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Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA)

By Julie Chambon and Bruce Marvin, Geosyntec Consultants, GRA Technical Committee

Introduction

Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are contaminants of emerging concern that have recently been the focus of regulatory attention (USEPA, 2014). PFOS and PFOA are fully fluorinated, 8-carbon chain organic compounds and belong to a class of chemicals known as polyfluoroalkyl and perfluoroalkyl substances (PFAS) (Buck et al., 2011). PFOS and PFOA are the two PFAS manufactured in the greatest quantities in the United States (ASTDR, 2015). Since the 1950s, PFAS, including PFOS and PFOA, have been manufactured and used in a variety of industrial and commercial applications (e.g., metal plating, protectants for paper and packaging products, surfactants in the semiconductor industry and photographic industry, coatings on non-stick pans and pots, and firefighting foams) (ASTDR, 2015). More specifically, PFOS and PFOA are ingredients in Aqueous Film Forming Foam (AFFF) for extinguishing of flammable liquid fires (Fujii et al., 2007) and were released to the environment at many federal and commercial facilities in the United States and elsewhere as a result of historical uses of AFFF. Due to the strength of their carbon-fluorine bonds, PFAS are persistent in the environment and difficult to remediate.

Public attention on these compounds has arisen with cases of their detection in private water supply wells and public drinking water systems, e.g., in Washington County, Minnesota (Yingling, 2016); near former Plattsburgh Air Force Base (NCPR, 2016); and in Portsmouth, New Hampshire (Goetz, 2016). A recent study (Hu, 2016), compiling 2013–2015 national drinking-water PFAS concentrations from USEPA Unregulated Contaminant Monitoring Rule (UCMR3) program, documented that PFAS were detected in 194 of 4,864 sampled public water systems, located in 33 states. The existing regulatory standards for PFOA and PFOS are in the part-per-trillion range and are summarized in Table 1.

PFOS/PFOA Chemistry, Transport and Fate Processes

PFOS and PFOA structures are shown in Figure 1. Both contain a long eight-carbon chain that is hydrophobic, fully saturated with fluorine atoms (i.e., perfluoroalkyl chains), and a hydrophilic polar functional group. Their unique hydrophobic and oleophobic properties contributed to their former use as surfactants (ASTDR, 2015).

As acids, PFOA and PFOS exist in both anionic and neutral forms, depending on the pH. At environmental pH values, both PFOA and PFOS exist primarily under their anionic forms, which are significantly more water-soluble than their neutral forms (Russell, 2009). PFOA and PFAS adsorb to soil and sediment through two mechanisms; the hydrophobic fluorinated carbon tail interacting with the organic-carbon fraction of the soil, and to a lesser extent through electrostatic interactions of polar head group with the charged clay fraction (Higgins and Luthy, 2006). PFOA is found mainly in the dissolved phase, whereas PFOS has a higher sorption capacity (Higgins and Luthy, 2006). In addition, both compounds have

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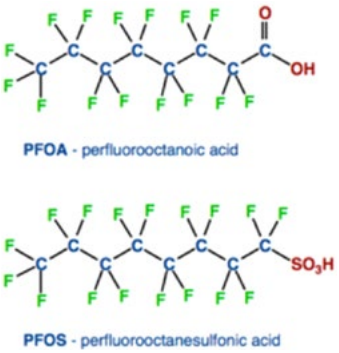

Figure 1. *Chemical Structure of PFOS and PFOA*

The Groundwater Resources Association of California is dedicated to resource management that protects and improves groundwater supply and quality through education and technical leadership.

Photo above: Old abandoned irrigation water "lift pump," surrounded by new urban development in South Natomas (City of Sactamento), CA.

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When it Rains, it Pours!

By Chris Petersen

Hello Again Folks.

As I'm writing this Presidents Message, I'm struck with how quickly conditions change in California Water. We've just endured the most punishing multiyear drought in our history and now we're on pace for the wettest year on record.

If you are like me, you were riveted to your television and computer last week as images and information came in regarding the damaged spillway and rising water levels in Lake Oroville. I was so gripped by this development that I drove to Oroville last Saturday, February 11th, with my friend Roger Nommensen, and together we scoured the City hoping to get a good look and photograph the damaged main spillway and emergency spillway. Water had just begun flowing over the emergency spillway for the first time early that morning. Frustrated by all the road closures, late in the day we were finally rewarded with a great view of the action from a rock outcrop about 1.5 miles northwest of the emergency spillway. These photos show water flowing over the 1,700-foot-wide spillway for the first time. Also very impressive was the mist plume rising 75–100' above the damaged portion of the spillway as water flowing at 100,000 cubic feet per second quickly destroyed the lower portion of the spillway and carved a deep canyon into the adjacent hillside. The power of this water was truly awesome.

The very next day, Sunday February 12th, erosion near the base of the emergency spillway nearly resulted in catastrophe, and an evacuation order was issued for Oroville and many downstream communities, affecting 200,000 people. Thankfully disaster was averted that week and the evacuees were allowed back to their homes. It's clear now that renewed focus on improved maintenance of our flood-control infrastructure is needed and will be a priority in the years ahead. As these improvements are made, we also need to develop new infrastructure to increase our ability to direct these surplus flows, when available, to our depleted groundwater aquifers across our Golden State.

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Is the drought over? One could certainly conclude yes, given the current surface-water conditions and the volume of rain, snow and river flows we've experienced over the past months. Here are a couple of relevant statistics:

1. Combined snow and surface storage in CA amount to 55–60 million acre-ft per year, on average. A big number, right? These reservoirs fill and sometimes spill, as we are seeing this winter, on the order of days, weeks and months.
2. Total combined groundwater storage potential in our CA aquifers is estimated at 800–1,300 million acre-ft. Staggering, isn't it? Storage in our aquifers is depleted or replenished on the order of years and decades, and for decades now, we have been depleting storage in many, if not most, aquifers in our developed groundwater basins.

So, the challenge remains: how do we better harness these surplus flows, when available, and get them into our depleted groundwater aquifers? Local agencies that have already invested in managed aquifer recharge (MAR) facilities are really benefiting from the surplus water this year. Now that the Sustainable Groundwater Management Act is beginning to be implemented, I am hopeful that we will see a significant increase in the number of MAR facilities as we work together to stabilize and replenish freshwater storage in aquifers throughout the state. To do this, we need to work together to develop and implement innovative local solutions for better harnessing these surplus surface flows for aquifer replenishment.

UC Davis hydrologist Helen Dahlke stands in a Modesto almond orchard during an experiment she is leading to recharge the aquifer by flooding farmland in the winter.
Source: https://www.ucdavis.edu/news/flooding-farms-rain-restore-groundwater.

Speaking of innovations, I was talking to our newest GRA Director, Paul Hendrix, earlier this month at our Board meeting. Paul is the General Manager of the Tulare Irrigation District (TID) and an active member of the Mid-Kaweah Groundwater Sustainability Agency. Paul is encouraging his agricultural water users to take surplus water this year, at no charge, and apply it to their fields for the purpose of groundwater replenishment. UC Davis, among others, is studying the effect of winter flooding on vineyards, orchards and other crops, and is finding that the practice looks promising.

GRA will continue to play a leadership role in increasing MAR throughout the state by shining a light on the need for this type of water management action, and providing education and informational materials to legislators, policy advisors, water managers and groundwater-management experts/practitioners.

SGMA Began Taking Shape in 2016

2016 was a fantastic year for GRA as we celebrated our 25th Anniversary. I look forward to 2017 with excitement as together we build on the initiatives we began last year and launch a few news ones this year.

SGMA began taking shape last year as the California Department of Water Resources (DWR) rose to the challenge of meeting each of their legislative mandates, including:

- Publishing Basin Boundary Adjustments in the Interim Update of Bulletin 118
- Publishing Groundwater Sustainability Plans (GSP) Regulations focused on outcomes rather than prescription and process
- Publishing Best Management Practices and Guidance Documents to assist locals in developing GSPs
- Completing the Evaluation of Water Available for Replenishment and then Publishing in January 2017.

I want to acknowledge David Gutierrez, Trevor Joseph, Steven Springhorn, Mark Nordberg, Tim Godwin, Dan McManus, Rich Juricich and all the other scientists and engineers at DWR that worked tirelessly in 2016 to successfully complete this foundational work.

GRA provided relevant and timely information on these topics by hosting and encouraging DWR and State Water Resources Control Board participation in multiple webcasts and conference venues focused on the topics listed above in 2016, most notably:

- Data and Models in Feb 2016,
- Legislative Symposium in March 2016,
- Developing GSPs for Success in June of 2016, and
- Our Annual Meeting in October 2016.

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GRA Conference attendees are given access to speaker's presentations shortly after the event on GRA's website; access is opened to all GRA members about two months later. We also had numerous GRACasts on SGMA topics in 2016, and I encourage you to view these and consider purchasing and viewing these webcasts available in the GRA Store: http://cart.grac.org/.

Groundwater Issues Facing California in 2017

For 2017 we already have a fantastic lineup of events, GRAcast and legislative activities planned that address the most pressing groundwater topics facing CA today, such as:

- GSA filing deadline of June 30, 2017
- Tools, data and information needed to develop GSPs
- How to fund SGMA?
- Naturally-occurring constituents complicating the use of groundwater
- Constituents of emerging concern complicating the use of groundwater
- Impact of storms of 2016–17 on aquifer conditions
- Improving aquifer conditions through increased managed aquifer recharge
- Grants for increased groundwater storage and conjunctive use
- Grants for development of GSPs
- Grants for clean-up of contaminated groundwater.

This year GRA has already made tremendous progress planning 3 events and has identified a couple of others planned for later in the year. Here's what is in the works for 2017:

- Legislative Symposium, March 28, 2017
- Data and tools for GSPs, May 3–4, 2017
- Role of Geophysics in Addressing Basin Setting chapter of GSPs – September 2017
- GRA Annual Conference and Meeting, October 3–4, 2017
- Dry Cleaner event in November 2017.

Please visit our Event Page for more information and registration details on all our conferences and GRACasts.

A Charge to Continue GRA's Pioneering Spirit

At our first GRA Board meeting of 2017, I shared with the Board my hope that we continue to embrace the pioneering spirit that has built GRA into the exceptional organization that we are today. I shared with the team a quote from Walt Disney, one of California's most imaginative pioneers, who once said of his growing empire:

> "Around here we don't look backwards for very long. We keep moving forward, opening up new doors and doing new things, because we are curious…and curiosity keeps leading us down new paths."

SGMA is a game changer for water management in California! Success will require imagination, innovation and a lot of work. We need your help at GRA. Please consider joining if you are not yet a member, get involved and help us help California become the global leader in sustainable groundwater management.

Until Next Time!

