JULY 31, 2018

COUNTY OF INYO
WATER DEPARTMENT

PROPOSAL FOR

Request for Statement of Qualifications - Groundwater Sustainability Planning for the Owens Valley Groundwater Basin

SUBMITTED BY

LARRY WALKER ASSOCIATES

THE UNIVERSITY OF CALIFORNIA DAVIS

UC DAVIS EXTENSION

TODD GROUNDWATER

RCS RICHARD C. SLADE & ASSOCIATES LLC
CONSULTING GROUNDWATER GEOLOGISTS

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July 30, 2018

County of Inyo
Water Department
ATTN: Bob Harrington, Director
Inyo County Water Department
135 S. Jackson St.
Independence, CA 93526
bharrington@inyocounty.us

Subject: Statement of Qualifications - Consulting Services for Groundwater Sustainability Planning for the Owens Valley Groundwater Basin, Inyo County, California

Dear Mr. Harrington:

Larry Walker Associates, Inc. (LWA), in collaboration with Richard C. Slade & Associates (RCS), Todd Groundwater (Todd), and UC Cooperative Extension (LWA Team), is pleased to submit this Statement of Qualifications in response to the Request for Qualifications for *Consulting Services for Groundwater Sustainability Planning for the Owens Valley Groundwater Basin Inyo County, California*. We understand that the objective of this work is to maintain and enhance the existing sustainable management practices in the Basin in accordance with the requirements of the Sustainable Groundwater Management Act (SGMA).

LWA has assembled an excellent team with demonstrated experience and proven success in the management and delivery of SGMA and water resource planning services similar to those requested in the RFQ. Members of the LWA Team have effectively worked in the Owens Valley Groundwater basin and have strong knowledge of the issues the basin is facing. LWA is proposed as the lead consultant and will provide technical assistance for preparation of the Owens Valley Groundwater Sustainability Plan (GSP). Dr. Laura Foglia from LWA and UC Davis will be the Program Manager for the project, and the primary point of contact for the District and stakeholders during contract execution. Dr. Foglia is an expert in groundwater modeling with extensive experience with various modeling approaches in California and Europe. Dr. Thomas Harter of UC Davis and UC Cooperative Extension will play a prominent role as a strategic advisor, working closely with Dr. Foglia on the development of the GSP and providing extensive knowledge on issues such Groundwater Dependent Ecosystems, which is one of the undesirable results to be addressed in the Basin. Dr. Foglia and Dr. Harter have worked together since 2011 on different projects developing models and tools to address GDE concerns. RCS brings in depth understanding of the hydrogeology and groundwater conditions in the Owens Valley

Groundwater Basin and experience developing hydrogeological conceptual models for SGMA, and Todd Groundwater brings valuable expertise in SGMA planning plus important knowledge of the Basin, including hands-on experience with some of the groundwater models that have been developed in different areas of the Basin. LWA Team members have longstanding and positive working relationships with staff of the Department of Water Resources (DWR), Lahontan Regional Board, and State Water Resources Control Board, including direct experience coordinating with DWR on SGMA.

The LWA Team offers the County of Inyo and the Owens Valley Groundwater Authority (OVGA) the following strengths:

- Important Owens Valley experience, including an understanding of varied hydrogeology and groundwater conditions;
- Strong knowledge of the SGMA issues and needs in the Basin and the skills and experience needed to successfully support GSP implementation for different management areas within the Basin;
- Extensive groundwater modeling skills, knowledge of the data needed by groundwater models, and technical insight to design and implement the special studies requested in the RFQ;
- Data analysis, modeling and stakeholder skills required to develop attainable sustainability criteria for management areas within the Basin;
- Demonstrated success developing productive relationships with key stakeholders through effective communication and transparent technical evaluations;
- Strong connections to the academic community, groundwater model developers, and Department of Water Resources (DWR) modeling experts;
- Ability to successfully communicate complex hydrogeologic and groundwater concepts to a wide variety of stakeholders; and
- Capacity to perform the work on time – our team is ready to hit the ground running to deliver the excellent service and responsiveness to individual and collective stakeholder needs that is required for this project.

As part of the above, our LWA Team has the technical capabilities to efficiently compile and manage data from different sources, evaluate existing models, develop recommendations for consolidation of models, work with stakeholders to understand differences between existing models, understand the impact and challenges of using models to properly simulate different land use and management practices, use models to assist in understanding of groundwater dependent ecosystems, and use data and model output to demonstrate the actual and future sustainable condition of the Basin.

In particular, our LWA Team is well qualified to perform the special studies identified in the RFQ, which include:

- Development of a GSP that is compatible with the existing Inyo/Los Angeles Long Term Water Agreement
- Determination of groundwater flow paths and rates between the Tri-Valley region and the Bishop-Laws region
- Addressing the sustainability of Fish Slough, a groundwater dependent ecosystem

- Development of coordination and data sharing agreements between agencies managing groundwater in the Basin that are not subject to SGMA
- Performance of a cost and rate study for GSP implementation
- Incorporation of elements of LADWP's monitoring, management and mitigation program associated with Owens Lake groundwater development into the GSP
- Evaluation of hydrologic factors affecting high shallow groundwater levels in the West Bishop area
- Description of the existing groundwater monitoring network and recommended monitoring protocols and improvements

Our history of successful experience with stakeholder groups and regulators in California is a result of our abilities in practical problem-solving and effective application of science within regulatory policy constraints.

Thank you for the opportunity to propose on this project. Please, feel free to contact me at Lauraf@LWA.com or at 530-753-6400 with additional questions.

Sincerely,

Laura Foglia, Ph.D., Senior Engineer
Project Manager

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Overview

Larry Walker Associates, Inc. (LWA), in association with Richard C. Slade & Associates, LLC (RCS), Todd Groundwater (Todd) and the University of California, Davis (UC Davis) Department of Land, Air and Water Resources (LAWR), hereinafter "LWA Team", has the regulatory background, technical skills, and direct experience necessary to provide technical assistance for the development and preparation of the Groundwater Sustainability Plan (GSP) for the Owens Valley Groundwater Basin (Basin). The Owens Valley Groundwater Authority (OVGA) will benefit from our Team's considerable experience and proven capabilities, as well as our value-added insight and breadth of service. The Team has successfully collaborated on previous relevant projects *(see Sections 1.1 and 3.0)* to perform similar tasks and develop high-quality work products within budget and schedule constraints. As demonstrated throughout our proposal, the LWA Team offers an in-depth understanding of the requirements of the California Sustainable Groundwater Management Act (SGMA) and how to develop a pragmatic and thorough GSP. Of significant value is our understanding of the Owens Valley Basin, our experience working with the Lahontan Regional Water Quality Control Board (Regional Board) and Department of Water Resources (DWR), our experience with similar groundwater sustainability efforts for other California basins, and our expertise in hydrogeological modeling and public outreach. In addition, the LWA Team has worked extensively with multi-stakeholder SGMA related efforts throughout the State. ***As the Prime Consultant with the sole responsibility to the OVGA for the successful delivery of the project, LWA will coordinate the efforts of the Team to provide seamless support to OVGA.***

VALUE-ADDED ADVANTAGE

The LWA Team offers the OVGA 50 years of experience in California, including in-depth knowledge of and direct experience with:

- *Evaluating conditions in the Owens Valley Basin and other similar groundwater basins*
- *Working with diverse coalitions and stakeholder groups*
- *Working with groundwater and surface water models*

Proposal Sections Addressing Information Requested in the RFP

RFP Requested Information	Section Where Item is Addressed in Proposal
1. Staff Capabilities and Key Personnel	1.0 Qualifications 2.0 Key Personnel; Appendix B. Key Personnel Resumes
2. Project Experience	3.0 Project Experience
3. Scope of Work and Not-To Exceed Budget	4.0 Project Work Plan 5.0 Cost Proposal, Appendix C. Fee Schedules
4. References	3.0 Project Experience
5. Subconsultants.	Included in Sections 1-3
6. Experience in Meeting Deadlines	6.0 General Firm Operating Information
7. Disclosure of Relationships with OVGA/ LADWP	6.0 General Firm Operating Information, Appendix A
8. Ability to enter into agreement with Inyo County	6.0 General Firm Operating Information
9. Additional Information	Appendix D
10. Signature	Transmittal Letter

1.0 Qualifications

The LWA Team was formulated based on experience performing similar work, availability, and commitment to support the OVGA throughout the term of the contract. The roles for each firm were carefully defined to maximize each firm's strengths and to meet the goals of the project. The LWA Team brings five decades of proven experience and extensive knowledge of the Basin and regions with similar characteristics through California, and statewide water resource regulations and policies. The Team has supported more than a dozen municipal water districts, more than 20 counties and 80 cities, as well as more than 30 sanitation, wastewater, and other special districts and government agencies with water resources management and engineering services. We understand California's water resources and challenges and the need for flexibility in providing complex planning services and are prepared to adjust approaches to meet changing client needs and regulatory interpretations.

A description of LWA (Prime Consultant) and subconsultant firms on the Team are provided below. Additional highly qualified and experienced staff are readily available to augment the team as needed and as requested by OVGA. Provided in *Sections 1.2 and 3.0* are project examples of similar work and references who can attest to our Team's competence and quality of work.

Independence and License to Practice in California. Members of LWA Team's staff hold advanced degrees, including Ph.D.s as well as the certifications and licenses required to perform the work, including Professional Geologists (PGs), Certified Hydrogeologists, Certified Engineering Geologists (CEGs), and Professional Engineers (PE). ***All staff proposed for the contract maintain active and current professional licenses as required to perform their assigned tasks.*** *Section 2.0 and Appendix B* provide additional details on our Team's licenses, qualifications, credentials, training, and expertise.

VALUE-ADDED ADVANTAGE

The LWA Team's joint experience will enhance coordination, communication, and quality for the OVGA on this project.

- *Todd Groundwater has worked with LWA since 2007 on 14 projects.*
- *RCS's history with LWA dates back to 2004 when the firms supported the City of Los Angeles with "Highly Specialized and Expert Assistance for Wastewater and Stormwater Regulatory and Permit Issues."*
- *Thomas Harter leads the UC Cooperative Extension Groundwater Program conducting research, education and outreach to support agencies engaged in sustainable groundwater management.*
- *The principals of Todd Groundwater and RCS have been colleagues in the industry for 25 years. Currently, the firms are jointly preparing the SNMP for ULARA and providing on-call hydrogeological services to Mojave Water Agency for projects involving managed aquifer recharge.*

1.1. Company History and Capabilities

LWA is a privately-owned corporation providing environmental engineering and management services throughout California. Headquartered in Davis, CA, LWA has regional offices in Owens Valley, Carlsbad, Berkeley, San Jose, and Ventura, as well as an office in Seattle, Washington. Founded in 1979, LWA has been a partner, innovator, and industry leader, assisting municipalities and private businesses in navigating and solving complex and important environmental and public policy challenges. LWA provides a wide range of consulting services ranging from traditional water and wastewater engineering to highly specialized water resource management; groundwater modeling, scenario analysis and sustainable planning; surface water and groundwater monitoring; stormwater; and watershed management.

VALUE-ADDED ADVANTAGE

LWA offers the OVGA over 20 years of experience working with public agencies and managing complex stakeholder processes to achieve sustainability goals. As a lean and nimble firm, LWA offers the OVGA the qualifications found at larger firms but with the benefits of enhanced responsiveness and direct access to Laura Foglia, Project Manager, for any project matter.

Regulatory Assistance. LWA regulatory assistance includes SGMA, Reports of Waste Discharge (ROWDs), anti-degradation analyses, site specific objective studies, use attainability analyses, Basin Plan amendments, and water quality policy review. LWA works with irrigated agricultural coalitions, water, stormwater, wastewater, and recycled water agencies throughout California to ensure adoption of requirements that can be complied with and provide reasonable protection of beneficial uses of California waters. LWA utilizes in-depth knowledge of the Clean Water Act, Porter-Cologne Water Quality Act, California Water Code, and SGMA to support and guide our clients.

Groundwater Modeling. LWA staff has extensive experience in developing, calibrating, and validating groundwater models to support groundwater management efforts across California. The firm has a highly skilled team of Ph.D. groundwater modelers led by Dr. Laura Foglia (Project Manager), who currently teaches courses to future groundwater modelers at UC Davis, with a focus on how to address the uncertainty and data gaps that might confound less-experienced modeling teams. The LWA groundwater modeling team regularly attends workshops and training opportunities derived from SGMA and diligently works to ensure that the range of approaches and tools are consistent with the state of the art science. LWA practitioners are also keenly aware of the delicate balance between expending limited resources on complex models and the potential to spend a portion of those limited resources on acquiring site-specific data. The modeling team is prepared to engage OVGA and other stakeholders to ensure that limited groundwater evaluation resources are allocated to allow for effective groundwater management. LWA also has unique capabilities in analyzing and effectively communicating the output of groundwater modeling work. Our team combines skills for teaching courses related to groundwater hydrology, groundwater model development, and data assessment at the academic level with excellent skills for presenting and conveying technical results in an accessible manner to stakeholders.

Groundwater Surface Water Interconnectivity. LWA combines knowledge of geology, hydrology (both surface water and vadose zone hydrology), and hydrogeology with experience in understanding all the processes of interest within a hydrologic basin. LWA staff operates within an internal "One Water" framework where water resources are comprehensively managed. We use our broad understanding of groundwater and surface water requirements to work within existing regulatory structures to comprehensively to identify integrated solutions that achieve multiple goals. LWA provides a complete range of hydrogeology assessment capabilities, understanding of the latest research and regulatory requirements, and data interpretation using industry standard and innovative methods to provide a holistic assessment of groundwater basin conditions and factors influencing basin management. In other similar projects, LWA approaches have minimized or eliminated the need for costly on-site drilling, digging and sampling, identified program overlaps and project opportunities that minimized or eliminated additional implementation costs and facilitated reductions in planning and reporting costs across programs by effectively integrating requirements.

Groundwater Dependent Eco-systems. Dr. Diana Engle, a senior scientist with LWA, has the background and experience to address the challenges presented by the presence of groundwater dependent eco-systems. Her academic expertise lies in the ecology of rivers, streams, lakes, and floodplains. Among other appointments prior to joining LWA, she served as a lecturer in the department of Ecology, Evolution and Marine Biology at UC Santa Barbara for many years, and was a private consultant to the USGS and National Park Service. At LWA, Dr. Engle provides diverse technical and regulatory assistance related to hypothesized roles of nutrients and other contaminants on water quality and biological resources in the Sacramento-San Joaquin and other regulated water bodies, and conducts investigations of surface water/groundwater interactions in arid watersheds. In addition, she currently serves as a director of the Upper Ventura River Groundwater Agency, Meiners Oaks Water District, and Association of Water Agencies of Ventura County.
From another perspective, Dr. Thomas Harter and Dr. Laura Foglia have looked at the importance of properly representing GDEs in numerical models in the Scott Valley basin, Siskiyou County. Results of the extensive 10-year research are presented in the additional information (Appendix D). Approaches similar to the ones applied in the Scott Valley example can be transferred and tailored for the OVGB.

Multi-Stakeholder Facilitation. LWA offers over 20 years of experience in the facilitation of and collaboration with stakeholders at the regional, state, and federal levels. LWA is known for our ability to diplomatically communicate, interact, and forge productive relationships with clients' staff, regulators, and other diverse stakeholders, including DWR, Resource Conservation Districts, California Farm Bureau, and UC Cooperative Extensions. LWA has coordinated and facilitated multi-agency collaborative programs in the Central Valley, San Diego County, Ventura County, Orange County and Los Angeles County. LWA assumed a significant coordinating role in the stakeholder groups associated with the Central Valley Salinity Alternatives Long Term Sustainability (CV-SALTS), Siskyou County GSPs development, Ochumne-Hartnell Water District Basin Boundary Adjustment, Calleguas Creek Watershed Total Maximum Daily Load (TMDL) Development and Implementation, Newport Bay Nitrogen and Selenium Management Program, Santa Margarita River Water Quality Improvement Plan, development of the Lower Santa Clara River Salt and Nutrient Management Plan, development of the Ventura River Watershed Algae TMDL, and the California Statewide Biological Integrity Regulated Community Stakeholder Group

RICHARD C. SLADE & ASSOCIATES LLC
CONSULTING GROUNDWATER GEOLOGISTS

Established in 1983, RCS is comprised of a group of groundwater geologists focused on the development, protection, and management of groundwater resources throughout California. The firm's Principal Hydrogeologist and owner, Mr. Richard C. Slade has more than 51 years of hydrogeologic experience in California. Specific areas of expertise for RCS include:

- **Development of conceptual models of groundwater basins**, including characterizing the water-bearing sediments and the base of fresh water in groundwater basins; conducting detailed studies of groundwater conditions in adjudicated and unadjudicated groundwater basins; conducting analysis and correlations of the resistivity signatures on geophysical electric logs available from water wells, oil wells, and groundwater monitoring wells; preparing detailed cross sections using E-logs, to define key aquifer systems and the base of fresh water; defining groundwater flow directions and possible barriers to groundwater flow (e.g., from faults); assessing groundwater quality in individual wells and on a basin-wide basis.
- **Development of groundwater supplies**, including identifying the feasibility of constructing new water wells and determining well depths and drilling methods for new wells; preparing Technical Specifications and detailed line item bid sheets for the preliminary design and cost analysis of new wells and deep monitoring wells; providing experienced geologists to field monitor the drilling, final design, construction and testing of new water wells and groundwater monitoring wells; conducting pumping tests and providing technical analyses of pumping test data; and evaluating and monitoring of the rehabilitation of older wells.
- **Groundwater management**, including preparing groundwater management plans; evaluating groundwater contamination; providing independent reviews of technical reports prepared by others; and providing expert witness services in hydrogeology. He has also provided presentations to Commissions and Boards in the project area.

VALUE-ADDED ADVANTAGE

RCS has performed hydrogeologic work in California for more than 50 years, including:

- *Evaluating the "safe yield" and the "perennial yield" of major aquifer systems in entire groundwater basins (for example, the Santa Monica and Hollywood groundwater basins in southern California), and estimating the amount of groundwater in storage for several other groundwater basins.*
- *Conducting hydrogeologic studies for new domestic- and public-supply water wells, and also providing the final design and testing of those new wells for several clients in Inyo and Mono counties.*
- *Ongoing work as the Court-appointed Watermaster to the Upper Los Angeles River Area (ULARA) since 2009 offers a unique perspective on groundwater management.*

RCS, a privately held company, is on a sound and stable financial footing and has continuously been in business in California since 1983. RCS has one Principal Groundwater Geologist and six additional full-time professional groundwater geologists, including two senior project-level hydrogeologists, who are licensed Professional Geologists and Certified Hydrogeologists in California. Additional resources to support the project as needed include four full-time staff/field-level geologists who are degreed geologists and licensed Professional Geologists.

Todd Groundwater is a consulting firm specializing in groundwater studies, including evaluation, monitoring, modeling, management, and protection of groundwater resources and associated surface water resources. The firm was founded in 1978 by Dr. David Keith Todd, internationally-recognized expert in groundwater and author of the textbook, Groundwater Hydrology. While providing the breadth of training and experience needed for groundwater planning, management, development, and protection, Todd Groundwater has remained a small firm (currently 16 employees), in order to provide specialized and responsive groundwater services to its clients. Based in Alameda, California, most of the firm's work is conducted for California public agencies (water agencies, cities, and counties) and more than half of its projects are in Southern California.

VALUE-ADDED ADVANTAGE

Todd Groundwater brings a unique depth of expertise in groundwater basin management, particularly SGMA. Todd Groundwater has worked for numerous public agencies in Southern California.

Todd provides the full range of groundwater services with a focus on groundwater basin management, particularly compliance with SGMA. Todd brings a unique depth of experience and commitment to groundwater management planning in California, beginning with preparation of one of the first four AB 3030 plans in 1994. This groundwater management plan (for Scotts Valley Water District) included a comprehensive water resources monitoring program that was featured as an exemplar in the 2003 DWR Bulletin 118, California Groundwater. Dr. Iris Priestaf, President, participated actively with DWR in planning for SGMA through the Groundwater Committee of the Association of California Water Agencies (ACWA).

Todd brings comprehensive experience with development and application of numerical modeling tools (most notably MODFLOW) for quantification of various scenarios for water and land use to achieve sustainability.

Todd Groundwater's professional staff members have advanced degrees in civil engineering, geology, hydrogeology, geochemistry, geography, and environmental sciences with the ability to perform services on this contract. Almost all senior staff are professionally registered geologists, engineering geologists, hydrogeologists, or civil engineers in California. The firm, owned by its employees and Board of Directors chairman, has always been profitable and financially stable throughout its 40 years of history.

LWA has teamed with the Department of LAWR at the **University of California, Davis**, which is a multidisciplinary department with faculty who specialize in atmospheric science, plant science, soils and biogeochemistry, hydrology, and water engineering. Teaching, research, and outreach efforts focus on agricultural and environmental aspects of these disciplines. LAWR hosts the UC Cooperative Extension Groundwater program, led by Dr. Thomas Harter, Robert M. Hagan Endowed Chair for Water Management and Policy.

The UC Cooperative Extension Groundwater program engages in research, education, and outreach. They primarily work with the water resources industry (i.e., public water supply utilities, irrigation districts, water districts, etc.); research, planning, and regulatory agencies on the local, county, state, and federal level; farm advisors in county cooperative extension; the agricultural industry; and Non-Governmental Organizations (NGO) engaged in agricultural and rural areas. The components of the program include: (1) an integrated basic and applied research program that emphasizes regional groundwater hydrology and sustainable groundwater management planning/modeling/assessment, water quality and contaminant fate and transport in both vadose zone and groundwater, and techniques for sampling and monitoring groundwater systems; (2) an extension program that provides educational and technical support to local, state, and federal agencies, to groundwater sustainability agencies, irrigation and water districts, county farm advisors, conservation districts, and policy makers in both the agricultural and urban sectors in the state; and (3) coordination of groundwater related programs and events among faculty in hydrology related areas at UC Davis, with other extension specialists and farm advisors, with federal, state and local agencies, water districts, irrigation districts, conservation districts, NGOs, and other groups that are concerned with and engaged in sustainable groundwater management.

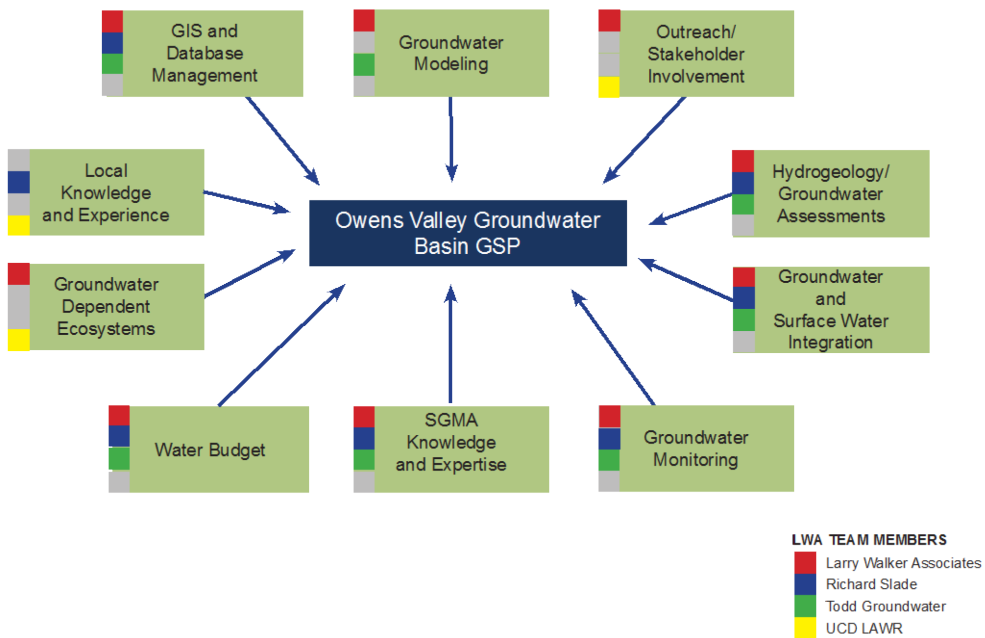
The program provides multi-faceted research, technical advising, outreach, and education support toward the implementation of California's SGMA and of California's regulatory groundwater quality programs to address nitrate, salinity, and other emerging nonpoint source/ diffuse contaminants. The program offers support throughout California with emphasis on rural and agricultural regions. We also engage with national and international partners to support global discovery, learning, and best management adaptation in this arena. Since 2007, the program has been an integral part of the Robert M. Hagan Endowed Chair in Water Management and Policy.

In 2007, the program received the Kevin J. Neese Award, presented by the California Groundwater Resources Association for the best groundwater project of the year. The award was given in recognition of the program's efforts to better understand groundwater quality issues related to dairy activities and its engagement in improving management practices on dairy farms.

1.2. Recent, Relevant Experience on Similar Projects

The LWA Team has the experience and expertise needed to navigate the regulatory and technical requirements, as well as successfully and promptly perform the management and technical tasks required for the development of the GSP within the specified time. Team members have overlapping expertise to provide backup and support for project completion, as shown in the ***Figure 1***.

Figure 1. LWA Team Member Expertise to Support the Development of the GSP



The LWA Team has extensive experience on similar projects for municipal clients; our most relevant representative projects performed within the last five years are summarized in ***Table 1***. All projects are on track with their corresponding schedule and budget requirements. Detailed descriptions and references for projects of comparable scale, nature, and complexity are provided in *Section 3.0, Project Experience*.

As demonstrated by the projects and summarized below, the LWA Team has relevant experience and knowledge as well as the technical competence in all services required by the RFP.

Project Management and Public Engagement Process

The LWA Team has extensive experience working with a range of stakeholders including landowners and private well owners, non-governmental organizations, business interests, irrigated agricultural coalitions and farm bureaus, planning agencies, and water supply, stormwater, wastewater, and recycled water agencies throughout California to ensure adoption of requirements that can be complied with and provide reasonable protection of beneficial uses of California waters. Members of the LWA Team are known for the ability to diplomatically communicate, interact, and forge productive relationships with clients' staff, regulators, and other diverse stakeholders. Many past and present projects undertaken by the LWA Team have required extensive engagement with a stakeholder group while executing a project that affects multiple groups of people, oftentimes with competing or non-overlapping interests. LWA has coordinated and facilitated collaborative programs with many diverse stakeholders for groups in the Central Valley, San Diego, Orange, Los Angeles, and Ventura County.

The LWA Team actively supports GSP and SGMA compliance throughout California, working closely with various public agencies to analyze SGMA requirements, organize GSAs, assess and modify basin boundaries, and develop detailed work plans that comply with SGMA and reflect the public agency's goals, needs, and resources. Members of our team have served on advisory committees – for example, assisting with the development of DWR's modeling Best Management Practices (BMPs) for SGMA -- and continue to be involved in meetings and discussion with DWR.

