsenic data
3,000 wells

Arsenic (µg/L)
- > 100
- 10 - 100
- 5 - 10
- < 5
MCL = 10 µg/L
Dr. Claudia Faunt

Email: ccfaut@usgs.gov
Phone: 619.225.6142
About: Dr. Claudia Faunt, a USGS hydrologist since 1988, has led studies focusing on regional groundwater flow systems, including the Central Valley, California. Her research has specialized in water availability and hydrogeologic framework modeling. Claudia received her Doctorate in Geological Engineering in 1994 from the Colorado School of Mines and currently leads USGS California Water Science Center's Groundwater Availability and Use section.

Hydrologist,
U.S. Geological Survey,
California Water Science Center
Central Valley
Hydrologic Model (CVHM)

Claudia Faunt, PhD, PE
and others
California Water Science Center

http://ca.water.usgs.gov/projects/central-valley/

Outline:

1) Background on CVHM
2) Development of CVHM
3) Application of CVHM to
   - Subsidence
   - Flow Paths
4) Next Steps
Overview of Central Valley Hydrologic Model (CVHM)

- A Regional Integrated Hydrologic Model of California’s Central Valley
- USGS Groundwater Resources Program
- Focus on groundwater availability and changes in storage
- Developed in consultation with CA-DWR
- Updates in conjunction with Reclamation
  - Subsidence focus
- Recent updates with NAWQA to look at flow paths and effects of refined models

Central Valley:

- 20,000 square miles
- Using about 1% of U.S. farmland, California’s Central Valley - Produces more than 250 different crops
  - Supplies 7% of the U.S. agricultural output (by value) — 1/4 of the Nation’s food, including about half of the Nation’s fruits, nuts, and vegetables
- Approximately 15% of the Nation’s groundwater is pumped from the Central Valley aquifer system
Central Valley:
DEVELOPMENT AND IRRIGATED AGRICULTURE

Significant effect on volume and distribution of ground-water recharge and discharge

- PRE-DEVELOPMENT
  - Natural system
- DEVELOPMENT
  - Began in about 1850
  - Engineered system –
    - Canal network
    - Reservoirs
    - control inflows

“California has manipulated and interfered with and managed the hydrologic cycle in ways that probably have no comparison anywhere in the world. California is a highly engineered and managed water state [...] it’s incredible.”
CA Governor Jerry Brown, 10/20/2014

USGS Central Valley Hydrologic Model

Integrated Hydrologic Model

- Simplification of a real hydrogeologic system
- Is not a unique solution
- A tool to estimate water budget
- Supplemental water management tool

USGS

• Unconfined and confined aquifers – Ground-water flow and storage changes
• Faults and other barriers – Resistance to horizontal ground-water flow
• Fine-grained confining units and interbeds
• Confining units – Ground-water flow and storage changes
• Rivers – Exchange of water with aquifers
• Drains and springs – Discharge of water from aquifer
• Evapotranspiration
• Reservoirs — Exchange of water with aquifers
• Recharge from precipitation and irrigation
• Wells — Withdrawal of recharge at specified rates
Central Valley Hydrologic Model (CVHM2)

- MODFLOW-OWHM
- 13 layers
- 1 square mile cells
- Calibration for 1961-2013 period
- Monthly stress periods
- Simulates 1921-2013
Texture Analysis:

- 3D model
  - Based on about 10,000 drillers logs
  - Interpolated to one-mile spatial grid at 50 foot depth intervals
  - Defines sediment characteristics of the aquifer
  - Used for hydraulic properties
CVHM2 Hydrologic budget:

Simulate components (in/out)

Current estimations based on:
- available surface-water deliveries
- the consumptive use of water

Pumping typically not metered
Water Use Driven by Landuse

- Categories:
  - Natural
  - Urban
  - Agriculture

Landuse changes

Area of Native Vegetation in Central Valley
- 1920 deep well turbine pump
- 1925 mechanical harvesting
- 1935 refrigerated railroad transportation
- 1940

USGS Central Valley Hydrologic Model
Precipitation, Inflows, and Climate

Large spatial and interannual changes

Water Supply
Conjunctive Use
- Surface Water
- Groundwater
Climate Change/Variability

- Early in growing season, dominantly surface water deliveries
- Later in growing season, surface-water shortfall made up by groundwater pumpage
  - Drought '77 (high pumping all growing season)
  - Wet Period '83 (lower delivery, mostly surface water)

Proportions of surface water and groundwater used for irrigation vary yearly and seasonally in response to climate.