Chris

extremely high chemical and thermal stabilities due to the presence of strong carbon-fluorine bonds (Rahman et al., 2014), and are therefore challenging to remediate. PFOA and PFOS are extremely persistent, with half-lives in water of 92 and 41 years, respectively (USEPA, 2014); they are not known to undergo abiotic or biotic degradation under relevant environmental conditions (Parsons et al., 2008).

PFAS and PFOA presence in the environment is the result of direct release, but also degradation of precursor compounds, i.e., polyfluorinated substances that degrade in the environment via abiotic and biotic processes into the stable end products PFOS and PFOA (e.g., Conder et al., 2010; Paul et al., 2009). These precursors are not detected using the standard analytical method for PFAS (USEPA Method 537) and little is known about their properties, chemistry, and fate, which complicate PFOS and PFOA investigation and characterization, as well as design and testing of treatment technologies.

Treatment Technologies

The development of effective remedial strategies for PFAS is ongoing as researchers seek to improve the overall understanding of degradation and transformation pathways. The maturity and scale of technology demonstrations ranges from laboratory studies to full-scale treatment systems.

Ex-Situ

The most common approach for groundwater remediation impacted by PFOS and PFOA involves groundwater extraction followed by granular activated carbon (GAC) adsorption. Other commonly used ex-situ treatment methods include reverse osmosis and nanofiltration (USEPA, 2014). These methods are well established and show high removal rates; however, they are associated with high cost of operation. Furthermore, incineration of the concentrated waste at very high temperatures is necessary to completely destroy PFOA and PFOS (USEPA, 2014). In addition, ex-situ treatment is optimized for specific chemicals (e.g., PFOA or PFOS) and might result in other PFAS passing through the treatment system (DON, 2015). Research into more cost-effective new adsorbents with higher selectivity and increased PFAS adsorption performance is ongoing (USEPA, 2014).

Alternative ex-situ treatment technologies being tested at the laboratory scale include photochemical oxidation, thermal degradation, and sonochemical destruction (USEPA, 2014; DON, 2015).

In-Situ

In-situ treatment is relatively immature for PFOS and PFOA and is an active research area (DON, 2015). No full-scale demonstrations have been conducted to date and pilot-scale applications are limited (DON, 2015). Most of the development in this area is performed at the laboratory scale with the objective of demonstrating effective destruction of PFOS and PFOA. Several destruction processes are being explored as possible means to treat PFOS and PFOA in-situ. Laboratory studies of chemical oxidation using advanced oxidation processes have yielded mixed results (e.g., Yates et al., 2014). Similarly, limited studies exist on microbial degrada-

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TABLE 1. REGULATORY STANDARDS DERIVED BY VARIOUS STATES AND USEPA FOR PFOS AND PFOA

Location	*Regulatory Standard*	*Values*	*Reference*
USEPA (Federal – Nationwide)	Lifetime Health Advisory Level	PFOA: 0.07 µg/L PFOS: 0.07 µg/L PFOS + PFOA: 0.07 µg/L	(USEPA, 2016)
Maine	Remedial Action Guideline	PFOA: 0.13 µg/L PFOS: 0.56 µg/L	(MDEP, 2016)
Minnesota	Chronic health risk limit in drinking water	PFOA: 0.3 µg/L PFOS: 0.3 µg/L	(MDH, 2016)
New Jersey	Health-based drinking water guidance level	PFOA: 0.04 µg/L	(NJDEP, 2017)
North Carolina	Interim Maximum Allowable Concentration in Groundwater	PFOA: 2 µg/L	(NCDENR, 2012)
Texas	Tier 1 Protective Concentration Level in Groundwater	PFOA: 029 µg/L PFOS: 0.56 µg/L	(TCEQ, 2016)

tion of PFOS and PFOA and resulted in conflicted results, as the biotic transformation processes of these compounds are not fully understood (e.g., Parsons, 2008; Mahendra, 2014). However, preliminary work on fungal degradation has shown promising results in laboratory studies and is the subject of active research (Mahendra, 2014). Other technologies, such as chemical reduction using ZVI (e.g., Arvaniti et al., 2015), electrochemical and catalytic approaches (Schafer, 2014) or coagulants approaches (Simcik, 2014) have also provided promising preliminary results in laboratory studies; additional research and testing will need to be performed prior to development of these technologies for in-situ applications.

Regulations

Regulations are quickly evolving, as are human-health and ecological-risk studies that inform those regulatory and advisory levels. In 2009, USEPA issued provisional health advisories for PFOA at 0.4 micrograms per liter (µg/L) and PFOS at 0.2 µg/L. In 2016, USEPA's Office of Water issued a lifetime Health Advisory Level of 0.07 µg/L for both PFOA and PFOS, based on a reference dose derived from a development toxicity study on mice (PFOA) and rats (PFOS) (USEPA, 2016). Although California has yet to publish regulatory standards for PFOS and PFOA, other states, including Minnesota, Alaska, New Jersey and Florida, have published health-based drinking-water concentrations, generic screening levels, and site-specific regulations for these compounds (Table 1); USEPA has listed six PFASs as candidates for future drinking-water regulatory determinations.

Conclusions and Perspectives

PFOS, PFOA and related chemicals pose a threat to California's groundwater resources. While these compounds are detected in groundwater and drinking water systems, research is ongoing to better characterize and understand PFOS and PFOA fate and behavior in groundwater, including occurrence and degradation pathways and processes, identification of precursors and transformation products, and development and standardization of accurate and efficient analysis methods. These advancements are necessary to support the development of more cost-effective ex-situ treatment methods and of promising in-situ treatment methods.

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Use of Stable-Isotope Ratios to Determine Water Source

By Jim Ulrick, PG, CEG, CHG

A landslide damages a home in the middle of summer and water is seeping from the head scarp. A water seep into the backyard and crawl space of a house near the bottom of a hill slope causes foundation and structural damage, or mold, or someone slips and falls on the slime growing in the water. Water is seeping through cracks in the floor of an underground office or parking garage. For each of these conditions, a key question to answer is, "What is the source of the water?" Before you can look for specific sources, you must first answer the question, "Is it native water or potable (tap) water?"

The author has collected 181 samples over the past 14 years for stable-isotope-ratio analyses. An additional 28 isotope ratios of water from selected wells, creeks, and surface water in the Bay Area have been compiled from USGS reports (Muir and Coplen, 1981; Newhouse and others, 2004). I also collected monthly rainfall isotope samples for volume-weighted composite 2012 water-year stable isotope values. A database, with GPS coordinates, is available upon request. This article represents my experience with the practical application of stable isotope ratios in the San Francisco Bay Area. References are included as an introduction to further research.

Water utilities may test a water sample for chlorine, chloride, fluoride, TDS (total dissolved solids), or EC (electrical conductivity) to determine whether it is their water, but the inorganic-chemistry testing commonly used is not reliable. The problem is that the original source-water chemistry is changed by contact with soil or rock. Chlorine and fluoride compounds, for example, are adsorbed onto soil, much like an activated-carbon filter.

In the Bay Area, most of our tap water is imported. The East Bay Municipal Utility District imports water from Pardee Reservoir in the Sierra Nevada, with supplemental water from the Sacramento River (Freeport Regional Water Project) and local storage reservoirs and their watersheds. San Francisco and their water contractors import water from Hetch Hetchy Reservoir in the Sierra Nevada, with supplemental water from local reservoirs and watersheds. Santa Clara Valley Water District imports surface water from the Sacramento-San Joaquin River Delta via the South Bay Aqueduct for direct use and recharges their groundwater basin with both local and imported water. Marin County is an exception, deriving their municipal water from local reservoirs and the Russian River.

Head scarp of a landslide near homes.

The most reliable method for distinguishing tap water from native water is by measuring the hydrogen and oxygen stable-isotope ratios of the water. The atoms of hydrogen and oxygen that compose water each occur as several different isotope-specific variants, or nuclides. A nuclide is defined by the number of protons, which defines the element, and the number of neutrons, which defines the specific isotope of that element. Varying the number of neutrons does not change the identity of an atom. The atomic weight of a nuclide is the sum of the protons and neutrons.

Most hydrogen (^{1}H) has an atomic weight of 1 (1 proton and no neutrons). Heavy hydrogen, or deuterium (^{2}H or D), has an atomic weight of 2 (1 proton and 1 neutron). Most oxygen (^{16}O) has an atomic weight of 16 (8 protons and 8 neutrons). Heavy oxygen (^{18}O) has an atomic weight of 18 (8 protons and 10 neutrons). Stable isotopes of water are measured as the ratios of the two most stable and abundant isotopes of each element. The stable-isotope ratio of oxygen is the ratio of ^{18}O (0.204 percent of all oxygen) to ^{16}O (99.796 percent of all oxygen). Thus, the $^{18}O/^{16}O$ ratio is about 0.00204. Similarly, the stable-isotope ratio of hydrogen is the ratio of ^{2}H (0.015 percent of all hydrogen) to ^{1}H (99.985 percent of all hydrogen). Thus, the $^{2}H/^{1}H$ ratio is about 0.00015.

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The stable-isotope ratio of a sample is measured relative to a known reference (Vienna Standard Mean Ocean Water). The difference between the sample and VSMOW is expressed using delta (δ) notation. Because these differences are small, δ values are expressed as parts per thousand, or per mil (‰). For example, a positive δvalue of +10‰ for oxygen ($\delta^{18}O$ = +10‰) means that the sample is enriched in ^{18}O by 10‰ compared to the reference.

The $\delta^{18}O$ and $\delta^{2}H$ ratios of precipitation worldwide vary as a function of temperature, elevation, and latitude, and are linearly related by the global meteoric water line (GMWL, Figure 1). In California, extreme changes in elevation occur over relatively short distances between the coast and interior mountain ranges. As storm systems move onshore from the Pacific Ocean the heavy isotopes ^{18}O and ^{2}H are depleted relative to the light isotopes by condensation and precipitation (think of heavy isotopes as being less volatile). For example, $\delta^{18}O$ in precipitation varies from approximately -4‰ along the Pacific coast to -15‰ in the Sierra Nevada (Figure 1).

Stable-isotope ratios are a reliable indicator of the source of a water sample because they are unchanged by most of the organic and inorganic chemical reactions in soil and rock. The main exception is evaporation. Evaporation of surface waters, such as in a reservoir or swimming pool, depletes light isotopes and leaves behind a water that is enriched in the heavy isotopes (think of light isotopes as being more volatile). Evaporated water plots along a line with a lower slope than the GMWL (Figure 1).

The interpretation of stable-isotope results is based on a linear mixing ratio between two endpoints of native water (local rainfall, groundwater, or surface water) and imported tap water.

