Toward Sustainable Groundwater in Agriculture: Linking Science and Policy

2nd International Conference
June 28-30, 2016 in Burlingame, California

Contributed by Thomas Harter and Session Moderators David Hyndman, Karen Villholth, Karen R Burow, Dico Fraters, Paul Pavelic, Vicki Kretsinger Grabert, Jay Famiglietti, Timothy Parker, Debra Perrone, Rob Gailey, Helen Dahlke, Graham Fogg, David Rudolph, Chris Green, Mary Scruggs, Bernadette Conant, Bill Alley, and Gus Tolley; edited by Leigh Bernacchi, UC Water

For three days, 300 attendees embodied the subject of groundwater by going underground in the Hyatt San Francisco Airport conference center. This unique conference at the intersections of science and policy, groundwater and agriculture, water quality, and water supply brought together people from over 30 countries and six continents.

Groundwater is the lifeline for many rural and agricultural regions around the world. The conference created an opportunity for researchers and practitioners from a variety of agricultural and political systems to share their similar challenges, such as declining water tables, deteriorating water quality, and solutions, such as long-term monitoring and creative engineering.

The meeting was a much needed expansion of the 2010 version of this conference. Presentations were expanded to four parallel tracks, and each of the three days was opened with a 2-hour plenary session. A luncheon keynote was given on the first day, and poster sessions were held on two evenings. The conference closed with a high-caliber closing panel reflecting on the challenges and opportunities. If you missed the conference—or even if you were there, but missed seeing the other tracks—presentations and videos of more than half the presentations will be publicly available by early September 2016 at the conference website, ag-groundwater.org.

Plenary Session 1 – California Perspective: Agriculture at a Crossroads to Groundwater Sustainability?

Opening Remarks and Moderator: Glenda Humiston

California agriculture's large economic size and importance hangs in balance with the groundwater supplements to surface-water deliveries, especially during ongoing drought. Adapting to the state's new Sustainable Groundwater Management Act (SGMA, pronounced "sigma") became a de facto theme of the conference overall, and the importance of agriculture to successful implementation of SGMA was highlighted throughout. University of California Division of Agriculture and Natural Resources (UCANR) supports the agricultural industry and communities with resources for innovation and learning. Secretary of Food and Agriculture **Karen Ross** emphasized that scientists and policy makers need to work together to address the challenges at the agriculture-groundwater nexus, saying "the magic comes when the right decisions are made to make the right changes." Undersecretary **Gordon Burns** of the California Environmental Protection Agency cautioned against blaming farmers for groundwater overdraft and pollution, because they have followed the rules in place and are guided by sound economic decision making. The new policy was needed to avoid the "tragedy of the commons." **Parry Klassen**, lead of the Eastern San Joaquin Valley Agricultural Water Quality Coali-

Continued on the following page…

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Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

tion provided a grower's perspective on nutrient management and the pressures to get it right. In the implementation of the irrigated lands regulatory program, the credibility of the farmer with the regulatory agency and the public is at stake. A large joint effort between university cooperative extension, commodity groups, agricultural coalition, and others is needed to make the necessary improvements at the farm level.

Plenary Session 2 – Toward Sustainable Agriculture: Global Perspectives

Moderator: Thomas Harter

How much groundwater do we have in the world? **Petra Doell** described a long-term effort to build a global water model and assess the uncertainties inherent in the data supporting such a global model. Model results impressively demonstrate groundwater use in agriculture, agriculture as a proportion of total groundwater use, recharge, and the impact of groundwater pumping on streamflow—all in global maps! **Karen Villholth** took this global assessment one step further, showing that 7% of global irrigated food production (15% of groundwater-irrigated food production) depends on overdrafting groundwater. Urgent attention is needed to address our reliance on unsustainable groundwater for an increasing fraction of global food production. Ms. Villholth suggested that broader global food policies and interventions in developing and developed countries are needed. To answer this call, the United States Geological Survey is designing metrics to allow for a rigorous assessment of sustainability. **Ken Belitz** described an example of such metrics, involving properly designed monitoring networks across the country to identify trends and spatial patterns in water quality. Ultimately, it is the action of individual farmers that will bring about sustainability. **Gabriele Ludwig** summarized stepping stones to bring about such changes in practice, using the almond industry as an example. Her presentation highlighted the need for leadership, development of better tools for growers to manage their practices, and the need for tools to be accessible.