Additional detail in accounting units

- Additional breakdown in the Delta Mendota Canal area
- Allows the utilization of detailed surface water delivery data without the need to aggregate
- Improves distribution of groundwater pumping
- Addition of groundwater banking activities
Calibration Data

- Groundwater elevation (260 sites - 24,801 obs)
- Streamflow (32 sites - 11,997 monthly averaged obs)
- Subsidence
  - Benchmark (829 sites - 2,837 obs)
  - Extensometer (25 sites - 30,213 obs)
  - Continuous GPS (40 sites - 56,547 obs)
  - InSAR (27 sites - 77 obs)
- Drainflow (7 sites - 1,056 monthly averaged obs)
**Calibration Methodology**

- Semi-automated calibration using model-independent parameter estimation software - PEST
- Numerous Model parameters including:
  - End Member Hydraulic Conductivity (4)
  - Power Mean Exponent (2)
  - Zonal Horizontal Hydraulic Conductivity (5)
  - Zonal Vertical Hydraulic Conductivity (5)
  - Hydraulic Conductivity Depth Decay (6)
  - Specific Storage (4)
  - Specific Yield (5) – as function of texture
  - Streambed Hydraulic Conductivity (11)
  - Drain Hydraulic Conductivity (1)
  - Boundary Conductance (1)
  - Ungagged Watershed Conductance (1)
  - Crop Coefficients (Kc) (2)
  - Irrigation Efficiency (4)
  - Runoff Coefficients (2)

**Effects on Central Valley:**

The recent drought, land-use changes, and restrictions on surface-water flows have resulted in extensive pumping, large groundwater-level declines, widespread land subsidence, and salinity issues.

Results – Storage Change

Preliminary and subject to revision

Snapshot from CVHM2

Central Valley Aquifer System
Schematic Diagram
What is Subsidence?

Compaction of fine-grained materials in the aquifer system can occur when water levels exceed previous lows.

Results – Subsidence

- Water-level declines cause compaction of fine-grained deposits, which results in subsidence
- Surface-water deliveries since the late 1960s have reduced the dependence on groundwater
- Recently water levels were again reaching their historic lows and subsidence renewed and started in some areas
- Management constraint
Historical Subsidence

Subsidence, Land use, and Water Availability

- Renewed subsidence concern during drought
  - Reduced surface water importation
  - More reliance on the groundwater resources

- Not just a problem during droughts for some areas without surface-water access
  - Continued subsidence between droughts

- Near Mendota, CA
  - Groundwater Level
  - Subsidence (CGPS P304)

- Near Madera, CA
  - Groundwater Level
  - Subsidence (CGPS P307)
Subsidence and Geology

Most compaction occurs below the Corcoran Clay.

Mendota

Los Banos

Water level in shallow well:

CGPS P303

CGPS P304
Model Applications

- Predict groundwater elevations and storage changes
- Predict location and amount of land subsidence
- Simulate future scenarios including
  - Climate change (like extended drought)
  - Reduced surface water deliveries
- Examine regional flow paths
- Provide data sets for other models and studies
- Provide boundary conditions for local scale models
- USGS is always looking for cooperators would like to apply CVHM in their studies

Example: Relative Groundwater Age Calculation

- Groundwater age was simulated using MODPATH
- Particles were placed at the end of the simulation and then backwards tracked to their point of recharge
- Assumed 30% porosity
- Ages were then calculated based on a grid (1km x 1km, 17 layers, 3 particles per layer = 2,715,648 particles)
- Assumed 40 foot screen for shallow (less than 300 feet) and 210 screen for deep
Particle paths from wells and relative ages

Relative Groundwater Age Calculation

Results where were used as a predictor variable in the subsequent nitrate prediction model developed by Katie Ransom and Bernard Nolan.
Summary and Conclusions

- Models are **TOOLS** that can be used to understand historical patterns and simulate climate/management scenarios
  - anticipated locations and magnitudes of subsidence and
  - flow paths based on alternative scenarios
- CVHM (as well as C2VSIM) is a regional model that characterizes the integrated hydrologic system
  - provide a data and analyses of the geology and stresses on the hydrologic system
  - help us better understand water resources and the interaction of groundwater with subsidence
- The model data sets can be used to make more detailed models for local simulations

Next Steps:

- How could or should the model be used to predict the presence, movement, and migration of As in groundwater . . . Assuming timing and funding were unlimited, what new or additional data would you like to see collected or developed for the CVHM to enhance its value and benefit to water managers in the SJ Valley . . .
  - More detailed geology to get at where subsidence and As is coming from
  - Geophysics and new methods for details in geology (AEM)
  - Local calibration to water quality and age dates
  - Local scale models with more detailed water delivery and use information to get at local flow paths
  - And ......
Thank you!
Questions?

Contact Claudia Faunt for more information:
cffaunt@usgs.gov  619-225-6142

http://ca.water.usgs.gov/projects/central-valley/
Darrin Polhemus
Deputy Director

John Borkovich
California Professional Geologist

Eric Miguelino
Research Scientist

Eugene Leung
Drinking Water Technical Specialist

Email:
Darrin.Polhemus@waterboards.ca.gov
Phone:
916.341.5045

**Darrin Polhemus** is a Deputy Director for the State Water Board and in charge of the Division of Drinking Water. The Division of Drinking Water administers the federal and California Safe Drinking Water Acts, regulating over 7,400 public water systems throughout the State to assure the delivery of safe drinking water to all Californians. In addition, the Division permits recycled water usage, manages the Environmental Laboratory Accreditation Program, oversees the work of county health departments that have been delegated the authority to regulate small water systems, and develops regulations pertaining to drinking water.