Monthly rainfall samples were collected during the 2012 water year using the IAEA method (International Atomic Energy Association, 1997), which consists of a bucket with a spigot at the bottom and a sealed lid with a funnel

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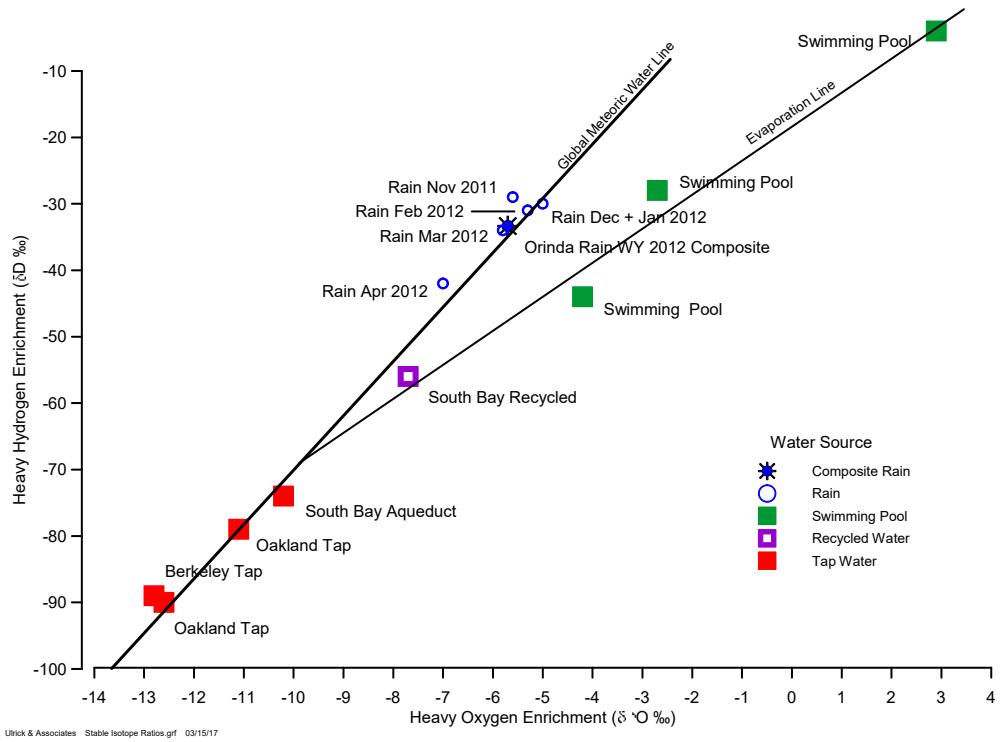
Figure 1. Stable Isotope Ratios of Water



covering the top. At the start of each month, the bucket is emptied and approximately one pint of pure inert mineral oil (approximately one- half inch) is added. As rainwater enters the bucket through the funnel, it drips through and accumulates underneath the mineral oil. This prevents evaporation and protects the original isotope ratio of the rainfall. At the end of each month, a sample of the water is collected and analyzed, the bucket emptied, and the process is repeated. The total rainfall for the month is measured by a tipping-bucket rain gage. At the end of the water year, the isotope ratio of each monthly sample is weighted by the total rainfall for that month to derive a volume-weighted composite isotope ratio (Table 1).

A simpler method (without mineral oil or a rain gauge) is to empty the rain bucket into a two-liter bottle immediately after each rain event. Fill additional bottles as necessary and keep the bottles capped and cool. At the end of the rainy season, combine all of the bottles and pour off a sample for analysis (Eastoe, 2012).

Stable-isotope ratios of rainfall can vary widely between storms, time of year, and micro climate. There is also variation between water years.

The basic method used to determine whether an unknown-source water sample (unknown) is tap water or native water is to plot the two endpoints and the unknown (Figure 1). The proportion of the end-point waters in the unknown will be a linear function of the distance between the unknown and the end points – a linear mixing ratio.

The tap water endpoint represents source water for possible leaks of potable drinking water, irrigation water, sanitary sewer water, or swimming-pool water. The isotope ratios of tap water can vary over time due to changes in the source waters used by water districts. If the isotope ratios of the tap water are similar to the native water, then the method cannot be used.

Local rainfall may be taken as a source for the native endpoint. It has been my experience, from sampling residential hillsides throughout the Bay Area, that apparently native waters in developed areas typically have isotope results that indicate small amounts of tap water. This may result from excess irrigation return flows to groundwater.

Jim can be reached at julrick@ulrick.com.

Table 1.
Precipitation Stable Isotope Ratios
2012 Water Year, Orinda, CA

Month	Precipitation Inches	Heavy Oxygen Enrichment $\delta^{18}O$‰	Heavy Hydrogen Enrichment δD‰
September	0.04	na	na
October	1.78		not sampled
November	2.31	-5.60	-29.00
December	0.18	combined with January	
January	4.65	-5.00	-30.00
February	2.40	-5.30	-31.00
March	12.00	-5.80	-34.00
April	3.94	-7.00	-42.00
May	0.16	na	na
June	0.14	na	na
Total	25.78		
Weighted Composite		-5.70	-33.35

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Tools for Developing SGMA Groundwater Sustainability Plans

Conference Details:

A critical step for compliance with the Sustainable Groundwater Management Act (SGMA) is the development of a successful Groundwater Sustainability Plan (GSP). This conference focuses on tools and techniques that can support key elements and programmatic considerations for GSP development.

- Best Management Practices (BMPs) for Sustainable Groundwater Management
- Quantifying GSP Measurable Objectives
- Water Available for Replenishment
- Streamflow Depletion and Groundwater Dependent Ecosystems (GDEs)

The conference program provides policy-makers, stakeholders, regulators and other government entities, NGOs, consulting professionals and practitioners, growers, and landowners the opportunity to present their work, and to interact and learn about the emerging BMPs; quantifying measurable objectives for GSPs under the six criteria defined by the SGMA for groundwater sustainability; and new research on water availability, streamflow depletion, and GDEs.

Outline of Presentations:

William Alley, PhD., of the National Ground Water Association, will be the keynote presenter, discussing "Lessons for SGMA Plans from around the World." Dr. Alley will be using examples and lessons learned from his recently released book, *High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater*, and will be doing a book-signing at the conference.

This two-day conference also features additional speakers on water resource management practices and presentations from state and federal agencies, NGOs, water resource stakeholders, and academic and consulting industry leaders. Featured topics for abstracts for podium and poster presentations include:

- BMPs for Sustainable Groundwater Management
  - Groundwater Monitoring Networks
  - Water Budgets
  - Hydrogeologic Conceptual Models
  - Modeling
- Quantifying GSP Measurable Objectives
  - Groundwater Data Collection and Uses
  - Subbasin Baseline Assessment – Methods for Hydrogeologic Analysis
  - Practices, Techniques, and Tools in Hydrologic Modeling
  - California's Open and Transparent Water Data Act
- Water Available for Replenishment
  - Beneficial Use of Water in Replenishment
  - Type and Timing of Water Available for Replenishment
  - Effects of Climate Change Scenarios on Water Availability
- Stream Depletion and Groundwater Dependent Ecosystems
  - Understanding and Quantifying Surface/Groundwater Interactions
  - GDE Impacts/Mitigation
  - Field Methods and Simulation Approaches
  - Legal, Policy and Regulatory Compliance

Need Additional Information? Contact:

Technical – Brett Wyckoff, DWR
Brett.Wyckoff@water.ca.gov or (916) 651-9283

Administrative – Sarah Kline
skline@grac.org or (916) 446-3626

Sponsor & Exhibitor Opportunities:

If you are interested in being a sponsor or exhibiting your organization's services or products, please contact us at conference@grac.org or by telephone – Sarah Kline (916) 446-3626, or click here to register as a sponsor or exhibitor.

Groundwater Resources Association of California
in cooperation with the
California Groundwater Coalition
Presents its

Annual Legislative Symposium
California's Groundwater Future: Decision Time?

Luncheon Keynote Speaker (invited)
Robert Hertzberg, Chair, Senate Committee on Natural Resources and Water

Decision Time 2017:

Flooding and drought, SGMA implementation, funding challenges, unimpaired stream flows, long-term groundwater replenishment, California WaterFix, federal infrastructure programs and more!

After suffering through another year of historic drought in 2016, California has experienced record-breaking rainfall in 2017, raising questions about California's aging infrastructure, like Oroville Dam. Will abundant rainfall take the pressure off ongoing efforts to implement long-term solutions? With 2017 a make-or-break year for the Governor's California WaterFix, will the election of Donald Trump help or hurt that effort? Will the feds have a different idea of how to address California's infrastructure challenges? Add the recent decision by the state's top water regulators to maintain emergency drought rules in place until May, SGMA implementation, and a host of legal issues in the Delta, and join us for an action-packed day!

Meeting Agenda

8:30 AM to 4:30 PM - Program

5:00 PM - Hosted Cocktail Reception

Prices will increase on Monday, March 13th. Register now for the Early-Bird Discount!

Exhibitor Opportunities

A limited number of exhibitor booths are available at this event. If you are interested in attending and showcasing your company's services, please contact Sarah Kline at 916-446-3626 or skline@grac.org

Exhibitors will receive a 6' draped table with 2 chairs suitable for a tabletop display, name recognition in the onsite program, signage at the event and one full program registration.

Questions? Contact Sarah Kline, 916-446-3626 skline@grac.org.

Wells and Words

By David W. Abbott, P.G., C.Hg., Consulting Geoloist

Distance-Drawdown Straight-Line Method for Evaluating Pumping Tests

Previously[1], I discussed using straight-line (Cooper Jacob [C-J]) and curve-matching methods (Theis) to estimate Transmissivity (T) and Storativity (S) from water levels collected in observation (obs) wells during a pumping test. The *time-drawdown* (dd) plots were based on non-equilibrium (transient) data sets for each obs well. Another method often used to evaluate pumping tests and water-level data consistency is *distance-dd* plots for equilibrium conditions (steady state). Recall that the Theis and C-J equations describe the shape of the cone-of-depression around a pumping well at any given constant discharge (Q) and time (t)[2]; and are the basis for evaluation of pumping tests[3]:

Theis Equation **Cooper-Jacob Equation**

$$s = \frac{114.6 \times Q}{T} W(u) \approx \frac{264 \times Q}{T} \text{Log}\left(\frac{0.3 \times T \times t}{r^2 \times S}\right)$$

$$u = \frac{1.87 \times r^2 \times S}{T \times t}$$

Q in gallons per minute (gpm)

s = drawdown in feet (ft)

t = elapsed time of pumping in days

r = the distance from the pumping well to an obs well in ft (radius)

Aquifer parameters: T in gallons per day per foot (gpd/ft), and S (unitless)

W(u) is the well function, which is an exponential integral[3]

Note that if T and S are constants for any given aquifer, then two of the three other variables (s, t, and r) can be used to evaluate the third variable. Using the transient method, estimates of T and S are made by observing the time-dd series at specific distances from the pumping well (i.e., r is constant). Steady-state estimates of T and S are made by plotting the distance-dd series at specific times (i.e., t is constant). When applied to the above formulae, transformed for using distance-dd plots, the solutions to the C-J equation become:

$$T = \frac{528 \times Q}{\Delta s} \quad and \quad S = \frac{0.3 \times T \times t}{r_0^2}$$

Note that this form of the equation is the same as for the C-J time-dd solutions[1] and that the lead constant (264) has doubled to 528. The term r_0 is now the distance between the pumping well and the location where the dd = 0 at a specific elapsed time of pumping, t, which differs from the use of t_0 for the time-dd solutions. A corresponding equation for the Theis formula can also be derived to evaluate distance-dd data using curve-matching methods[4,5] (double logarithmic [log] plots of t/r^2 versus s).