Plenary Session 3 – Stepping Toward Sustainable Groundwater in Agriculture

Moderator: David Rudolph

The third day's opening session was a forward-looking spotlight on national and global sustainable groundwater management efforts. The USDA is actively engaging on groundwater-related issues at many different angles and levels, from the federal policy arena to financial support for farmers and scientists, as outlined by USDA Deputy Undersecretary **Ann Mills**. **Guillaume Gruère** from the OECD outlined a recent study surveying groundwater management efforts across the developed world, concluding that modeling tools are increasingly part of informing policy and implementation. At the groundwater-agriculture nexus, regional and global models are complex as they integrate groundwater/water/climate systems with cropping/farmer systems. **David Hyndman** provided a cutting-edge example of efforts covering the central US. Yet, even with much information available, policies are counterproductive or forcing scientists to reassess within policy limitations. **Anker Hojberg** from Denmark illustrated this point for Danish nitrate policy, which over the past 30 years of EU nitrate policy has fluctuated in its design. According to Hojberg, policy mayhem can spur good science; and good science, including advanced science and modeling, are beneficial to designing policy.

Continued on the following page…

Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

Plenary Session 4 – Toward Sustainable Groundwater in Agriculture: Challenges, Observations, and Key Outcomes

Moderator: Bernadette Conant

In the closing plenary, panelists and conference participants alike reflected on how the agriculture-groundwater nexus has changed since the last international meeting, our current knowledge, and what the future might hold. The breadth of the conference discussions embraced and explored industry, socio-political, economic, environmental and ethical views, in addition to the more conventional "hard science" perspective.

As is often said, "it really doesn't matter how right you are if nobody believes you." This concept was underlined by many speakers: effective communication of what is important depends upon trusted relationships. Encouragingly, the conference's diverse community has built tremendous trust equity in the area of groundwater management. The future will depend on the ability of this community to effectively engage those around them.

The overarching theme of the closing discussion was the fundamental importance of getting the narrative right and being strategic in seizing opportunities, like the California drought, to effectively deliver messages aimed toward avoiding bigger future crises. As Australian **Cameron Holley** reminded us, "Keep water on the agenda—once it starts to rain, people forget."

Nitrate Policy

Moderators: Dico Fraters and Vicki Kretsinger

We discussed current and new policy case studies to abate nitrate pollution of groundwater, especially drinking water resources, in the USA, Europe, and New Zealand. In the Netherlands, groundwater quality in natural areas improved after prescribing low-emission application techniques for manure and other measures to reduce ammonia emissions—A provincial authority, a drinking-water company, and farmers are successfully cooperating to decrease nitrate concentrations. Also, in Washington State (USA), drinking-water resources are threatened by agriculturally-derived nitrate, but the contribution from legacy activities versus current agricultural activities is a subject of ongoing debate in the affected, mostly agricultural, communities.

A comparison was presented of two very different communities having faced challenges at the local level. An experiment in New Zealand showed the sometimes simple measures at farm level (e.g., using variable-rate irrigation instead of uniform spray) that can reduce water pollution and consumption. Secondly, the Danish Mitigation Assessment shows that different strategies—consumer driven, integrated practice, and policy solutions—are needed to achieve nitrogen source control and mitigation of the unintended consequences of excess nitrogen, including discussion of the human (over-) consumption of animal-based proteins.

Globally, water resources are becoming scarcer, and approaches to sustaining the quantity and quality of our resources are becoming more pressing. Challenges include determining what is considered an equitable allocation of water and land. Nitrate-impaired groundwater has occurred through the actions and interests of many. To improve groundwater conditions and attain safe drinking water requires:

1. Identification of vulnerable groundwater areas
2. Engagement in decision-making discussions
3. Effort from all dischargers toward reasonable progress.