Email:
John.Borkovich@waterboards.ca.gov
Phone:
916.341.5779

**John Borkovich** is a California Professional Geologist. He received his Bachelor’s in geology from UC Santa Barbara in 1985. From 1986 to 2000, he worked in both the geotechnical engineering and groundwater cleanup sectors. John came to the California State Water Board in 2001 to work in the groundwater protection program. He was unit chief of the brownfields and Department of Defense site cleanup program in 2005 and later led the Groundwater Ambient Monitoring & Assessment (GAMA) Unit from 2006 to 2014. John is currently the Groundwater Monitoring Section Chief that oversees GAMA and oil and gas monitoring activities.

Email:
Eric.Miguelino@waterboards.ca.gov
Phone:
916.449.556

**Dr. Eric Miguelino** is a research scientist for the State of California, where he works within the Regulatory Development Unit in the Division of Drinking Water. He serves as a technical advisor to staff and management on scientific and public health matters associated with drinking water contaminants, and assists in the development of standards in accordance with the federal and California Safe Drinking Water Acts. After his postdoctoral fellowship at the University of California, Davis Medical Center, he joined the State of California in 2009. He has served as a toxicologist and risk assessor for the Department of Pesticide Regulation, and a research scientist for the Food and Drug Branch in the Department of Public Health.

Email:
Eugene.Leung@waterboards.ca.gov
Phone:
510.620.3460

**Eugene Leung** is a Drinking Water Technical Specialist in the Drinking Water Technical Operations Section and is based at the Richmond office. He has been with DDW since June of 1997. He was a Sanitary Engineer and Associate Sanitary Engineer at Santa Clara District through March 2010. He graduated from UCLA, with BS and MS degrees in Civil & Environmental Engineering. He is also a registered Civil Engineer and a T4 Water Treatment Operator.
Key Regulatory Challenges for Arsenic in Drinking Water

Arsenic Symposium
October 11, 2018
Fresno State University

Presenters:

- **John Borkovich, P.G.** – Section Chief for the State Water Board – Division of Water Quality’s GAMA Program
- **Dr. Eric Miguelino, M.D.** – Research Scientist/Toxicologist for State Water Board – Division of Drinking Water
- **Eugene Leung, P.E.** – Senior Sanitary Engineer for the State Water Board – Division of Drinking Water
- **Darrin Polhemus, P.E.** – Deputy Director for the State Water Board – Division of Drinking Water
Overview:

- Module 1: Data and Statistics on the Presence of As in PWSs in the San Joaquin Valley (John)
- Module 2: Public Health Risks Associated with As (Eric)
- Module 3: Best Available Technology for As Treatment and Case Study (Eugene)
- Module 4: Key Regulatory Challenges that Remain for As in Drinking Water and Next Steps (Darrin)
- Questions

Arsenic in Groundwater Wells

Arsenic Symposium
Fresno State University
October 11, 2018

John Borkovich, State Water Board
Key Regulatory Challenges for Arsenic in Drinking Water

Public Water System Wells

Historic statewide sampling, Division of Drinking Water:

- 200,000 sampling events for 16,000 wells
- 6,300 detections of arsenic (40%)
- 1,300 above arsenic MCL (8%)

GAMA Small Community and Private Domestic Wells

- Data includes:
  - GAMA USGS shallow aquifer statewide sampling, with trends sampling, in progress
  - State Water Board Domestic Well Project sampling
- Over 1,300 wells
- About 800 detections of arsenic (60%)
- About 60 Above Arsenic MCL of 10 µg/L (5%)
Key Regulatory Challenges for Arsenic in Drinking Water

USGS GAMA Study: Northern San Joaquin Valley Arsenic

1. Most frequently detected chemical constituent (9%) at high levels
2. Source: eroded volcanics and granitics of the Sierra Nevada
3. High levels found in southwestern part of E. San Joaquin study area
4. High As: dissolution of Fe- or MnO-Hs under reducing conditions

GAMA Groundwater Information System

- Water quality data on a Google-based map
- Interactive queries
- Over 83 million analytical results from 286,000 wells
- Provides analytical tools and reporting features
Key Regulatory Challenges for Arsenic in Drinking Water

GAMA Online Tools

- GAMA Groundwater Information System
- Salt and Nutrient Management Plan Tool
- USGS GAMA Groundwater Quality Mapping Tool

Coming Soon
- Digitized Well Completion Reports
- Groundwater Susceptibility Tool: using relative groundwater age
- New Nitrate Tool
- New 1,2,3 TCP Tool
- Source Water Protection Information Hub
- Trends Data Tools
Key Regulatory Challenges for Arsenic in Drinking Water

Arsenic Fact Sheet
Available on GAMA Webpage

- Summary of General Information
- Regulatory and Water Quality Levels
- Summary of detections in PWS Wells
- Analytical info
- Occurrence
- Remediation and Treatment
- Health Effects
- References

GAMA Website includes eighteen others

Public Health Risks of Arsenic

Eric Miguelino, M.D.
Division of Drinking Water
State Water Resources Control Board (SWRCB)

Arsenic Symposium – Fresno State University
October 11, 2018
Key Regulatory Challenges for Arsenic in Drinking Water

Background

* Arsenic is a naturally occurring element that is widely distributed in the Earth’s crust.