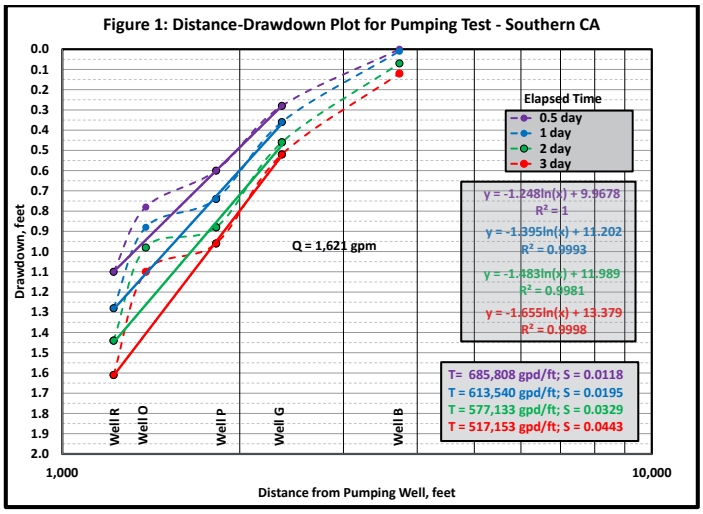

Figure 1 shows a family of semi-log plots representing conditions at four times during pumping, ranging from 0.5 day to three days, at five obs wells (Wells R, O, P, G, and B) which correspond to the obs wells used in the previous exercise[1]. The x-axis (log) is distance from the pumping well and the y-axis (arithmetic) is the measured dd from the static (non-pumping) water level. The dashed curvilinear lines are smoothed curves connecting the data points. The solid lines are best-fit trend-lines through the data (except Well O) for each time. Note that the curves and trend-lines are generally parallel to each other and have similar slopes. This representation shows the vertical profile and the expansion of the cone-of-depression at various times between 1,222 (Well R) and 3,732 ft (Well B) from the pumping well.

Continued on the following page…

The dd in Well O seems to lag behind that of the other wells; this could be caused by local hydraulic conditions (aquifer texture or well efficiency [likely]). Well B was not included in this analysis because the dd had not fully stabilized[1]. Relative to the pumping well, the obs wells are located along the following azimuths: 193° (Well R), 13° (Well O), 57° (Well P), 359° (Well G), and 57° (Well B). Note that Wells P and B are located along the same azimuth; Wells R and O are along the same diameter, but on opposite sides of the pumping well; and, with the exception of Well R, all are located on the same side of the pumping well within a 58° arc. The pumping well, not shown, was pumped at an average of 1,621 gpm for 72 hours with no significant changes in the dd (26 ft) during the test.

The best-fit trend-line equations (color coded to the elapsed times) are shown on Figure 1; the regression coefficient (R^2) is nearly perfect for all the trend-lines. The slope s or "delta s") of the straight line in ft per log cycle is used to estimate T from the distance-dd data (see above); s for days 0.5, 1, 2, and 3 are 1.248, 1.395, 1.483, and 1.655 ft, respectively. Calculations show that the transmissivity ranges from 517,000 to 686,000 gpd/ft.

Forward-projection of the trend-line to the 0-dd axis shows that for 0.5, 1, 2, and 3 days, r_0 = 2,943, 3,072, 3,243, and 3,242 ft, respectively. In 48 hours (from the end of day 1 to the end of day 3), the cone-of-depression expanded by about 171 ft! Calculations show that S ranges from 1.2% to 4.4%. T and S estimates from this method are summarized in the lower right corner of Figure 1.

To summarize the T and S estimates computed for this data set (including the previous article[1]):

C-J (time-dd)	T = 528,326 to 1,060,860 gpd/ft S = 0.16 to 0.68%
Theis	T = 520,146 to 984,563 gpd/ft S = 0.27 to 4.2%
C-J (distance-dd)	T = 517,000 to 686,000 gpd/ft S = 1.2 to 4.4%

This relatively narrow range of values is quite good, especially when recognizing that T and S can range by several orders of magnitude and obs-well responses can be affected by small differences in aquifer architecture (anisotropy, aquifer thickness, heterogeneity, etc.), obs-well construction profiles, screen locations, and well efficiency, or by not meeting the u < 0.05 criteria[1] for the C-J applications. Remember that these estimates of aquifer parameters are integrated averages for the aquifer.

The estimates for T depend on the value of s provided from the distance-dd curves; s ranges for this data set from 1.25 to 1.66 ft (a difference of 0.41 ft, or 5 inches), based on a partial log-distance cycle with a relatively small amount of dd (less than 1.6 ft). Although it is relatively rare to have an obs well during any pumping test, a higher level of confidence for estimating aquifer parameters from pumping tests can be facilitated with the installation of at least one obs well within 10 to 20 feet of the pumping well. The other obs wells, if available, should be scaled along a log-distance distribution from the pumping well to the anticipated extent of the cone-of-depression under the planned testing and operating conditions; distance-dd plots should include at least 1.5 log-cycles.

While conducting pumping tests, as always, be flexible, methodical, and forward-thinking. Always estimate if u < 0.05 for distance-dd data. Larger dds in obs wells are better, more significant, and reliable than smaller dds for estimating T and S. Straight-line back-projections of the curves can provide information on the expected dd in the pumping well. The y-intercept of the trend-line at one-ft radius shows an expected dd in the pumping well at 1 day to be 11.2 ft; the actual dd at the pumping well was 26 ft. Hence, the well efficiency of the pumping well is about 43%. Well development or rehabilitation on the pumping well could improve the well efficiency and result in an annual savings of $6,340/year if pumped at 1,621 gpm for 18 hours/day and 365 days/year[6].

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[3] UOP Johnson, 1966, Ground Water and Wells (1st Edition), Johnson Division, UOP Inc., Saint Paul, MN, 440pp.

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Legislative Update – February 2017

By Timothy K. Parker, PG, CEG, CHG, GRA Director and Legislative Committee Chairman

Changes to GRA's Advocacy Program – Back to Grass Roots

Faced in late 2015 with a fee increase for our long-term Legislative Advocates, Chris Frahm and Rosanna Carvacho with Brownstein Farber Hyatt Shreck, GRA opted to remain at the same cost with a lower level of support. The fee increase was requested as a result of significantly increased groundwater policy and legislative activities at the Capitol in developing and implementing the Sustainable Groundwater Management Act (SGMA) – groundwater became much more visible in Sacramento. Services no longer provided by Brownstein include attending monthly Legislative Committee calls and providing insights on the status of current bills and State Administration activities and actions, writing and delivering letters to the Legislature, drafting this quarterly update for HydroVisions, and representing GRA at Legislative Members offices and in Committee hearings. GRA is a member of the California Groundwater Coalition (CGC), an organization formed through a joint initiative by GRA and the Association of Groundwater Agencies in 2007. The CGC membership provides the GRA Legislative Committee with a list of bills and their status monthly, and GRA occupies a Director seat on the CGC Board and attends quarterly meetings. GRA is now contracting Brownstein mainly for planning and helping execute GRA's Annual Legislative Symposium, which will be held this year on March 29th at the Citizen Hotel (see page 12 of this issue for more information).

GRA established a Legislative Steering Committee in early 2016 that finalized a GRA Legislative Committee 2017 Vision and Recommendations (2017 Legislative Vision) to the GRA Board in late 2016. The 2017 Legislative Vision outlines a number of actions and activities for the GRA Legislative Committee moving forward, including:

- Update the GRA Board Policy Principles and Legislative Guidelines
- Establish a common understanding of roles and responsibilities among GRA's members, our legislative advocacy service provider, and the California Groundwater Coalition
- Provide focus to the Legislative Committee and Board in preparing and adopting an annual budget to sustain our legislative function
- Provide improved structure for the role of GRA volunteers participating on the Legislative Committee.

Changes in the Administration

There have been a number of changes within Governor Brown's Administration:

- Martha Guzman Aceves had been a deputy legislative affairs secretary in the Office of the Governor since 2011, focusing on natural resources, environmental protection, energy and food and agriculture. The Governor recently appointed her to the California Public Utilities Commission.
- Cliff Rechtschaffen had served as the Governor's senior advisor on climate and energy issues for more than five years. The Governor recently appointed him to the California Public Utilities Commission.
- Wade Crowfoot had been a Deputy Cabinet Secretary and Senior Advisor to Governor Brown since 2013, and prior to that, he served as Deputy Director of the Governor's Office of Planning and Research. Wade recently moved to the (California) Water Foundation as its new Executive Director.
- DWR Director Mark Cowin and Sustainable Groundwater Management Program Manager David Gutierrez both retired in December 2016. William Croyle was appointed Acting Director for DWR effective January 1, 2017. Prior to his appointment, William served as Deputy Director for Statewide Emergency Preparedness and Security. Rich Juricich is now serving as the Sustainable Groundwater Management Program Manager.
- Alice Busching Reynolds has been appointed senior advisor to the Governor for climate, the environment and energy. She previously served as deputy secretary for law enforcement and counsel at the California Environmental Protection Agency since 2011.
- Cindy Messner has been appointed Chief Deputy Director of DWR, where she has served as Assistant Chief Deputy Director since 2016.

Continued on the following page…

Water and Groundwater-Related Legislation Introduced

There does not appear to be nearly as much water/groundwater legislation shaping up this year, compared to the previous several years. Here are the bills GRA is currently tracking:

AB 18 Garcia – California Clean Water, Climate, Coastal Protection and Outdoor Access for All Act of 2018. This bill would enact the California Clean Water, Climate, and Coastal Protection and Outdoor Access For All Act of 2018, which, if approved by the voters, would authorize the issuance of bonds in an amount of $3,005,000,000 (pursuant to the State General Obligation Bond Law) to finance such a program.