GSP preparation is predicated on substantive public engagement throughout the process. This requires abilities to identify interested parties and to encourage their participation through notices, announcements, websites, and workshops. The LWA Project Manager (PM), Laura Foglia, Assistant Project Manager (APM) and Betsy Elzufon bring skills and experience to this key GSP element through numerous projects conducted for the Ochumne-Hartnel Water District, California Farm Bureau and the Cities of Davis, Santa Paula, and Santa Maria. Masih Akhbari also brings facilitation and stakeholder outreach skills through his work in the San Joaquin watershed and for the Colorado River Basin. In addition, Ms. Elzufon has worked with several agencies in the Lahontan region and has good working relationships with the Lahontan Regional Water Quality Control Board staff.

In addition, GSPs require clear communication to diverse participants of complex and sometimes controversial technical issues. All the technical team leaders bring substantial capabilities in engaging the public through well-written documents, effective presentations, collaborative meetings with other agencies, and stakeholder workshops. For example, Dr. Foglia and Mr. Grovhoug are actively engaged with the California Farm Bureau developing outreach material regarding SGMA and groundwater hydrology for SGMA; Dr. Priestaf and Mr. Yates led successful outreach to highly varied participants in preparing the groundwater management plan for East Palo Alto; this involved explanation of technical topics (e.g., hydrogeology, water balance and sustainable yield, pumping impacts, saltwater intrusion, creek impacts, subsidence) to participants including residents and representatives of cities, counties, water agencies, developers, and environmental organizations. LWA has extensive experience on interacting with stakeholders regarding data collection and groundwater and surface water model development and on demonstrating how they can be used as meaningful tools for understanding the basin and for the simulation of future management.

SGMA and GSP Development

The LWA Team brings substantial recent experience with SGMA including technical support to Groundwater Sustainability Agencies (GSAs) and preparation of GSPs. LWA utilizes in-depth knowledge of the Clean Water Act, Porter-Cologne Water Quality Act, California Water Code, and SGMA to support and guide our clients. LWA's role in the groundwater service area has become more prominent in recent years. LWA has played key roles in projects for the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS), a collaborative basin planning effort aimed at protecting vulnerable and essential water resources. LWA also led the development of Salt and Nutrient Management Plans (SNMP) for the Santa Clara River (2014) and Calleguas Creek in Ventura County, as well as supported development of an SNMP for the City of Oxnard and Goleta Water District (2016). After SGMA was passed in 2014, LWA became directly involved in projects related to the new law, including the Basin Boundary Modification process and preliminary groundwater management plan assessments. LWA is currently involved in the development of 4 Groundwater Sustainability Plans in Mendocino County (Ukiah Valley Groundwater Basin), and Siskiyou County (Scott Valley, Shasta Valley and Butte valley groundwater basins).

RCS has worked with Inyo and Mono County officials and conducted numerous hydrogeological investigations and monitoring programs in the Owens Valley region. RCS was the lead firm for the development of the SNMP for the four groundwater basins within the adjudicated ULARA, including descriptions of the hydrogeologic conceptual model for the basins, and compilation of data used as part of the analyses. Todd Groundwater was a subconsultant to RCS in that SNMP and performed modeling work and project review based on their experience with SNMPs in other local groundwater basins.

Since passage of SGMA in 2014, Todd Groundwater has provided technical support to 10 agencies: Alameda County Water District, Cawelo Water District GSA, City of Corona/Temescal Subbasin GSA, City of Paso Robles, James Irrigation District GSA, Kern River GSA, San Benito County Water District GSA, Stanislaus and Tuolumne Rivers Groundwater Basin Association, West Turlock GSA, and Zone 7 Water Agency. These agencies are diverse, together representing urban and rural areas across California, utilizing various water supplies (groundwater, local surface water, imported water, recycled water), and facing the full range of challenges including groundwater level and storage decline, salt water intrusion, water quality degradation, subsidence, and adverse impacts on connected surface water and groundwater-dependent ecosystems (GDEs). Some of these agencies are in critically over drafted basins and some are preparing GSPs for compliance and optimization of existing water resources management. Todd Groundwater assisted with two Alternate Plans (functionally equivalent to GSPs and submitted in 2016) and is preparing six GSPs.

Owens Valley Basin Hydrogeology and Structure

The Inyo County Water Department prepared a Hydrogeologic Conceptual Model for DWR in 2016. This study along with previous groundwater studies investigated the Owens Valley Basin hydrogeology and geologic structure. Alluvial, fluvial and lacustrine deposits, consisting of interbedded gravel, sand, silt, and clay, predominate in the study area. Aquifers typically exhibit flowing artesian conditions when penetrated by wells located at lower elevations near Owens Lake. Where wells of different depths are present, the hydraulic gradient is typically upward, and discharging to the lake bed. Horizontal groundwater flow is typically toward the center of the lake.

According to the Inyo County Water Department’s study, the principal geologic structures affecting groundwater flow are the basin’s bedrock boundaries and faults in the valley-fill material. The bedrock boundaries delineate the geometry of permeable valley fill. Evidence for faults acting as groundwater flow barriers includes emergence of springs along fault traces and declines in water table elevation across faults. North of the Alabama Hills, blocks of aquifer are compartmentalized by en echelon faults, restricting lateral flow into the compartment. Recharge to the compartment is limited to local sources such as a stream segment within the compartment or precipitation. Absent lateral inflow, effects of pumping may be more long-lasting in compartmentalized areas, because recharge in compartmentalized aquifers may be limited to direct precipitation, which provides relatively low recharge rates.

Numerical Groundwater Models

The LWA Team has assembled a robust team of numerical modelers and supporting hydrogeologists, including experienced groundwater modelers who are trained on various model platforms and graphical user interfaces to support modeling, with three modelers each having approximately 30 years of experience with groundwater modeling. In the following, some main numerical models developed in the study area by USGS, MWH, and the Inyo County Water Department are described:

USGS Groundwater Flow Model

USGS has developed a valley-wide groundwater flow model to integrate and test the concepts about the structure and physical properties of the aquifer system, the quantity of recharge and discharge, and the likely effects of water-management decisions. This model, which used a distributed-parameter approach, is comprised of a group of mathematical equations that describe the flow of water through an aquifer. Variables (parameters) in the equations include hydraulic heads, transmissive characteristics, storage characteristics, and the rates of inflow and outflow. This model uses standard finite-difference techniques to approximate the partial differential equations that describe saturated groundwater flow. Boundaries of the ground-water flow model conform to the physical boundaries of the Owens Valley aquifer system. Lateral underflow boundaries are present in eight locations: Chalfant Valley, the edge of the Volcanic Tableland, Round Valley, Bishop Creek, Big Pine Creek, Waucoba Canyon, and east and west of the Alabama Hills. All other boundaries of the aquifer system were assumed to be impermeable and were simulated with no-flow boundary conditions. The top of the aquifer system is the water table, and the bottom is either bedrock, the top of a partly consolidated unit, or an arbitrary depth based on the depth of production wells. The aquifer system was simulated using two model layers. The upper model layer represents the unconfined part of the aquifer system. The lower model layer represents the confined part of the aquifer system. Each model layer is composed of 7,200 cells created by 180 rows and 40 columns. This model contains four packages: well package, river package, evapotranspiration package, and drain package.

MWH Numerical Groundwater Model for Owens Lake

MWH has also created a numerical groundwater model for Owens Lake. They prepared a preliminary conceptual model which represented the initial conceptual understanding of the study area and hydrologic system based on the voluminous body of work conducted on or around the lake in the last century as a framework for defining key hydrologic components and their interrelationships. This model initially described the following concepts:

- Geology, Structure, Depositional History, and Hydrostratigraphy
- Groundwater Flow
- Water Quality
- Water Budget
- Summary of Private Entities and Commercial Interests that may be Affected by Changes in Groundwater or Surface Water in the Vicinity of Owens Lake
- Review of Environmental Considerations
- Recommendations for New Monitoring Wells
- Recommendations for Aquifer Testing

Using newly-acquired data, interpretation of surface seismic data, lessons learned from development of another groundwater model north of the area, as well as review and re-analysis of the water budget, MWH updated this preliminary conceptual model. Key findings of the revised conceptual model included: stratigraphy, depositional environment, structural geology, depth to bedrock, variation of groundwater head at depth, aquifer parameters, groundwater budget, effects of the lower Owens river project and dust control measures on the study area water budget, surface water/groundwater interaction, groundwater quality, characterization of springs, and water level and flowing well evaluation.

The updated conceptual model formed the basis for development of the numerical groundwater model, which was developed using MODFLOW-2000. Main model functionality included the ability of the groundwater model to simulate: spring flow, variable groundwater flow direction at various depth horizons, effects of existing and proposed groundwater pumping, effects on local wells, evapotranspiration, vertical gradients between aquifers, results of pump tests (regional-scale representation), hydraulic effects of faults.

Inyo County Water Department's Groundwater Flow Model

Inyo County Water Department developed a steady-state numerical groundwater model of the Bishop-Laws area, using MODFLOW, to evaluate the effect of water management activities on groundwater dependent resources and existing groundwater users. This model assists Inyo County in meeting its joint management obligations under the "Long Term Groundwater Management Plan for the Owens Valley and Inyo County" plan between the County of Inyo and the City of Los Angeles and LADWP. This model is based on a conceptual model incorporating the study area's geologic materials, tectonic setting, and surface water hydrology. The steady-state model was calibrated manually and automatically to recent hydrologic conditions.

The appropriate use of this model is to evaluate the change in head or change in water budget components due to hydrologic perturbations. The model area is 33 Km x25 Km. The model grid is oriented in the north-south/east-west directions. In the vertical direction, the model domain extends from the land surface to an elevation of 900 meters above sea level. The domain is discretized uniformly into a 132 x 100 cell grid of 250 x 250 m cells. The model has five layers; layers 1 through 4 are 50, 50, 75, and 100 m thick, and the fifth layer extends to the bottom of the model domain. The spatial distribution of hydraulic conductivity was based on the distribution of geologic units, aquifer tests on production wells, and both manual and automated model calibration.

Constant head boundaries were used to simulate areas of underflow within valley fill. Constant head boundary conditions were assigned in the area of Pleasant Valley Dam at the western boundary, at Chalfant Valley on the northern boundary, and in the valley fill at the southern boundary. Head-dependent boundary conditions were used to simulate the Owens River using the MODFLOW river package, and to simulate flowing wells along the Owens River and springs at Fish Slough using the MODFLOW drain package. For the Owens River, the starting and ending elevations of seven river reaches were determined from the digital elevation model. The river stage was set at 1 m (3.3 ft) below the land surface, river depth at 2 m (6.6 m), river width at 4 m (13.2 ft), river bottom thickness at 2 m (6.6 ft), and streambed hydraulic conductivity set at 2 m/day (6.6 ft/day).

Groundwater Investigations and Groundwater-Dependent Projects

The LWA Team has direct experience working on groundwater and water quality projects throughout California

- RCS has has been involved with conducting hydrogeologic investigations within the Lone Pine and Cartago areas of Inyo County regarding the impact of planned developments using groundwater resources and in the Chalfant Valley region of Mono County.
- RCS has completed numerous projects in the Santa Monica Basin, including preparing the initial conceptual groundwater basin model and an assessment of the available groundwater supplies in 2013, evaluating subsurface geologic conditions, and selecting drill sites and new water-supply well locations. RCS has also provided groundwater services since 1999 for a major golf course in the basin; work has included locating and designing new irrigation-supply wells, and providing, carrying out, and reporting on a detailed groundwater monitoring program for all onsite wells.
- The LWA Team has worked with current models developed by USGS, DWR and others and has modified them to fit the specific conditions of individual groundwater basins and to account for surface water-groundwater interactions such as is likely to be present for the Owens Valley Groundwater Basin.

- The LWA Team has extensive experience on developing tailored approaches to develop detailed water budget and to understand surface water/groundwater interactions and how models should address them. [1]
- The LWA is supporting local agencies in the development of specific groundwater recharge projects aiming at improve groundwater sustainability (Siskiyou County, and Omochumne-Hartnel Water District)
- The LWA Team has evaluated groundwater systems and impacts to groundwater systems throughout California (California WaterFix on behalf of Sacramento County Water Agency). LWA has evaluated groundwater monitoring networks and impacts to groundwater in the Central Valley for coalitons, municipalities, and water districts including CV-SALTS, EBMUD, Modesto, Omochumne-Hartnel Water District. In addition, LWA has evaluated groundwater systems in the High Desert (VVWRA, City of Victorville, Helendale Community Services District), Palm Springs, Ventura County (Santa Clara River SNMP) and the North Coast Region (Cities of Ukiah, Santa Rosa).
- In addition to analysis of groundwater systems, LWA has evaluated impacts to both surface water and groundwater due to recycled water uses (City of LA, City of Santa Paula), and due to stormwater infiltration (Examination of impacts from rockwells for Modesto).

Inyo and Mono Counties Experience

Within Inyo and Mono counties, RCS has been involved with conducting hydrogeologic investigations within the Lone Pine Bishop and Cartago areas and in the Chalfant Valley regarding the impact of planned developments using groundwater resources. To this end, RCS staff has worked with the Planning Commissions and the Boards of Supervisors in both Inyo and Mono counties.

RCS, Todd and LWA have all worked in the South Lahontan Region evaluating impacts to groundwater and regarding sustainable groundwater management for Mojave Water Agency, Victor Valley Wastewater Reclamation Authority and other municipalities in the region. In addition, LWA has worked closely with Lahontan Regional Board staff to support clients on regulatory issues.

The LWA Team has also worked in other remote, less populated areas of California with similar issues to those in the Owens Valley region including Kern, Mendocino and Siskiyou Counties.

[1] Foglia L, Neumann J, Tolley D, Orloff S, Snyder R, Harter T. 2018. Modeling guides groundwater management in a basin with river–aquifer interactions. Calif Agr 72(1):84-95. https://doi.org/10.3733/ca.2018a0011

Table 1. LWA Team Experience

	Project Management			Technical Expertise													Local Experience		Regulatory Expertise			
Project	Facilitate & Coordinate with Client and Stakeholders	Prepare for/Attend Meetings and Workshops	Manage Multiagency Plan Development.	Public Engagement Plan (Task 2)	Data & document compilation, review & management (Task 3)	Coordination with GSA & landowners, local agencies, tribes (Task 4,15)	GSP Area & GSA Information. Basin Setting (Tasks 5,6)	Preparation of Groundwater Models (Task 6)	Develop Hydrogeologic Conceptual Models (Task 6)	Establish Historical and Future Water Budget Terms (Task 6)	Sustainable management criteria (Task 7)	Develop/ refine monitoring program (Task 9)	Identify projects and management actions to maintain or achieve sustainability (Task 10)	GSP Compilation, presentation & submittal (Task 13)	Develop GSP Implementation Schedule and Budget (Task 13)	DWR Coordination/Notification & correct deficiencies (task 14)	Mono County	Inyo County	Sustainable Groundwater Management Act (SGMA)	Lahontan Regional Water Quality Control Board	Department of Water Resources (DWR)	**Key Personnel**
Ukiah Valley Basin GSP Development*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	Foglia, Grovhoug, Mani, Arredondo
Siskiyou County - Basin GSP Development for Shasta, Scott and Butte Valley Groundwater Basins*	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	Foglia, Harter, Grovhoug, Elzufon
Omochumne-Hartnell Water District Groundwater Recharge and Groundwater Observatory*	•				•	•		•	•	•		•	•						•		•	Foglia, Grovhoug
Irrigated Land Project: Northern California Water Association Water Quality Monitoring*	•		•		•							•									•	Grovhoug, Trouchon, Arredondo
Scott Valley Groundwater Study*	•	•	•	•	•		•	•	•	•		•										Harter, Foglia
California WaterFix Groundwater Modeling Impact Assessment *	•				•		•	•														Foglia, Mani
Lower Santa Clara River Salt and Nutrient Management Plan *	•	•	•	•	•	•	•				•	•	•								•	Desai
Calleguas Creek Watershed Salt and Nutrient Management Plan	•	•	•	•	•	•	•		•		•	•	•									Desai, Mani
Omochumne-Hartnell Water District Basin Boundary Adjustment Request	•				•		•		•						•				•		•	Foglia
Calleguas Creek Watershed TMDL Implementation	•	•	•	•							•		•									Desai, Mani, Lewis
City of Santa Paula WDR Renewal, Recycled Water Program Development & Groundwater Impact Assessment	•	•			•		•	•				•	•									Elzufon, Desai
Victor Valley Wastewater Reclamation Authority	•	•			•			•				•	•							•		Elzufon
Nitrate in California Drinking Water - Tulare Lake Basin and Salinas Valley, CA*	•	•	•	•	•	•	•	•	•				•						•		•	Harter
Aqufer Testing of Two Water-Supply Wells & Associated Monitoring Well Network at Yosemite-Mammoth Airport	•				•		•	•		•		•					•			•		Slade, Hicke, LaPensee
Initial Site Study, Preparation of Technical Guidelines & Technical Oversight on two domestic water supply wells for development in Paradise Camp	•				•		•	•		•							•			•		Slade, Hicke, LaPensee
Hydrogeologic Evaluation and Well Siting Study for Bridgeport Indian Colony	•				•		•	•	•	•							•			•		Slade, Hicke, LaPensee
Limited Well Rehabilitation and Pumping Testing of Existing Water Supply Well in Rovana	•				•		•											•		•		Slade, Hicke, LaPensee

Table 1. LWA Team Experience (con't)

	Project Management			Technical Expertise													Local Experience		Regulatory Expertise			
Project	Facilitate & Coordinate with Client and Stakeholders	Prepare for/Attend Meetings and Workshops	Manage Multiagency Plan Development.	Public Engagement Plan (Task 2)	Data & document compilation, review & management (Task 3)	Coordination with GSA & landowners, local agencies, tribes (Task 4,15)	GSP Area & GSA Information. Basin Setting (Tasks 5,6)	Preparation of Groundwater Models (Task 6)	Develop Hydrogeologic Conceptual Models (Task 6)	Establish Historical and Future Water Budget Terms (Task 6)	Sustainable management criteria (Task 7)	Develop/ refine monitoring program (Task 9)	Identify projects and management actions to maintain or achieve sustainability (Task 10)	GSP Compilation, presentation & submittal (Task 13)	Develop GSP Implementation Schedule and Budget (Task 13)	DWR Coordination/Notification & correct deficiencies (task 14)	Mono County	Inyo County	Sustainable Groundwater Management Act (SGMA)	Lahontan Regional Water Quality Control Board	Department of Water Resources (DWR)	Key Personnel
Preparation of Drilling Guidelines and Technical Oversight of new Water-Supply Well at Tom's Place	•				•		•										•			•		Slade, Hicke, LaPensee
Hydrogeologic Evaluation of Crystal Geyser Pumping Facility at Cartago	•				•		•	•	•	•								•		•		Slade, Hicke, LaPensee
GSP Preparation, Cawelo Water District	•	•		•	•		•	•	•	•				•	•				•		•	Priestaf
GWMP and SGMA Support, San Benito County Water District *	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	Priestaf, Yates, McCraven
SGMA Support, City of Paso Robles						•		•						•					•		•	Priestaf, Yates
Groundwater Management Plan, City of East Palo Alto	•	•	•	•	•	•	•		•	•	•	•	•						•		•	Priestaf, Craig
GSP Preparation, Kern River GSA	•	•	•	•	•	•	•	•	•	•				•	•	•			•		•	Priestaf
SGMA Support, Stanislaus and Tuolumne Rivers Groundwater Basin Association	•													•		•			•		•	Priestaf
SGMA Support, West Turlock GSA	•													•		•			•		•	Yates
GWMP and SGMA Support, City of Corona	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•			•		•	Priestaf, Craig
SGMA Alternative Plan Support, Alameda County Water District	•					•	•	•	•	•	•		•		•				•		•	Priestaf, Craig
SGMA Alternative Plan, Zone 7 Water Agency	•	•	•		•		•		•	•	•	•	•	•	•				•		•	Priestaf
EIR, State of California DOGGR					•																	McCraven, Priestaf
Montebello Forebay Studies, WDR and LACSD		•			•		•	•	•	•		•				•					•	McCraven, Priestaf, Craig

2.0 Key Personnel

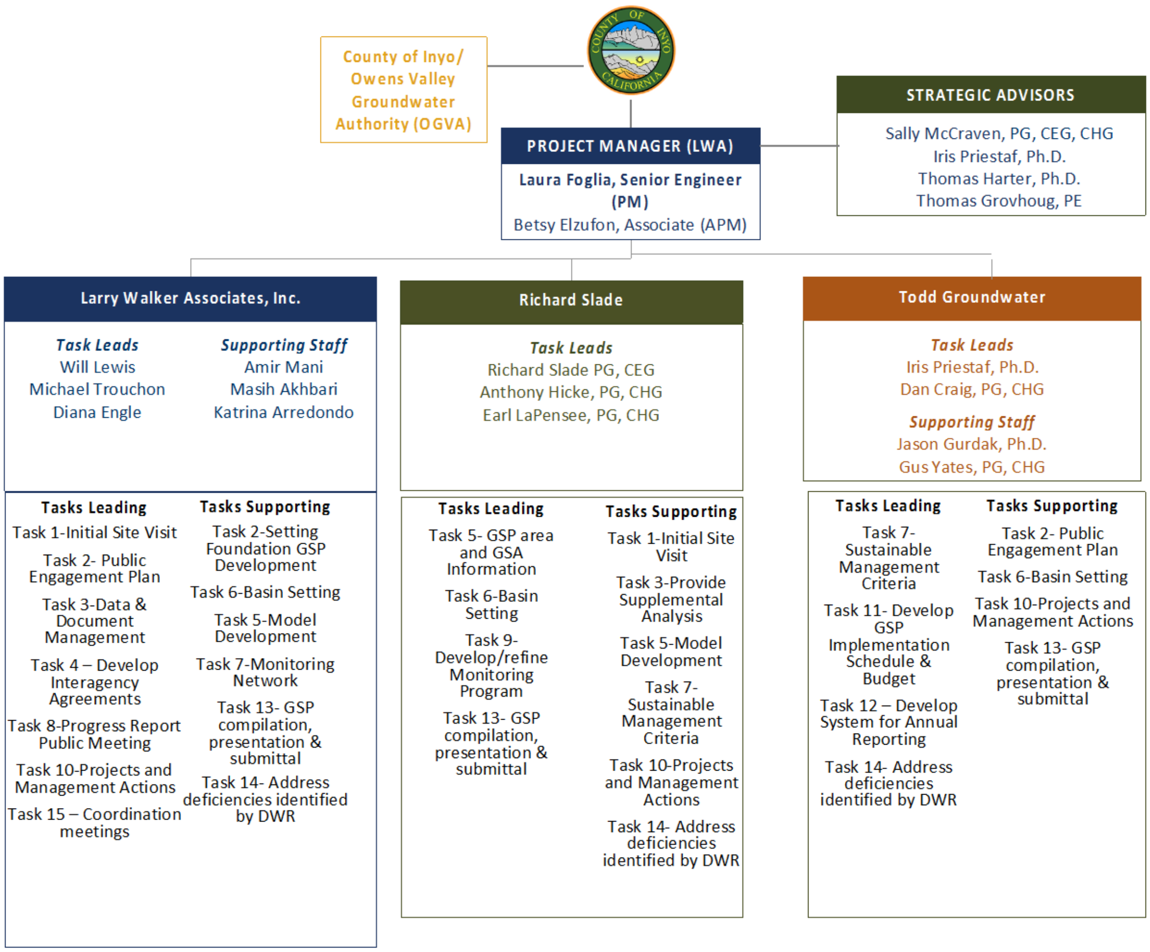
The LWA Team has available and qualified staff as well as the management efficiency and flexibility to meet the needs of the OVGA and this contract. Comprising individuals with relevant experience in groundwater resources management, the proposed personnel offer solid qualifications and experience in their field and are available for immediate assignment. The staff members will be available for the duration of the engagement starting from 90 days after the proposal due date, and changes to management and Team representatives will not occur without the OVGA's review and approval.

LWA utilizes a transparent management structure that offers the OVGA a single point of contact (POC) for the contract, yet provides direct access to the project's technical staff leading the tasks. The project team will be led by PM, Laura Foglia, who brings proven organizational and project management skills, coupled with a strong track record in leading project teams to accomplish specific technical tasks and addressing complex regulatory issues. Dr. Foglia will have contract implementation and coordination support from Ms. Betsy Elzufon who will perform as Assistant Project Manager. As the primary and day-to-day POC to the OVGA, Dr. Foglia will oversee the work performed for each task order, manage the contract, and ensure that work is completed on time and within budget. Dr. Foglia will be responsible for overseeing and coordinating all work and deliverables to be provided by subcontractors.

LWA will have the overall responsibility to the OVGA for the successful completion of all task orders and the delivery of high-quality project deliverables. The organizational chart ***(Figure 2)*** illustrates the project team composition and the functional relationships of the team members and primary personnel. Dr. Foglia will work closely with Thomas Harter, Thomas Grovhoug, Iris Priestaf and Sally McCraven as Strategic Advisors who will provide valuable statewide expertise in groundwater management. Dr. Foglia and the Strategic Advisors have worked closely together as a seamless team on other groundwater management projects and have the capacity to undertake this important work.

Below are highlights of the credentials and experience for LWA's PM and other key personnel, along with their assigned responsibilities. The project team has the unique experience, as well as the regulatory and technical expertise, to perform the tasks required to develop the GSP. The staff members have worked together for many years, including on the projects provided in *Sections 1.2 and 3.0*, thereby offering a seamless and efficient team with complementary skills. Detailed information on personnel assigned to perform on this project, including technical knowledge, education, licenses, training, certifications, and relevant experience, is provided in *Appendix B. Key Personnel Resumes*.