In terms of agricultural discharge, growers are broadly engaged in establishing management practices that are protective of water quality. These practices include field-level planning to evaluate nitrogen application and to reduce residual nitrogen load. Comprehensive efforts are being undertaken to characterize impaired drinking water in irrigated agricultural areas and inform well users and growers of severe nitrate impacts to groundwater in some areas, but significantly reducing nitrate load and ensuring safe drinking water for communities will take a long time.

Nitrogen Losses to Groundwater and Attenuation

Moderator: Karen Burow

These sessions featured a global perspective on groundwater-quality risks and opportunities:

- In the UK, many areas may not have seen peak loading of nitrate in groundwater yet. A study based on groundwater age indicated that much nitrate resides in the vadose zone and has not yet arrived at the water table.
- In Australia, agricultural production has contributed to a decline in water quality entering the Great Barrier Reef lagoon from riverine discharge. Interestingly, the groundwater does not contain elevated nitrate concentrations, but further information is needed on flow paths and the role of denitrification.
- In Canada, the Root Zone Water Quality model (RZWQM) was used in a field-scale study to complete a nitrogen mass balance under a potato field. Plant uptake is the most important process, followed by leaching, with all other losses being insignificant in removing nitrogen from soil.

Continued on the following page…

Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

- A data-driven estimation of nitrate transport and reactions was done for 14 sites across the US using a vertical flux model (VFM). The VFM is a relatively simple way to obtain a close match with regional observations when applied with spatially varying parameters.
- In California, leaching of nitrogen to groundwater accounts for roughly 16% of total N imports, with about 90% of the nitrate originating from crop and livestock production. Among possible policy approaches to mitigation, nitrogen may be a good candidate to pioneer the next generation of integrated environmental policies and streamlined regulatory approaches.
- Two regional studies in the San Joaquin Valley, CA were described. One researcher demonstrated the use of isotopes and iodine, and a Bayesian mixing model, to estimate the relative contribution of fertilizer, natural, manure, and septic sources of N to groundwater. Septic was a significant contributor overall, whereas manure was more variable. Nitrate, uranium, and arsenic are of concern for domestic well-water quality, with nitrate exceeding the MCL in 44% of the wells, uranium in 17%, and arsenic in 11%. Cluster analysis indicated that young water was associated with nitrate and/or uranium. Arsenic was associated with old water.
- There are two web-based mapping tools for water quality assessment based on more than 25 years of data. The Wisconsin Statewide Well Water Quality mapper, shows that 10% of samples exceeded the MCL for nitrate. Wells located in agricultural regions and in sand and gravel aquifers or shallow carbonate rock aquifers are particularly vulnerable to nitrate. The USGS National Water Quality Assessment program has been sampling national groundwater monitoring networks to evaluate changes in water quality on a decadal scale. Users of the mapping tool see statistical results for groundwater networks for 24 constituents, including agricultural contaminants, such as nitrate, phosphorus, and several pesticide compounds.

Nonpoint Source Pollution in Animal Farming

Moderator: David Rudolph

This session focused on the unique conditions associated with nutrient management within livestock operations. Researchers provided excellent field examples of emerging geochemical fingerprinting tools that can be used to distinguish mineral and animal nitrogen sources, particularly useful among mixed-farming operations. The research also indicated that long-term data sets are mandatory in order to determine trends in water quality associated with given agricultural land-use management systems. One researcher incorporated natural hydrological systems, irrigation, and enhanced drainage systems to evaluate the combined impact of manure storage facilities, regional land application of manure, and other by-products of livestock operations.