AB 196 Bigelow – Greenhouse Gas Reduction Fund – Water Supply Repairs – This bill would authorize the use of the moneys in the fund for water supply repairs if the investment furthers the regulatory purposes of the act and is consistent with law.

AB 313 Gray – Water – This bill would transfer authority over water-rights matters from the State Water Resources Control Board (SWRCB) to DWR, would transfer all SWRCB SGMA authorities to DWR, and would establish a State Water Commission (SWC) within the Natural Resources Agency, and would transfer authority relating to the State Water Project from DWR to the new SWC.

AB 321 Mathis – Groundwater Sustainability Plans – This bill would additionally require the groundwater sustainability agency to solicit the participation of farmers, ranchers, and other qualified professionals within the groundwater basin prior to and during the development and implementation of the plan.

SB 5 De León – California Drought, Water, Parks, Climate, Coastal Protection and Outdoor Access for All Act of 2018 – This bill would enact the California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access For All Act of 2018, which, if approved by the voters, would authorize the issuance of bonds in an amount of $3,000,000,000 pursuant to the State General Obligation Bond Law to finance a drought, water, parks, climate, coastal protection, and outdoor access for all programs. The bill would provide for the submission of these provisions to the voters at the June 5, 2018, statewide primary direct election.

SB 193 Cannella – Groundwater Sustainability Agencies – This is a "spot bill" or place-holder; it is something to watch for actual language and intent.

I would like to note with the recent Oroville dam spillways failure, we understand that staff for Senate President Pro Tem Kevin De León are amending the SB 5 bond bill to include money for flood control measures. Further amendments we should all be asking for include additional funding for groundwater projects to help replenish our drought-depleted subsurface reservoirs. There also should be ties to publicly-funded flood-control measures that increase the opportunities for groundwater replenishment, making these multi-beneficiary projects; such projects could also include enhancements for ecosystem and recreation.

GRA Board Receives Annual Legislative Process Briefing

The GRA Board received an annual State Legislative Process briefing at the February 4th Board meeting in Davis. Legislative Committee Chair Tim Parker covered the online Legislative Process Guide located on the California State Senate website. Tim also gave an online demonstration of the California Legislative Information website, including how to look up information on bills and their current status, Assembly and Senate Daily Files, California Laws and other useful publications. GRA encourages our membership to visit the California Legislative Information website and contact GRA if you have questions or want more information on the GRA Board and Legislative Committee activities and actions.

Changes at the State Legislature

The Senate President pro tempore remains Kevin de León and the Assembly Speaker remains Anthony Rendon. The new-member count is nine in the 40-member Senate and 22 in the 80-member Assembly; Democrats now hold a super-majority in both houses with 27 Democrats to 13 Republicans in the Senate, and 55 Democrats to 25 Republicans in the Assembly.

Continued on the following page…

California's "WaterFix" Final Environmental Documents Released

The product of 10 years of study, analysis, and public input, California WaterFix is a key element of the Brown Administration's five-year California Water Action Plan to build more reliable, resilient water systems and to restore important ecosystems in the waterways of the Bay-Delta estuary. The basic elements of WaterFix were chosen to satisfy the 2009 Delta Reform Act, which established the co-equal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The 2009 law directed state agencies to analyze a reasonable range of Delta conveyance alternatives, including various routes and carrying capacities.

WaterFix is the state's plan to upgrade infrastructure in the Bay-Delta estuary (largely referred to as the "Delta") where the Sacramento and San Joaquin Rivers meet before flowing to San Francisco Bay and out to the Pacific Ocean. The Delta provides critical habitat for wildlife, including several endangered and threatened species of native fish. The state's two biggest surface water projects, the State Water Project and the federal Central Valley Project, deliver water that passes through the Delta. Together, the two projects deliver water to 25 million people across California. Water project operations in the south Delta have caused reverse flows that have been increasingly curtailed to protect listed fish species, reducing the amount available to meet urban and agricultural demands in the south state, causing concern and conflict for many water users. The WaterFix project proposes to reduce that conflict so that water supplies are stabilized and harmful reverse flows are reduced. The project consists of three new intakes in the northern Delta and two 35-mile-long tunnels to transport water to the existing pumping plants in the south Delta. The new intakes and tunnels are proposed also to help guard water supplies against saltwater intrusion as sea levels rise, and in the event of an earthquake or storm powerful enough to destroy levees in the low-lying Delta.

The Final Environmental Impact Report (EIR) and Environmental Impact Statement (EIS) describe environmental impacts that could arise from modernizing California's infrastructure, and includes mitigation measures to avoid or minimize those impacts. The document analyzed 18 project alternatives, including the status quo, and ultimately concluded that WaterFix, known as Alternative 4A, was the best option for both increasing water supply reliability and addressing current Delta ecosystem concerns while minimizing environmental impact. WaterFix was chosen because of its ability to provide a reliable source of clean water while minimizing unnatural flows in the Sacramento-San Joaquin Delta that harm native fish and habitat. More than 100 alternatives were also considered in the development of the WaterFix EIR/EIS and screened out for lack of feasibility or public benefit. The next step for the state: Biological Opinions are planned to be finalized in early 2017, clearing the way for final environmental clearances, completion of other necessary agreements, and construction planned for initiation as soon as 2018.

GRA is an organization of diverse members that neither supports nor opposes the WaterFix. However, we recognize the need to address aging infrastructure and the need for the state to continue to move water south to help Groundwater Sustainability Agencies meet SGMA mandates, including but not limited to, reducing groundwater demands and increasing groundwater recharge.

2017–2018 Two-Year Session Legislative Calendar

- January 4th – Legislature reconvened
- February 17th – Last day to introduce bills
- June 2nd – Last day to pass bills out of house of origin
- September 15th – Last day for any bill to be passed
- October 15th – Last day for Governor to sign or veto bills passed by the Legislature on or before September 15 and in the Governor's possession after September 15.

New State Legislature Water Committee Chairs and Members

Senate Natural Resources and Water Committee – Robert Hertzberg (Chair), Stone (Vice Chair), Allen, Atkins, Hueso, Jackson, Monning, Stern and Vidak – Chief Consultant: Bill Craven. Principal Consultant: O'Connor.

Assembly Water, Parks, and Wildlife Committee – Eduardo Garcia (Chair), Gallagher (Vice Chair), Bigelow, Choi, Chu, Friedman, Gloria, Gomez, Harper, Levine, Mathis, Rubio, Salas, Thurmond, and Wood. Chief Consultant: Freeman.

GRA's Annual Legislative Symposium

March 29th at the Citizen Hotel Sacramento

Don't miss this event! Please see page 12 in this issue for registration and other information.

Continued on the following page…

SGMA Activities Update

The following provides an update and links for more information on State SGMA activities.

Best Management Practices (BMPs)

- Final BMPs posted on the DWR website
- Phase II BMPs may be developed subsequently
- Guidance Documents
  - Preparation Checklist for Submittal of GSP
  - GSP Annotated Outline
  - Establishing Sustainable Management Criteria (in development)
  - Engagement with Tribal Governments (in development)
  - Stakeholder Engagement and Communications (in development).

Basin Boundary Modifications Update

- Final basin boundary modifications were released – included in map online
- 54 requests were submitted – 39 approved, 12 denied, and 3 incomplete
- Basin Boundary Assessment Tool
- Basin Boundary Modification Request System.

Groundwater Sustainability Plans Regulations Update

- GSP Regulations Guide
- 24 Alternatives were submitted to DWR by January 1, 2017
- Article 6 Plan Evaluation criteria will be used to assess alternative plans functional equivalency of Alternatives
- Alternative Reporting system web portal available for public review.

Groundwater Sustainability Agency Formation Notifications (December 1)

- 133 separate GSA formation notices
  - 73 have overlap with another GSA in one or more basins that must be resolved by June 30, 2017
  - 50 GSAs are Exclusive GSAs in one or more basins
  - 11 GSAs have an active 90-day period in one or more basins
  - 4 in review.
- 82 basins have GSAs
  - 51 high or medium priory
  - 31 low or very low priority.
- 29 counties have GSAs
- New DWR portal being developed to coordinate formation of GSAs – webinar conducted January 26th and February 10th available at online webinar.

Water Available for Groundwater Replenishment Report

- DWR has drafted the Report available online at the WAFR website
- Focused largely on SWP and CVP deliveries, reliability and uncertainty, and includes WAFR estimates for all ten hydrologic planning areas
- Analysis done with WEAP model using 1977-2012 precipitation and runoff
- Provides information on diversion capacity, in-stream flow requirements and replenishment method (in-lieu or managed aquifer recharge)
- Public workshop scheduled January-February 2017, Final report mid-2017.

Prop 1 SGMA Funding

- $10M for Disadvantaged Communities (DACs)/ $90M for grants
- Counties with Stressed Basins $6.7M awarded in March 2016
- Next round anticipated for summer 2017 – $86.3M available—likely to be one round—10% to DACs and $76.3M to plans and projects, but no large projects
- Draft Proposal Solicitation Package (PSP) spring 2017; Final PSP summer 2017
- Award funding availability – late 2017 to early 2018.

Bulletin 118

- Interim Update 2016, including basin boundary modifications and critically overdrafted basins, available online
- Interim Update 2017 with revised basin prioritization available Fall 2017
- Update 2020 – comprehensive update.

California Water Commission Update

- California Water Action Plan 2016 Implementation Report – January 2017
- Overview of 2017 Activities
  - Commission's Strategic Plan Update
  - Coordination with DWR on Regulations, visits to State Water Project facilities, preparation for implementation of the Water Storage Investment Program.

Continued on the following page…

Governor's Budget

The Governor released his budget for fiscal year 2017–18 on Tuesday, January 10, 2017, and it includes a number of water- and groundwater-related items:

- Sustainable Groundwater Management Act Implementation:
  - DWR – An increase of $15 million General Fund for 29 existing positions for statewide technical assistance and to provide detailed information on basin-scale water use, water supplies, and groundwater conditions. Gathering data on a statewide level will be more efficient and provide greater consistency.
  - State Water Board – An increase of $2.3 million Water Rights Fund for 5 new positions and $1.5 million in contract funds to enforce reporting requirements and protect local groundwater resources beginning July 1, 2017 in high- or medium-priority groundwater basins that fail to form local governance structures as required by SGMA.
- Continued Effects of Drought – The budget includes an additional $178.7 million of one-time resources for 2017–18 to reflect current drought conditions and provide immediate response to drought impacts. The Administration will continue to monitor drought conditions through the 2017 rainy season.
- Emergency Drinking Water – The budget provides $5 million General Fund for DWR to provide emergency drinking water support for small communities by working to develop additional water supplies. Furthermore, the State Water Board will continue to address critical water-supply impacts of drought on small communities by funding the installation or deepening of wells, and where appropriate, requiring the consolidation of small failing water systems with functioning systems that are able to provide a safe and reliable supply.
- Water Investment Storage Program – An increase of $1.9 million in reimbursements, from the California Water Commission's allotment of $2.7 billion Proposition 1 water storage funding, for the Dept. of Fish and Wildlife to support initial outreach and technical review of the ecosystem benefits of water storage project proposals submitted to the Commission.
- Integrated Regional Water Management Program – An increase of $248 million Proposition 1 funding for DWR for integrated regional water management projects. This funding supports regionally driven multi-benefit projects that help meet the long-term water needs of the state, including assisting water infrastructure systems to adapt to climate change, encouraging collaboration in managing a region's water resources and setting regional priorities for water infrastructure, and improving regional water self-reliance.
- Irrigated Lands Regulatory Program – An increase of $1 million Waste Discharge Permit Fund and 5 new positions for the State Water Board, in coordination with the Department of Food and Agriculture, to address contamination of groundwater basins from agricultural practices.