Figure 2. LWA Team Organization



LAURA FOGLIA
Project Manager

Responsibilities:

- Overall project performance and execution
- Ensure regulatory and contract compliance
- Primary day-to-day POC, communication and coordination with the OVGA
- Establish and implement processes and procedures to effectively manage project and obtain effective input from the OVGA and stakeholders
- Integrate extensive expertise on GDEs into the OVGB GSP.
- Review LWA and subcontractor work products

Dr. Laura Foglia is Senior Engineer with LWA and Adjunct Faculty in the department of Land, Air and Water Resources at University of California Davis (UCD). Dr. Foglia has 20 years of experience in groundwater modeling, integrated watershed modeling, and implementation with a focus on understanding integrated groundwater/surface water systems at the local and macro-scale. Her expertise emphasizes model calibration and uncertainty analysis and applications to different watersheds coupled to ecohydrological problems and enhanced water management solutions. Dr. Foglia has a M.S. in Physics from the University of Milan, Italy, and a Ph.D. in Civil and Environmental Engineering from the ETH in Zurich (Switzerland). Dr. Foglia has worked on large, complex projects involving water scarcity, salinity, and nitrate loads in Central Valley, California, seawater intrusion in the Mediterranean area, and in general with projects in the areas of hydrological modeling, and groundwater management assistance. Dr. Foglia is adjunct Associate Professor in the Land, Air, and Water Resources Department at UCD, where she teaches a graduate class on model calibration, supervises students, and works on a variety of model developments, such as the Scott Valley project for the assistance of the Scott Valley community with the development of the groundwater management plan. Dr. Foglia brings to the project an extensive knowledge about modeling and evaluating groundwater/surface water interactions and advanced expertise on sensitivity analysis and uncertainty evaluation, which are critical for the success of this project.

BETSY ELZUFON
Assistant Project Manager

Responsibilities:

- Assist the Project Manager with communication and coordination with the OVGA and contract implementation
- Provide day to day management of resources and subcontractor, and work plan and schedule
- Review LWA and subcontractor work products
- Support analysis of supplemental projects, stakeholder outreach, project and management action assessment, and other technical tasks as needed

Betsy Elzufon is an Associate with LWA and has more than 30 years' experience in the areas of chemical engineering, industrial processes, regulatory assistance and pollution prevention. Ms. Elzufon coordinates wastewater permit renewal for discharges to surface water (NPDES) and discharges to land [Waste Discharge Requirements (WDRs)] and permit implementation efforts for clients throughout California including the Lahontan Regions, Los Angeles, Central Valley, and Central Coast. Her familiarity with California's regulatory framework associated with groundwater management and the issues that face municipalities in the high desert and eastern regions of California is important for strategic oversight of groundwater projects. For WDRs in the Lahontan, Colorado River and Los Angeles Regions, she has managed projects to evaluate impacts to groundwater from wastewater and recycled water. In addition, she has worked with a coalition of stakeholders to evaluate sustainable water supply management approaches in the Mojave River Valley Groundwater Basin. She also assisted municipalities in

Ventura and San Bernardino Counties with obtaining and implementing Water Recycling Permits [Water Reclamation Requirements (WRRs), Master Reclamation Permits (MRPs)]. This included training staff and educating stakeholders and potential recycled water users on the benefits of recycled water. Stakeholder outreach was a key element in the development of an Integrated Plan for the City of Santa Maria. She conducted source identification studies and developed pollution prevention and outreach programs for several stormwater and wastewater programs in California. She also assisted several municipalities in evaluating and updating various elements of their pretreatment programs. She managed national studies on source control and program effectiveness measurement for the Water Environment Research Foundation and the National Association of Clean Water Agencies (NACWA). She managed a national study on Municipal-Agricultural Collaboration for NACWA. Ms. Elzufon has a B.S. and an M.S. in Chemical Engineering.

DIANA ENGLE, PH.D.

Groundwater Dependent Eco-System Assessment

Responsibilities:

- Develops technical information and analysis associated with groundwater dependent ecosystems
- Review project documents, plans, and reports
- Communication of technical results to stakeholders

Diana Engle will serve as Project Advisor. Dr. Engle is a Senior Scientist managing the Ventura office of LWA, where she has worked for more than 9 years in such areas as water quality assessment and monitoring, contaminant source assessment, watershed balances, fate and transport of nutrients and other constituents, aquatic toxicity, algal and food web dynamics, surface- and ground water interactions, impacts of effluent diversion and reuse, nutrient criteria development, biocriteria, pathogen monitoring and special studies, and other areas of nexus between water quality regulation and watershed science. In addition, Dr. Engle provides support on a wide variety of other regulatory issues affecting wastewater, stormwater and agricultural clients. Recent projects include TMDL implementation plans and special studies, Salt and Nutrient Management Plans, continuous monitoring of salts, surface flow, and groundwater recharge, agricultural BMP evaluation and tailwater monitoring. Prior to joining LWA, Dr. Engle held appointments in several arms of the University of California, Santa Barbara, including the Marine Science Institute, the Donald Bren School of Environmental Science & Management, and the Institute for Computational and Earth System Science. In addition, she has worked as a consultant for the U.S. National Park Service, U.S. Geological Survey, private firms and NGOs. She holds a B.S. in Biology from the University of Michigan, Ann Arbor, and a Ph.D. in Aquatic & Population Biology from the University of California, Santa Barbara.

THOMAS HARTER, PH.D.
Strategic Advisor

Responsibilities:

- Supports the Project Manager with day-to-day execution of specific tasks
- Provide technical expertise and extensive experience on groundwater modelling, water budget and representation of GDEs into numerical models
- Communication of technical results to stakeholders

Thomas Harter is the Robert M. Hagan Endowed Chair for Water Resources Management and Policy at the UC Davis. Dr. Harter holds a joint appointment as Professor and Cooperative Extension Specialist in the Department of LAWR, and is currently chair of the Hydrologic Sciences Graduate Group. He spent the first six years of his career with UC Davis at the Kearney Agricultural Research Center in Fresno County, where he became familiar with the San Joaquin Valley groundwater management and protection issues and established his research program in agricultural groundwater hydrology – a program he has continued to pioneer over the past 15 years at UC Davis. Dr. Harter is a member of the American Geophysical Union and is serving on the Board of Directors of the Groundwater Resources Association and of the Water Education Foundation. Dr. Harter's research and extension emphasizes the nexus between groundwater and agriculture. His research group focuses on nonpoint-source pollution of groundwater, sustainable groundwater management, groundwater and vadose zone modeling, groundwater resources evaluation under uncertainty, groundwater-surface water interaction, and on contaminant transport. Dr. Harter's work uses a range of numerical, statistical, and stochastic modeling approaches as well as field work to evaluate the impacts of agriculture and human activity on groundwater flow and contaminant transport in complex aquifer and soil systems. These approaches support development of tools needed by agriculture industry stakeholders as well as decision- and policy-makers. In 2008, Dr. Harter's research and extension program received the Kevin J. Neese Award in recognition of 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.

RICHARD SLADE, PG, CEG
Monitoring Network Task Lead

Responsibilities:

- Lead development of groundwater monitoring plan for GSP
- Coordinate RCS work, and oversee/review all RCS work products
- Provide expert review of GSP sections
- Provide insight into history of groundwater development in the OVGB.

Richard Slade, PG, CEG, is President and a Principal Hydrologist with RCS. He maintains professional licenses as a PG and CEG in California. Mr. Slade has more than 51 years of groundwater experience in Southern California and has lived and/or worked in the San Fernando Valley as a groundwater geologist for his entire professional career. Mr. Slade has a B.S. and an M.S. in Geology from University of California, Los Angeles (UCLA) and University of Southern California (USC), respectively, and has conducted and/or managed/supervised more than ***700 groundwater projects in many groundwater basins throughout California, including the Owens Valley Basin*** and virtually every recognized groundwater basin in Southern California that has active water wells. Since 2009, Mr. Slade has served the Superior Court as the court-appointed Watermaster for ULARA.

EARL LAPENSEE, PG, CHG
Hydrogeologic Conceptual Model Task Lead

Responsibilities:
- Lead development of hydrogeologic conceptual model
- Oversee support staff during creation of geologic cross sections and report preparation.

Earl LaPensee, PG, CHG, is Senior Groundwater Geologist and PM with RCS. Since starting with RCS in 1989, Mr. LaPensee has conducted many diverse groundwater projects including; the siting, design, construction monitoring and aquifer testing of more than 300 municipal-supply and irrigation water wells; analyses of aquifer systems in numerous groundwater basins (involving the definition of geologic/hydrogeologic conditions, water level and water quality conditions, groundwater underflow, calculation of groundwater in storage and changes in storage). A primary focus in these projects has been on the characterization of aquifer systems (determination of physical parameters such as transmissivity and storativity) and spatial delineation of natural groundwater chemistry (especially with regard to trace element concentrations) and contaminant chemistry, evaluation of water level trends over time, definition of groundwater flow directions, and the use and correlation of geophysical electric logs from water wells and oil wells to help define aquifer continuity and extent.

ANTHONY HICKE, PG, CHG
Basin Setting Task Lead

Responsibilities:
- Lead data collection and analysis effort
- Oversee field visits to collect new data and/or verify existing data
- Compile data into format consistent with DWR data requirements.

Anthony Hicke, PG, CHG, is a Senior Groundwater Geologist and PM with RCS and has been with the company since 2001. Major areas of groundwater work include numerous groundwater development projects, including well construction projects, groundwater basin evaluations, and aquifer testing studies throughout California for Municipal entities and agricultural clients. In addition, Mr. Hicke serves as the lead geologist during the creation of hydrogeologic conceptual models, including the management and utilization of large electronic databases of subsurface geologic data for use in preparing Hydrogeologic Evaluations of California Groundwater basins. Such evaluations include calculating estimates of underflow and groundwater in storage, review and analysis of water quality data; pumping data analysis, and performing groundwater in storage calculations. For previous basin study projects, Mr. Hicke has managed multiple large databases of water level data, geologic data, and GIS data. Since Mr. Richard Slade's appointment as the ULARA Watermaster in December 2008, Mr. Hicke has performed the duties of the Assistant ULARA Watermaster.

Iris Priestaf, Ph.D., President of Todd Groundwater, has more than 30 years' experience in groundwater investigations with a focus on groundwater basin management. She has worked with numerous water agencies, cities, and counties in preparation of management plans, including recent work supporting agencies with SGMA planning and Alternative Plan/GSP development. Dr. Priestaf is a recognized expert on SGMA. She will provide for pre-GSP notification and outlining of the GSP and will apply her SGMA expertise to description of the GSP area, definition of management areas, and determination of quantitative sustainability criteria. Dr. Priestaf is experienced with public speaking and workshops and will participate in outreach. Following preparation of the GSP, she will be available for coordination with the DWR. Dr. Priestaf participated actively in planning SGMA through the ACWA and works with water agency representatives from throughout California, discussing SGMA in terms of its ramifications for local agencies and communities, and developing commentary and advice for DWR. Dr. Priestaf currently is co-chair of the Subcommittee on Groundwater Management and Land Use Planning which seeks to improve the coordination for SGMA between water and land use planning agencies that is fundamental for lasting sustainability.

IRIS PRIESTAF, PH.D.

Pre-GSP and DWR Coordination Task Lead

Responsibilities:

- Lead preparation of Plan Area and Management Area sections of Basin Setting section
- Coordinate communications with DWR
- Oversee preparation of Todd technical tasks
- Participate in meetings and workshops

GUS YATES, PG, CHG

Groundwater Modeling Support

Responsibilities:

- Hydrogeologic Conceptual Model
- Numerical Modeling Technical Review

Mr. Yates is a senior hydrologist with Todd Groundwater and an accomplished hydrogeologist with 30 years' experience, including work with water budget studies and numerical modeling. He is an acknowledged expert in basin yield analysis, groundwater modeling, quantification of groundwater budgets, and evaluation of stream-aquifer interactions. Mr. Yates will apply his analytical and modeling skills to assessment, reconciliation, and consolidation of existing groundwater models in the Tri-Valley region. He will provide review and direction for the hydrogeologic conceptual model development. As an example of his experience on a similar study, he evaluated all available models for the Santa Clara Valley Subbasin, refined and extended the selected numerical model into the San Mateo Plain Subbasin based on a detailed refined hydrogeologic conceptual model, and applied the model to evaluate impacts of increased pumping and artificial recharge.

MAHSI AKHBARI, PH.D.

Public Engagement Process, Water Resources Support

Responsibilities:

- Supports the Project Manager with day-to-day execution of specific tasks
- Supports model building, hydrologic analysis, and tailored analytical and numerical tools development
- Supports preparation of Public Engagement Plan
- Develops materials and provides facilitation for public meetings

Masih Akhbari joined LWA as a Project Engineer II in July 2018. He is experienced with interdisciplinary projects that require systemic approaches to plan and manage water supply in the context of environmental concerns, sustainability, and climate change. He has co-authored a textbook on groundwater hydrology and developed multiple conceptual, hydrologic, and integrated models as decision-making support tools to plan and manage water resources. Masih obtained his PhD (2012) in Civil and Environmental Engineering from Colorado State University followed by two postdoctoral research positions at UC Davis and Colorado Water Institute. Then, he joined RTI International (formerly Riverside Technology) as a water resources engineer. Aside from engineering design, model building, and hydrologic analysis, the projects that Masih has conducted involved collaboration with decision-makers and stakeholders, facilitation among them, incorporation of social science concepts into the engineering models, managing and analyzing large data sets, and computer programming. He has facilitated meetings in highly interdisciplinary settings where farmers, environmentalists, water lawyers, policy analysts, academic figures, and water conservation districts' staff convened to share their concerns about conserving agricultural water. Masih has also facilitated a working group at a workshop, where experts from the Department of State, USACE, Department of Energy's national laboratories, nongovernmental organizations, industry, and academia convened to provide feedback on the U.S. perspective on the water-energy-food nexus. In 2015, Masih partnered with a sociologist at Colorado State University to co-facilitate an impactful short-course on "Student Water Dialogues". The course was designed to help undergraduate and graduate students from different disciplines, departments, and backgrounds to expand their perspective about water-related wicked problems, especially in the West, and develop skills on how to productively engage in/ or facilitate water conflicts. Additionally, Masih has served as a review panelist for NSF Graduate Research Fellowship Program, as a session chair at the AGU Fall Meeting, and as a discussion panelist at the AWRA Annual Water Resources Management Conference.

WILL LEWIS, CPESC, CPSWQ
Modeling support

Responsibilities:
- Lead incorporation of EWMP goals and projects
- Oversee staff in modeling of surface water/groundwater interaction
- Oversee assessment of other opportunities to optimize basin use
- Support assessment of projects and management actions

Will Lewis is a Senior Scientist at LWA with more than 15 years of experience in the water resource management field. Mr. Lewis has focused on utilizing computational tools, specifically GIS and hydrologic modeling programs with focus on integrating surface water/groundwater to support the one-water approach for watershed planning efforts. Most recently, he has been involved in the development of modeling approaches to support stormwater permit requirements across California, including involvement in several EWMPs. Mr. Lewis has also developed a series of novel approaches to support the development of a series of TMDL implementation plans, stormwater resource plans, and watershed management plans in the San Francisco Bay Area, Central Valley, and southern California. At his previous firm, Mr. Lewis was involved in the preparation of the Los Angeles Department of Water and Power Stormwater Capture Master Plan and the Water Replenishment District of California's Southern California Groundwater Augmentation Study. Mr. Lewis has a M.S. in Environmental Science and Management, Water Resources Concentration and a B.A. in Environmental Studies. He is a Certified Professional in Erosion and Sediment Control (CPESC) and Certified Professional in Stormwater Quality (CPSWQ).

MIKE TROUCHON
Data Management Task Lead

Responsibilities:
- Lead development of data management system if requested
- Oversee all task activities performed by support staff

Mike Trouchon is a Senior Scientist and the Lead Data Management Architect with LWA. Mr. Trouchon has 25 years of experience in the water quality and water resources fields, with multiple assignments that have required the development of data management processes and data management systems (DMS) to store, analyze, and report a wide variety of environmental data types to various State regulatory agencies. He also has 22 years of experience designing, building, and managing relational databases for a variety of surface water, stormwater, and wastewater monitoring programs. His experience includes developing relational databases with Microsoft Access and Microsoft Visual Basic; developing and implementing protocols for data reporting, data processing, data validation, and data archiving; and leading the development of data quality evaluation plans and Quality Assurance/Quality Control (QA/QC) procedures that oversee the data management activities of various wastewater, surface water, stormwater, and agricultural monitoring programs. Mr. Trouchon has significant experience in aiding water quality monitoring programs comply with California Integrated Water Quality System (CIWQS), Surface Water Ambient Monitoring Program (SWAMP), and California Environmental Data Exchange Network (CEDEN) data requirements. He is also a specialist in the validation and analysis of environmental and QA/QC water quality data, and water quality standards compliance assessment. Mr. Trouchon has a B.S. in Botany and an M.S. in Aquatic Ecology.

3.0 Project Experience

The LWA Team's reputation is a direct result of the dedication of our professional staff and our commitment to fostering long-term relationships built on trust with our clients. Below are 12 public agency references who can attest to each firm's experience and past performance on projects with comparable services, including our ability to deliver work of the highest quality and our history of meeting schedule and budget requirements. We are listing 12 references, but we can provide additional references who can confirm our expertise, professional character and integrity, and proven processes that deliver projects on time, within budget, and to the satisfaction of our clients. Further demonstration of the LWA Team's experience performing similar scope and services is provided in ***Table 1*** in *Section 1.2*.

Project 1. Ukiah Valley Basin GSP Development

Organization Name:	Ukiah Valley Basin Groundwater Sustainability Agency
Address	501 Low Gap Road, Room 1010, Ukiah, CA 95482
Contact	Sarah Dukett, (707) 463-4441, uvbgsa@mendocinocounty.org
Dates of Service:	2018 – present
Key Personnel:	Laura Foglia, Ph.D.; Tom Grovhoug, P.E.; Amir Mani, Ph.D.; Katrina Arredondo, Ph.D.

Brief Description of Products/Services Provided:

Starting in 2016, LWA has led a consultant team to work with the Ukiah Valley Basin Groundwater Sustainability Agency (UVBGSA) in developing a GSP for the Ukiah Valley groundwater basin.

The LWA Team will assist UVBGSA with evaluating the most cost and resource effective plan toward groundwater sustainability, in compliance with SGMA. Extensive communication with UVBGSA members and Ukiah Valley stakeholders will ensure that groundwater management remains at the local level, while sustainably managing groundwater resources.

LWA's efforts include:

- **Program Management and Client Coordination.** Given the complexity of the work effort and the need to communicate with and involve a diverse set of stakeholders, the LWA Team will maintain clear lines of communication, inform and receive input from stakeholders on an ongoing basis, and ensure completion of quality work on time and within budget.
- **Communication, Facilitation, and Outreach.** The LWA Team will develop and establish a Project Communication Plan to ensure efficient and effective communication with stakeholders, including: how interested parties/stakeholders will be informed regarding project status, access to reports and data, public meeting opportunities, methods for promoting active participation, and an internet communications strategy.

RELEVANCE TO RFQ

- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop and document groundwater budget
- ✓ Spatiotemporal distribution of groundwater pumping, surface water diversions, groundwater recharge, and evapotranspiration
- ✓ Develop groundwater quality database, perform water quality assessment, implement groundwater quality modeling
- ✓ Develop future modeling scenarios
- ✓ Assessment of impacts and benefits of each potential land and water management activity
- ✓ Public outreach for the Basin SGMA and GSP process
- ✓ Data collection, development, and management
- ✓ Develop protocols for achieving and/or maintaining sustainability
- ✓ Develop groundwater management, assessment, and implementation
- ✓ SGMA
- ✓ Support for groundwater quality regulatory programs
- ✓ California agricultural practices and challenges

- **Data Gap Analysis on Surface Water/Groundwater Interaction and Monitoring Protocol.** LWA will assist as needed with updating monitoring protocols as recommended by the Technical Advisory Committee (TAC) review of the Phase 1 gap analysis technical memorandum, surface water/ groundwater interaction data gap analysis, and monitoring protocol manual.
- **Integrate Management Strategies, Define Alternatives, and Select UVGSP Preferred Alternative.** LWA will condense UVBGSA proposed groundwater management scenarios into testable models within MODFLOW-2005. The MODFLOW alternative models will be used to evaluate and compare alternatives against each other and a future baseline developed by the LWA Team. The technical

analysis results will be used to identify any undesirable results and analyzed for the SGMA sustainability indicators and thresholds.

- **MODFLOW Alternatives Evaluation.** LWA will use the calibrated MODFLOW-2005 model developed by the LWA Team and the testable alternative model developed by LWA to characterize the benefits of groundwater projects, programs, and policies proposed by UVBGSA. The alternatives will be compared and evaluated against a future baseline (no-action) analysis and water budget, along with climate change scenarios.
- **Develop Sustainability Goals and Measurable Objectives.** Measurable objectives are goals reflecting the desired condition of the groundwater basin in 20 years, and are shaped by an understanding of current demands and forecast of future demands for the Ukiah Region. LWA will work with the TAC throughout their review process and incorporate new analysis of water quality, potential recharge and discharge areas, as well as areas sensitive to surface water depletion from groundwater pumping when defining measurable objectives and minimum thresholds.
- **Inventory and Review Plans, Projects, Programs, and Policies.** Groundwater management requires knowledge of existing and planned land use or water use within the given groundwater basin as the associated implementation actions may affect groundwater management. LWA will identify and review current local, state, and federal land use and water use plans such as General Plans and other land use plans, including capital improvement plans, urban and agricultural water management plans, and the North Coast Integrated Regional Water Management Plan (IRWMP), to ascertain existing land use or water use implementation actions that may affect groundwater management and the Russian River.
- **Review Groundwater and Resources Management Measures.** We will work with the UVBGSA and the various committees and work groups to ensure those making management decisions are fully informed about possible management measures and strategies. As part of this work, the LWA Team will review various groundwater management measures and the BMPs identified by the DWR for possible consideration by the UVBGSA.
- **Develop UVBGSP Implementation Plan.** As the final step of the project and building upon the results produced in the previous tasks, LWA will assist the UVBGSA with developing an implementation plan to meet all SGMA and State of California regulations. The implementation plan is a highly detailed document defining monitoring and reporting requirements, roles and responsibilities, schedules, funding requirements, adaptive management strategies, how to assess public and stakeholder reactions to project implementation, and how project sequencing may be altered as implementation is carried out.

Prepare Administrative Draft, Public Draft, and Final UVBGSP. LWA will compile the technical work completed by the LWA Team and UVBGSA input into a document that can be adopted by the UVBGSA. An administrative draft of the UVBGSP will be reviewed by Groundwater Sustainability Agency (GSA) members and the TAC, followed by a public draft presented to the public for review. Public written and oral comments will be received at UVBGSA meetings and after review, used to prepare the final UVBGSP.

Project 2. County of Siskiyou – Developing Groundwater Sustainability Plans for the Shasta, Scott and Butte Valley Groundwater Basins

Organization Name:	Siskiyou County Natural Resources Department ***<<Similar Organization***
Address	1312 Fairlane Rd., Yreka, CA 96097
Contact	Elizabeth Nielson, (530) 842-8012, enielsen@co.siskiyou.ca.us
Dates of Service:	2018 – present
Key Personnel:	Laura Foglia, Ph.D.; Tom Grovhoug, P.E.

Brief Description of Products/Services Provided:

Starting in 2018, LWA will lead a consultant team to work with the Siskiyou County Flood Control and Water Conservation District (District) in developing three separate GSPs for the Shasta, Scott and Butte Valley groundwater basins.

The LWA Team will assist the District with evaluating the most cost and resource effective plan toward groundwater sustainability, in compliance with SGMA. Extensive communication with District members and Shasta, Scott and Butte Valley stakeholders will ensure that groundwater management remains at the local level, while sustainably managing groundwater resources.

LWA's efforts include:

- Public Outreach and Engagement
- Data Collection, Development, and Management
- Water Budget Development
- Development of Sustainability Criteria
- Monitoring Programs, Protocols and Networks
- Writing and Reporting of Documents

RELEVANCE TO RFQ

- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop and document groundwater budget
- ✓ Spatiotemporal distribution of groundwater pumping, surface water diversions, groundwater recharge, and evapotranspiration
- ✓ Develop groundwater quality database, perform water quality assessment, implement groundwater quality modeling
- ✓ Develop future modeling scenarios
- ✓ Assessment of impacts and benefits of potential land and water management activity
- ✓ Public outreach for the Basin SGMA and GSP process
- ✓ Data collection, development, and management
- ✓ Develop protocols for achieving and/or maintaining sustainability
- ✓ Develop groundwater management, assessment, and implementation
- ✓ Support for groundwater quality regulatory programs

Project 3. Omochumne-Hartnell Water District Groundwater Recharge and Groundwater Observatory

Organization Name:	Omochumne-Hartnell Water District
Address	7513 Sloughouse Road, Elk Grove, CA 95624
Contact	Mike Wackman, (916) 682-5958, info@ohwd.org
Dates of Service:	2016 – present
Key Personnel:	Laura Foglia, Ph.D.; Tom Grovhoug, P.E.

Brief Description of Products/Services Provided:

OHWD received funding in 2011 to implement a groundwater banking project through a Proposition 84 Integrated Regional Water Management (IRWM) grant submitted by the Regional Water Authority (RWA). As the lead consultant, LWA assisted OHWD with repurposing the existing grant into an off-season irrigation project to enhance aquifer recharge to the underlying groundwater aquifer and the South American and Cosumnes groundwater basins. LWA provided a revised Proposition 84 grant proposal, including detailed scope and budget, for submittal to the DWR for project approval.

The funding received will be used to divert 4,000 acre-feet (AF) per year of surface water to a more than 80 acre spreading basin between the Cosumnes River and Deer Creek. This water would help enhance aquifer recharge to the underlying groundwater aquifer and the South American and Cosumnes groundwater basins. The anticipated water table increase would allow the Cosumnes River to run for longer periods during the spring and summer, and earlier flowing in the fall. This would provide benefits to the environment by better simulating the nature flow regime of the Cosumnes River, and increasing the sustainability of the groundwater basins.

RELEVANCE TO RFQ

- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop and document groundwater budget
- ✓ Assessment of impacts and benefits of each potential land and water management activity
- ✓ Public outreach for the Basin SGMA and GSP process
- ✓ Data collection, development, and management
- ✓ Knowledge of numerical groundwater models
- ✓ Develop monitoring program
- ✓ Develop groundwater management, assessment, and implementation
- ✓ Support for groundwater quality regulatory programs
- ✓ California agricultural practices and challenges

OWHD is currently in the process of optimizing and finalizing the design and construction of the groundwater recharge project, with results presented here. Over a 10-year period, the project will use two existing diversion points on the Cosumnes River to flood dormant agricultural fields in the off-(irrigation) season between the months of November and March when streamflow is high and excess water is available. The project goal is to divert a minimum of approximately 4,000-AF of water per year to recharge the groundwater aquifer, but based on water availability in the river, the system will be designed to divert and recharge up to 6,000-AF per year. The region between Deer Creek and the Cosumnes River provides an ideal region for groundwater banking due to readily transmissible and lower salinity soils, suitable topography, and root zone residence time. A preliminary overview of the area identified agricultural fields with good water access, crop suitability, soil permeability, and land owner interest and agreement.

Continued performance monitoring of the project is required to show that it is meeting the objectives and priorities of the IRWMP. Groundwater monitoring for quantity, water quality, evapotranspiration, and soil moisture will provide a quantitative metric of the off-season irrigation on local groundwater levels and storage.