* Most inorganic and organic arsenic compounds are white or colorless powders that do not evaporate. They have no smell, and most have no special taste.

What is arsenic used for?

Arsenic has been used in the manufacturing of electronics, glass, lumber, and pesticides.
How are we exposed to arsenic?

* Most people are exposed to some arsenic by eating food, drinking water, or breathing air.
* Food is usually the largest source of arsenic exposure.
* Children may also be exposed to arsenic by eating soil or from hand-to-mouth activities while playing on arsenic treated wood structures.
* Occupational exposures

What are the public health risks of arsenic?

* Ingestion of arsenic over a long period of time may pose a risk for cancer
* The public health goal (PHG)* of 0.004 μg/L is based on lung and urinary bladder cancer risk from a lifetime of exposure
* Prolonged ingestion of arsenic can cause skin damage
* Acute effects from arsenic could cause gastrointestinal distress.

* PHG is established by the Office of Environmental Health Hazard Assessment (OEHHA)
What are the clinical features of the arsenic poisoning?

<table>
<thead>
<tr>
<th>Dose</th>
<th>Period of Exposure</th>
<th>General Health Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 mg/day (~2500 µg/L)</td>
<td>acute (one day)</td>
<td>vomiting and diarrhea</td>
</tr>
<tr>
<td>100 -300 mg/day (~50,000 – 150,000 µg/L)</td>
<td>acute (one day)</td>
<td>death</td>
</tr>
<tr>
<td>10 to &gt;50 µg/L in water</td>
<td>chronic (years)</td>
<td>skin changes, nerve damage, organ damage</td>
</tr>
<tr>
<td>10 µg/L in water</td>
<td>chronic (~70 years)</td>
<td>may cause lung or bladder cancers</td>
</tr>
</tbody>
</table>
What are other sources of arsenic exposure?

Arsenic Treatment Techniques and Small Systems Treatment Challenges

Eugene H. Leung, P.E.
Senior Sanitary Engineer
Technical Operations Section
California State Water Resources Control Board, Division of Drinking Water
October 2018
Challenges in Providing Arsenic Treatment in California

- Announced in 2001, Arsenic Maximum Contaminant Level (MCL) was lowered from 50 ppb to 10 ppb in January 2006
- More than 12 years later, many small water systems in California are still struggling with compliance
- Multiple issues: Water quality, high treatment costs, pilot testing, Point-of-Use (POU) limitation in CA, treatment residuals, other system specific issues

Treatment Options

- BATs or “Best Available Technologies” are technologies that have been proven effective for water systems to use. However, source water quality may impact effectiveness of a BAT.
- SSCT or “Small Systems Compliance Technologies” are specified in the Federal Safe Drinking Water Act. SSCTs must be affordable and technically feasible for small systems.
- Key Costs to consider:
  - Capital Costs
  - Operation and Maintenance Costs
    - Certified Treatment Operator, Increased Testing
    - Waste Disposal Costs – Liquid & Solid Treatment Residuals
Key Regulatory Challenges for Arsenic in Drinking Water

Treatment Options (2)

- Centralized Treatment – treating all water coming from a well

- Point-of-Entry Treatment – treating only water that enters a building for human consumption (useful for some businesses, schools (NTNC) or community water systems with a lot of outdoor water use)

- Point-of Use Treatment – treating only water that is used for drinking and cooking (useful for small community water systems and NTNC)

Best Available Technologies for Arsenic 40 CFR 141.62 (b) & CA Title 22, Section 64447.2

- Activated Alumina
- Coagulation/Filtration (not BAT for systems < 500 service connections)
- Ion Exchange
- Lime Softening (not BAT for systems < 500 service connections)
- Reverse Osmosis
- Electrodialysis
- Oxidation/Filtration
**Key Regulatory Challenges for Arsenic in Drinking Water**

**Arsenic Small Systems Compliance Technologies (SSCT) 40 CFR 141.62 (d)**

<table>
<thead>
<tr>
<th>SMALL SYSTEM COMPLIANCE TECHNOLOGIES (SSCT)</th>
<th>Affordable for listed small system categories</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated Alumina (centralized)</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Activated Alumina (Point-of-Use)</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Coagulation/Filtration</td>
<td>501–3,300, 3,301–10,000, 501–3,300, 3,301–10,000</td>
<td></td>
</tr>
<tr>
<td>Centralized Treatment Options</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Enhanced Coagulation/Filtration</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Enhanced lime softening</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Ion Exchange</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Lime Softening</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Oxidation/Filtration</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Reverse Osmosis (centralized)</td>
<td>All size categories</td>
<td></td>
</tr>
<tr>
<td>Reverse Osmosis (Point-of-Use)</td>
<td>All size categories</td>
<td></td>
</tr>
</tbody>
</table>

Note: The range of numbers provided in this table are based on the number of persons served.