Look for a revised budget to be issued by the Governor in May 2017.

GRA Legislative Efforts in 2017

GRA established itself at the Capitol as the only professional organization dedicated to groundwater in California by providing unbiased information and science to the Legislature to assist in the development of sound groundwater policies and laws. GRA is excited about implementing its 2017 Legislative Vision. This year, GRA looks forward to conducting some joint activities with CGC, and other activities. We will also be advocating the critical need for additional funding for groundwater infrastructure and projects in California, where groundwater provides 40% of supply in average years, and up to 65% or more in dry years; about 75% of the population relies, at least in part, on groundwater for supply; and groundwater is the sole source of supply for about 6 million people. We encourage volunteer participation on the Legislative Committee. Please consider joining us and helping to increase our influence at the Capitol. If interested, please contact Sarah Kline (skline@grac.org) for more information.

The Federal Corner

By Jamie Marincola, U.S. EPA

EPA Releases Sampling Guidance for Unknown Contaminants in Drinking Water and Guidance for Sampling and Field Testing During Water Contamination Incidents

EPA released an updated version of its *Sampling Guidance for Unknown Contaminants in Drinking Water*. The guidance provides procedures for conducting routine and baseline monitoring in response to a triggered event and sampling in support of remediation or decontamination efforts. The agency also released its *Guidance for Building Field Capabilities to Respond to Drinking Water Contamination* to aid drinking-water utilities in preparing for sampling and field testing that could occur during water contamination incidents. To learn more, visit here and here.

EPA Awards $12.7 Million to Assist Small Drinking-Water and Wastewater Systems

In January, U.S. EPA awarded $12.7 million in grants to help small drinking and wastewater systems and private well owners. Water systems staff will receive training and technical assistance to improve operations and management practices, promote system sustainability, and better protect public health and the environment. Grantees include the National Rural Water Association and the Rural Community Assistance Partnership to help small public water systems across the country achieve and maintain compliance with the Safe Drinking Water Act, and the University of North Carolina at Chapel Hill to improve the financial and managerial capabilities of small public water systems. Since 2009, EPA has provided $95 million in technical assistance grants to assist small drinking-water and wastewater systems, and private well owners. Go here for more information.

USGS Study: Changes in Rainfall, Temperature Expected to Transform Coastal Wetlands This Century

Sea-level rise isn't the only aspect of climate change expected to affect coastal wetlands; changes in rainfall and temperature are predicted to transform wetlands in the Gulf of Mexico and around the world within the century. These changes will take place regardless of sea-level rise, a new study from the US Geological Survey and the University of Texas Rio Grande Valley concludes. Click here for more information.

EPA Adds Subsurface Intrusion to the Superfund Hazard Ranking System

EPA has finalized a proposal to expand the hazards that qualify sites for the Superfund National Priorities List (NPL). EPA assesses sites using the Hazard Ranking System (HRS), which quantifies negative impacts to air, groundwater, surface water and soil. Sites receiving HRS scores above a specific threshold can be proposed for placement on the NPL. Subsurface intrusion is the migration of hazardous substances, pollutants or contaminants from contaminated groundwater or soil into an overlying building. Subsurface intrusion can result in people being exposed to harmful levels of hazardous substances, which can raise the lifetime risk of cancer or chronic disease. This modification only augments criteria for applying the HRS to sites being evaluated in the future. See this site for more information.

EPA Releases Protective Action Guide for Drinking Water Following a Radiological Incident

EPA released a non-regulatory Protective Action Guide (PAG) to help officials determine the best way to prevent the public from experiencing the harmful effects from radiation in drinking water during an emergency. The drinking water PAG are doses of radiation that should be avoided during an emergency event and can be used to determine when alternative drinking water should be provided, and when the use of contaminated water supplies should be restricted. To read about the new PAG, click here.

Jamie Marincola is an Environmental Engineer at the U.S. Environmental Protection Agency Region 9 Water Division. For more information on any of the above topics, please contact Jamie at 415-972-3520 or marincola.jamespaul@epa.gov.

Capture the Carbon

By Bart Simmons

Despite Donald Trump, climate change is happening, triggered by the rapid increase in CO_2 concentration in the atmosphere since the beginning of the Industrial Revolution. As the concern regarding climate change increases, the importance of carbon capture has risen. Political influences aside, the long-term effects of increased atmospheric CO_2 are serious, and solutions look promising. Some methods involve injecting CO_2 into abandoned coal mines, saline aquifers, or other material; however, leakage of the stored CO_2 is a major issue, and chemical reaction in situ has been demonstrated effective. Technologies to capture and sequester CO_2 include the following:

1. Post-combustion solvent scrubbing with amines, particularly alkanolamines and piperazine, has been investigated using a variety of empirical models
2. Ionic liquids may provide an alternative trapping solution; imidazolium salts, with various lengths of hydrocarbon side chains, show some promise based on Henry's law constants
3. Oxyfuel combustion, using recycled flue gas and oxygen, can produce high concentrations of CO_2, thus reducing the volume of gas to be captured
4. Chemical-Looping Combustion, increasing the efficiency of the oxidation process
5. Carbon mineralization, the focus of this article.

Carbon Mineralization

An often touted and debated issue is capture and mineralization of CO_2, particularly to offset emissions from coal combustion. Recent research (JM Matter, et al., Science, Vol 352, issue 6291) has provided some insight into the mineralization process and the viability of carbon capture.

Among the hurdles for carbon capture are: community acceptance, cost, long-term security, and CO_2 leakage. One popular mechanism for some of these factors is the conversion of CO_2 to carbonate minerals (mineral carbonization). One alternative for carbonization is the injection of CO_2 into basaltic rocks, which contain up to 25% by weight of calcium, magnesium, and iron. Basaltic rocks seem to be a good target for mineralization, since they constitute 10% of continental surface area and most of the subterranean ocean floor. The ocean floor off the Oregon Coast has a promising volume of basaltic minerals.

A pilot project for mineralization, called CarbFix, was conducted in Iceland. It treated two gas streams: pure CO_2, plus a mixture of CO_2 and H_2S; the CO_2 / H_2S mixture was injected to test the feasibility of injecting contaminated CO_2. A ^{14}C tracer plus SF_6 and SF_5CF_3 were used to determine the fate of the injected gases, which were injected at depths between 400 and 540 m. Results from monitoring ^{14}C and other tracers showed that >95% of the injected CO_2 was mineralized within 2 years. Precipitates were collected and found to be calcite ($CaCO_3$). Groundwater near the test sites was saturated with $CaCO_3$, showing that the storage of carbon is stable. Thus, the mineralization of CO_2 within two years was successfully demonstrated.

The chemistry of carbon capture is feasible, and will likely be widely utilized outside the U.S. Economics and politics will now determine whether it is used in the U.S. as well.

Bart can be reached at bartonps@aol.com.

Promote Groundwater Stewardship on National Groundwater Awareness Week: March 5-11

National Groundwater Awareness Week will take place March 5–11, 2017, and the National Ground Water Association (NGWA) would like to invite your organization to be a "Groundwater Advocate."

This is a time when NGWA and its partners educate the public about the resource of groundwater, its importance to public health, quality of living, and the environment. For those who rely on groundwater from a household water well, it also is a time to help them learn how to take care of their water-well system.

Being a Groundwater Advocate is easy. Just commit as an organization to promote groundwater awareness in connection with Groundwater Awareness Week—just how is up to you. Then ask to be an Advocate in an email to NGWA Director of General Public Outreach Cliff Treyens, and you will be listed as a Groundwater Advocate on our webpage.

NGWA encourages you to adapt your messaging to meet whatever your specific priorities are or, if you find it more convenient, simply use the tools and messaging we've provided. Organizations supporting Groundwater Awareness Week range from government agencies at the federal, state, and local levels to public health interests, environmental concerns, and agricultural groups.

Feel free to use the following resources. Some can be used as is; others can be adapted, modified, or customized to your state or locale:

- Groundwater Awareness Week landing page and infographics [Right click on image and "Save picture as;" then insert the Groundwater Awareness Week web address as a hyperlink into the image and share)
- Groundwater is Cool video
- Groundwater Awareness Week logos (click on link, then right-click on logo and "Save as")
- Flier
- Poster
- Well owner videos
- Groundwater Careers video
- State groundwater use data
- NGWA educator resources
- Groundwater Adventurers for Kids
- Well owner information sheets
- WellOwner.org.

NGWA encourages you to take advantage of National Groundwater Awareness Week to serve the public!

GRA Requests Nominations for the 2017 "Lifetime Achievement" and "Kevin J. Neese" Awards

The purpose of the GRA Awards Program is to recognize noteworthy projects and exceptional individual contributions related to the understanding, protection, and management of groundwater resources. The objectives of the annual Awards Program are:

1. To provide recognition to individuals who have demonstrated leadership and continuous dedication in groundwater hydrology
2. To provide recognition for recent unique contributions to groundwater hydrology.

All nominations for the Lifetime Achievement and Kevin J. Neese Awards must be received by David W. Abbott (dabbottgw@gmail.com or 607 Chetwood Street, Oakland, CA 94610-1433) no later than **Friday, June 23, 2017**.

Nominations should be completed using the nomination forms available on the GRA website at https://www.grac.org/forms/nomination/. Nominations should not exceed one page, identify the award for which the nomination is made, and include justification for the award based on the criteria listed below.

The GRA Awards will be presented to the recipients selected by the GRA Board of Directors during the 26th GRA Annual Meeting in Sacramento, CA, October 3–4, 2017.

Awards

Lifetime Achievement: presented to individuals for their exemplary contributions to the groundwater industry, and contributions that have been in the spirit of GRA's mission and organization objectives. Individuals that receive the Lifetime Achievement Award have dedicated their lives to the groundwater industry and have been pioneers in their field of expertise.