LWA is providing overall project management for the planning, design, engineering, and construction of the surface water diversion pumps and conveyances along the lower Cosumnes River, as well as any irrigation design modifications which would allow for groundwater recharge on the identified land parcels. LWA will assist with the installation of new, or identification of existing, monitoring wells or monitoring well networks in the vicinity of the irrigation flooding to provide a means to assess and quantify groundwater impacts.

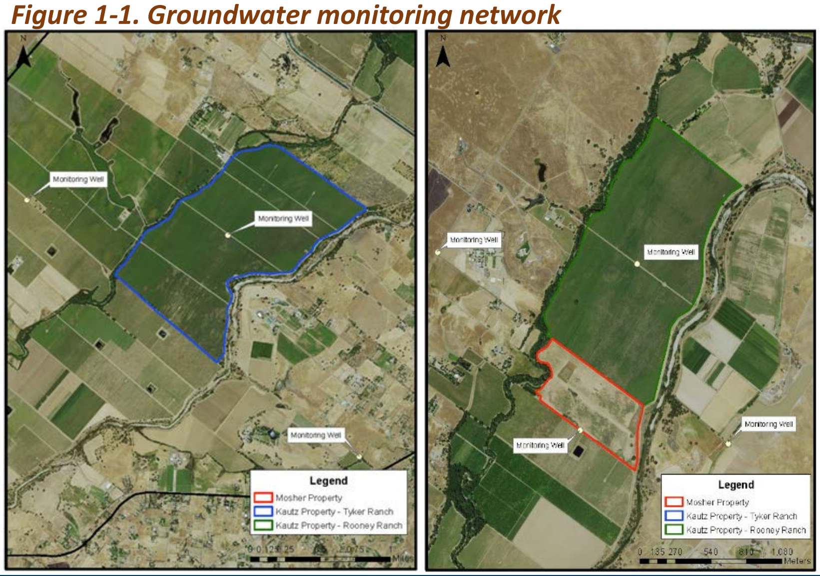
LWA has worked on, or is currently working on, the following activities on behalf of the OHWD:

- Ongoing stakeholder coordination;
- Developing RFPs for irrigation system design and monitoring well installation;
- Mapping and GIS shapefiles creation;
- Selection and characterization of recharge sites;
- Regulatory permitting assistance;
- Calculations for water application rates; and
- Overseeing groundwater monitoring network installation and ongoing monitoring implementation.

LWA is actively collaborating with the UC Water Team to include the groundwater level data collected in the framework of the recharge project into the larger groundwater observatory that is under development in the South American and Cosumnes subbasins.

Monitoring is an important component of the groundwater recharge project in order to measure the impact of the off-season application on local groundwater levels and storage. Currently, there is an extensive array of privately-owned wells installed along the Lower Cosumnes River that have been manually monitored by UC Davis researchers in the past. Existing wells have been analyzed and will be used as extensively as possible. OHWD will install the remaining needed monitoring wells (4 new wells) closer to the project location and will coordinate the monitoring efforts. An idealized groundwater monitoring network with a minimum of 7 wells between the three site locations are show in ***Figure 1-1.*** Two locations would include nested monitoring wells to assist with measuring the vertical gradients. OHWD will coordinate with Sacramento County to obtain the necessary permits to drill and install the groundwater monitoring wells. Field experience during drilling will determine the final well design.

Figure 1-1. Groundwater monitoring network



Self-sustained Solar Data loggers will be purchased and installed at each well to monitor water level. The same Data Loggers will be used in other areas of the Cosumnes river basin and will be installed by scientists from UC Davis and CSU Sacramento. The goal is to create a unique network of data that will be used as an example for future groundwater monitoring for the SGMA compliance.

Project 4. Irrigated Land Project: Northern California Water Association Water Quality Monitoring

Organization Name:	Sacramento Valley Water Quality Coalition
Address	455 Capitol Mall, Suite 335, Sacramento, CA 95814
Contact	Bruce Houdesheldt, (916) 442-8333, bruceh@norcalwater.org
Dates of Service:	2004 – present
Key Personnel:	Thom Grovhoug, P.E.; Katrina Arredondo, Ph.D.

Brief Description of Products/Services Provided:

RELEVANCE TO RFQ

- ✓ Data collection, development, and management
- ✓ Public engagement and stakeholder outreach
- ✓ Multi-agency coordination
- ✓ California agricultural practices and challenges

Since 2004, LWA has managed and implemented the surface water quality Monitoring and Reporting Program (MRP) in the Sacramento River watershed for the Sacramento Valley Water Quality Coalition (SVWQC) to meet the conditions of the Central Valley Water Board's Conditional Waiver of Waste Discharge Requirements (Conditional Waiver, 2004 – 2013) and WDRs (2014 – present) for the ILRP. LWA developed the monitoring strategy to meet the requirements of the Coalition's original Conditional Waiver and its current WDR, including the requirement to perform compliance monitoring for the Diazinon and Chlorpyrifos Total Maximum Daily Load (TMDL) in the Sacramento and Feather Rivers and the Sacramento-San Joaquin Delta. LWA is the lead consultant with the SVWQC in managing and implementing this monitoring program and assisted in negotiating the scope of the MRP adopted by the Central Valley Water Board.

LWA is responsible for managing the Coalition's compliance monitoring and reporting of water column and sediment chemistry and toxicity data, including follow-up sample collection; development of an annual Monitoring Plan Update that reflects WDR and MPR requirements and recent monitoring results; preparation and maintenance of the Quality Assurance Project Plan (QAPP); development and annual updating of the Comprehensive Surface Water Quality Management Plan (CSQMP); development and completion of individual site and pollutant-based Management Plans; preparation of Source Evaluation Reports (SERs); monthly exceedance report preparation based on compliance evaluations with numeric and narrative Basin Plan objectives for water chemistry and toxicity; and data validation, management, and quarterly reporting to the ILRP.

LWA works closely with NCWA and SVWQC to develop WDR and MRP-required communications for submittal to the Central Valley Water Board, including: Annual Monitoring Report (AMR), Management Plan Progress Report (MPPR), and an annual update of monitoring activities in support of compliance with the Diazinon and Chlorpyrifos TMDLs.

LWA also aids the Coalition with interpretation of Central Valley Water Board policy, and outreach and education programs for subwatersheds, landowners, and growers. Outreach and education efforts include informing subwatersheds and farmers of their responsibilities for WDR compliance, as well as summaries of water quality monitoring data. As part of LWA's support for this project, staff also participates in the Technical Issues Committee that provides technical guidance to the Central Valley Water Board on the design and modification of the ILRP MRP. LWA and PER communicate and coordinate extensively with Central Valley regulators to develop the monitoring and assessment program for the Coalition's ***large group of landowners with their own unique issues and constraints***.

Project 5. Scott Valley Groundwater Study, Scott Valley, California

Organization Name:	North Coast Regional Water Quality Control Board ***<<Similar Organization***
Address	5550 Skylane Blvd Ste. A, Santa Rosa, CA 95403
Contact	Bryan McFadin, 707.576.2751, bryan.mcfadin@waterboards.ca.gov
Dates of Service:	2007 – Present
Key Personnel:	Thomas Harter, Ph.D.; Laura Foglia, Ph.D.

Brief Description of Products/Services Provided:

The Scott Valley Groundwater/Surface Water Management Project was funded by the North Coast Regional Water Quality Board. The aim of the project is to assist the Scott Valley community with the implementation of the Scott River TMDL requirements for the basin. The Scott River experiences locally high temperatures during low flow periods due to impacts from groundwater pumping and climate change on groundwater discharge to baseflow. UC Davis developed the Groundwater Study Plan (2008) and the Scott Valley Integrated Hydrologic Model (2013), which has since been calibrated and an update of which is currently being completed to develop water management scenarios and to test the effectiveness of some proposed solutions. The modeling tools provide a better understanding of the groundwater, agricultural irrigation, and surface water systems and hydrology in Scott Valley; and they provide decision support on the development and evaluation of groundwater management practices that address streamflow conditions during the summer months while preserving water needed for agricultural land uses. UC Davis, with the local Cooperative Extension office, employed a participatory stakeholder approach and engaged voluntary assistance from communities, landowners, the Groundwater Advisory Committee, and the Siskiyou Resource Conservation District (SRCD). Stakeholders help inform the modeling process and scenario development, and communicate with decision-makers and regulatory agencies engaged in balancing salmon ecosystem protection and water management in Scott Valley. The participatory approach was structured to include the following steps:

- Identify common goals;
- Identify range of potential solutions;
- Select agreeable management options and identify potential concerns;
- Evaluate promising options (modeling / field testing); and
- Select and test workable solution for implementation.

RELEVANCE TO RFQ

- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop and document groundwater budget
- ✓ Spatiotemporal distribution of groundwater pumping, surface water diversions, groundwater recharge, and evapotranspiration
- ✓ Develop future modeling scenarios
- ✓ Assessment of impacts and benefits of each potential land and water management activity
- ✓ Public outreach for the Basin SGMA and GSP process
- ✓ Data collection, development, and management
- ✓ Develop protocols for achieving and/or maintaining sustainability
- ✓ Develop groundwater management, assessment, and implementation

Project 6. Addressing Nitrate in California's Drinking Water with a Focus on the Tulare Lake Basin and Salinas Valley, California

Organization Name:	State Water Resources Control Board
Address	1001 I Street, Sacramento, CA 95814
Contact	Erik Ekdahl, 916.341.5300, erik.ekdahl@waterboards.ca.gov
Dates of Service:	2010 – 2012
Key Personnel:	Thomas Harter, Ph.D.

Brief Description of Products/Services Provided:

The Nitrate Report was funded by the State Water Resources Control Board (SWRCB) based on a request by the legislature, SBX2 1 (2008). The project implemented a comprehensive assessment of nitrate sources, groundwater nitrate, and communities impacted by nitrate in drinking water. The report provided the foundation for SWRCB recommendations to the legislature to address nitrate in drinking water.

The interdisciplinary UC Davis project team included 9 faculty principal investigators and 17 graduate students and academic researchers. The UCD team worked closely with SWRCB, counties, and stakeholders to identify and quantify past and current potential sources of nitrate, to identify management practices that lead to future reductions in groundwater nitrate, to assess past and current groundwater nitrate conditions, to identify groundwater remediation options, to assess the impact to communities with nitrate in drinking water, to develop alternative drinking water supply, and to develop and assess costs for and policies for a range of potential actions.

Stakeholder engagement included regular meetings with the SWRCB, the organization of three workshops with an Interagency Task Force (ITF) of over one dozen local and state agencies, numerous stakeholder group outreach meetings during the preparation of the report and following the release of the report in 2012. Project deliverables included a press conference, a report workshop, English and Spanish versions of the project summary, an 80-page main report, eight detailed technical reports, and the creation of a project website that also serves as a data and publication repository, http://groundwaternitrate.ucdavis.edu.

RELEVANCE TO RFQ

- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop groundwater quality database, perform water quality assessment, implement groundwater quality modeling
- ✓ Develop future modeling scenarios
- ✓ Assessment of impacts and benefits of each potential land and water management activity
- ✓ Public outreach for the Basin SGMA and GSP process
- ✓ Data collection, development, and management
- ✓ Develop protocols for achieving and/or maintaining sustainability
- ✓ Develop groundwater management, assessment, and implementation
- ✓ Support for groundwater quality regulatory programs

Project 7. Sacramento County Water Agency: California WaterFix Groundwater Modeling Impact Assessment

Organization Name:	Sacramento County Water Agency ***<<Similar Organization***
Reference Contact:	Kerry Schmitz, Chief, Division of Water Resources, Sacramento County Water Agency | 209-577-5200, schmitzk@saccounty.net
Project Dates:	7/2016 - Ongoing
Consultant Name and Role:	Larry Walker Associates (Lead Consultant)
Key Personnel:	Laura Foglia, Ph.D.; Steffen Mehl, Ph.D.; Katrina Arredondo, Ph.D.; Nima Jabbari, Ph.D.; Amir Mani, Ph.D.

Description of Nature, Scope, and Services:

Technical Competence: As the lead consultant, LWA assisted California WaterFix with evaluating the potential impact of its project on the groundwater system in the South American Subbasin. LWA performed groundwater model evaluation, development of testimony, and evaluation of various groundwater resources. The data sets and models provided by the Petitioners have been carefully evaluated and results explained and reported to stakeholders.

Two different potential effects were considered and analyzed:

- Short-term impact on groundwater elevation; and
- Long-term impact on the conjunctive use of water. Changes in surface water flow are expected to have an impact on the connection between the Sacramento River and groundwater. A thorough understanding of interaction (e.g. gaining/losing reaches) is required to fully evaluate the impacts.

The data sets and models included: the modified regional Central Valley model (CVHM) with input from the CalSIM model for the surface water and the refined Delta model (CVHM-D). The models were carefully evaluated: in the original testimony, it was noted that these models were not developed for understanding the impact of the project on local groundwater resources and on the river/aquifer interaction. Through further analysis, it was demonstrated that the models present numerical anomalies and instabilities such that they cannot be used with confidence to estimate the impact of the project on the groundwater resources in the South American Subbasin.

Efficiency, Timeliness, Quality Control (QA/QC), and Cost Control: All deliverables and reporting requirements were met in accordance with the project deadlines and time frame. Because the nature of the project (i.e., expert testimony), LWA staff was called upon to provide testimony on short notice and was been able respond in a timely manner as needed. With respect to QC, all work products are reviewed by the team's legal counsel to ensure objectives were achieved. For the initial phase of the project, LWA provided the needed services well within the available budget which has resulted in the client being very flexible with respect to cost of services for the later phases.

RELEVANCE TO RFP

- ✓ California agricultural practices and challenges
- ✓ Central Valley Basins/Subbasins
- ✓ Develop and document conceptual model of the groundwater basin
- ✓ Develop and document groundwater budget
- ✓ Develop future modeling scenarios
- ✓ Data collection, development, and management
- ✓ Develop protocols for achieving and/or maintaining sustainability
- ✓ Develop monitoring program
- ✓ Provided overall project management
- ✓ Evaluated groundwater models, groundwater resources, and short- and long-term groundwater impacts
- ✓ Provided services directly applicable to GSA needs (preparation of groundwater models; compile and manage groundwater data; describe groundwater conditions, evaluate projects and management actions)
- ✓ Comparable in complexity, scale, and nature
- ✓ On time and within budget

Project 8. City of Beverly Hills Groundwater Services

Organization Name:	City of Beverly Hills
Reference Contact:	Shana Epstein, Director of Public Works, City of Beverly Hills | (310) 285-2570, Director.Publicworks@beverlyhills.org
Project Dates:	09/2006 - Ongoing
Consultant Name and Role:	Richard C. Slade & Associates LLC (Lead Consultant on most projects)
Key Personnel:	Richard Slade (Project Director), Earl LaPensee (Project Manager), Anthony Hicke (Task Lead)

Description of Nature, Scope, and Services:

Technical Competence: For many years, RCS has provided a variety of groundwater services to the City of Beverly Hills (the City) in both the Hollywood Basin and the La Brea Subarea to the south; the latter is an unadjudicated portion of the adjudicated Central Basin.

RELEVANCE TO RFQ

- ✓ Completed projects with goals similar to OVGA's goals
- ✓ Provided services directly applicable to GSA needs (compile and manage groundwater data; develop hydrogeologic conceptual models; describe groundwater conditions; identify projects and management actions to meet goals)
- ✓ Comparable in complexity, scale, and nature
- ✓ On time and within budget

Complexities and tasks included:

a) A detailed hydrogeologic evaluation of ±12 to 15 known building sites in and near the City which have deep foundations and permanent dewatering systems. Each building owner collects the shallow groundwater beneath the lowest most subterranean parking garage level and pumps it up to a nearby storm drain or the sanitary sewer; as a result, the pumped groundwater is not being put to beneficial use, but is instead being wasted from the groundwater basin. RCS acquired and evaluated the NPDES data on flows for these sites and ranked the sites on flow volumes and utilized an engineer to help identify collection costs. Note that certain buildings in and near the City of Santa Monica have similar types of discharge permits.

b) RCS conducted a hydrogeologic assessment of the feasibility for the City to develop shallow groundwater near the City's Water Treatment Plant, and to provide the locations and the preliminary design for two shallow water wells. RCS field monitored the construction and testing of these two municipal-supply water wells in Hollywood Basin, and these wells will soon be used to augment the City's current groundwater supplies available from its existing four water-supply wells. Importantly, these new shallow wells provide a new and independent source of groundwater that is wholly separate from the aquifers that provide groundwater to the City's existing deep wells.

c) RCS evaluated the logistical and hydrogeologic feasibility for siting and constructing a new municipal-supply water well at the City-owned Robertson Corporate Yard in the Hollywood Basin. Technical Specifications and Line Item Bid Sheets were prepared for the drilling of an exploratory test hole at this site, and RCS provided experienced field geologists to handle the field work during drilling and down-hole testing operations.

d) Prepared a report on the Assessment of Geological and Groundwater Conditions beneath La Cienega Park and Fenton field in the City for possible stormwater infiltration as part of an onsite groundwater recharge project. Even though the gross feasibility of the project was determined to not be viable, RCS recommended two other options to consider, to "acquire" more local groundwater for potential recharge: pump shallow groundwater from nearby NPDES discharge sites to local storm drains; and use the shallow groundwater to be collected by the Los Angeles County Metropolitan Transportation Agency (MTA) during its forthcoming extension of its Purple Line subway into the City.

e) Various hydrogeologic assessments of down-well problems in the City's five main water-supply wells along Santa Monica Blvd. These deep wells have displayed varying water quality, sanding, and well efficiency declines over time. RCS reviewed E-logs, casing records, and specific capacity data. Through this review, RCS was able to develop detailed geologic cross sections across the Hollywood Basin, in conjunction with our independent correlation of many E-logs of water wells and oil wells in the region. These aquifer systems and geologic formations are the same as those in the Santa Monica basin.

f) RCS conducted a detailed hydrogeologic study of the La Brea Subarea for the purposes of siting and designing a new water-supply well in this unadjudicated region. Instead of a water-supply well, due to the in-situ field data and the numerous prior studies and long-term historic data that were reviewed, RCS recommended that the borehole be completed as a multi-port groundwater monitoring well for future use by the City to help fill in a known data gap.

g) RCS prepared a detailed groundwater monitoring and management plan for the City for its local Hollywood Basin. RCS evaluated historic data from the City's numerous former wells and its four current wells in this basin; plotted various graphs of water levels and water quality; correlated a large number of E-logs from water wells and oil/gas wells; and provided specific recommendations to the City for improving their types and methods for ongoing groundwater monitoring in existing wells and groundwater monitoring wells.

h) While at a previous company, Mr. Slade was the lead Groundwater Investigator to help prepare a detailed conceptual model of subsurface conditions in the Hollywood Basin and in the adjoining La Brea Subarea to the south. Mr. Slade correlated electric logs of water wells and oil/gas wells, identified the base of fresh water, prepared groundwater elevation contour maps, and calculated the perennial yield of the Hollywood Basin and the La Brea Subarea.

Efficiency and Timeliness, Quality Control (QA/QC), and Cost Control: All deliverables and reporting requirements were met in accordance with the project deadlines and time frame. To ensure the project achieves all objectives, RCS utilizes strict QA/QC efforts developed and refined over the past 35 years, including detailed in-house peer review of all reports. Each of our consulting projects and report requirements for the City have been prepared on time and within budget. RCS tracks and monitors the budget and communicates regularly with the City to ensure that the City is continuously informed of project costs and progress.

Project 9. Watermaster for the Upper Los Angeles River Area

Organization Names:	Cities of Burbank, Glendale and Los Angeles
Reference Contact:	Mr. Bill Mace, Assistant General Manager for Water Systems, City of Burbank | (818) 238-3558, bmace@burbank.ca.gov Mr. Michael De Ghetto, Chief Assistant General Manager, City of Glendale | (818) 551-3023, mdeghetto@glendale.ca.gov Mr. Rafael Villegas, Manager, Water Rights and Groundwater Management Group, City of Los Angeles, LADWP | (213) 367-1289, Rafael.villegas@ladwp.com
Project Dates:	01/2018 - 12/2020
Consultant Name and Role:	Richard C. Slade & Associates LLC (Lead Consultant)
Key Personnel:	Richard C. Slade (Watermaster/Project Manager), Anthony Hicke (Assistant Watermaster/Task Lead)

Description of Nature, Scope, and Services:

Technical Competence: Since January of 2009, Mr. Slade, Principal Groundwater Geologist for RCS, has been serving as the Court-appointed Watermaster for the Superior Court-adjudicated ULARA region. ULARA includes not only the watershed area for the upper portion of the Los Angeles River (the southern boundary for which roughly coincides with Mullholland Drive, atop the Santa Monica Mountains), but also four groundwater basins (the San Fernando, Verdugo, Sylmar, and Eagle Rock basins). The largest of these groundwater basins is the San Fernando Basin, and major pumping from this basin is for municipal-supply by the cities of Burbank, Glendale, and Los Angeles. Even though ULARA and its groundwater basins are technically exempt from SGMA because these basins have been adjudicated, the job as Watermaster entails conducting the work tasks typically associated with SGMA and GSPs. Complexities and tasks include:

- Provides overall management of the four groundwater basins to maintain the sustainability of the adjudicated ULARA Groundwater basins.
- Attends various types of meetings with different regulators and the Parties to the Judgment and conducts information meetings with the public as necessary.
- Responds to questions from technical persons or members of the public and maintains a publicly-accessible informational website.
- Collects and interprets data and publishes reports to help maintain a sustainable groundwater supply in each of the four ULARA groundwater basins, and to show compliance with the Judgment.
- Discusses downhole problems and/or testing of wells by local Parties.
- Obtains data and reports on flow volume monitoring and water level monitoring of basin-wide wells owned by all Parties.
- Collects and tabulates data including extraction, recycled water use, water levels, etc.
- Provided updated “safe yield” calculations for the Sylmar Basin, one of the four basins in ULARA.

RELEVANCE TO RFQ

- ✓ Work with multiple stakeholder agencies and address sensitive political issues
- ✓ Facilitate meetings and workshops with agencies and interested parties from the public
- ✓ Experience with DWR
- ✓ Provide services directly applicable to GSA needs (compile and manage groundwater data; expand existing hydrogeologic conceptual models; describe groundwater conditions; establish water budget terms; identify sustainable management criteria and goals; develop groundwater monitoring networks and plans; conduct public outreach and manage stakeholder processes; coordinate with adjacent groundwater basins)
- ✓ Comparable in complexity, scale, and nature
- ✓ On time and within budget

Efficiency and Timeliness, Quality Control (QA/QC), and Cost Control: All reporting deadlines have been met and the project is progressing on schedule. Watermaster services requires extensive coordination with multiple stakeholders for a wide variety of tasks. RCS manages the schedule and continuously communicates with all parties to facilitate timely completion of the tasks, including attending various meetings with different regulators, reading/commenting on reports by others, attending hearings with the Court and/or meeting with the Administrative Committee attended by the five Parties to the Judgment, preparing annual reports for the court. Since 1983, RCS has implemented strict QA/QC procedures, including detailed in-house peer review of all reports, to achieve project goals. RCS tracks and monitors the budget and communicates regularly with the cities to inform the cities on project costs and progress. Each of our three-year long contracts for the first nine years of Watermaster Service has been completed under budget (i.e., with more than 10% of the estimated budget remaining). Our current three-year contract began in January 2018, and we anticipate project completion within the budget.

Project 10. Water Supply Availability Study for Indian Wells Valley, Kern County

Organization Name:	Kern County
Reference Contact:	Craig Murphy, Kern County Planning & Community, Development Department | (661)862-8866, murphyc@co.kern.ca.us
Project Dates:	06/2013 - 01/2014
Consultant Name and Role:	Todd Groundwater (Lead Consultant)
Key Personnel:	Dan Craig, Iris Priestaf

Description of Nature, Scope, and Services:

Technical Competence: Groundwater, the sole source of water supply in the arid Indian Wells Valley, has been characterized by groundwater level declines for decades. Despite ongoing monitoring and numerous studies, little agreement existed within the community about the occurrence of groundwater in the basin, sources or recharge, perennial yield, seriousness of the overdraft or potential solutions. Recent expansion of irrigated agriculture, however, raised public concern and prompted Kern County to sponsor an independent evaluation of the local groundwater supply. This evaluation would support land use planning by the County (which had initiated a specific plan process) and water supply planning by several local water agencies.

RELEVANCE TO RFQ

- ✓ Independent technical review of hydrogeology and groundwater basin status
- ✓ Assessment of perennial yield and overdraft
- ✓ Evaluation of groundwater quality trends and overdraft
- ✓ Identification of alternative supplemental supplies and demand management actions

Kern County retained Todd Groundwater (then Todd Engineers) to provide an independent and credible expert opinion on the state of local groundwater resources. Mr. Yates evaluated the local hydrogeology. He reviewed previous groundwater investigations and available data, evaluated the water balance, assessed overdraft and pumping, and reviewed potential supplemental water supplies and water conservation measures. Dr. Priestaf focused on the institutional and planning framework, documented water resource goals and objectives, and helped evaluate management alternatives, including an interim urgency ordinance, adjudication, and formation of a new special act district.

The resulting Water Supply Availability Report demonstrated that the basin has been in overdraft for decades, and that adverse impacts of overdraft are occurring, including loss of yield in wells and water quality declines. Assessment of current and future potential pumping indicated the need to bring in supplemental water and to manage pumping. Mr. Yates and Dr. Priestaf also assisted the Kern County Planning Department in a public education process, involving a series of well-attended and lively workshops in an effort to unite around a solution to chronic overdraft. The Todd report was foundational for subsequent completion of the County's specific plan and associated environmental documentation.

In August 2015, the basin was deemed by the California Department of Water Resources to be critically overdrafted. As of 2017, local agencies currently are organizing a joint powers authority for sustainable groundwater management.

Project 11. Regulatory Assistance for Victor Valley Wastewater Reclamation Authority (VVWRA)

Organization Name:	Victor Valley Wastewater Reclamation Authority
Address	20111 Shay Road, Victorville CA 92394
Contact	Logan Olds, General Manager, VVWRA 760-246-8638. lolds@vvwra.com
Dates of Service:	2008-prese t
Key Personnel:	Betsy Elzufon, Denise Conners, Alina Constantinescu

Description of Nature, Scope, and Services:

Larry Walker Associates, Inc. (LWA), provides assistance to Victor Valley Wastewater Reclamation Authority (VVWRA) to negotiate its NPDES permit for discharge to the Mojave River, Waste Discharge Requirements for discharge to percolation ponds at its main wastewater reclamation facility and Subregional Facilities and Recycled Water General Order for the Main and Subregional Facilities. LWA also assists VVWRA with implementation of permit requirements and Pretreatment Program elements and preparation of annual reports required by its WDRs. LWA has also assisted with the development and implementation of recycled water programs to meet the requirements of the Statewide General Order for VVWRA and for its member agencies (City of Hesperia and Town of Apple Valley). Ms. Betsy Elzufon manages on this project.