Emerging Contaminants and Nitrate Monitoring and Modeling

Moderator: Chris Green

Water quality is affected by many local environmental and human-caused sources. These sessions revealed new ways of tracking contamination and bringing science and management together in innovative ways:

- Uranium concentrations in US groundwater are greatest in arid regions and are increasing most rapidly in irrigated arid areas
- The RAMP tool allows for practical and efficient evaluation of risks associated with pesticide contamination of groundwater
- Microbial indicators were reduced in a controlled drainage system relative to free drainage, whereas antibiotics were not significantly different
- A screening of more than 50 products in the Baix Fluvià aquifer of northeast Spain found only six antibiotics; spatial distributions were not completely linked to the hydrogeological dynamics
- Natural attenuation has potential to mitigate a variety of emerging contaminants, and biomolecular tools are key to understanding and predicting biodegradation
- In early-warning monitoring systems to protect Netherlands groundwater, multiple sampling methods led to varying estimates and lively debate in the agrarian, scientific, and political arenas
- Use of statistics in California helped prioritize sub-regions for management by estimating groundwater vulnerability to nitrate contamination; statistical-learning methods for estimating nitrate distributions mitigated the tendency of machine-learning models to overfit predictions to observations
- Developments to improve nitrate monitoring include optimization of the sampling domain, time-averaged concentration samplers, distributed chemical sensors, and smartphone-based measurements
- Nitrate monitoring programs in Denmark found that cost-efficient and knowledge-based management of groundwater protection requires mapping, modeling, and monitoring of the effectiveness of actions taken.

Continued on the following page…

Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

Climate Change Adaptation

Moderator: Graham Fogg

Climate change requires adapting to more extreme wet and dry periods, challenging both water supply and allocation policy and planning. This session explored economic aspects of water management reform and innovative ways of enhancing irrigation water supply through California's bottom-up and Australia's top-down approaches. A provocative talk on economic perspectives of California's SGMA suggested economic costs of *not* exploiting groundwater resources to their fullest use—at non-sustainable rates in overdrafted basins—had not been taken into account with SGMA. On the other hand, by analyzing Australian groundwater markets and law, researchers identified shortcomings that include impediments to optimal trading and deficiencies in market regulation. This led to a lively discussion that continued in an impromptu panel discussion, culminating in a consensus that although SGMA is necessary, a fuller economic analysis of its consequences would be beneficial.

Turning to water supply, a modeling and field study in the Netherlands pursued the use of treated industrial and domestic wastewater for irrigation, accomplished through subirrigation techniques. Results quantify the amount of water that could be made available and benefits with respect to soil moisture and reduction in demand for above-ground irrigation. Lastly, trends in drought and their effects on grain yields in China were analyzed over the last half-century. Interestingly, the frequencies and intensities of extreme droughts were found to increase in most areas of China while groundwater levels decreased, attributed to increased irrigation demand.

Irrigation and Sustainability

Moderator: Helen Dahlke

Using examples from around the world (India, Canada, the Great Lakes region, California and the northern Midwest), presenters focused on the interrelationships between irrigation consumption and groundwater use. All presentations raised questions about:

- reliably estimating the effect of agricultural water use on groundwater storage
- achieving better groundwater management, particularly in preparation for increased drought occurrence.

Groundwater-management regulation of pumping, streamflow depletion, and ecosystem function as means to reduce undesirable effects was debated. Researchers argued that science needs to better estimate irrigation consumption and groundwater pumping effects on surface-water/groundwater interactions. Toward that end, the concept of field kites provides a better estimate of yield per unit of water used, potentially leading to widespread improvements in water-use efficiency. Necessity is the mother of conservation: In California, where local surface-water supply does not meet irrigation demand, SGMA implementation likely results in an estimated water cutback of up to 30%, resulting in a 10% decrease of the irrigated land.

Groundwater and Livelihoods

Moderator: Debra Perrone

Recognizing the importance of rural livelihoods and environmental justice is fundamental for achieving sustainable groundwater in agriculture. Water-rich countries, especially economically developing countries like Lao PDR, depend on the expansion of irrigation to help alleviate poverty. Consequently, investments in institutional capacity, groundwater assessment, and multi-scale management programs are not only critical priorities for water-poor areas, but ensure economic, food and water security in water-rich areas too.

BMPs for Water Quality

Moderator: David Rudolph

One of the major impetuses for improving novel nutrient management is the legacy time lag between the implementation of BMPs and the full effect being realized at the receptor. Targeting site-specific nutrient management BMPs can be very effective. Novel nutrient management options were the focus of this session, augmented by emerging field monitoring technologies and remedial nitrate concentration reduction.