Previous Lifetime Achievement Award recipients include:

2016 – Dr. Miguel A. Mariño (1940 - 2016)

2015 – Dr. John A. Izbicki

2014 – Dr. David Huntley (1950 – 2015)

2013 – Dr. Shlomo P. Neuman

2012 – Anne J. Schneider, Esq. (1947 – 2010)

2011 – Joseph C. Scalmanini, P.E. (1945 – 2014)

2010 – Dr. John A. Cherry

2009 – Dr. T.N. Narasimhan, P.G. (1935 – 2011)

2008 – Dr. Perry L. McCarty

2007 – Dr. Herman Bouwer (1927-2013)

2006 – Glenn A. Brown, PG, CEG (1924 – 2015)

2005 – Dr. Luna B Leopold, P.G. (1915 – 2006)

2004 – Dr. John D. Bredehoeft

2003 – Rita Schmidt Sudman

2002 – Thomas W. Dibblee, Jr., PG (1911 – 2004)

2001 – Carl J. Hauge, P.G., CEG

2000 – Dr. Joseph H. Birman, PG, Gp, CEG, CHg (1924 – 2015)

1999 – Dr. David Keith Todd, P.E. (1923 – 2006)

1998 – Eugene E. Luhdorff, Jr., P.E. (1930 – 2010)

Kevin J. Neese: recognizes a recent significant accomplishment by a person or entity that fosters the understanding, development, protection, or management of groundwater.

Previous Kevin J. Neese Award recipients include:

2015 – California Department of Water Resources for its significant contributions to local agencies to advance groundwater planning, management, and conjunctive use with Regional Partnerships, Integrated Regional Water Management, and Drought Grant programs

2014 – Governor Edmund "Jerry" G. Brown for his leadership in developing sustainable groundwater management legislation and shepherding it through the legislative process

2013 – Santa Clara Valley Water District for its implementing its unique Domestic Well Testing Program

2012 – David L. Orth, General Manager of the Kings River Conservation District for his leadership and dedication to the collaborative initiatives to develop the Upper Kings River Basin Integrated Regional Water Management Plan

2011 – Sacramento County Environmental Management Department for its Abandoned Well program, the first of its kind in California

2010 – Senator Fran Pavley for her leadership in the enactment of the comprehensive, statewide groundwater level monitoring legislation in California

2009 – U.S. Geological Survey, California Water Science Center for its development of a new 3-dimensional groundwater-modeling tool for California's Central Valley and report "Groundwater Availability of the Central Valley Aquifer," Professional Paper 1766

2008 – Orange County Water District for its Groundwater Replenishment System (GRS), a new water purification plant that became operational last January

2007 – University of California Cooperative Extension Groundwater Hydrology Program for its efforts to engage scientists, regulators, farm advisors, dairy industry representatives, and dairy farmers to better understand the effects of dairy operations on water quality

2006 – Senator Sheila Kuehl for her work to improve the production and availability of information about California's groundwater resources

2004 – California Department of Water Resources for its publication in 2003 of its updated Bulletin 118: "California's Groundwater"

2002 – Glenn County Water Advisory Committee for its formulating a significant groundwater management ordinance that was adopted by the Glenn County Board of Supervisors

2001 – American River Basin Cooperating Agencies and Sacramento Groundwater Authority Partnership for fostering the understanding and development of a cooperative approach to regional planning, protection and management of groundwater

2000 – Board of Directors of the Chino Basin Watermaster for delivering a remarkable OBMP that created a consensus-based approach for making water supplies in the Chino Basin more reliable and cost effective

1999 – Governor Gray Davis for his work and leadership in addressing MTBE.

The Groundwater Visibility Initiative

By Brett Wyckoff, GRA Director

In April 2016, the National Groundwater Association (NGWA) and the American Water Resources Association (AWRA) held a workshop attended by 25 water experts from the United States and Canada. The purpose of the workshop was to launch a Groundwater Visibility Initiative (GVI). The objective of the workshop was to discuss the best way to elevate groundwater's status in the international discourse on water policy, governance, and management by developing recommendations for action.

The attendees articulated ways to better integrate groundwater into existing or planned water resources management, and incorporate it into policies for agriculture, energy, environment, land-use planning, and urban development. The findings of this collaboration were summarized in a 5-page report, *The Groundwater Visibility Initiative: Integrating Groundwater and Surface Water Management*. The primary authors of the report are William Alley, Lisa Beutler, Michael Campana, Sharon Megdal, and John Tracy.

Key concepts described in the report include:

1. Achieving groundwater sustainability requires societal decisions made through informed and transparent public participation. The concept of groundwater governance focuses on promoting responsible collective action, and is an important part of resilient aquifer management. Governance efforts require collaboration by multidisciplinary teams providing expertise to address problems encountered through governance efforts. Communication is critical to remove misperceptions about the connectivity between surface water and groundwater.
2. Better data acquisition and archiving of water withdrawals and consumptive use are needed for both groundwater and surface-water management. Aquifers vary in structure and properties affecting both storage and flow rates. Also, water budgets rely on good accounting of hydraulic inputs and outputs. Monitoring for the purpose of understanding trends in groundwater quality and quantity is necessary, and needs to be conducted at the appropriate spatial and time scales. Groundwater data collection and analyses should be transparent.
3. Improvement is needed on the understanding of the climate impacts on supply and demand for groundwater and its interaction with surface water. Groundwater and surface-water interactions can have long lag times for observable system responses; these need to be understood and accommodated in water management.
4. Groundwater and surface-water management must include planning and investment with respect to infrastructure rehabilitation and maintenance.
5. Diverse integrated water-management portfolios need effective groundwater management to provide adaptivity and resiliency to drought and climate change.
6. Groundwater planning and management need to be integrated across agriculture, energy, environment, land-use planning, and urban development sectors. Water issues may cross multiple sectors where mutually beneficial management decisions can be found. Water managers should consider innovative ways of education and outreach to the agricultural sector.

The report concludes with a *call to action* for additional recommended measures to promote the GVI and increase groundwater's visibility in scientific, management, and policy dialogues. These actions include:

1. Encourage fellow professionals to present the GVI to their respective professional societies for possible adoption and other actions
2. Present the GVI to non-professional groups
3. Build a coalition with other professional societies and similar organizations to support the GVI
4. Distribute the GVI statement to members of Congress, appropriate state and local political leaders, and agency personnel, and discuss the GVI with them
5. Give presentations and convene sessions on GVI-related topics at state, regional, national, and international meetings
6. Write Op-Ed columns and articles in print and other media; engage journalists
7. Produce journal articles on the GVI topics.

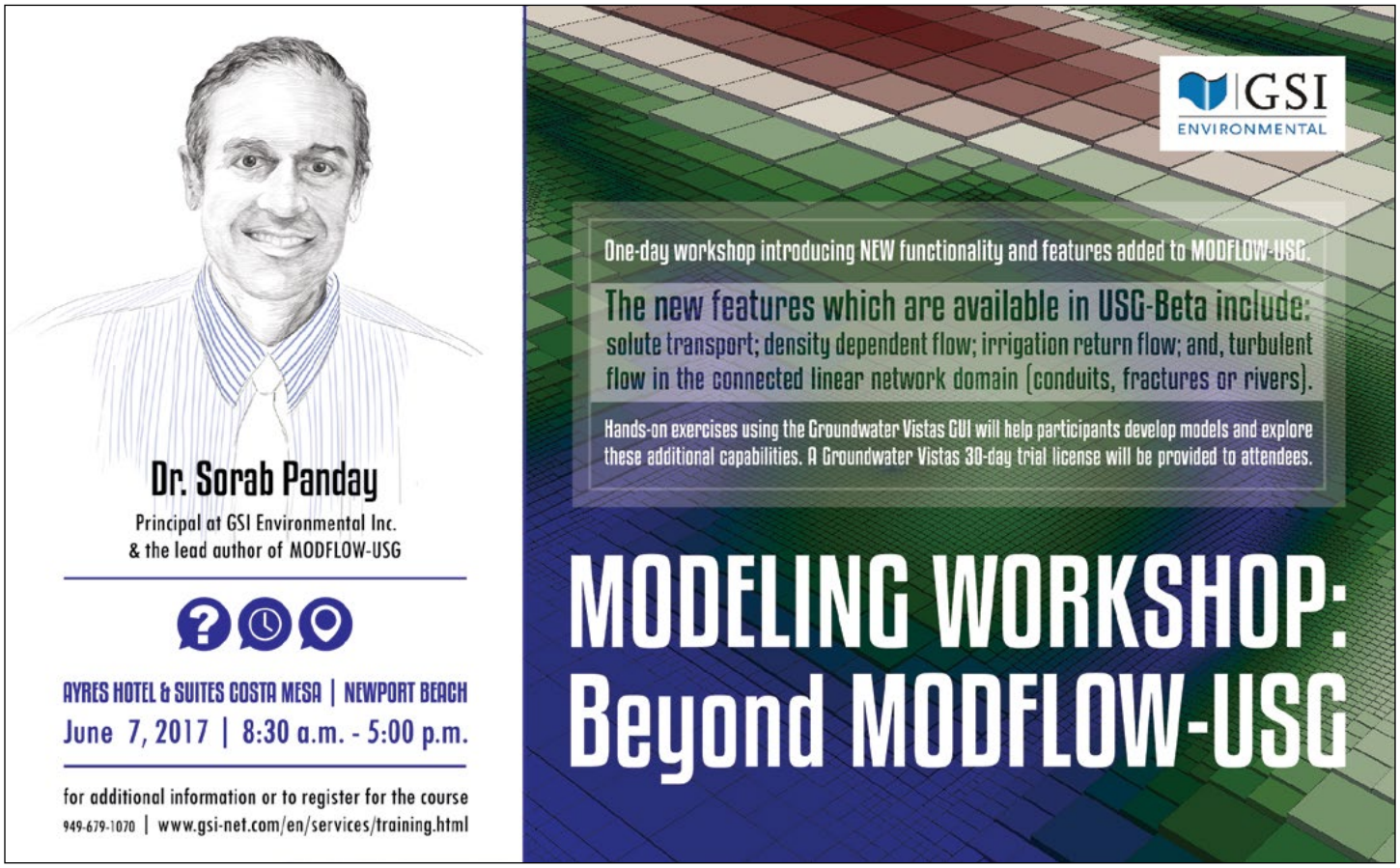
Continued on the following page…

The Groundwater Resources Association of California joins the NGWA, AWRA, International Association of Hydrogeologists, and other organizations, in support of the Groundwater Visibility Initiative. GRA's mission is dedication to resource management that protects and improves groundwater supply and quality through education and technical leadership. The Groundwater Visibility Initiative is consistent with GRA's mission, and GRA will continue to raise the *visibility* of groundwater through its events, workshops, legislative efforts, and other activities. GRA members and the public have the opportunity to learn about groundwater management and the GVI by:

- Attending one of GRA's many groundwater-themed symposia and conferences
- Attending GRA groundwater-related webinars ("GRACasts")
- Attending a local GRA Branch meeting
- Reading GRA's quarterly publication, *HydroVisions*.