RELEVANCE TO RFQ

- ✓ Independent technical review of hydrogeology and groundwater basin status
- ✓ Modeling of groundwater impacts
- ✓ Evaluation of groundwater quality trends and overdraft
- ✓ Working with Lahontan Regional Water Board

Tasks performed for the permit renewal included preparation and submittal of Reports of Waste Discharge, Title 27 exemption analysis, capacity analyses, Title 22 Engineering reports and anti-degradation analyses. Impacts to groundwater were assessed using mixing models and review of groundwater well data with an emphasis on analysis of Total Dissolved Solids and nitrogen compounds. In addition, the LWA team conducted extensive analysis of the quality of the groundwater basin through well data available publicly and provided by Mojave Water Agency. LWA have been able to document decreasing trends in levels of nitrogen compounds in local groundwater as treatment plant effluent quality has improved due to plant upgrades. In addition, our analysis was able to demonstrate that all groundwater impacts are localized due to natural barriers (Shay Road fault) that prevent flow of groundwater beyond a certain point in the basin. In addition, LWA works closely with Lahontan Regional Board staff to negotiate various aspects of each permit.

In addition, LWA assisted the City in responding to a sewer line breach in the Mojave River that occurred during heavy storms in December 2010. LWA prepared reports and provided the necessary documentation required by Lahontan Regional Board, California Department of Fish and Game and other regulatory agencies. LWA also assisted with contacting well owners that may have been impacted by the spill to assist with sampling the wells and providing monitoring results.

Project 12. California Farm Bureau Federation – Sustainable Groundwater Management Act (SGMA) and California Groundwater Law Informational Resource

Organization Name:	California Farm Bureau Federation
Address	2300 River Plaza Drive, Sacramento, CA 95833
Contact	Jack Rice, (916) 561-5500, jrice@CFBF.com
Dates of Service:	2018 – present
Key Personnel:	Laura Foglia, Ph.D.; Tom Grovhoug, P.E.

Brief Description of Products/Services Provided:

Starting in 2018, LWA has led a consultant team to work with the California Farm Bureau Federation (Farm Bureau) in developing informational resources on groundwater hydrology, groundwater law and the California Sustainable Groundwater Management Act (SGMA) for Farm Bureau members and other agricultural water users.

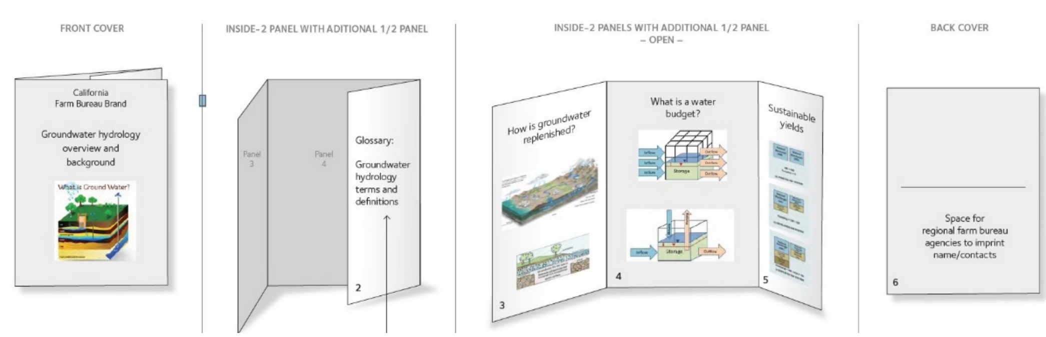
In order to meaningfully participate in SGMA implementation and contribute to the long term success of local groundwater management, Farm Bureau members and other farmers and ranchers must have a working knowledge of groundwater hydrology, law and management. The LWA Team is assisting the Farm Bureau in developing printed and electronic resources to elevate the working knowledge of the agricultural community on key groundwater issues.

RELEVANCE TO RFQ

- ✓ Develop educational materials for Farm Bureau members and other agricultural water users
- ✓ Improve working knowledge of groundwater hydrology, law and management for farmers and ranchers
- ✓ Improve agricultural stakeholder participation in SGMA and local groundwater management
- ✓ Strengthen agricultural voice during SGMA implementation and local groundwater management

LWA's efforts include:

- **Educational Brochures.** LWA is developing the content of several educational brochures on groundwater hydrology, groundwater law and SGMA for the Farm Bureau member audience.
- **Power Point Slides.** LWA is developing over a dozen educational PowerPoint slides with more detailed content from the educational brochures for use during educational presentations.
- **Web-based Videos.** LWA is developing the content of web-based educational videos for the Farm Bureau website. One video will focus on groundwater and hydrology in California and how they relate to the current agricultural community, using animated storytelling. A separate video will focus on SGMA and groundwater law in California using live action story telling with interviews at regional locations, narration and simple graphics to communicate key ideas.



4.0 Project Work Plan

California's SGMA was passed in 2014, with subsequent regulations promulgated in 2016. Under SGMA, all groundwater basins in the state are required to be managed sustainably at the local level. Our fundamental goal for this project is to collaboratively work with the recently-formed OVGA to support the development and implementation of its GSP for the Owens Valley Groundwater Basin. The LWA Team is uniquely qualified to develop a GSP that will meet local objectives because of our local experience, recognized groundwater and surface water expertise, SGMA experience in basins facing similar issues, technical skills and experience in meeting regulatory requirements and addressing stakeholder needs. The LWA Team will work with Inyo County (County) and the other member agencies of the OVGA (i.e., Mono County, the city of Bishop, Tri Valley Groundwater Management District and community services districts of Indian Creek-Westridge, Big Pine, Starlite, Eastern Sierra, Keeler and Sierra Highlands) to develop a GSP for the Basin that satisfies the requirements of SGMA, addresses issues unique to the Basin, enhances existing sustainable management practices in the basin, and reflects the goals of the OVGA member agencies and other interested parties and stakeholders.

Our understanding of the project and approach to the project as described in the RFP is provided below.

4.1. Understanding of the Project

The Owens Valley Groundwater Basin includes two subbasins, the Owens Valley Subbasin (6-012.01) and the Fish Slough Subbasin (6-012.02). The Owens Valley Subbasin is a large basin: 1036 square miles with a linear extent of about 125 miles. The Fish Slough Subbasin is a small basin (5 square miles) that was added to the Basin during the most recent Bulletin 118 update.

The aquifer system is conceptualized as having a shallow unconfined zone and a deep confined or semi-confined zone, separated by a confining layer or layers. Groundwater has been developed for domestic, municipal, agricultural uses and to supply water to Los Angeles via the Los Angeles Aqueduct. The principal pumper in the basin is the Los Angeles Department of Water and Power, which pumps water both for export and for use on Los Angeles-owned lands in Owens Valley. Total groundwater extraction from pumped and flowing wells is approximately 43-54% of recharge on average.

In the new prioritization, the OVGB is rated as high priority, by the Department of Water Resources (DWR), while Fish Slough groundwater basin is low priority. The basin was first rated as medium priority because of minor impairments locally due to inorganics, but reprioritized by DWR as high priority in 2018. This was due to multiple factors including impacts to surface habitat and streamflow from groundwater pumping, subbasin dependency on groundwater derived from north of the Basin (groundwater from Chalfant, Hammil, and Benton Valleys is believed to enter the Bishop Basin near Fish Slough, a very-low priority basin), and out-of-basin groundwater related transfers from the Inyo County/Los Angeles Water Agreement. It is noted that basins identified with groundwater related transfers were assigned maximum points by DWR and as a result rated high priority. In our approach we will evaluate the effects that management practices and actions developed in the OVGA can have on the Fish Slough Basin.

Actual groundwater volume in the basin has not been fully captured due to its exports out of the basin. Groundwater volume should reflect the additional 100K AF of pumping that is exported. As a high priority basin, a GSP is required for the Owens Valley Groundwater Basin. SGMA provides that Basin lands managed pursuant to the Inyo/Los Angeles Long-Term Water Agreement (about 400 square miles) are considered adjudicated for the purposes of SGMA. Since the basin is only partially adjudicated, a GSP is necessary for the remainder of the basin, and a key component of the GSP will be compatibility of the GSP with the Inyo/Los Angeles Agreement. Data, documents, and analytical tools available through the Inyo/Los Angeles Agreement will be available to GSP preparers.

The Basin currently is covered by four GSA's, each formed by a single local agency; however, these four agencies – County of Mono, County of Inyo, City of Bishop, and the Tri Valley Groundwater Management District – along with other local agencies have formed the Owens Valley Groundwater Authority (OVGA) through a joint powers agreement, with the intent that the OVGA will take over the role of GSA from the four GSAs that currently cover the Basin.

Key basin-specific issues to be addressed by the GSP are:

- Compatibility of the GSP with the Inyo/Los Angeles LongTerm Water Agreement
- Basin-wide consistency in data acquisition and management
- Evaluation of effects of groundwater pumping on the Fish Slough Subbasin
- Factors affecting groundwater levels in West Bishop
- Reconciliation and consolidation of existing groundwater models
- Groundwater management at Owens Lake

In essence, we see the GSP as a mechanism for pulling together numerous goals and interests to create a shared vision for the Basin that is based in the reality of existing constraints, potential future impacts (if not appropriately managed), and climate change. In addition, the GSP must be supported by strong technical analysis, stakeholder buy-in into the vision and supporting analysis, and acceptability to DWR by meeting all SGMA requirements.

The primary goal of this project is to develop a GSP that supports a framework to effectively manage the entire groundwater basin to optimize the public benefits of the groundwater resource. The LWA Team will support the County (as the coordinating entity for the OVGA) in achieving this goal and managing all the elements of the process to develop the GSP. This will include stakeholder outreach, coordination with member agencies, and overall project management with the goal of an efficient process that results in a sustainable plan for managing the local groundwater resources.

4.2. Project Approach

The LWA Team has extensive experience in managing stakeholder-driven processes to develop effective and compliant planning documents. We will use our proven approach to efficiently gather and process existing data and information, facilitate stakeholder input, and identify flexible and yet cost-effective implementation measures to support groundwater sustainability. We will use our in-depth local knowledge and technical expertise to leverage existing modeling tools, while providing an outside review of the tools and existing analyses to identify any needed modifications or adjustments.

The LWA Team also recognizes the need to conduct a process that is understandable to key stakeholders and supports effective collaboration among the GSA member agencies and communication with DWR and to the extent possible all interested stakeholders. A key aspect of our approach is upfront stakeholder and visioning work help so that varied interests are understood prior to initiating the key technical work. This will allow the approach to the technical work to be informed by a bigger picture perspective. While not all interests may directly fall under the scope of SGMA, understanding and considering the impact and relationship of the GSP to other programs and agreements (e.g. Inyo/Los Angeles Long-Term Water Agreement) will allow for development of a GSP that is holistic in supporting overall sustainability goals.

The development of a GSP is complex and involves substantial, interrelated technical work. The LWA Team will conduct the work using the guidance and tools provided by DWR and align the work with the DWR developed Best Management Practices (BMPs), tailored to meet the local conditions. The LWA Team's general approach to the project involves four major steps:

1) **Setting the foundation for a successful GSP**. This will be done through identifying upfront processes, communication plans, and key decisions and points for working with the OVGA, adjacent groundwater basins, and interested parties (stakeholders). This step also includes notifying DWR and establishing protocols for meeting and engaging with this agency throughout the development process. Finally, needed data and technical information will be identified and procedures for managing and using the data will be developed so that data are easily accessible and required information can be provided to DWR in the recommended format.
2) **Understanding the broader context for the GSP development.** This step will identify related activities and requirements that should be considered during GSP development. This will be accomplished using our understanding of the Lahontan Regional Water Board and State Water Resources Control Board (SWRCB) requirements, and requirements to address potential impact on groundwater dependent ecosystems with input from the OVGA member agencies and interested stakeholders. As part of this step, the LWA Team will gather an understanding of the interests of the OVGA members and key interested stakeholders. All this information will be used to inform the identification of beneficial uses and development of the sustainability goal for the Basin.
3) **Developing the GSP**. This step forms the bulk of the work and will consist of multiple technical tasks (as detailed in the proposed scope of work below), stakeholder engagement, and project management. Many of the technical tasks are related; for example, it will be important to discuss potential undesirable results and conceptual projects early in the process so that modeling is appropriately structured for reliable evaluation of identified project and management action scenarios. Based on our previous work on these types of projects, we anticipate developing initial materials or presentations that will allow the OVGA to provide feedback on our proposed approach to key elements of the GSP. Once the approach is agreed upon, the LWA Team will conduct the work and prepare the administrative draft sections of the GSP for review by the OVGA. After comments from the OVGA have been incorporated, the drafts will be provided to the OVGA agencies and interested stakeholders for review. Comments from interested stakeholders will be incorporated into the draft GSP document. In addition, we anticipate identifying key interested stakeholders to provide input on the approach for respective elements, such as input from adjacent basins on the approach to developing the water balance. At a minimum, we will gather early input from interested stakeholders on the approach to developing the sustainability criteria and projects and management actions. We will work with the OVGA to identify the key decision points and interested stakeholders to engage at various points in the GSP development.
4) **Identifying methods for GSP implementation.** This step involves developing the requested implementation work plan for the GSP and evaluation of cost recovery opportunities.

4.3. Scope of Work

The scope of work presented in this section is provided in linear fashion; however, as shown in Figure 3, most of the tasks are interrelated. As a result, we anticipate an interactive process for GSP development with some subtasks being conducted in parallel. An overview of the schedule and proposed deliverables is provided at the end of this section to provide a clearer understanding of the project work flow. This scope of work provides a detailed discussion of the subtasks necessary to develop a successful GSP.

Task 1. Initial Site Visit

To initiate the GSP work, the LWA Team will attend an initial site visit that will include a public meeting with the OVGA Board, as well as a staff kick-off meeting to initiate and coordinate the work. A common understanding of GSP requirements, goals and objectives, and outline is a critical first step in GSP development. As a result, the LWA Team has developed strategies to support gathering effective feedback and facilitate decision-making at the initial meeting. Strategies include providing a concise presentation and other meeting materials that outline approaches or impacts of key decisions ahead of the meeting. An agenda will be prepared that includes the desired outcome or goals for each agenda item. The LWA Team will present the requisite materials at the meeting and lead a discussion to achieve the outlined goals. Within 1 week of the meetings, LWA will prepare draft meeting summaries with identified action items and submit these summaries to the OVGA Board.

Throughout the duration of the project, the LWA Team will conduct site visits in the field as deemed necessary. These visits will provide the Team with increased knowledge of previously recorded data, a better understanding of spatial and temporal variability within the region, and enhanced ability to collect good quality field data in the future. Following each site visit, the LWA Team will prepare and submit a site visit summary containing pertinent information such as employees in attendance, itinerary, key findings, and relevant photos to the OVGA Board.

***Deliverable**: Meeting Agendas, presentation materials, and site visit summary.*

Task 2. Public Engagement Plan

Our extensive experience working with a diverse set of entities in the Los Angeles Region will allow us to communicate effectively and develop work products that are understandable and accessible. We are experienced at explaining complex hydrogeological data and model results to audiences ranging from laypersons to academics and will apply those talents in explaining investigative results to all interested parties (stakeholders) and customers.

A key element of the LWA Team's approach is to gain early input on the potential future uses, stakeholder interests, potential issues of concern, Basin beneficial uses and other requirements faced by the OVGA. This input will inform the approach for the technical work.

Building off the DWR Guidance Documents including the January 2018 Stakeholder Communication and Engagement Guidance Document, the LWA Team will develop and establish a Public Engagement Plan (Engagement Plan) and then execute the Engagement Plan for the efficient and effective coordination of internal/external communications and stakeholder engagement. The Engagement Plan will be an iterative document that is updated as needed throughout the project term. This will ensure the most up-to-date information related to project communication is contained in the Engagement Plan.

The greatest benefit the LWA Team, led by LWA for this task, can give to the OVGA is our successfully tried-and-tested communication and public engagement approach. Our public engagement projects begin with a deep understanding of the social science that concentrates on engagement and awareness. From this foundation, we work to develop successful communication tactics for public programs and policies. We help our clients identify the audience they want to reach, provide insight into the various barriers and motivators that can affect communication, and lastly, find the most effective strategy to communicate to their audience.

This approach will help us develop an Engagement Plan that encourages active involvement of a community comprised of diverse social, cultural and economic elements. The Plan will be developed to facilitate achieving the goals of the OVGA and meeting the requirements of the GSP. LWA will first assess the OVGA's current understanding of the groundwater basin and water resources and gather basic demographic information about the area and the people who live in Basin area. Next, LWA will develop a situational analysis using the information gathered through initial stakeholder engagement. The situational analysis will take a snapshot view of the perspectives of the OVGA member agencies and stakeholders. This analysis can help us understand the context for the OVGA's communications, identify the strategic goals we will work toward and characterize the target audiences. This strategy maximizes public engagement and inclusion of the diverse social, cultural, and economic elements within the Basin. The next stage in the communications planning cycle is to select the strategy and communication methods most appropriate to achieving the OVGA's aim and objectives.

LWA will develop an Engagement Plan that describes the overall approach, the issues to consider in different operational situations and how to choose the most appropriate mix of communication methods. The Engagement Plan will include: communication requirements and methods; interested parties/stakeholders; how the project is organized; how standing and ad hoc committees may be used; decision making processes; outreach strategies and methods; expected stakeholder meetings and location; compilation of comments received and how comments are considered for incorporation into the GSP; the potential risks to meeting the scope, schedule, and budget; as well as a recovery plan. The Engagement Plan will also include: how stakeholders will be informed regarding project status; how reports and data will be provided to the stakeholders; public meeting opportunities; methods for promoting active stakeholder participation; and an internet communications strategy.

Specific elements of the Engagement Plan which will be discussed and coordinated with the GSAs may include, as needed, guidelines for establishing a representative Technical Advisory Committee, framework for the OVGA website or other identified communication platform, and an approach to Adjacent Basin Coordination. In addition, messages, notification strategies and outreach materials will be developed based on our understanding of interested parties' and stakeholders' interests.

The LWA Team will conduct public meetings where the plan is discussed that are located strategically throughout the region to ensure that all stakeholders are engaged and their interests are represented in the process. Early and effective stakeholder input on the sustainability criteria, projects and management action and the criteria for evaluating those projects will be critical to the success of the GSP. We will coordinate with the OVGA to summarize the results of public meetings. The LWA Team will assist OVGA with promoting the workshops.

Accomplishment of this task completes the requirements of Reg § 354.10 and helps the LWA Team frame technical subjects in a way that stakeholders can understand and relate. From our experience, technical data and findings are great tools to guide and direct the public outreach, but the outgoing public message shouldn't be comprised of stats or numbers. The public is more concerned with the "why" and "what," rather than the "how." More often than not, stakeholders want to know the following: *Why should I care about this project? What benefits do I get from it? Why get involved with the project?* Contrarily, the public tends to be less interested in studies, demographic profiles and other technical findings. It's LWA's responsibility to take the technical information and convey it in a manner that is relatable and engaging to the public.

***Deliverable**: A public engagement plan, and a summary for inclusion in the GSP describing the plan and input received, and addressing notification and communication with interested parties as per Reg. § 354.10*

Task 3. Data and Document Compilation, Review and Management

For this initial project effort, the LWA Team will collect available data and reports that are relevant to the development of a hydrogeologic conceptual model, a numerical groundwater flow model, and the GSP.

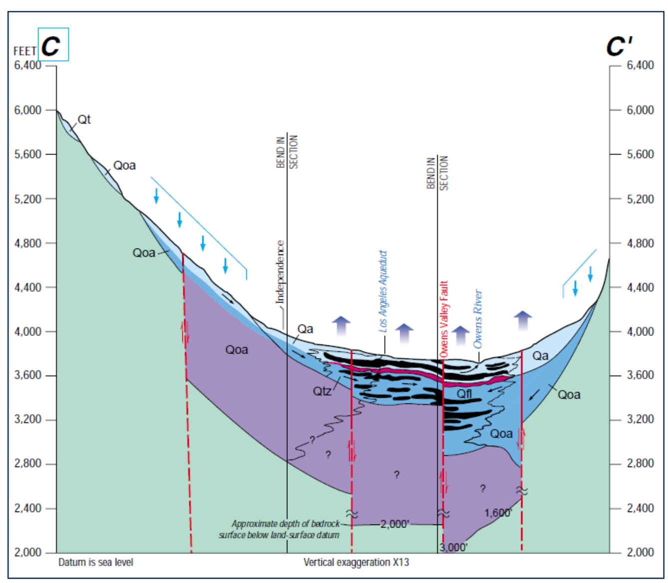
Key sources of information for this effort will include:

- Inyo County Water Department;
- Los Angeles Department of Water and Power;
- California Geological Survey, DWR, DDW, and LRWQCB; and,
- Federal agencies, for example USEPA, USGS, NOAA.

Compile and List Planning Documents and Technical Studies Related to GSP Preparation

A number of references are available that will contain data used for the GSP development work. The references will be located, scanned/digitized (if not already), and included as part of the data storage plan developed for the project. In addition to those references, the following are among the typical data sources also envisioned to be useful to the GSP development effort:

- 2005 – 2018 LADWP Annual Owens Valley Reports.
- 1991 – 2017 Inyo County Water Department, Annual Reports.
- Inyo-Mono Integrated Regional Water Management Plan Update 2014 (previous IRWM reports will be used as needed).
- Inyo County Water Department, 2016. Hydrogeologic Conceptual Model for the Owens Valley Groundwater Basin (6-12), Inyo and Mono Counties. Submitted to DWR.
- LADWP, Ecosystem Sciences. April, 2010. Owens Valley Land Management Plan.
- The 1991 Agreement between the County of Inyo and the City of Los Angeles and its Department of Water and Power on a Long-Term Groundwater Management Plan for Owens Valley and Inyo County.
- LADWP, Inyo County. 1990. Green Book for the Long-Term Groundwater Management Plan for the Owens Valley and Inyo County. June 1990.
- Harrington, B. 2007. Development of a Groundwater Flow Model for the Bishop/Laws Area. Final Report for Local Groundwater Assistance Grant Agreement No. 4600004129.
- Hollett, K., Danskin., W., McCaffrey, W., Walti, C. 1991. Geology and Water Resources of Owens Valley, California. USGS Water-Supply Paper 2370.
- Danskin, W. 1998. Evaluation of the Hydrologic System and Selected Water-Management Alternatives in the Owens Valley, California. USGS Survey Water-Supply Paper 2370-B.
- Danskin, W. 1988. Preliminary Evaluation of the Hydrogeologic System in Owens Valley, California. Prepared in cooperation with Inyo County and the Los Angeles Department of Water and Power. USGS, Water-Resources Investigations Report 88-4003.
- Guymon, G.L., Yen, C. 1990. An efficient deterministic-probabilistic approach to modeling regional groundwater flow: 2. Application to Owens Valley, California. Water Resources Research.
- 2014. Inyo County Public Works Department, EIR for ATV Adventure Trails of the Eastern Sierra Project. Relevant Sections include: Environmental Setting, Ag and Forestry Resources, Geology and Soils, Hydrology and Water Quality, and Land Use and Planning.
- Steinwand, A., Jackson, R., ICWD, Jorat, S., Hubbard, P., LADWP. 2004. Inyo/LA Geochemical Cooperative Study.
- Jackson, R., ICWD, Jorat, S., LADWP. 2000. Characterization of Confining Layer Hydrologic Conductivity and Storage Properties in the Owens Valley.
- Pakiser, L.C., M.F. Kane, and W.H. Jackson. 1964. Structural Geology and Volcanism of Owens Valley Region, California – A Geophysical Study, USGS Professional Paper 438.
- USEPA. Basewide Hydrogeologic Characterization Case Study: Naval Air Weapons Stations China Lake.
- USGS, website for [Owens Valley Hydrogeology Data](#).



Danskin, W.R., 1998, Evaluation of the Hydrologic System and Selected Water-Management Alternatives in the Owens Valley, California, USGS Water Supply Paper 2370-H. *http://ca.water.usgs.gov/archive/reports/wsp2370/*

- Harrington, R., 2004. Evapotranspiration from Groundwater Dependent Plant Communities: Comparison of Micrometeorological and Vegetation-Based Measurements. Cooperative Study by County of Inyo Water Department and LADWP.

Assemble, Update and Expand Databases of Geographic and Hydrologic Data

The following is a preliminary list of the types of data needed for GSP preparation. Our team has already obtained many of the documents and databases listed below, which are necessary to complete the hydrogeologic conceptual model and prepare the GSP. These existing data sets will be augmented with new studies or updated data collected over time for the Basin. Data will be organized on a data sharing site to help centralize data collection; development of a data management system will be consistent with Reg. § 352.6. The data management system will become the shared data set for components of GSP development work so that our team and interested parties are working with and reviewing a common data set. If/where appropriate, relational databases may be developed for some of the data sets.

Key data compiled for the GSP work will include:

- Accurate location information (land survey and global positioning system [GPS] data plotted in a GIS database) of currently known water-supply wells and groundwater monitoring wells, surface water gaging stations, and proximal rainfall stations.
- State DWR well completion reports (driller's logs) and depths/screen intervals of known, historically-drilled, private and municipal monitoring and supply water wells in the Basin, including geophysical data where available.
- Groundwater elevation data (hydraulic head) reported relative to NAVD88. This will include monitoring programs within the basin, as well as DWR's Water Data Library and CASGEM.
- Drilling permit data for both historic well drilling work and recently-drilled wells and monitoring wells in the Basin.
- Groundwater pumping and groundwater use data.
- Groundwater elevation contour maps and change maps for different time periods.
- A topographic base map of the area, and a digital elevation model (DEM) of the Basin.
- GIS-based watershed boundaries, groundwater basin boundaries, and groundwater subbasin boundaries.
- As applicable, geologic and geophysical data for exploratory wells drilled over the years in the Basin to help identify the thickness of water-bearing sediments and the depth to the underlying nonwater-bearing bedrock at those drill sites.
- Hydrogeologic characterization of key aquifer/aquicludes, as available from pumping test data and existing modeling efforts within the Basin; all available aquifer test data and calculations by others for the hydrogeologic properties of the aquifers (transmissivity, storativity and hydraulic conductivity).
- Geologic fault data collected over the years to display the locations and alignments of various faults in/near Basin and their effects on groundwater flow.
- Soil surveys, including maps in GIS format (as available) and soil characteristics within the Basin. This will be bolstered with UC Davis SAGBI information from the SGMA Data Viewer.
- Climatic data, including precipitation and potential evapotranspiration (PET) data over time from climate and CIMIS (California Irrigation Management Information System) stations. This will include Inyo County data stations (as available), plus isohyetal (USGS, County, PRISM) and ET maps (DWR).
- Historical and recent surface water runoff/discharge data as available (USGS National Water Information System). Additional streamflow measurements and synoptic studies, and associated surface water modeling efforts, will be reviewed.