Salinity Policy

Moderator: Vicki Kretsinger

This session covered a myriad of salinity issues, including methods to address salinity problems and novel water-management approaches. Salinization and waterlogging of irrigated agricultural land is a serious threat in Central Asia, especially the Aral Sea basin, and in California's San Joaquin Valley. Salinization is often dealt with by pre-planting, leaching, or over-irrigation. Unfortunately, excessive applied water can result in high groundwater tables, which then inhibit leaching of salts from the soil root zone. Several management strategies have been utilized, including alternative irrigation systems, crop switching, moisture stressing, reducing cropped area, tile drainage, and disposal of drainage water in evaporation ponds. Regional drain-water management has been evaluated using models with spatial and economic variables.

The Water Nexus, implemented in 2015, is an innovative, solution-oriented program directed at developing solutions for

Continued on the following page…

Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

problems with water scarcity in delta areas worldwide. This new program views salt-impacted water as a resource; saline water is used where possible, and freshwater is used where essential. For example, oil and gas production occurs in the vicinity of agricultural production in many arid regions and there is interest in using produced water, extracted from hydrocarbon bearing formations, for crop irrigation. Growers faced with scarce water supplies are looking for new water sources, and oil and gas producers are interested in alternative water management practices, including energy savings from already-pumped water, and potential revenue streams.

Environmental Justice

Moderator: Debra Perrone

Common approaches used in the agricultural sector to achieve sustainable groundwater include regulatory frameworks, hydro-economic models that integrate local stakeholder values, participatory irrigation management, and community advocacy groups. Successful implementation of these approaches is not universal and may depend on local social and physical science dynamics. For example, regulatory frameworks have been useful in mitigating pollution in the Central Valley, but rural communities are still absorbing the brunt of the impacts of contamination. Community advocacy groups, such as AGUA in the Central Valley, have been essential in increasing awareness of the impacts of agricultural groundwater pollution and in driving local solutions.

Groundwater-dependent Ecosystems and Groundwater-Surface Water Interaction

Moderator: Gus Tolley

How can we effectively monitor and model the complex feedbacks between groundwater and surface water in agricultural areas? The large contrast in spatial and temporal scales between groundwater and surface water provide unique challenges, but several tools are available:

- Remote sensing methods can be used to calculate ET at high spatial and temporal resolutions that can be used for model boundary conditions or calibration
- Traditional and advanced statistics on long-term datasets, such as streamflow and groundwater levels, can provide information about the current state of the system and inform both management and restoration practices
- Despite uncertainties, advances in integrated models allow us to simultaneously simulate both the groundwater and surface-water components of the hydrologic system, improving our understanding of impacts to agricultural and groundwater-dependent-ecosystem interests.

These areas can be targeted for future data collection, resulting in the most efficient use of limited resources. Common themes during these two sessions were the need to involve local stakeholders early and often, and the desire to connect with biologists and ecologists to help establish minimum-flow requirements for certain species at different life stages.

Recharge and Managed Aquifer Recharge (MAR)

Moderator: Joseph Mas-Pla

Sessions on Managed Aquifer Recharge (MAR) were devoted to methods and case studies illustrating the benefits of optimizing available water resources. Agricultural investors see recharge as a means to improve their water availability to face irrigation and SGMA expenses. MAR studies included:

- Capture of flood-flows
- Identification of optimal recharge areas where surface water is available (data from historical stream gage records) and the land use, geology and soil are permeable
- Benefitting natural systems, environmental conservation, and stream-aquifer relationships through MAR.

Incentives for adoption of MAR were created by researcher-practitioner cooperatives. Groundwater banking on agricultural land was developed using water demands, local-scale hydrological balances, and agronomic models, resulting in a pilot of monetary incentives and net metering.