**Arsenic Treatment Options**

- **Non-Treatment Options**
  - Well Abandonment or New Well
  - Alternative Sources and Source Modifications
  - Blending
  - Limiting Use (Peak Use Only)

- **Centralized Treatment Options**
  - Anion Exchange
  - Adsorptive Media
  - Oxidation
  - Coagulation/Filtration
  - Reverse Osmosis
  - Electro dialysis
  - Modified Lime Softening

- **Point-of-Use**
  - Adsorptive Media
  - Reverse Osmosis

- **Point-of-Entry**
  - Adsorptive Media
  - Reverse Osmosis (with Blending)

- **Vending Machines**
  - Reverse Osmosis

* Centralized chlorination may be required
** Site specific engineered solutions
Centralized Treatment vs POU

Key POU Considerations

1. High customer acceptance with goal of full participation.
2. Routine water system personnel or contractor access to inside of customer homes for maintenance.
3. Annual monitoring of each treatment unit.

Point-of-Use devices must be installed and maintained by public water system. Routine maintenance may be contracted out.

Source: USEPA Complying with the Revised Drinking Water Standard for Arsenic: Small Entity Compliance Guidance

Arsenic Treatment Options *(in California)*

- Non-Treatment Options
  - Well Abandonment or New Well
  - Alternative Sources and Source Modifications
  - Blending
- Centralized Treatment Options
  - Anion Exchange
  - Adsorptive Media
  - Oxidation
  - Coagulation Filtration
  - Reverse Osmosis
  - Electrodialysis
  - Modified Lime Softening
- Point-of-Use
  - Adsorptive Media
  - Reverse Osmosis
- Point-of-Entry
  - Adsorptive Media
  - Reverse Osmosis (with Blending)
- Vending Machines

* Centralized chlorination may be required
** Site specific engineered solutions
Treatment Issues (Technical)

- Naturally High Raw Water pH (~ 8.0), resulting in low treatment capacity for Activated Alumina and other Adsorptive Media
- Treatment Residuals (liquid and solid)
- Pre-oxidation requirement (adsorptive media and reverse osmosis treatment)
- pH adjustments needed to improve treatment capacity

Managerial and Financial + State Limitation

- General lack of TMF at very small water systems
- Water system may not have a good relationship with community members (general distrust)
- Severely disadvantaged communities (treatment affordability)
- Rental property owners or tenants – who pays for the water bill? Will property owners allow modifications to the rental units?

- State law prohibiting the use of Point-of-Use or Point-of-Entry devices as a permanent solution
Potential Solutions...

- **Well Modifications**
  - Shallower wells have alleviated arsenic problems
- **Point-of-Use at NTNC’s**
  - 100% participation not applicable
  - No individual homeowners to deal with
  - Business owner has ultimate control of every unit
- **Consolidation and blending of sources**
- **Split distribution system to separate outdoor (non-treated) and indoor use water**
- **Coagulation Filtration treatment**

Promising Interim Solution...

- **Arvin Community Service District**
- **Centralized treatment scheduled for completion in about 3 years**
- **Point-of-Use devices and Vending Machines are used to provide children and community with safe drinking water at many locations**
- **Partnership between water system, environmental justice group, technical assistance provider and State program**
Key Regulatory Challenges for Arsenic in Drinking Water

For more information on the Agua4All Project, please visit:
http://www.calendow.org/
http://www.rcac.org/agua4all

Adsorptive Media Treatment
Multiple certified POU devices

Drinking Fountains and Bottle Filling Stations at Schools and other public.

Joint educational program to encourage drinking of water.

Certified POU’s with a separate Performance Indication Device (PID) for each unit.

Multiple units operate in parallel.

Photos courtesy of:
David Wallis and Sarah Buck
Rural Community Assistance Corporation,
Community Water Center and
Arvin Community Service District
Reverse Osmosis Treatment
Bottle Water Vending Machines

Reverse Osmosis based Bottle Water Vending Machines for a low cost (or free) source of drinking water.

Vending machines are jointly regulated by SWRCB DDW and CDPH Food and Drug Branch.

RO reject is discharged into public sewer.

What kind of treatment can I use at home?

• Point-of-Entry Treatment
  – Whole-house adsorptive media

• Point-of-Use Treatment
  – Adsorptive media based Point-of-Use
  – Reverse osmosis based Point-of-Use
Key Regulatory Challenges for Arsenic in Drinking Water

Disclaimer:
Photos are shown as examples and should not be considered endorsement of the products / vendors

Examples: Culligan Whole House Arsenic Reduction Filter (www.culligan.com) (left)
Multipure Aquaversa Undersink or Countertop Water Filter (https://www.multipure.com/aquaversa.html) (right)

Certified Home Treatment Devices

- Devices marketed to consumers in CA must be registered with the Division of Drinking Water’s Residential Water Treatment Devices

https://www.waterboards.ca.gov/drinking_water/certlic/device/watertreatmentdevices.html

Sample Listing

California-Registered Water Treatment Devices for Arsenic Reduction as of August 11, 2017

Arsenic in groundwater has two forms: Arsenic 3 and Arsenic 5. In well water, arsenic is typically found in both forms. However, the amount of each form in the well water varies from location to location.