- Historical and current land use information and aerial photos to evaluate extent and density of land use, groundwater dependent ecosystems and natural vegetation including riparian areas, and channelized streams.
- Water demand information.
- Additional water supply information, including imports to the Basin, and groundwater pumping amounts over time for Basin and the adjoining hill/mountain areas, as well as waters used for municipal, industrial, agricultural, and domestic purposes.
- Groundwater quality data from known wells and groundwater monitoring wells, and the GeoTracker website.
- Water quality data from surface waters.

Define and Document Study Periods, Identify Data Gaps

SGMA documentation and analysis involves definition of various study periods (and time steps) for historical, current, and projected future conditions; for example, historical conditions must include at least 10 years and future conditions involve projection of 50 years of rainfall/streamflow conditions. These Study periods will be defined in accordance with SGMA requirements but will also consider other factors that could serve as "endpoints" for historical periods.

Above-average and below-average rainfall years will be considered when defining the study periods. Data will be compiled from DWR's CDEC as well as County resources. Historical rainfall trends from the earliest data will be used to characterize early rainfall conditions.

Document Technical and Reporting Standards

Compilation of data and information to support the GSP will adhere to applicable standards for data collection, reporting, monitoring, and GIS, as applicable (Reg. § 352). Data will be documented with the source of the data, types and methods of measurements, and comments on protocols, when available. Well information will include the available requirements from Reg. § 352.4 (c)

Develop Data Management System, and Prepare for Data Submittal per DWR Forms and Instructions Data will be organized, stored, available for access, and submitted in accordance with Reg. § 352.6, based on templates and protocols provided by DWR. The development of a data management system will begin with a needs assessment to determine the goals of the OVGA DMS and to provide guidance on the central tasks and approach to efficiently produce an effective DMS. Following completion of the needs assessment, the LWA Team in coordination with the OVGA will develop the Data Management Plan. The plan will serve as guidance for the collection and management of groundwater and surface water information required for GSP development and will be used as part of continued reporting during the GSP implementation phase (2022+). The Plan will also present a long-term strategy for building and expand the size and functionality of the DMS.

This task will be initiated with a meeting that includes key managerial and technical staff from each of the OVGA member agencies.

The needs assessment will:

- Identify key questions that should be addressed prior to DMS development;
- Decide key data components/modules to be included in the DMS;
- Determine the appropriate type of database to be used based upon costs, utility, and potential future SGMA-related activities;
- Review the spatial and temporal gaps in available data sets and qualitatively estimate uncertainty for required data;

- Determine the required features and functionality to be included in the first version of the DMS;
- Determine the level of user access for various project entities;
- Assess the degree of effort to load existing or future data into the proposed DMS; and
- Assess software, hosting, maintenance, and deployment requirements.

Based on the needs assessment, a proposed DMS will be developed. For the purposes of our cost estimate, a simple relational database that can be used by experienced data managers within the OVGA member agencies has been assumed. Development of a more complex or stakeholder-facing database determined through the needs assessment would require a modification to the scope and budget.

***Deliverable**: Data management system for housing a library of source documents and a repository of historical and future documents, maps, and monitoring data necessary for preparation and implementation of a GSP.*

Task 4. Develop Interagency Agreements

In monitoring for either surface water or groundwater, each program has its own purpose and mission and our team acknowledges that the key is to show to the different parties how it is in their interest to develop shared agreements to increase the amount of available information.

We have extensive experience working with stakeholders with varied interests and we can provide assistance in the development of these agreements. Examples of our work include our facilitation role in the Delta RMP Regional Monitoring Program. We will apply our skills in interest based negotiation to help the county in this effort. We will support the county and the legal staff to provide assistance in the development of these agreements.

***Deliverable**: Written agreements between the GSA and agencies with data that would benefit the preparation of a GSP.*

Task 5. GSP area and GSA information

The Basin Setting provides the background description and characterization of the Owens Valley Groundwater Basin (OVGB) and includes multiple tasks that form a substantial portion of the GSP development.

Subtask 5.1. Describe Plan Area

This task begins preparation of the GSP with provision of required information (per Reg. §354.2 – §354.6) on the GSA. This task describes the GSP Area (Reg. §354.8) with description of jurisdictions, water supply agencies and land use planning agencies, agricultural use and maps of groundwater dependent ecosystems (GDEs) which sets the stage for cooperation and collaboration among agencies. This task will document the distribution of water supply wells and provide succinct descriptions of water resources management and monitoring programs. These will lay the groundwork for considering the interaction of the GSP with existing management and monitoring programs and land use plans. Our approach is to provide this evaluation upfront and promptly, not to *just get it done*, but to allow it to inform the GSP process. This is consistent with the ongoing analysis of conceptual projects in Task 3 and allows GSP Regulations to prompt identification of institutions, policies, and programs that need to be recognized. This may uncover potential conflicts and allow prompt resolution.

Provide Administrative Information

This task will provide basic up-front information for DWR and for interested parties per Reg. §354.2–§354.6. We will document the name and address of the OVGA, persons with management authority for implementation of the GSP, GSP Manager with contact information, and the legal authority to implement the GSP. We will also provide a placeholder for the Executive Summary and for the documentation of the costs of GSP implementation and how the OVGA plan to meet those costs. These items will be described later, when the GSP document is being finalized.

Describe Plan Area and Institutional Setting

This task will describe the GSP Area (per Reg. §354.8), including development of GIS maps showing groundwater basins, the GSP Area, jurisdictional boundaries, and land use designations. This task will rely on previous work, build on existing GIS, and utilize existing documents (e.g., county general plans). Jurisdictional boundaries of federal lands, state land, cities, counties, and agencies with water management responsibilities will be identified using appropriate maps and will be described.

We recommend brief introduction of water supply agencies and purveyors in this section. Although not specifically required here, our experience writing other GSPs indicates that the GSP in later sections will refer to water providers, their roles, and water supplies; this section can provide a cogent summary. Given that water supplies (imported water, local surface water, and groundwater) will be affected variously by climate change, we also recommend a brief discussion here of climate change as an overarching issue for the OVGA.

In addition, information on other small public water systems (if any) and groundwater users can be incorporated here (such as agricultural uses). Although groundwater pumping associated with some of these systems may involve small (de minimis) amounts, a better understanding and documentation of all pumping in the groundwater Basin will be an objective of this GSP consistent with Reg. §354.8 (a) (5).

Document Density of Wells

As described in Task 3, to the extent possible, we will identify pumping well locations and uses . Under this task, the LWA Team will utilize the collected data to develop a well density map with wells per square mile, consistent with Reg. §354.8 (a) (5). Although applicability of such a grid to the Basin is uncertain, such maps are intended to support identification of groundwater-dependent areas and the prepared map warrants review. Well completion records available from DWR are a source of well numbers and general locations, and DWR has compiled information from these well records as part of its SGMA Technical Assistance Program. Mapped data are available at the link below.

https://dwr.maps.arcgis.com/apps/webappviewer/index.html?id=181078580a214c0986e2da28f8623b37

Describe Current Monitoring and Management Programs

This task will use information developed in previous tasks to provide a description of existing regional water resource monitoring program for the GSP Area (per Reg. §354.8 (c, d, e). Detailed list of available sources have been provide in Task 3, and the LWA team will collect, analyze and organize all the existing data. The description will summarize programs that collect monitoring data or assign management actions for climate, groundwater levels/storage, water quality, surface water flow, water imports, wastewater discharges and water recycling, managed aquifer recharge (percolation), water demands (by use, source, and subbasins within the Basin), land surface and subsidence monitoring, and other data types relevant for the GSP, as applicable. In response to Reg. §354.8 (d), we will include consideration of how existing monitoring and management may impact future operational flexibility. Initial information will be provided to facilitate gathering input on this task, but the GSP section discussion will be completed toward the end of the GSP process when GSP implementation is planned; the discussion also must address the adaptation of the GSP to such limitations.

Describe Land Use Designations, Policies, and Well Permitting

This task will describe land uses and land use planning (per Reg. §354.8). We will use maps from the cities and county to depict land use and zoning at a reasonable scale. We will download and review relevant portions of local General Plans, specific plans, and other planning documents for the GSP Plan Area and provide a plain language summary. Based on our experience with Urban Water Management Plans, water supply assessments, and the initial development of SGMA itself, a communication gap often exists between water agency staff and land use planners. This task helps bridge that gap and supports discussion of the mutual impacts of SGMA and land use planning.

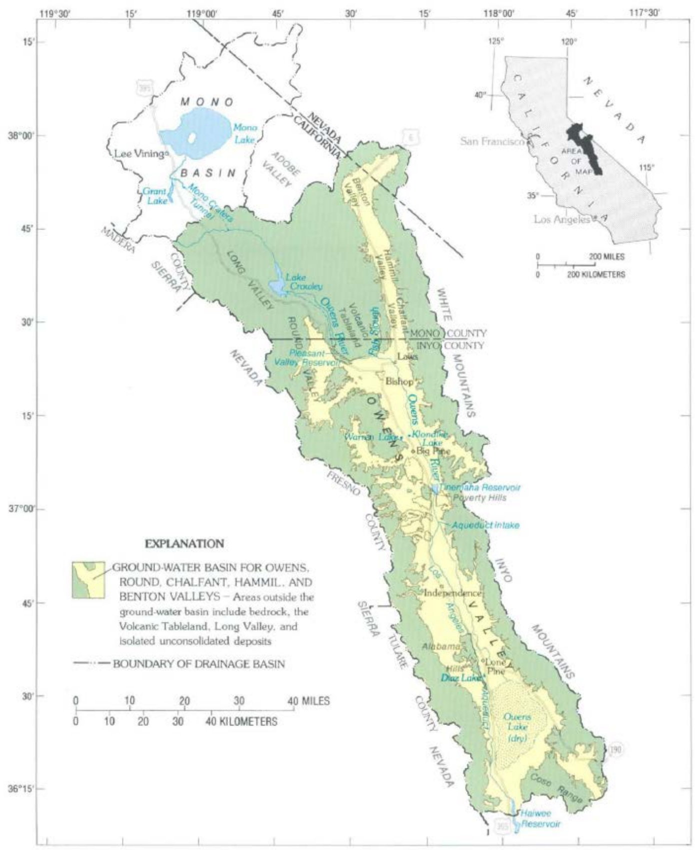
Specifically, this task will address 1) how local land use plans could affect the ability of the GSA to achieve sustainable groundwater management over the planning and implementation horizon, and 2) how GSP implementation will affect the water supply assumptions of land use plans.

Incorporate Additional GSP Elements (from AB3030 and SB1938 management plan legislation)
Additional elements are referenced in Reg. §354.8 (g) for possible inclusion in the GSP. A complete list of these elements is provided below, and we recommend review for the GSP of the elements that most closely apply to the OVGB. These elements are derived from the AB3030 and SB1938 legislation that preceded SGMA; however, based on our experience preparing numerous management plans, we have found that consideration of these can contribute to a robust GSP, and will be reviewed in that light.

- Wellhead protection
- Migration of contaminated groundwater
- Well abandonment and well destruction program
- Replenishment of groundwater extractions
- Conjunctive use and underground storage
- Well construction policies
- Groundwater contamination cleanup, recharge, diversions to storage, conservation, water recycling, conveyance, and extraction projects
- Efficient water management practices
- Relationships with State and federal regulatory agencies
- Impacts on GDE

Subtask 5.5. Define Management Area(s)

The GSP Area can be divided into Management Areas (Reg. §354.20) that are defined to facilitate sustainable groundwater management and GSP implementation. Previous tasks describing water supply, groundwater management, groundwater conditions, and hydrogeology will form the basis for proposing Management Areas. The GSP regulations note that a Management Area may involve different criteria (minimum thresholds and management objectives) and distinct management actions. Nonetheless, the Management Areas need to work together and not cause undesirable results beyond their boundaries.



Owens River watershed and Owens Valley Groundwater Basin[2]

***Deliverable**: GSP chapter describing the GSP area (Reg. § 358.4)*

Task 6. Basin Setting

Subtask 6.1. Describe Hydrogeologic Conceptual Model

Inyo County Water Department has developed a hydrogeologic conceptual model for the OVGB in 2016. We will use the corresponding report as a base and compile data and information regarding geologic/hydrogeologic conditions for subbasins in the Basin. Data obtained and reviewed will be analyzed with regard to: surface and subsurface geology to help provide a basic framework for the geometry and basic hydrogeologic properties of the geologic formations, their main aquifer systems, and the base of fresh water in the subbasins within the Basin. Using the available data, we will create independent interpretation regarding the degree to which subbasin delineations represent groundwater flow boundaries.

Describe Basin Setting and Principal Aquifers and Aquitards

The Basin will be described with respect to the following conditions in accordance with the GSP regulations (§ 354.14), and large-format maps where applicable will be included:

[2] Hollett, K.J., W.R. Danskin, W.F. McCaffery, and C.L. Walti, 1991, Geology and Water Resources of Owens Valley, California, USGS Water Supply Paper 2370-B. http://pubs.er.usgs.gov/publication/wsp2370B.

- Topography, including topographic mapping of the basin. Descriptions of general drainage patterns throughout the basin, topographic high points, and surface water features (including known spring locations), historic artesian areas, etc.
- Soil survey maps, outlining the soil characteristics within the OVGB. Soils are significant to rainfall recharge, landscaping return flow, and low impact development (LID) and will be summarized.
- Regional geologic and structural setting, including surficial geologic mapping and the interpreted locations of faults in the region.
- Boundaries of the five subbasins, as defined by others.
- Descriptions and maps of the Principal Aquifers and Aquitards.

Prepare Cross Sections

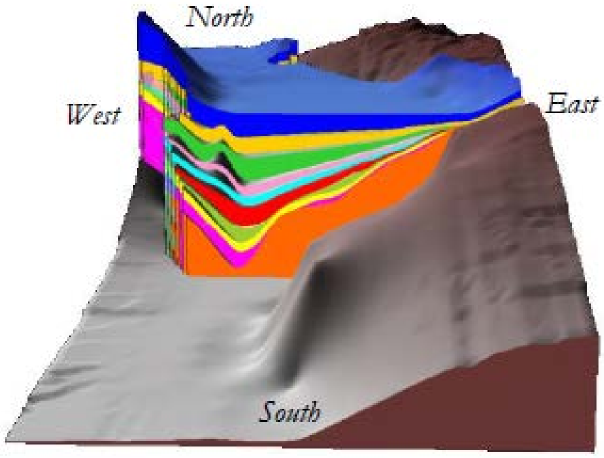
Using the available subsurface geologic data at least four geologic cross sections will be constructed that traverse the entirety of the OVGB; two sections will be roughly oriented in a north/south direction, and two will be oriented in a roughly east/west direction. It is anticipated that these geologic cross sections will be tied into both historic and existing well sites.

Describe Aquifer Properties

Aquifer parameters will be determined for wells within the basin. MWH has evaluated Owens Lake Groundwater in 2012. In their study, pump testing at monitoring wells allowed for estimation of transmissivity (T) and hydraulic conductivity (K) in discrete aquifer zones and provided a table summary of these parameters. The distribution of T and K estimated from the monitoring wells by aquifer unit shows a decreasing trend with depth. The decrease in T and K with depth is consistent with the understanding that compaction and aquifer induration increases with depth.

Describe Boundaries and Bottom of the Basin

The bottom, or base, of the Basin will also be defined. As such, a clear definition of "basin bottom" will be provided as part of the hydrogeologic conceptual model for the Basin. MWH characterized the bedrock boundary and basin geometry by evaluation of seismic and drilling data as illustrated in the figure below. Relatively shallow bedrock was found underlying the east side of the Basin. Bedrock was not identified on the southwestern and western margin. On the northeast and southeast margins, the Basin is terminated structurally by bedrock highs causing thinning or pinching-out of the mapped sequences. On the west, the sequences coarsen and lacustrine deposits are absent. Bedrock depth on the west side of the Basin can neither be resolved based on the seismic data nor have any boreholes encountered bedrock in this area.



Conceptualization of Basin Geometry and Bedrock Boundary (view north along eastern margin of the Basin)[3]

Identify data gaps and uncertainties

The team will identify key data gaps in the Basin to serve as a reference for areas of future study when funding for such studies may become available. Based on MWH's 2012 study on the Owens Lake Groundwater Evaluation Project, the most significant data gaps identified and later addressed by MWH were:

1. Geology, Structure, Depositional History, and Hydrostratigraphy
    - Elevations of tops and bottoms of each aquifer
    - Characterization of deeper confined aquifers.
    - Definition of the bedrock contact
    - Characterization of aquifer and aquitard parameters
2. Groundwater Flow
    - Although groundwater flow conditions in the vicinity of Owens Lake were reasonably well documented in the shallower system, flow conditions in deeper aquifers were less documented because of the scarcity of wells screened only in the deeper zones.
    - The quantification of impacts associated with the Lower Owens River Project (LORP) and Dust control measure (DCM) projects required further evaluation.
3. Water Quality
    - Water quality data was more limited in certain portions of the study area (along
    - southern margin and northwest of brine pool)
    - Additional water quality data with depth was needed
    - Characterization of water quality by aquifer was needed
    - Relationship of water quality and spring origin was unknown
4. Water Budget
    - Down-valley flow is one of the most significant components of the water budget, and had a relatively high uncertainty.

[3] MWH, 2012, Final Report on the Owens Lake Groundwater Evaluation Project, prepared for the Los Angeles Department of Water and Power. http://www.ovcweb.org/docs/Final-OLGEP-Report.pdf.

- Mountain block recharge is not known and cannot be measured; therefore, evaluation of CDM's mountain block recharge component, which accounted for 55% of their inflows, was needed.
- Calculation of other components (i.e., stream channel recharge) using alternate techniques was desired.
- Previous studies identified subsurface flow at the southern end of the Basin as an uncertainty.
- Quantification and evaluation of the effects of LORP and DCMs on the water budget was needed.

Subtask 6.2. Document Groundwater Conditions

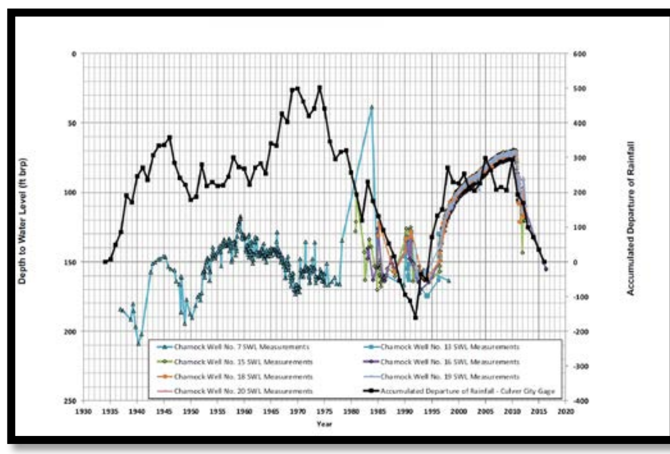
The documentation of groundwater conditions will form the basis for evaluating the sustainability of the basin and assessing the presence or potential for undesirable results and will comply with GSP regulations § 354.16.

Document Historical and Current Groundwater Elevations

We will review available historic maps on groundwater elevations and groundwater flow directions in the Basin and prepare a current water level elevation contour map (or maps, as necessary) using recent static water level available from wells owned by current pumpers, and also from groundwater monitoring wells available through Geotracker (for example, monitoring wells at gas stations and dry cleaners), and for the numerous monitoring wells at large-scale contamination sites.

Develop Hydrographs to Analyze Trends, Fluctuations

Water level hydrographs will be prepared for key wells (both production wells and monitoring wells) to evaluate historic water level trends in each groundwater subbasin. These hydrographs, coupled with well construction information, will help to identify water level trends in the basin, and help to determine the driving forces behind those trends (i.e., precipitation trends, concentrated areas of groundwater extraction, etc.). Those hydrographs will be compared to rainfall trends identified on accumulated departure of rainfall graphs. Hydrographs will be prepared for the GSP in accordance with the regulations of § 352.4 (e) and will include the required information listed therein.



Prepare Water Level Contour Maps

Review available historic maps on groundwater elevations and groundwater flow directions in the Basin and prepare a current water level elevation contour map (or maps, as necessary) using recent static water level available from known pumpers and monitoring well owners in the Basin. In accordance with § 354.16 contour maps depicting seasonal high and seasonal low water levels for each principal aquifer within the basin will be created.

Estimate Change of Groundwater in Storage

Using existing data and new data collected as part of this GSP preparation effort, change in groundwater storage will be calculated in each of the subareas of the Basin, for different time periods. Calculations will be made for time periods that help support the goals of the GSP development. These data will be presented on a graph consistent with GSP regulation § 354.16 (b).

Document Groundwater Quality Issues

Groundwater quality data will be primarily derived from data collected form the municipal-supply wells in the Basin, and from private well pumpers where data are available. Data will be documented as described in § 354.16 (d) of the GSP regulations. Based on MWH 2012 study, the quality of groundwater in the study area is highly heterogeneous, and its composition is influenced by multiple past and current hydrogeologic processes. Salinity and arsenic concentrations decrease with depth and tend to be higher under the eastern portion of the lake where sediments have been exposed to evaporation.

Describe Land Subsidence and Potential for Subsidence

SGMA defines land subsidence from groundwater mismanagement as an undesirable result at the point that significant and unreasonable land subsidence substantially interferes with surface land uses. Subsidence potential is currently being evaluated for the LADWP groundwater development at Owens Lake. The LWA Team will work with Inyo County and LADWP to measure and mitigate land subsidence throughout the Owens Valley Basin.

Examine Interconnected Surface Water/Groundwater and GDEs

The LWA team has extensive knowledge about understanding and monitoring GDEs. Our work on GDEs throughout Northern California is documented in the Additional Information that we provided in Appendix D. We combine knowledge on how to include GDEs into numerical models and how to evaluate GDEs and their importance from a biological evaluation. As a consequence of our interest on understanding GDEs, we already gathered some key information about GDEs condition in the OVGB to eventually prepare ourselves towards the challenging of properly including GDEs in the future OVGB GSP.

Not all groundwater-dependent ecosystems (GDEs) are equal in degree of groundwater dependence and GDEs such as wetlands and riparian zones, which are protected under the U.S. Clean Water Act, have been the subject of much ecological research (USEPA 2011). Non-wetland, non-riparian GDEs lack federal protection and have been studied less. Notwithstanding, such GDEs may be important for their biodiversity and economic value, especially in arid lands of the Intermountain West. GDEs in Owens Valley cover over 23,000 ha, and most do not meet the legal wetland definition (City of Los Angeles and County of Inyo 1991a). Groundwater is not expressed on the surface in these systems, and GDEs may be several kilometers from the nearest surface water. Following the classification of Eamus (2006), these systems can be referred to as Type III GDEs.

Owens Valley Type III GDEs sustain a variety of sensitive species including endemics such as Sidalcea covillei (Owens Valley checker bloom), Calochortus excavatus (Inyo County star-tulip), Astragalus lentiginosus var. piscinensis (Fish Slough milkvetch), and Microtus californicus ssp. vallicola (Owens Valley vole). Type III GDEs support livestock grazing and provide recreational opportunities. Owens Valley Type III GDEs also encompass or adjoin nearly 100 wells, which are used to extract about 11,225 hectare meters (91,000 acre-feet) of water annually. Operation of these wells is conducted under the terms of the Inyo County/Los Angeles Long Term Water Agreement. Management is based on a conceptual model of exploiting the ecological resilience of GDEs by imposing cycles of pumping-induced water table drawdown and recovery. Pursuant to the Water Agreement, certain sites have been the subject of intensive monitoring of vegetation and groundwater levels.

The depth of the water table below ground surface constrains the spatial distribution of groundwater-dependent ecosystems (GDEs) in Owens Valley. Recent studies have documented losses of grass cover coinciding with decreased water table depths in many locations in the Owens Valley. These changes in community composition are assumed to be associated with shallower rooting depths and greater vulnerability to declining water table depths in grasses compared to neighboring shrubs. Groundwater depth is correlated with a number of ecosystem traits in these Great Basin Desert ecosystems and should be considered when evaluating future changes in groundwater depth.

Inyo County Water Department has classified five vegetation management types based on parcel-scale evapotranspiration (ET) estimates derived from species-level leaf porometer measurements scaled up to the parcel using baseline vegetation cover and composition data. Parcels in which ET was equivalent to annual precipitation were classified as Type A. Parcels in which ET exceeded annual precipitation were classified as groundwater-dependent meadow or shrubland (Types C and B respectively), riparian/marsh (type D) and irrigated lands (type E).

Identify data gaps and uncertainties

Data gaps related to groundwater conditions within the Basin will be identified and their potential impact on the GSP development or basin management will be summarized. Recommendations for methods/studies to fill those data gaps will be suggested and prioritized.

Subtask 6.3. Prepare Water Budgets

Water budgets will be quantified for historical and current conditions per Reg. § 354.18. This will involve use of past studies, basin-wide models, recent monitoring data and investigations, and other relevant data about water balance components from previous and recent studies. Accordingly, our approach builds on the available data and evaluations from Task 3 data compilation and organization. We also will closely coordinate the water budget and we will reconcile the information that can be extracted by the existing models. This recognizes that a water budget is integral to a numerical groundwater model and, even if not required in the scope of work, it may require the development of a new single groundwater model that includes and combines the three existing models and extends the current simulation period to current. Utilization of such a model to evaluate the water budget is cost effective, ensures that the conceptual water budget and numerical modeling tool are consistent, and supports collaboration with other agencies using the model. Nonetheless, we also recognize that independent water budget analysis allows cross-checking of the model and analysis of specific issues or possible enhancements (e.g., groundwater recharge) that are not effectively addressed with a regional model.

Document Water Balance Information

This task will use the data compilation and study period selection in Task 3 to document the available data for a historical water balance of the basin. Existing water budgets will be used as a starting point for development of the water balance. OVGA and interested party input, particularly from interested parties in adjacent basins, will be gathered early in the process.

Describe Water Balance: Inflows, Outflows, Change in Storage

Consistent with the hydrogeologic conceptual model and with the information extracted from the existing groundwater flow models , this task will provide detailed qualitative descriptions of the inflows and outflows of the Basin. Inflow and outflow between management areas will be discussed. Estimates of subsurface inflows and outflows between subbasins and across the Basin boundaries will leverage the GSP groundwater model, if developed, which can provide information on historical and current subsurface inflows and outflows, changes in flow rates over time, and predicted future flows. The relative uncertainty in the storativity values of the Basin and its impact on change in storage volumetric estimates will be documented. If multiple Management Areas are defined, water budgets will be described for each as required by the GSP Regulations §354.20(c).