Let's all do our part to make groundwater visible to everyone!

Click here for the full GVI report.



GRA Welcomes the Following New Members

12/1/2016 – 2/21/2017

Ryan Waterman
Wendy Nwosu
Dwight Smith
Charles Blanchard
Candace Jantzen-Marson
Jeevan jayakody
Paul F. Bertucci
Mitchell Partovi
Melanie Lindsey
Terrance Topits
Guadalupe Rivera
Robert Ennis
Justin Nakano
Peter Kavounas
Edgar Tellez Foster
Greg Sherman
Michael Pantell
Bill Leever
Randall Holmes
Mo Tangestani
Andrew Francis
Morteza Naraghi
Madelaine Montilla
Paige Tripp
Gerard Aarons
Ailco Wolf
Avery Whitmarsh
Gwendoline Caviness
Chris Baker
Autumn DeWoody
Mary Fahey
Marcus Mendiola
Deborah Hathaway
Michael Campana
Dave Veratti
Danny Ramsey
Rodney Mann
Mike Montag
Scott McLaughlin
Todd Miller
Darcelle Pruitt
Bill Chen
Travis Wicks
Maulik Bavishi
Taylor Barrett
Alexi Snyder
Elizabeth Hightower
Joshua Harrington
Claudia Mack
James Schwartz
Michael Ward
Craig Altare
Kelley Capone
Ryan Beane
David Brown
Maria Lorca
Barbara Rudnick
Sara Harper
Nick Colley
Matt Naftaly
Cab Esposito

Dates & Details

GRA EVENTS & KEY DATES

(Please visit www.grac.org for detailed information, updates and registration unless noted)

2017 Legislative Symposium
March 29, 2017 | Sacramento, CA

SGMA Conference
Tools for Developing A GSP
May 3-4, 2017 | Sacramento, CA

2017 Conference and 26th Annual Meeting
October 3-4, 2017 | Sacramento, CA

For information on how to sponsor or exhibit at an upcoming event, please contact Sarah Kline at skline@grac.org.

Thank You to Our 2017 Contributors

PATRON ($500-$999)
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Darren Scott Dressler
Eric Reichard
Sorab Panday
Paul Bertucci
Brett Wyckoff
Kevin Brown
Thomas Harter

SUPPORTERS
Gabrielle Boisrame
Aaron Cuthbertson
Ryan Fay
Claire Wilkin
Jared Wilson
Stephanie Uriostegui

CENTRAL COAST

By Bryan Bondy, Branch Secretary

On December 6, 2016, the Central Coast Branch was excited to have **Dr. Jason Sun** and **John Lindquist**, of United Water Conservation District (UWCD), who presented *Vertical Flow, Faults, and MODFLOW – Groundwater Model Development for the Oxnard Coastal Plain*. They provided a clear explanation of UWCD's development of a groundwater flow model of the Oxnard Plain Subbasin, Pleasant Valley Basin, and Mound basins in Ventura County, California. A key aspect of the model development was careful delineation of the hydrostratigraphy and structural geology of the basins, which includes as many as 13 principal hydrostratigraphic units: 7 aquifers and 6 aquitards. The model treats all 7 aquifers and 6 aquitards as individual model layers to allow for comprehensive evaluation of inter-aquifer flows. The hydrostratigraphic model was developed based on 309 e-logs that were used to create dozens of fence diagrams and, ultimately, a 3-dimensional hydrostratigraphic model. The groundwater model was calibrated over the historical time period January 1985 to December 2012 and was verified using the period January 2013 to December 2015. Dr. Sun and Mr. Lindquist focused their discussions on the model development and calibration process. The model was constructed using MODFLOW 2005 with the Newton Solver. The speakers explained the challenges experienced during calibration and some of the lessons learned. Particular emphasis was placed on revisiting the hydrostratigraphic model during calibration when the model results indicated that something was wrong. This iterative process has resulted in increased confidence in both the hydrostratigraphic and numerical models. The model will be used by UWCD to evaluate travel times and distances for recharge of recycled water, and to evaluate impacts on groundwater supply resulting from a range of potential future operational scenarios for surface-water diversions from the Santa Clara River.

Our Branch members very much enjoyed Dr. Sun and Mr. Lindquist's presentation. The meeting was very well attended.

SOUTHERN CALIFORNIA

By Herbert (Bert) Vogler, Branch Secretary

The Southern California Branch, focusing on Los Angeles and Orange Counties, had only limited activities in 2016, but we are gearing up for 2017 with a new group of officers to be confirmed at the first meeting of 2017.

For spring 2017, the Branch is presently scheduling two dinner meetings. One is to include a presentation about the Flint, Michigan water-supply issues, and the other is to include GRA's Southern California David Keith Todd Distinguished Lecturer for this year, Dr. Claudia Faunt of the USGS.

As always, the Branch thanks all GRA Members and others who participate in the Southern California Branch.

SACRAMENTO

By David Von Aspern, Branch Secretary

The Sacramento Branch is off to a productive start in 2017! A new slate of Branch Officers was voted on, is in place, and they held their first Officer's Meeting of the new year. The first several months of 2017 Branch Meeting speakers are confirmed. The Branch will continue to meet in Sacramento at the Aviators restaurant, and will hold one or two meetings at other locations, such as the annual on-campus meeting at Sac State (held each spring). The long-standing tradition of a joint Holiday meeting with the Sacramento Section of the Association of Environmental & Engineering Geologists continued last December, and included a voluntary gift exchange among company and individual donors.

Under the chipper leadership of new Branch President Linda Bond, of DWR, a member survey was recently completed. The members' responses were numerous (at least 50 as of this writing!), and were varied and detailed. Perhaps the high-quality responses are not surprising knowing the passion and dedication to their respective fields of practice displayed by so many GRA members! The Branch Officers have already preliminarily reviewed the survey responses, with in-depth considerations to follow. Rest assured the Branch Officers are strongly committed to pursuing as many of the suggested speakers and/or topics as we possibly can. The Branch remains fiscally solid, which allows us to help offset any costs of bringing in quality speakers. Most speakers give freely of their time, but those who travel nationally sometimes request travel assistance. The Branch Officers at their first 2017 meeting certainly sense that nearly everyone is busy in their jobs, often doing 'more with less,' and we are all expecting the new year to be prosperous.

From Linda D. Bond, Branch President

Recent Activities: Election of New Officers

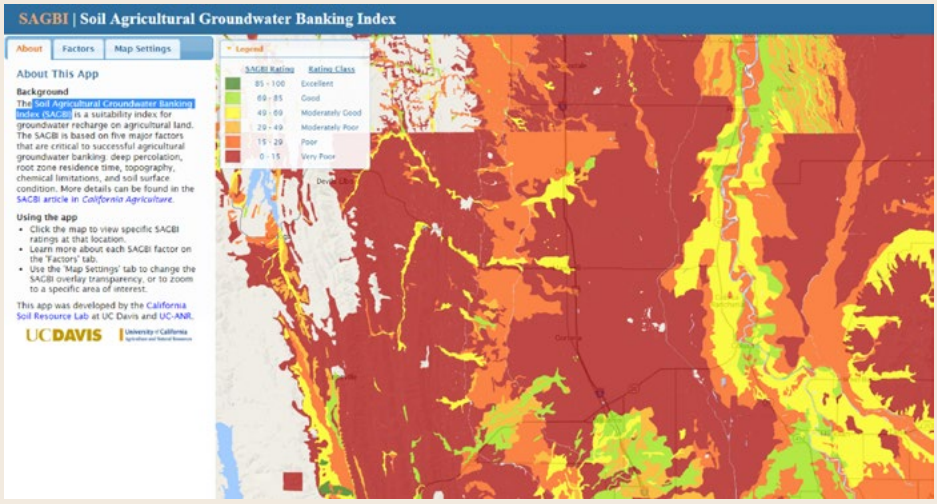
- President, Linda Bond
- Vice President, Ellen Pyatt
- Treasurer, Rodney Fricke
- Secretary, David Von Aspern
- Members at Large: Scott Furnas, Kent Parish, Pat Dunn, Chris Bonds, and Hugh Klein.

Accomplishments

- Treasurer's report: 9-year report on meeting attendance and revenues, costs, and scholarship funding
- Successful member survey – issues of concern: topics and speakers for 2017.

Future Activities: Upcoming Sacramento Branch Meeting Speakers

- February 8: Mr. Larry Ernst, Wood Rodgers – Vertical Flow in Wells
- March 8: Dr. Helen Dahlke, UC Davis – Soil Agricultural Groundwater Banking Index (SAGBI) and On Farm Flooding Research
- April 17 (Monday): Dr. Rosemary Knight, Stanford University – The Use of Geophysical Methods for Groundwater Evaluation and Management (2017 Northern CA David Keith Todd Distinguished Lecturer)
- May 10: Mr. Rick Cramer, Burns & McDonnell – Why Focus on the Geology – Understanding Fluid Migration in the Subsurface.



The Parting Shot

In The *Winemaker's Dance – Exploring Terroir in the Napa Valley* (University of California Press, 2004), Jonathan Swinchatt and David G. Howell refer to terroir as all the qualities that characterize place: topography, bedrock, sediments and soils, temperature, and rainfall. Some wine writers and professionals include viticultural practices, and others recognize the impact of both winegrower and winemaker. The authors also recount a story by the late geologist/winemaker David Jones while standing on a ridgetop above the Napa Valley, "What you're tasting in a bottle of wine is a hundred million years of geologic history."

This photograph was taken at the Harlan Estate vineyard in the western hills of the Oakville American Viticultural Area (AVA), in the middle of the Napa Valley. The pictured vineyard is underlain by 9- to 3-million-year-old rhyolite and thin residual soils of the Sonoma Volcanics. This regional volcanism was associated with the so-called "crustal slab window," when subduction of the Farallon Plate was replaced by sliding motion between the North American and Pacific Plates along the San Andreas Fault system.

In contrast to the Napa Valley floor, where plant roots easily penetrate the unconsolidated sediments, Harlan's vineyards on the slopes of the Mayacamas Mountains commonly take root in less than a foot of soil before penetrating bedrock along cracks and fissures. The well-drained soil and fractured bedrock forces the vine roots to struggle for both space and moisture, a stress that many winegrowers believe benefits the character and quality of the grapes.

This photograph was taken during a Northern California Geological Society (NCGS) field trip to the Harlan Estate in February 2016 by John Karachewski, Ph.D.