Both forms of arsenic are of health concern. Arsenic 3 is much more difficult to remove from the water. Most water treatment devices are certified to reduce Arsenic 3 but may provide a minimal reduction of Arsenic 5. For this reason, we have provided two tables below so that you can choose the device that meets your needs.

If you are concerned about the performance of a water treatment device, you should have the water tested periodically for reduction of arsenic.

Table 1.

<table>
<thead>
<tr>
<th>Registration Number</th>
<th>Manufacturer</th>
<th>Model Number</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1238</td>
<td>Culligan International</td>
<td>Gold Arsenic 14&quot;</td>
<td>Absorption Module</td>
</tr>
</tbody>
</table>

https://www.waterboards.ca.gov/drinking_water/certlic/device/watertreatmentdevices.html
Key Challenges and Next Steps

Darrin Polhemus, P.E. – Deputy Director
Division of Drinking Water
State Water Resources Control Board (SWRCB)
Dr. Scott Fendorf

Email: fendorf@stanford.edu
Phone: 650.723.5238

About: Scott Fendorf is soil scientist and biogeochemist, whose particular area of interest is on the chemical and biological processes involving contaminants and nutrients. His work on the fundamental biogeochemistry of arsenic coupled with field work from Bangladesh, Cambodia, and Vietnam to the Central Valley of California has led to an understanding of how arsenic enters groundwater, a process that is impacting aquifers across the globe. He has helped lead a bridging of groups focused on solving what is termed ‘the largest mass poisoning in history’. Scott is the Huffington Family Professor of Earth Science at Stanford University. He is the founding chair of the Earth System Science Department and presently the Senior Associate Dean in the School of Earth, Energy, and Environmental Science at Stanford. He is also a Senior Fellow in Stanford’s Woods Institute for the Environment.

Soil Scientist and Biogeochemist, Stanford University
Overpumping Leads to California Groundwater Arsenic Threat

Scott Fendorf
Stanford University

CONTRIBUTORS and Collaborators
- Ryan Smith
- Laura Erban
- Sarah Fakhreddine
- Steve Gorelick
- Rosemary Knight
- Jason Dadakis
- Debra Hausladen
- Cynthia McClain
- Randall Holmes
- Arden Wells
Groundwater Threats

The Global Threat: Geogenic Groundwater Contaminants
Geogenic (indigenous) Threats

**Groundwater Quality Challenge**

Surface Water:Sediment Ratio, 1000:1

Groundwater:Sediment Ratio, 1:1000 → Water Quality Problems

Overpumping Leads to California Groundwater Arsenic Threat
Release Pathways
Oxidation-Reduction

**Oxidative (Aerobic) Release**
- Cr(III) (s) → Cr(VI) (aq)
- Se(0)/S(-II) (s) → Se(VI) (aq)
- U(IV) (s) → U(VI) (aq)

**Reductive (Anaerobic) Release**
- As(V) (s) → As(III) (aq)
- MnO₂ (s) → Mn²⁺ (aq)

A pervasive, bad actor

Overpumping Leads to California Groundwater Arsenic Threat
Geogenic (natural) Arsenic Sources

Arsenic Background

- Drinking water standard: 10 µg/L
- Arsenic generally persists in two forms: As(V) (arsenate, HAsO$_4^{2-}$) and As(III) (arsenite, H$_2$AsO$_3$)
- Arsenic normally binds strongly to soils and sediments, and thus stays within the solids

Except….
Arsenic Mobilization Processes

**Known processes**
- Transition to persistent anaerobic conditions
- Alkaline pH (greater than 8.5)
- Competing anions (e.g., phosphate)

**Emerging processes**
- Change in ionic composition
- Aquifer compression with pumping

Asian Groundwater Crisis: Contaminated Shallow Groundwater

- Ganges Delta: 125-143 million
- Indus River Delta: 12 million
- Irrawaddy and Salween River Delta: 10-15 million
- Mekong River Delta: 20-30 million
- Yellow River Plain: 30-50 million
- Red River Delta: 17 million
- Yangtze River Plain: 50-80 million

Overpumping Leads to California Groundwater Arsenic Threat
Reductive Release of Arsenic

OM Degradation

Food

CO₂

As/Fe reduction

Arsenic in sediment

bacteria

Arsenic in water

As(V)

How might arsenic enter groundwater within the Central Valley?
Overpumping Leads to California Groundwater Arsenic Threat

Groundwater Pumping Impacts

Arsenic in Lower Mekong Delta -- Vietnam

Erban et al. PNAS 2013
Overpumping Leads to California Groundwater Arsenic Threat