Quantify Water Balance: Sustainable Yield and Overdraft

Historical water budgets will be used to consider how past conditions, land use development, groundwater use, and water availability have affected overdraft/sustainability. Quantification of the water budget will extend back, accounting for the availability of data over time and the selection of representative study periods from the data collected in previous tasks. A sustainable yield will be estimated and discussed in terms of the availability/reliability of surface water supply deliveries, which have been important to local sustainability. This section also will discuss Basin responses to water supply and demand trends relative to water year types.

Consistent methods will be applied to estimate the inflows and outflows for the historical water balance and these same methods will be used to apply to a forecasted future water balance under climate change (see additional discussion below). It is understood that DWR will provide guidance and tools for evaluating climate change and forecasted changes to precipitation, and air temperature. When DWR guidance and tools are available, we will evaluate their applicability to the Basin conditions and conceptual projects. Assumptions on future conditions such as climate, water use and water availability will be documented, and the uncertainty of the future water balance will be addressed.

Identify Data Gaps and Uncertainties

The water balances (past and future) will be based on best available data, provided through previous tasks. Data gaps will be evaluated regarding their significance to GSP preparation. Data gaps may include:

- Groundwater pumping;
- Groundwater-surface water interactions (location, rate, timing) and ramifications for GDEs;
- Storativity estimates across the Basin; and
- Subsurface flow rates between management areas.

As discussed in previous tasks, many of these already have been recognized. The key task is to evaluate and prioritize the data gaps. This effectively addresses SGMA requirements for use of best available science, which refers to use of sufficient and credible information, while recognizing that data gaps and uncertainties will be identified and knowing that the SGMA time frame includes monitoring to fill data gaps later.

Deliverable*: GSP chapter describing the basin setting (Reg. Article 5 Subarticle 2).*

Task 7. Sustainable management criteria

SGMA legislation establishes definitions of the six undesirable results (Water Code § 10721. (x)), sets timelines for achieving sustainability, and identifies requirements that GSAs must follow to engage the beneficial uses and users of water within a basin. To achieve sustainability and avoid undesirable groundwater conditions, it is necessary for OVGA member agencies to collectively agree on current or potential problems facing the Basin and region and define measurable objectives that can be measured by interim milestones over the planning timeline. The LWA Team will leverage work completed in previous tasks and through the public outreach process to garner consensus among the OVGA members and other interested parties to lay the foundation for agreement while drafting goals and objectives for the GSP. The development of the goals, thresholds, objectives and milestones will involve significant input and coordination with the OVGA and interested parties. This engagement will begin early in the GSP development process even though the draft GSP chapters will not be fully developed until towards the end of the project. It is critical to understand the ultimate goals and evaluation metrics when developing the modeling tools and monitoring networks to ensure achievement of the goals can be assessed.

Subtask 7.1. Define Sustainability Goal

As outlined in the Draft DWR BMP for developing sustainability criteria, the Sustainability Goal is a qualitative discussion of the GSA's objective or mission statement for the Basin, combined with a discussion of the management measures that will be used to achieve that goal and the explanation of how those management measures will achieve the goal within 20 years. As one of the first steps in the project, the LWA Team will work with the OVGA and interested parties to define the qualitative goal statement for the Basin (Reg. § 354.24).

Subtask 7.2. Evaluate Each of Six Undesirable Results

The basin information and groundwater conditions documentation developed in Task 6 will be used to evaluate whether any undesirable results currently exist in the Basin. Based on our existing understanding of basin conditions, it will be important to carefully discuss the application of the sustainability indicator and minimum thresholds for significant and unreasonable degraded water quality in the context of SGMA, but undesirable results associated with the other sustainability criteria are unlikely to currently exist. Evaluation of undesirable results for degraded water quality will consider existing management programs to address the contamination and other Regional Water Board requirements and objectives.

Subtask 7.3. Define Minimum Thresholds

DWR Regulations establish six sustainability indicators for which minimum thresholds should be defined. All sustainability indicators must be included, regardless of whether or not there are any existing undesirable results associated with those indicators, unless there is a determination that an indicator is not applicable to the basin. Defining quantitative minimum thresholds is integral to the GSP, as exceeding them may cause undesirable results. Based on our current understanding of the Basin, all sustainability indicators are likely to be applicable and minimum thresholds will need to be established. The minimum thresholds will be developed based on the documented groundwater conditions, water budget, hydrogeologic conceptual model, the qualitative sustainability goal and the identified beneficial uses of the Basin. The minimum thresholds will include a description of how the thresholds will be evaluated using monitoring data to determine the presence of undesirable results. The minimum thresholds will be established using the metrics described in DWR Reg. §354.28.

Subtask 7.4. Define Measurable Objectives

Measurable objectives are goals reflecting the desired condition of the groundwater basin in 20 years and are shaped by an understanding of current demands and forecast of future demands for the region. While the minimum thresholds are designed to ensure that undesirable results do not occur, the measurable objectives are the metrics that will be used to manage the basin and implement projects and management measures to ensure the minimum thresholds are not exceeded in 20 years. The measurable objectives will be developed to allow for operational flexibility, provide a margin of safety, and account for uncertainties associated with future conditions.

The measurable objectives include the development of interim milestones that describe the pathway to attaining the objectives. The interim milestones will be developed based on the project identification and assessment described in Task 10.

***Deliverable**: GSP chapter describing sustainability criteria.*

Task 8. Progress Report Public Meeting

In order to update the OVGA Board and stakeholders regarding the project status, the LWA Team will conduct a public meeting at roughly the mid-point of GSP preparation to present GSP work to date, and future direction of the work. Based on the LWA Team's experience with projects similar to GSP development, feedback discussing and evaluating the progress of work, as well as next steps, is integral to the project's success and overall outcome. Ahead of the meeting, the LWA Team will review and assess interactions with stakeholders to date and identify their primary concerns and comments. Based on this review, LWA will prepare a meeting agenda and relevant meeting materials. The LWA Team will provide a presentation, facilitate meaningful discussion, and identify appropriate member agency representatives to present as applicable. It is assumed that the OVGA Board will identify the meeting date and location. LWA will prepare a draft meeting summary with identified action items within 1 week of the meeting, and will provide a final copy to the OVGA within 1 month of the meeting occurrence.

***Deliverables**: Meeting agenda, presentation materials, and meeting summary.*

Task 9. Develop/refine monitoring program.

This task will establish a monitoring network and monitoring protocols for the GSP. Whereas ongoing monitoring of certain types of data does exist within the Basin, work as a part of this task will unify those efforts as part of the GSP to benefit the entire Basin. Where appropriate, specific monitoring requirements will be attributed to each of the specific GSP members. The overall goal of the monitoring plan will be to collect the data necessary to demonstrate that current practices and management actions within the Basin are leading toward the overall goal of sustainability, with respect to the Sustainable Management Criteria previously developed. The monitoring plan will also serve to provide as a means by which “undesirable results” within the Basin are identified as they may occur.

The monitoring plan will be designed to collect basin-wide criteria, with a focus on the areas of the Basin where groundwater extraction is more significant or has the potential to cause measurable “undesirable results”. Protocols for data collection (including location, frequency, and methods) will be provided as part of the monitoring plan to help the various parties executing the plan to collect data of sufficient quality and quantity that are necessary to assess conditions in the Basin.

Subtask 9.1. Evaluate Existing Networks

Although no formal basin-wide monitoring plan is known to exist at this time, various monitoring networks are known to exist within Basin. These include:

- LADWP’s groundwater and surface water monitoring network.
- CASGEM monitoring conducted by LADWP, Mono County and the Tri-Valley Groundwater Management District
- Groundwater elevation monitoring in the Fish Slough Sub-basin and groundwater monitoring in the Swall Meadows Community Services District
- Groundwater monitoring conducted by tribes on tribal lands

These monitoring networks will be evaluated for their applicability to the GSP goals and sustainability objectives and will be incorporated as part of the GSP monitoring plan as appropriate.

Subtask 9.2. Describe GSP Monitoring Network

As described above, in addition to considering existing monitoring efforts, new monitoring data points will be described as part of the monitoring plan developed for this task to track achievement of measurable objectives and ensure minimum thresholds are being met. Essential elements of groundwater monitoring for the entire Basin will include methods to:

- Maximize data collection and permit ongoing plotting and hydrogeologic interpretation/analyses of the acquired data on a regular basis;
- Protect and maintain the operational pumping yields of current groundwater extractors within the Basin;
- Help to protect the groundwater quality of the shallow and deeper aquifer systems;

- Monitor the ongoing actions of various regulators, like the RWQCB and the DTSC, in regard to suspected and/or known, current and/or future soils and/or groundwater contamination sites in the Basin;
- Monitor groundwater extraction by the various dewatering entities and NPDES permit holders throughout the Basin;
- Monitor local agencies that collect data on possible subsidence; and
- Observe changes in water quality.

For this effort, the monitoring plan will include an explanation of the scientific rationale for the monitoring sites chosen, including the rational for:

- Spatial distribution of sites;
- Measurement frequencies;
- Corresponding sustainability indicator, minimum threshold, measurable objective, and interim milestone for each type of data collected;
- Types of data to be monitored;
- Types of equipment that can be used to conduct the monitoring; and
- Frequency and types of reporting to be provided.

A map will be created showing the location and monitoring type to be used for each monitored site.

Subtask 9.3. Document Monitoring Protocols

This subtask will define the technical standards, data collection methods, and other procedures or protocols to ensure reliable and comparable data and methodologies, consistent with GSP regulations sections § 352.2 and 352.4 and the Monitoring BMPs. Details regarding monitoring frequency, monitoring methods, QA/QC protocol, data recordation and storage protocol will be provided.

Subtask 9.4. Assess GSP Monitoring Network and Plan Improvements

This subtask will identify data gaps through the process identified above and in consideration of the hydrogeologic conceptual model, water balance, modeling, and sustainability indicators developed throughout execution of this scope of work. These data gaps may include augmented surface water data collection, subsidence monitoring, and other data needs. Resolution of data gaps will be addressed in the GSP Implementation Plan. Update of the GSP every five years will include ongoing evaluation of the monitoring network (Reg. § 354.38).

Deliverable*: GSP chapter describing monitoring network conditions, protocols, and improvements.*

Task 10. Identify and describe projects and management actions to maintain or achieve sustainability.

The extensive existing knowledge about the basin and the available data combined with the new information collected and organized in Task 6 will allow the LWA team to start the evaluation of possible projects that may be necessary to implement the GSP, as required in the regulation (Reg. § 354.44). Projects will be designed and discussed with the GSA, and the list below only address a preliminary list of projects, but more suggestions can be provide after the evaluation of the basin and of the groundwater condition that the LWA team will perform mostly in Task 6.

The projects suggested in the RFP include:

a. *A cost and rate study to estimate future expenses associated with GSP implementation*

LWA will explore funding mechanisms that are available for the implementation of the GSP that allow for the development of an equitable method of assessing fees. This will include an assessment of existing funding sources and potential additional sources. Additional sources may include grant and loan programs, bonds, utility fees, general funds/property taxes, and/or special assessments. Factors to be considered will be the overall schedule for project implementation under the GSP, existing resources, economic conditions, and opportunities for cost-sharing. Based on this review LWA will develop recommendations tailored to the needs of the communities in the Owens Valley Region.

b. Assessment, reconciliation, and consolidation of existing groundwater models.

From our preliminary research, we understand that a significant amount of valuable information is already included in the existing models for the area as previously described. The LWA team has in depth experience with groundwater models and is confident on using MODFLOW models and other models without any graphical interface. As needed, we can provide support on developing tailored tools for pre- and post-processing that can be more user-friendly.

Within this project, we will analyze and reconcile the existing models and provide suggestions about possible needs to update or to modify to develop a tool that is in compliance with GSP requirements and that can be used for simulations of future scenarios.

b. Coordination and compatibility with the Inyo/Los Angeles Water Agreement.

The LWA team has extensive experience dealing with GSP development in area where part of the land is adjudicated (Scott Valley in Siskiyou County) and will be able to apply the knowledge in dealing with the situation in the OVGA. We will work with the GSA and gather all the necessary data and tool available through the Inyo/Los Angeles Agreement to confirm that there is compatibility between the GSP and the Inyo/Los Angeles county agreement.

d. Coordination with other landowners, such as federal agencies and tribes, to identify the role of these stakeholders in the GSP, and interaction and impacts to the GSP requirements.

We acknowledge the importance of properly including all the stakeholders, the federal agencies and the tribes in the process. We believe this coordination should start at the very beginning of the project to ensure that information are widely distributed and each party is involved in the process.

e. Improvements to monitoring based on the results of Task 8.

We will evaluate the monitoring network based on the existing data previously collected (Task 8) and also we will use the existing models and their results to suggest key location for future monitoring and eventually key type of data to be monitored. Our experience suggests for example that in basins where groundwater-dependent ecosystems are of primary concern, continuous network of data that monitor both groundwater levels and streamflows are expected to provide critical information to better characterize the system and will lead to significant improvements in the model performances in terms of future predictions of groundwater/surface water interactions.

f. Incorporation of LADWP's work into the GSP

We already mentioned in our collection of data and information presented above all the material available through LADWP ongoing and future projects. We will further evaluate the proposed groundwater development at Owens Lake and we will incorporate this work into the GSP.

g. Determination of groundwater flow paths and rates between the Tri-Valley region and the Bishop-Laws region.

One of the main purposes of this GSP will be to *determine groundwater flow paths and rates between the Tri-Valley region and the Bishop-Laws region in order to better understand and quantify groundwater flow between the two regions. This will help address sustainability of Fish Slough, which its current sources and stresses on the groundwater system are poorly understood.* We understand the importance of addressing the sustainability of Fish Slough which is a federally *designated Area of Critical Environmental Concern (ACEC) harboring endemic plants and fishes*. We will apply our knowledge about GDEs to ensure that this area is properly included and simulated in the existing models that the LWA team will be reconciling, is covered by the necessary monitoring network, and biological and ecological aspects will also be carefully considered. Current and future inflows and outflows to the basin will be evaluated and measures aimed at protecting the habitat will be developed and included in the GSP

h. Determination of hydrologic factors affecting shallow groundwater in West Bishop.

We will also use the data collected in Task 3, the basin assessment of Task 6, and the existing basin-wide model to *determine hydrologic factors affecting shallow groundwater in West Bishop* and provide some preliminary understanding of what is causing these specific conditions. The model can then be eventually used to simulate scenarios specifically aimed at solving these high water conditions and at preventing the threat to private properties in the area.

i. Recommendations for other studies or plans.

Understanding the importance that a proper GDEs assessment can have for the success of the GSP, some more specific modelling and data collection can be suggested for the GDEs areas. Ideas such continuous monitoring of groundwater and eventually surface water in the vicinity of the critical GDEs and, for example, at the boundary of the Fish Slough subbasin may provide key information to characterize these areas in the GSP and to suggest successful sustainable measure for the future implementation.

Preparation of the GSP will be supported by evaluating projects for their potential to optimize use of the Basin for public benefit and evaluating funding mechanisms for GSP implementation.

Subtask 10.1. Describe Screening Criteria and Conduct Screening

During this process, we will work with the OVGA, federal agencies, landowners, tribes, and all interested stakeholders, through workshops or other measures, to develop screening and ranking criteria for the potential projects and management actions. During this screening, we will assess the coordination and compatibility of these projects and actions with the Inyo/Los Angeles Water Agreement to assure the compatibility of the GPS with this Agreement. We will also review studies and plans related to LADWP's ongoing monitoring, management, and mitigation program, proposed groundwater development at Owens Lake, to incorporate LADWP's work into the GSP. Upon completion of screening and ranking/prioritizing the potential projects and management actions, we will develop findings and recommendations and will present them to the OVGA and interested stakeholders. Eventually, the LWA Team will use the ranked/prioritized projects and management actions to define a preferred alternative and develop the implementation plan.

Subtask 10.2. Select/Prioritize Projects for Implementation

After ranking/prioritizing the potential projects and management actions, scenarios will be developed that can be modeled to compare potential projects and management actions to baseline future conditions.

The technical analysis results will be used to identify possible undesirable results and apply the sustainability indicators and thresholds identified for the GSP. In this way, the relative benefits and costs can be compared and a preferred alternative selected. The Team will assist the OVGA in establishing the criteria to select the preferred alternative for inclusion in the GSP implementation plan. The criteria may include technical (feasibility, yield, quality), social (economic, political, legal, social) and environmental (sustainability indicators, and California Environmental Quality Act (CEQA).

***Deliverable**: GSP chapter setting out the objectives, feasibility, work plans, budgets, schedules, CEQA and permitting requirements, and priority within the GSP of these projects, as well as describing the need and relationship of each project to basin-wide sustainability criteria, and identifying other projects that may be necessary to implement the GSP.*

Task 11. Develop GSP implementation schedule and budget.

This task will evaluate the budget for implementing the GSP after is has been adopted, and set out a schedule for implementation of tasks (Reg. § 354.6). Deliverable: GSP chapter setting out the budget and schedule.

Prepare 5-Year Work Plan for GSP Implementation

Building off the implementation plan developed under Task 4.11, the LWA Team will prepare a work plan to implement the GSP for the first five years of its full implementation (i.e., 2022-2027). The work plan will include the specific elements included in the GSP, a schedule for implementing the elements, a process for annual reporting and a process for evaluating progress. The work plan will provide sufficient detail to facilitate preparation of an RFP for GSP implementation.

Task 12. Develop system for annual reporting.

Our experience in the development of other GSPs will be applied to this specific task and we expect the LWA team to be very efficient in providing the OVGA with a streamlined tool for submitting annual reports to DWR. Our extensive internal coding capabilities will also allow us to tailor the database and its functions and capabilities to the needs of the OVGA. The DMS will be focused on enabling the GSAs to prepare the data and implement a protocol that complies with the requirements of SGMA.

The required computer hardware, operating system, database software (i.e. Oracle or Microsoft SQL Server, MS Access, etc.), tailored tools and protocols and required DMS functionality will be determined by GSA staff and consultants as part of the needs assessment; and the hardware, software, functionality, hosting, deployment and degree of data protection will be formally determined following the needs assessment.
The LWA team will finally develop a protocol and templates that the GSA will be able to use in the future to submit annual reports to DWR.

***Deliverable**: Protocols and templates for submittal of annual reports to DWR.*

Task 13. GSP compilation, presentation, and submittal of GSP.

SGMA and the GSP Regulations both have detailed requirements for the GSP and its technical content, and for collaboration among agencies, communication with the public and interested stakeholders, and notification to DWR through its SGMA Portal. Team key personnel are well versed in SGMA and the GSP Regulations, are familiar with the Portal, and already have assisted multiple agencies with tasks that precede preparation of the GSP itself.

Prepare Notification to DWR of GSP Preparation

The OVGA already has an account with the SGMA Portal, which was used to submit the GSA Formation notification. This account can be used by OVGA staff for the GSP Notification. If desired, one of our consultant team can be designated as an administrator to assist (the OVGA Plan Manager would be notified of any changes).

LWA Team members maintain regular communication with DWR and are familiar with all notification requirements. We have developed annotated GSP outlines for other GSAs and will customize them for the Owens Valley Basin.

In this task, we will work with OVGA staff to fulfill requirements of GSP Regulations §353.6.; first, note that no formal hearings or resolutions are required. As indicated by the template provided on the Portal, the main task is to provide general information about the planned processes for developing the GSP, including descriptions of how interested stakeholders can contact the OVGA and participate in the GSP. We recommend that OVGA identify a Plan Manager and provide a link to the website where GSP information is made available to the public. We will develop a succinct description of the Communication Plan including establishment of an advisory committee (if desired). Pursuant to SGMA §10727.8, we will also provide a brief letter template that can be used to provide formal GSP notification to land use planning agencies in the GSP plan area.

Prepare GSP Document

The technical work to prepare the GSP will have been conducted during previous tasks. As a result, this task consists primarily of compiling the technical work and OVGA inputs on the interim work products into a document that can be adopted by the OVGA. We will carefully tailor our findings from the previous tasks and proposed sustainable management plan to fully comply with Article 5 of the Emergency Regulations. Under this task, the LWA Team will prepare the remaining analyses necessary to complete the GSP and develop draft documents for review and comment by the interested parties and public.

An administrative draft SMBGSP will be prepared for review by OVGA members and the other interested stakeholders. Included in this effort will be preparation of an Executive Summary and compilation of electronic copies of specific references to be provided to DWR.

Feedback will be incorporated into a final public review draft OVGB GSP. Written comments from the public and interested stakeholders will be sought, and oral public comments will be received during up to two OVGA quarterly workshops.

The LWA Team will compile the public comments and will work with the OVGA to decide how public comments will be addressed and a final report will be prepared. Conflicting comments and significant policy differences implied by conflicting comments will be resolved by decision of the OVGA.

Public comments will be used to prepare the final SMBGSP that will be considered for adoption by the OVGA. The Executive Summary and reference documents will also be revised and finalized as needed based on public comments. A draft resolution to adopt the SMBGSP will be prepared by the LWA Team for consideration.

The LWA Team has extensive experience in developing regulatory documents that support stakeholder interests as outlined in *Qualifications section* of this proposal. This experience will allow us to prepare a GSP document that meets the needs of interested stakeholders and regulatory requirements necessary to adopt the GSP.

Provide Draft Annotated GSP outline

Team personnel have experience with developing GSP outlines based on the requirements of SGMA §10727.2 and GSP Regulations Article 5, Plan Contents. Moreover, we bring experience with writing GSPs (in progress) and preparing an entire Alternative Plan.

In this task, we will begin with DWR's Annotated Outline Guidance Document. We recognize that the DWR Outline can be considered as one-size-fits-all. Accordingly, we will start with the DWR Outline, retaining most of its features to expedite comparability with the regulations and to ease the eventual evaluation by

DWR. Nonetheless, we will also tailor it to the Owens Valley Basin conditions and reading audiences. This recognizes the GSP as the basis for local management.

Based on our experience, the GSP document will contain specific sections that cannot be written until the GSP process is completed. These include not only the Executive Summary, but other sections, for example, the §354.6(e) discussion of GSP implementation costs and how the OVGA will meet those costs. Similarly, the GSP document will include a summary of information on notification and communication. We will flag these items for timely completion.

We will provide a draft outline, submit it to the OVGA, and address any comments received. If the OVGA wishes, the final Annotated Outline will be suitable for posting on the OVGA website for informational purposes.

Deliverable*: A complete GSP submitted to DWR.*

Task 14. Address deficiencies and corrective actions identified by DWR, and resubmit.

Following adoption and submittal of the GSP, the next phase of the GSP process is DWR evaluation. This includes DWR review of the GSP for completeness and provision of all required information, and evaluation of the GSP in terms of substantial compliance, in other words, if the GSP is likely to achieve sustainability. DWR will determine if the GSP is Approved, Incomplete, or Inadequate. A determination of Inadequate means that deficiencies exist, but can be corrected in a timely manner, and DWR will define corrective actions. In the unlikely event that the GSP is not approved, we will commit to working with DWR and the OVGA to correct the deficiencies and provide for adoption of a revised, compliant GSP.

Deliverable*: Submittal of a revised GSP.*

Task 15. Coordination Meetings Between Consultant and GSA Staff

The LWA Team will coordinate and facilitate semi-monthly teleconferences with GSA staff. These calls will form the core of the decision-making input process for the GSP and keep the project on track. The LWA Team will also provide updates to the OVGA representatives on project status and schedule and discuss the overall process and upcoming work products and decisions. While all GSP-elements will be provided for input to the interested stakeholders and broader community, the GSA decision makers will provide the day-to-day guidance and direction for the project. As a result, the effectiveness of regular coordination meetings is a critical element to the success of the project.

LWA will work with the OVGA to develop a project charter or other guiding documents for communication and decision-making within the OVGA member agency meetings. Based on past experience, successful communication and engagement by this group is one of the most critical factors for project success.

For these project status calls/meetings to be effective, it is critical that a process be established to allow decision making and resolution of conflicting opinions within the OVGA. The LWA Team will work with the OVGA to develop a project charter or procedures that can be used throughout the project. Prior to the coordination meetings, the LWA Team will provide concise outlines and/or other meeting materials that outline approaches or impacts of key decisions ahead of the meetings. The LWA Tam will present the materials at each meeting and lead a discussion to achieve the outlined goals for the meeting. Within a week of each meeting, the LWA Team will distribute meeting summaries with clear actionable items to the GSA decision makers.

Deliverable*: Coordination of semi-monthly calls, meeting summaries, action items, and memoranda to GSA decision makers concerning GSP preparation activities and status.*

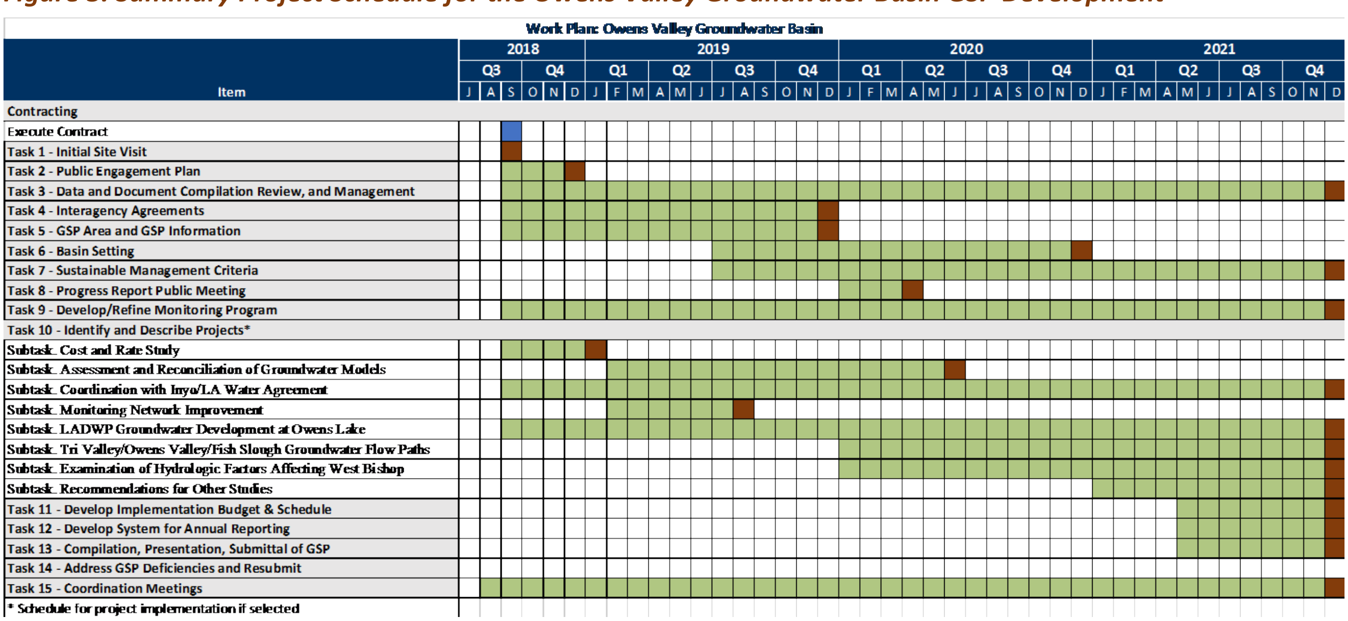
4.4. Project Schedule

The LWA Team has the capacity to perform the work according to the timeline and will be ready upon award to deliver the quality service that is required to ensure the success of this high-profile project. The Team will work closely with the OVGA to complete the required tasks to submit the GSP by January 31, 2022. Given the complexity of the work effort and the need to communicate with the County, our approach for successfully developing the GSP is based on: 1) maintaining clear lines of communication, 2) informing and receiving input from OVGA staff on an ongoing basis, 3) controls to complete tasks on schedule, and 4) controls to complete the project within budget. This approach has been used successfully on other projects to ensure completion of high quality work on time and within budget.