Energy/Biofuel – Groundwater Nexus

Moderator: Dico Fraters

Water sustainability is the most critical challenge to the future of agriculture. Over-pumping and drought may significantly increase the cost of drinking water and agricultural production. The studies presented covered:

- The critical components of the well construction process to maximize the production potential and service life of the well
- A new technology for water reuse and recycling developed in Idaho uses less energy than conventional technologies; nutrients selectively adsorbed to a recovered functionalized biochar demonstrates fertilizer potential in this carbon-sequestering substrate.
- Research carried out in Iowa shows that use of winter cover crop in corn production will help to meet both economic and environmental sustainability goals; however, increase in corn production for biofuel, while positive from an

Continued on the following page…

Toward Sustainable Groundwater in Agriculture: Linking Science and Policy – *Continued*

economic and energy sustainability perspective, threatens groundwater quality as corn production is a 'leak' process.

BMPs for Water Supply

Moderator: Karen Villholth

California is heavily reliant on groundwater for food production. Twenty-one percent of developed water resources in the state is exported as embedded water in nine unique products. Yet, these exports contribute only 2% to the gross domestic product. One challenge with allocation and regulation of groundwater is the process of calculating honest footprints. One presenter argued for a holistic approach to reduce water footprints synergistically with greenhouse gas and other ecological footprint indicators. For example, nutritional and economic benefits of almond production are lost in a water-footprint calculation that reports volume of water per unit weight of almonds.

To improve footprinting and decision-making, we will need:

- disclosure of water data, which would produce better public water resource modelling
- more monitoring and transparency of local water institutions charged with managing extractive and non-extractive uses
- means of encouraging more efficient private use of water.

The benefits of more information include accountability, credibility, and confidence in the integrity of laws governing water use; reduced delays in development caused by confidentiality; and implementation of socially beneficial water quantity or quality regulations.

USDA National Insights and Action

Moderator: Mary Scruggs

USDA scientists conduct a broad range of work at four different agencies to address sustainable groundwater issues. The presentations included work from the Agricultural Research Service (ARS), Economic Research Service (ERS), Natural Resource Conservation Service (NRCS), and National Institute for Food and Agriculture (NIFA). The talks ranged from on-the-ground field studies of water quality and irrigation practices to evaluation and modeling of USDA conservation practices at the watershed scale. Opportunities for collaboration include the integrated Water for Agriculture grant program.

Economics and Policy

Moderator: Mary Scruggs

Three economic evaluations of SGMA implementation revealed implications and possible outcomes of the historic act. The consensus: more work is to be done, more data are needed, a lot of unknown implications remain despite GSA formation, and further economic evaluation is needed as the plans are developed and implemented. One presenter focused on the difficulty of implementing SGMA, including financing, litigation, and deadlines. Implementing on-farm flood capture for groundwater recharge and solar farms offer alternatives to groundwater overdraft.

Groundwater Management and Policy

Moderator: Rob Gailey

These sessions spanned the globe in opportunities for management, incentives and laws. California is not alone in adjusting to new legislations; Mexico has introduced management guidelines and Australia is attempting to regulate water-bore drillers. Notable incentives include smart markets for transferable pumping rights and encouraging acceptance and use of managed aquifer recharge on farms. An important caveat for the science behind institutions: we need to differentiate methods to evaluate safe yield for both large and small aquifers in agricultural regions.

Managing Groundwater Quality

Moderator: Karen Villholth

New Zealand is home to few native mammals, but over 6 million cows. A new urine-seeking technology, Spikey, finds fresh cow urine patches and simultaneously treats them with N-inhibitors and growth promotants, reducing losses of N to the environment.

Napa County has established a Groundwater Resources Advisory Committee (GRAC), which assists county staff and technical consultants with recommendations, including synthesis of existing information and identification of critical data needs; development and implementation of an ongoing groundwater monitoring program; development of groundwater sustainability objectives; and building community support for these activities and next steps. GRAC, in an anticipatory manner, laid the foundation upon which to respond to SGMA with community involvement and support.

The lead planners for this conference were:

- *Thomas Harter, UC Davis*
- *David Rudolph, University of Waterloo*
- *Jennifer Bowles, Executive Director, Water Education Foundation*
- *Susan McClurg, Water Education Foundation*