Shallow vs Deep Aquifer Arsenic

Erban et al. EST 2014
Overpumping Leads to California Groundwater Arsenic Threat

Pumping Induced Land Subsidence

Deep Aquifer Arsenic and Pumping

Erban et al., PNAS 2013
Overpumping Leads to California Groundwater Arsenic Threat

Arsenic Release From Clay Pore-Water with Over Pumping

Erban et al., PNAS 2013

Tulare Basin Subsidence

Smith, Knight, Fendorf. 2018. Nature Geoscience
Overpumping Leads to California Groundwater Arsenic Threat

Arsenic Release with Groundwater Pumping

Orange County Water District
Non-oxidative Release of Low-Arsenic Strata
Overpumping Leads to California Groundwater Arsenic Threat

Modes of Recharge

Post-Treatment Infiltration
Cation bridging is key to arsenic retention

Overpumping Leads to California Groundwater Arsenic Threat
Overpumping Leads to California Groundwater Arsenic Threat

Destabilized Arsenic with Purified Water

Direct Injection to Confined Aquifers

Fakhreddine et al., EST 2015

Fakhreddine, 2018
Direct Injection to Confined Aquifers

Fakhreddine, 2018

Overpumping Leads to California Groundwater Arsenic Threat
What's Next
(or what should be next)?

NEEDED SCIENTIFIC ADVANCEMENTS

Process-based predictive model:
Coupled sedimentological, hydrological, and geochemical models

Sentry measurements:
Subsidence, manganese (and sulfate) concentrations

NEEDED MANAGEMENT ADVANCEMENTS

Multi-threat considerations:
Arsenic, uranium, chromium, nitrate…

Recharge-extraction management plans:
Means of recharge
Recharge water chemistry
Extraction vs recharge volumes

Overpumping Leads to California Groundwater Arsenic Threat
CONTRIBUTORS and Collaborators

• Ryan Smith
• Laura Erban
• Saran Fakhreddine
• Steve Gorelick
• Rosemary Knight
• Jason Dadakis
• Debra Hausladen
• Cynthia McClain
• Randall Holmes
• Arden Wells
Groundwater Cr(VI) Concentrations

Cr(VI) Contamination of California Groundwater

Overpumping Leads to California Groundwater Arsenic Threat
Overpumping Leads to California Groundwater Arsenic Threat

Cr(VI) Generation from Native Cr(III) Minerals
Overpumping Leads to California Groundwater Arsenic Threat

Chromite Oxidation

\[
\text{FeCr}_2\text{O}_4(s) + \frac{7}{2}\text{MnO}_2(s) + 5\text{H}^+ = 2\text{HCrO}_4^{-}\text{(aq)} + \text{Fe(OH)}_3\text{(am)} + \frac{7}{2}\text{Mn}^{2+}\text{(aq)}
\]

Oze et al., PNAS 2007
Cr – Mn Separation Distance is Key to Cr(VI) Deposition of MnO₂ Proximal to Cr(OH)₃

Overpumping Leads to California Groundwater Arsenic Threat
Overpumping Leads to California Groundwater Arsenic Threat
The event included a breakout session where attendees were able to provide their feedback on five key questions. In the following pages, you will see what the attendees had to say about those questions.

The questions were:

1. What should the new governor of CA know about the presence of arsenic in SJ Valley groundwater?

2. If there were no resource constraints (people, time, or money), how would you enhance the protection of the public’s health and safety from arsenic in SJ Valley groundwater?

3. How can future land use planning decisions impact future public health and safety risks associated with arsenic in SJ Valley groundwater?

4. How would you propose to reduce the public health and safety risks associated with arsenic in groundwater over the next 10 years?

5. How would you advise a community that has groundwater supply with arsenic concentrations above the primary drinking water standard (10 ug/L) to address their issues?
What should the new governor of CA know about the presence of arsenic in SJ Valley groundwater?

1. There is not one straightforward solution.

2. Move to consolidate water systems so expensive centralized treatment is feasible.

3. New dams are a bad idea when groundwater recharge can
   a. store water
   b. stop land subsidence
   c. slow or stop the contamination of our water with arsenic

4. We have a problem and we need to fix it.

5. Create community task force for awareness.

6. How the presence of Arsenic affects life (especially the low-income group), and how to educate the common people about it.

7. Remedy can be exacerbated by groundwater overdraft. Must prevent aquifers from dipping below historic low water surface elevations.

8. Arsenic is naturally occurring and small communities will need more assistance in treating it or help in finding a solution to providing all people with water meeting drinking water standards.

9. Treatment is very costly – very hard for tiny/small water systems to operate and support financially.

10. How do we educate users of (water) and help address private domestic well sources?

11. Why should it take 5-10 years to change maximum contaminant level (MCL) standards for a contaminant such as Arsenic, when we know the public health implications?
If there were no resource constraints (people, time, or money), how would you enhance the protection of the public’s health and safety from arsenic in SJ Valley groundwater?

1. Recharge aquifer with reclaimed water, because there is not enough surface water
2. Consolidate all small low-income communities into larger water systems wherever possible
3. Where too far away from a larger system, state and local resources should pay for Arsenic treatment plans and their ongoing maintenance and operations
4. Curb agricultural pumping of groundwater so that Arsenic levels do not increase
5. Put water from the coming high-rainfall years into aquifers, for later pumping, with no or diluted Arsenic
6. Educate at the youngest level possible
7. Do not use groundwater. Use desalination from the ocean if money was unlimited
8. Add water evaporation trays for distillation to all the solar panels we will soon install.
9. As water meters are put on all our wells under SGMA, add arsenic detectors with the data radioed to central places for recording and analysis. Maps could be developed for located arsenic-free wells
10. Install full As treatment systems fully funded by state
11. Take away the politics of having so many small water systems so that there’s a larger pool of customers to help pay for proper infrastructure to meet drinking water standards
12. Increase water recycling with tertiary treatment and water efficiency funding for major public works infrastructure projects

13. Big pipe – lots of connection to safe water – DW = < 10% water use issue GW for Ag.

14. State funded systems = jobs

15. Constant as monitoring and data logging of pumping rates.

16. Eliminate bad source first – new well, blend (long term) treat second (short term)

17. Stop over pumping of aquifer. Look for trace quantities of anaerobic condition indicators such as Mn and Fe.

18. Drill a new well in different locations based on hydrogeology studies.

How can future land use planning decisions impact future public health and safety risks associated with arsenic in SJ Valley groundwater?

1. Reduce extraction in high risk areas

2. Invest in direct potable reuse (DPR)

3. Need a public access clearing house to make available the needed information to help those who have issues and in continuing development.

4. Meter all groundwater use

5. Have basic infrastructure in place if land area has known water quality problems or don’t allow building homes in areas where water quality standards can’t be met.


7. Land use planning can (and should) only permit new or changed land uses that will not contribute to reduction in groundwater levels.

8. No new stand-alone public water system) PWS. Developments should be directed to existing large PWS.
9. From regional PWS like these that exist in the Midwest.

10. Limit use, culture change

11. Create incentives to re-use existing urban areas for housing and parkland to limit urban expansion.

12. Build with lawmaker. Use as a goal.

13. Reduce extraction in high risk areas.

14. Invest in direct portable reuse - DPR

15. Recycle DW water systems for irrigation (less GW demand for possible use)

16. Need public access clearing house to make available the needed information to help those who have issues and in continuing development.

17. Meter ALL groundwater use (AG industry etc.)

18. Find the arsenic-contaminated areas and designate and protect them as wildlife preserves (where wells won’t be drilled)

19. I hesitate to further limit development. Life must move on. But H20 quality (including arsenic) need to become more transparent to people buying/ developing that land + eventual use (esp. for housing.)

How would you propose to reduce the public health and safety risks associated with arsenic in groundwater over the next 10 years?

1. Make consumers aware that this problem exists

2. Inform consumers about health risks

3. Empower consumers on how to protect themselves from exposure

4. Measure exposure to Arsenic in consumers

5. Improve data access and the campaigns to inform consumers about Arsenic with data
6. Promote regional consolidations to take advantage of large customer rate for affordability

7. Subsidize free domestic well water quality testing (as in south coast water district)

8. Stop eating Brussel sprouts

9. Offer free testing to domestic well users then provide education on how to respond to high Arsenic concentrations

10. State supplied mechanical removal

11. Subsidize well-planning consultations

12. Make data accessible and easily usable by the public especially students in higher education

13. The government should provide funding to setup an Arsenic treatment pilot plant to see how it works

14. Ground water recharge

15. Better recycling

16. Continue to educate youth and classes

17. Reduce, reuse, recycle

18. Work towards more consolidation of water systems and eliminate all small mutual and small water systems

19. The citizens of CA have a right to safe drinking water at present, ~8% of Californian wells have unsafe arsenic, and especially so in DACs. We can do better

20. It is not a simple problem

21. It needs a long term solution with long term adequate funding and attention

22. Direct population growth, by regulation, to areas that are not affected with Arsenic until Arsenic problems are resolved
How would you advise a community that has groundwater supply with arsenic concentrations above the primary drinking water standard (10 ug/L) to address their issues?

1. Work with DDW to develop short term and long term solutions
2. Bring awareness; explain the science; build and educated community & think & look for remedial solutions!

3. Inform consumers of treatment options for arsenic contaminated water.
4. Provide funding and resources to purchase and install point-of-use or point of entry treatment devices
5. Provide free water testing service to consumers
6. Apply for Proposition 1 and State Revolving Fund funding for Arsenic treatment
7. Advocate for more state funding for ongoing operations and maintenance costs for new infrastructure or if on domestic wells, consolidate with nearby cities water system. SWRCB should use SB88 if city uncooperative
8. Pay the cost of water – many instances where cost are kept artificially low
9. Provide revers osmosis (RO) systems for consumers centrally
10. Drill a new well in an uncontaminated area