The summary project schedule presented in ***Figure 3*** pertains to the activities and deliverables described in our proposal and is based upon our understanding of the tasks to be completed as required within the RFP. The schedule is preliminary and based on an anticipated Notice to Proceed (NTP) in the Fall of 2018 (October 1, 2018), a draft GSP by June 30, 2021 and a final GSP to DWR by January 31, 2022. This schedule exceeds the three-year contract period described in the RFP but includes extra time for review and stakeholder input at several steps that could be reduced to shorten the schedule. The schedule will be refined based on discussions with the OVGA and finalization of the meeting and workshop schedule to include specific dates for deliverables and review periods. No less than two weeks will be provided for review for all interim work products and a minimum of one month will be provided for review of all draft GSP chapters. To the extent possible, depending on the NTP date and the contract period, the schedule will include extra time to allow for additional engagement or resolution of questions and conflicts, particularly for those elements requiring significant stakeholder engagement.

Once the specific schedule has been developed, adherence to timelines for work product development and review timelines will be needed to meet the draft GSP deadline for June 30, 2021, and submittal date of January 31, 2022. Should schedule steps require additional time by others, we will take all reasonable measures to accommodate the changes while minimizing disruption to other schedule elements. We will promptly identify potential delays and the best possible manner to rectify the schedule and communicate a revised schedule to the OVGA PM.

Figure 3. Summary Project Schedule for the Owens Valley Groundwater Basin GSP Development



4.5. Assumptions

The prepared scope of work and associated cost estimate assumes that the NTP will be provided in the Fall of 2018 to meet the timelines specified in the RFP. The approach also assumes that the three existing models will be provided in a timely manner and that after reconciling the three models, only minor modifications will be required. The budget does not include a development of a new model in case reconciling the existing models does not result in an efficient strategy.

Data collection work (Task 3) assumes that the county and the GSA will collaborate for the purposes of data collection, including reconnaissance of well sites, spring locations etc. We plan to collect the majority of the information during the first visit. If additional data collection is identified through the groundwater condition assessment modifications to the scope and budget for the project would be needed, or the additional field visits will be combined to required public meeting and/or workshop. Also included are visits as necessary to research/collect data in Agency files that may not be available electronically (may include member agencies, RWQCB-LA, DWR, etc.). However, additional data collection can likely be accommodated in the project schedule, with the NTP assumptions noted previously.

Data collected will be stored, formatted, and available to interested parties as required by GSP regulations, and will be tailored to the needs of the OVGA member agencies. Data compilation work described under Task 3 herein does not include the construction of a relational database; because the number of groundwater extractors in the basin is limited, such a database managed by a third party may not be warranted at this time. If during the development of the GSP a need for such a database is identified, then construction of the database can be addressed as an additional task as shown under Task 3 or as a specific project under Task 10. The proposed database to be developed under Task 3 would be a simple, relational database. Development of a stakeholder facing database for use by users not experienced with data management software or the ability to access the data through a website would require additional budget and scope.

For the stakeholder outreach workshops, the interested parties list provided by the OVGA will be used, maintained and updated for the project. Additionally, the LWA Team will attempt to repurpose and revise existing material assets to reduce design costs. If new materials are needed, then we will provide a cost estimate for each new material needed. As noted above, the workshop facilities and coordination of the meeting dates and times will be conducted by the GSA. Printing and postage are not included in the budget and will be expensed as a hard cost. If additional outreach is required, we can provide updated budget estimates.

5.0 Cost Proposal

Below we have provided the proposed budget to complete the tasks for Owen's Valley Groundwater Basin. *Table 2* reflects the budget in Attachment 5 to the RFQ which was included with the County's grant application, and includes all tasks as outlined in the Work Plan. The budget below reflects estimates of time, material, and other expenses to complete the proposed work and is consistent with the grant budget. Additionally, fee schedules are included in ***Appendix C***, which will remain in effect for the duration of the Services Contract.

While the budget is based on the grant application, Task 2, Public Engagement Plan, is not directly accounted for in the grant application budget. Therefore, the cost for this task is in addition to the total grant application budget. LWA will work with the County to incorporate these costs into the existing budget if needed. In addition, LWA is open to working with the County and OVGA to adjust the budget as needed to ensure that the GSP is developed according to SGMA requirements.

Should the County elect to complete some tasks using in-house resources, LWA is open to discussions of options to adjust the proposed budget according to the tasks which the County elects to pursue. The County will benefit from our cost estimating approach which is based on our Team's extensive experience in completing similar work for clients throughout the North Coast and Central Valley. As a small business, our Team is keenly cost-sensitive and have refined our work processes to perform the services in the most efficient manner while remaining focused on quality and compliance. Evidence of our effective cost control, management and communication approach, and quality and auditing practices is provided in Section 3 and Section 6.1. The Team will implement the same proven approach to manage this project and ensure successful completion of all tasks and deliverables.

Table 2. Fee Proposal for the Development of the Owens Valley Groundwater Basin GSP

Task	Cost
Task 1 - Initial Site Visit	$15,000
Task 2 - Public Engagement Plan	$20,000[1]
Task 3 - Data and Document Compilation Review, and Management	$60,000
Task 4 - Interagency Agreements	$25,000
Task 5 - GSP area and GSP Information	$22,000
Task 6 - Basin Setting	$132,500
Task 7 - Sustainable Management Criteria	$27,000
Task 8 - Progress Report Public Meeting	$15,000
Task 9 - Develop/Refine Monitoring Program	$30,000
Task 10 - Identify and Describe Projects	
a. Cost and Rate Study	$18,000
b. Assessment and Reconciliation of Groundwater Models	$25,000
c. Coordination with Inyo/LA Water Agreement	$12,000
d. Monitoring Network Improvement	$15,000
e. LADWP Groundwater Development at Owens Lake	$5,000
f. Tri Valley/Owens Valley/Fish Slough Groundwater Flow Paths	$25,000
g. Examination of Hydrologic Factors Affecting West Bishop	$23,500
h. Recommendations for Other Studies	$15,500
Task 11 - Develop Implementation Budget & Schedule	$7,000
Task 12 - Develop System for Annual Reporting	$12,000
Task 13 - Compilation, Presentation, Submittal of GSP	$135,000
Task 14 - Address GSP Deficiencies and Resubmit	$15,000
Task 15 - Coordination Meetings	$32,000
Total	**$686,500**

1 - The District's GSP budget does not cover this particular task. This cost is in addition to the grant-based budget but LWA can work to include this cost into the current grant funding if needed.

6.0 General Firm Operating Informaton

Additional company information (role, size and structure, and number of partners and owners) for LWA and our team partners is provided in this section. As illustrated in ***Table 3,*** the LWA Team has the capacity to support the work on this project and assigned staff members are available upon award.

Table 3. Responder Information

Name of Firm:	**Larry Walker Associates**	**Richard C. Slade Associates**	**Todd Groundwater**	**Thomas Harter, UC Cooperative Extension**
Role:	Prime Consultant	Subconsultant Team Partner - Groundwater Services	Subconsultant Team Partner - Groundwater Services	Subconsultant Team Partner - Groundwater Services
Company Size (No. of Employees):	45	8	16	N/A
Company Legal Structure:	Corporation	LLC	Corporation	University
Number of Partners & Owners:	4 Owners	2 Owners	16 Owners (15 Employees, 1 Board Chairman)	N/A

LWA has sufficient financial and personnel resources, as well as the management efficiency and flexibility, to successfully complete the scope of work outlined in the RFQ. LWA practices sound fiscal management through planning, organizing, controlling, and monitoring financial resources for our company and our client's projects. These practices sustain financial stability and ensure adequate resources are available to complete work. Notably, since 1979, the company has never taken a bank loan. LWA employs 45 professional engineers, scientists, and administrative personnel, and can readily supplement staff as needed to accommodate future resource needs or for other specialized technical services. LWA's continuous growth and the employees' longevity are indicative of the company's operational stability; 65% of the senior staff have been with the company for 10 years or more.

6.1. Experience in meeting deadlines

The LWA team members have worked on numerous multi-year, multi-faceted projects and have extensive experience in managing suchprojects to ensure that all deadlines are met. This is accomplished through regular check-ins with the consultant team and with agency staff. In addition, interim milestones are established for long projects to help ensure that final deadlines are met. To ensure the project achieves all objectives, the LWA team will utilize strict QA/QC efforts including detailed in-house peer review of all reports. The LWA team will work with OVGA staff to identify challenges in working with stakeholders or in obtaining needed information to help anticipate and plan for issues that may result in delays.

6.2. Disclosure of Relationships

A signed statement regarding financial, business or other relationships with OVGA, any OVGA member or the Los Angeles Department of Water and Power is found in ***Appendix A.***

6.3. Ability to Enter into Contract with County of Inyo

LWA has reviewed the County of Inyo Standard Contract No. 118 and will be able to accept the contract terms and enter into an agreement with the County of Inyo.

Appendix A. Non-Disclosure Statement

Included in this appendix are the following required documents:

- Non-disclosure statement

Disclosure Statement

LWA Team members do not currently have any financial, business or other relationships with OVGA or any OVGA member or the Los Angeles Department of Water and Power that would have an impact upon the outcome of the selection process for this project. While Larry Walker Associates Team members work for entities in Los Angeles County, team members do not have any financial or business relationships with Los Angeles Department of Water and Power that would have an impact upon the outcome of the selection process for this project.

Thomas Grovhoug 7-30-18

Thomas Grovhoug, Senior Executive
Larry Walker Associates

Appendix B. Key Personnel Resumes

Included in this appendix are resumes detailing the relevant experience, qualifications, credentials, professional licenses and certifications, and education for the following key personnel:

Larry Walker Associates

- Laura Foglia, Ph.D.
- Betsy Elzufon
- Thomas R. Grovhoug, P.E.
- Will Lewis, CPESC, CPSWQ
- Michael Trouchon
- Diana Engle, Ph.D.
- Masih Akhbari, Ph.D., P.E.

University of California, Davis

- Thomas Harter, Ph.D.

Richard C. Slade & Associates

- Richard Slade PG, CEG
- Earl LaPensee, PG, CHG
- Anthony Hicke, PG, CHG

Todd Groundwater

- Iris Priestaf, Ph.D.
- Eugene B. (Gus) Yates, PG, CHG

Laura Foglia, Ph.D.

Senior Engineer

EDUCATION

Ph.D. in Environmental Engineering, 2006, ETH Zurich Switzerland

M.S., Physics, 1999, University of Milan, Italy

YEARS OF EXPERIENCE

With LWA: 8

With UC Davis: 8

With Technical University Darmstadt: 3

SPECIALIZED TOOLS

MODFLOW and IWFM hydrologic models
Calibration models
Fortran, Python

PROFESSIONAL AFFILIATIONS

American Geophysical Union

European Geophysical Union

IAHS, International Association of Hydrological Sciences

Secretary of International Commission of Groundwater, IAHS

Dr. Foglia is a Senior Engineer with Larry Walker Associates (LWA) where she assists with projects in the areas of hydrological modelling, groundwater management assistance, and TMDL development. At LWA, she is leading the engineering services for the Omochumne-Hartnell Water districts and she managed the basin boundary modification project for OHWD and SRCD. Dr. Foglia and Prof. Steffen Mehl worked on behalf of Sacramento County Water Agency for the development of the testimony regarding the potential impact of the California WaterFix project on the groundwater resources in the South American Basin. She was involved in the first Pilot Project in 2009 that promoted by the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) coalition, a collaborative basin planning effort aimed at protecting vulnerable and essential water resources. Since January 2016, Dr. Foglia is also an Adjunct Faculty Staff in the Land, Air, and Water Resources (LAWR) Department at University of California, Davis where she teaches a graduate class on model calibration, supervises students, and works on the Scott Valley project for the assistance of the Scott Valley community with the development of the groundwater management plan. She has extensive experience teaching groundwater modelling and integrated hydrological modelling, with tailored material developed for short courses for stakeholders. She has relevant scientific publications on groundwater/surface water model development, assessment of data, evaluation of alternative models.

Local & Stakeholder Experience

Sacramento County Water Agency California WaterFix Groundwater Modeling Impact Assessment Support

Dr. Foglia teamed with Prof. Steffen Mehl to support the Sacramento County Water Agency in the Evaluation of the potential impact of the California WaterFix project on the groundwater system in South American Subbasin. Existing models for the entire Central Valley (CVHM) and for the Delta region (CVHM-D) have been extensively used and results analyzed to demonstrate wether the potential impact of the p;roject on water resources (mostly river/aquifer interactions) has been properly considered by the Petitioners. A testimony and a surrebuttal testimony have been submitted as results of this study.

Omochumne-Hartnell Water District: on-call engineering services

Dr. Foglia is managing the in-call engineering services contract with OHWD. Work includes the repurpose of an existing Proposition 84 grant Integrated Regional Water Management to design an off-season irrigation project to enhance aquifer recharge to the underlying groundwater aquifer and the South American and Cosumnes groundwater basins. The project includes repurpose of the grant, development of the RFPs for the construction services, groundwater monitoring design, stakeholder coordination.

Omochumne-Hartnell Water District and Sloughhouse Resource Conservation District Basin Boundary adjustment

Dr. Foglia, together with the LWA team, assisted Omochumne-Hartnell Water District (OHWD) and Sloughhouse conservation district (SRCD), in putting together and submitting a jurisdictional and scientific basin boundary adjustment request for the Cosumnes Subbasin's northern boundary, located along the Cosumnes River, to DWR in 2016. The project involved the development of technical material as well as the preparation of stakeholders meetings to support the boundary adjustment request.

CV-SALTS Salt & Nitrate Sources Pilot Implementation Study, Central Valley, CA

Dr. Foglia managed and performed analysis of salt loads in the Central Valley aquifers for the completion of a Salt and Nitrate Sources Pilot Implementation Study on behalf of the Central Valley Salinity Coalition (CVSC) to help develop a Basin Plan Amendment (BPA) to address the issue of salt and nutrient management in California's Central Valley. The resulting methodology provided a defensible means to relate downstream impacts to upstream sources in watersheds. The objectives were to develop and document procedures and methodologies to quantify the significant salt and nitrate sources in the Central Valley and to pilot test them by applying them in three areas to validate the region-wide applicability.

Groundwater (most recent)

Scott Valley Groundwater Study, Scott Valley, CA

As part of the LAWR Department at UC Davis, Dr. Foglia provided research services for the Scott Valley groundwater/surface water management project, funded by the North Coast Regional Water Quality Board. The aim of the project is to assist the Scott Valley community with the development of a groundwater management plan that can lead to better streamflow conditions mainly during the summer months, preserving the water needed for agriculture activity. Dr. Foglia assisted with the development of a new GIS-based, irrigation driven, conceptual model for the analysis of the soil and water balance in the Scott Valley watershed. She worked closely with the stakeholders, communities, and landowners.

Technical University Darmstadt (TUDa), Germany

During her three-year employment at Technical University Darmstadt (TUDa), Germany, Dr. Foglia managed and developed proposals related to water resources management and tools to assist authorities and stakeholders complying with the new EU Water regulation. She was actively involved with MARSOL (www.marsol.eu) and FREEWAT (www.freewat.eu).

MARSOL aims to demonstrate that Managed Aquifer Recharge (MAR) is a sound, safe, and sustainable strategy that can be applied with great confidence, therefore offering a key approach for tackling water scarcity in Southern Europe and worldwide.

FREEWAT represents a key project in the framework of the new EU regulation and aims at promoting water management and planning by simplifying the application of the Water Directives. FREEWAT is expected to be a modelling tool widely applied by stakeholders in and outside of Europe. Testing in U.S. and California case studies are in progress.

Most Relevant University Research Grants

2015 FREEWAT- H2020 - Water 2014 one stage: 642224 grant. EU Contribution: €1,411,078. Co-PI (PI: Dr Rudy Rossetto, SSSA, Pisa, Italy), April 2015-Sep. 2017.

2014 North Coast Regional Board, California, grant extension for Scott Valley management plan. Principal Investigator: Prof. Thomas Harter, UC Davis.

2013 MARSOL-Grant Agreement no:619120 FP7-ENV-2013-WATER-INNO-DEMO, PI: Prof. Christoph Schueth, TU Darmstadt. Total Costs: €8,039,988, Dec. 2013-Nov. 2016.

2007 Joint inversion of groundwater flow and environmental tracer data for aquifer characterization, 2007-2009, UC Center for Water Resources, co PI (PI: Prof. Timothy Ginn).

Journal Articles (Most Relevant)

De Filippis, G., Foglia, L., Giudici, M., Mehl, S.W., Margiotta, S., and Negri, S. (2016) Seawater intrusion in karstic, coastal aquifers: current challenges and future scenarios in the Taranto area (southern Italy), Science of Total Environment, 573: 1340-1351.

Rossetto, R., Borsi, I., Foglia, L., 2015, FREEWAT: FREE and open source software tools for WATer resource management, Rend. Online Soc. Geol. It., Vol. 35 (2015), pp. 252-255, DOI: 10.3301/ROL.2015.113.

Rasa E., Foglia L., Mackay D.M., and K.M. Scow, (2013) Effect of different transport observations on inverse modeling results: Case study of a long term tracer test at a high resolution groundwater monitoring site, Hydrogeology Journal 21: 1539-1554, DOI 10.1007/s10040-013-1026-8.

Foglia, L., A. McNally, and T. Harter (2013), Coupling a spatiotemporally distributed soil water budget with stream-depletion functions to inform stakeholder-driven management of groundwater-dependent ecosystems, Water Resour. Res., 49, DOI:10.1002/wrcr.20555.

Foglia, L., S. W. Mehl, M. C. Hill, and P. Burlando (2013), Evaluating model structure adequacy: The case of the Maggia Valley groundwater system, southern Switzerland, Water Resour. Res., 49, DOI:10.1029/2011WR011779.

Foglia, L., Mehl, S.W., Hill, M.C., Burlando, P. (2009) Calibration and testing of a distributed, physically based hydrological model using an error-weighted objective function, Water Resources Research, 45, DOI: 10.1029/2008WR007255.

Foglia, L., Mehl, S.W., Hill, M.C., Perona, P., Burlando, P. (2007): Testing alternative groundwater models using cross validation and other methods, Ground Water, Vol. 45:5, pp. 627-641, DOI: 10.1111/j.1745-6584.2007.00341.x.

Work History

Larry Walker Associates, Inc., Senior Engineer. 2007-present

Adjunct Professor, Land Air and Water Resources, UC Davis. Jan. 2016 - present

Technical University of Darmstadt, Germany, Assistant Professor w/o tenure track, research group of Prof. Christoph Schueth. March 2013-Dec. 2015

University of California, Davis, Department of Land, Air and Water Resources, Post-Doctoral associate, Prof. Thomas Harter. Aug. 2011-June 2013

University of California, Davis, Civil and Environmental Engineering Department, Post-Doctoral associate, Prof. Tim Ginn. 2007-2009

USGS National Research Program, Boulder, Colorado, Visiting researcher, Dr. Mary Hill. Oct.-Dec. 2003, Oct.-Dec. 2004, June-July 2005, May 2006, March 2007

University of Applied Sciences, Southern Switzerland (SUPSI), Institute for Earth Sciences (IST), and ETH Zurich, Scientific collaborator & Doctoral Student. 1999-2006

Betsy Elzufon

Associate

EDUCATION

M.S., Chemical Engineering, 1983, University of California, Berkeley

B.S., Chemical Engineering, 1981, Cornell University, Ithaca

YEARS OF EXPERIENCE

With LWA: 24
With other Firms: 11

PROFESSIONAL AFFILIATIONS

Past – Chair, California Water Environment Assoc. Industrial and Hazardous Waste Committee (1998-99)

Chair, Annual West Coast Water Pollution Prevention Symposium (1995, 1996, 1997)

Board of Trustees, Explorit Science Center (1997-2011, Davis, California)

Ms. Elzufon has more than 30 years' experience in the areas of chemical engineering, industrial processes, regulatory assistance and pollution prevention. She coordinates wastewater permit renewal for discharges to surface water (NPDES) and discharges to land (WDRs) and permit implementation efforts for clients throughout California including the Los Angeles, Central Coast, Central Valley and Lahontan Regions. For WDRs in the Lahontan and Colorado River Regions, she has managed projects to evaluate impacts to groundwater from wastewater and recycled water. In addition, she has worked with a coalition of stakeholders to evaluate sustainable water supply management approaches in the Mojave River Valley Groundwater Basin. She has also assisted municipalities with obtaining Water Recycling Permits (WRRs, MRPs). She has managed national studies on source control and program effectiveness measurement for the Water Environment Research Foundation and the National Association of Clean Water Agencies.

Regulatory Assistance

Victor Valley Wastewater Reclamation Authority (VVWRA), Hesperia, CA. 2008-Present

Project Manager for VVWRA regulatory assistance including issuance of WDRs/WRRs for its Subregional Facilities, implementation of its NPDES permit and technical and regulatory assistance associated with its December 2010 sewer line breach. LWA also assisted VVWRA with obtaining a WDR for additional percolation ponds at its main facility and renewing its NPDES permit. She has worked with VVWRA and Mojave Water Agency on comprehensive watershed planning to sustainably manage water supplies in the Mojave groundwater basin. Ms. Elzufon also assisted with obtaining coverage for its Recycled Water Program Statewide General Order and implementation of the approved program. Successful permit negotiation has relied heavily on analysis of impacts to groundwater including an antidegradation analysis for groundwater. She assisted VVWRA with preparing a non-waste determination to allow use of VVWRA biosolids as a fuel for nearby cement kilns.

City of Palm Springs, Palm Springs, CA. 2017-Present

Project manager for WDR permit renewal and required technical studies. Ms. Elzufon assisted the City of Palm Springs with the review of the WDR issued in 2017 including modifying elements of technical studies required by the WDR to assess the groundwater monitoring network and groundwater impacts associated with nitrates and TDS. LWA is currently assisting the City with these technical studies.

City of Santa Paula, Santa Paula, CA. 2015-Present

Project manager for WDR permit renewal and development of Recycled Water Program. WDR permit renewal has relied heavily on the development and implementation of a chloride compliance strategy and analysis of localized impacts to groundwater and nearby water supply wells. Ms. Elzufon assisted with developing the recycled water program and applying for coverage under the Statewide General Order for Water Recycling Requirements. She also assisted with stakeholder outreach to educate potential recycled water users and gain their support for the program.

City of Victorville, Victorville, CA. 2011-Present

Project Manager for City of Victorville WDR/WRR issuance for the Industrial Wastewater Treatment Plant. Includes preparation of ROWD, groundwater antidegradation analysis, Title 27 exemption analysis and revisions to Title 22 Engineering Report. LWA also assists the City with updates to the City's Sewer System Management Plan and with submittal of annual reports.

NPDES Permit Renewals, CA. 2007-Present

Ms. Elzufon currently works with the Cities of Redding and Davis, Paradise Irrigation District and VVWRA on NPDES permit renewals for 2018. She previously assisted with permit renewals for Cities of Burbank (2012, 2017), San Luis Obispo (2012, 2017), Cities of Thousand Oaks and Simi Valley and Camarillo Sanitary District (2014), City of Burbank (2012, 2017), City of Lompoc (2011), City of Davis (2013), Cities of Rio Vista (2015), and Roseville's (2008).

Watershed Management/TMDLs

Integrated Plan Development, Santa Maria, CA. 2015-2016

Assistant Project Manager for the City of Santa Maria Integrated Plan development. Managed a team of consultants to assist the City in development of the first California Integrated Plan based on the EPA Framework intended to address the City's regulatory requirements associated with the Phase II Stormwater Permit; Nutrient, Bacteria and Pesticide TMDLs; Trash Policy; Central Coast Post-Construction Requirements; Wastewater Waste Discharge Requirements; Safe Drinking Water Act; and other regulatory programs. Projects considered included stormwater capture, expansion of secondary water system for irrigation and nutrient trading.

Municipal Agricultural Collaboration, USA. 2014

Project Manager for the preparation of a Municipal-Agriculture Collaboration White Paper for the National Association of Clean Water Agencies (NACWA). Developed eight case study examples of Municipal Agricultural collaborations throughout the United States.

Water Environment Research Foundation, Washington, DC. 1996-2001

Principal investigator for a study to develop tools to measure source control program effectiveness and a nationwide literature assessment regarding commercial and residential sources of wastewater and stormwater pollution for the Water Environment Research Foundation.

Relevant Experience Prior To Larry Walker Associates

Regulatory Assistance, Alexandria, VA. 1992-1993

Assisted New Jersey Department of Environmental Protection and Energy (NJDEPE) in drafting the rules and regulations for New Jersey Pollution Prevention Act.

Research and Development, Columbia, MD. 1983-1992

Research Engineer working in research and development for Fortune 100 specialty chemicals company. Five years' experience evaluating photopolymers and coating processes used in printed circuit board fabrication which includes experience in metal finishing. Three years' experience in fermentation and amino acid production at the pilot plant scale.

Thomas R. Grovhoug, P.E.

Senior Executive

EDUCATION

M.S., Civil Engineering, 1975, University of California, Davis

B.S., Civil Engineering, 1973, University of California, Davis

REGISTRATIONS

Civil Engineering, State of California, No. 27901

YEARS OF EXPERIENCE

With LWA: 34
Other: 7

PROFESSIONAL AFFILIATIONS

Member, Water Environment Federation

Member, California Water Environment Association

Associate Member, California Association of Sanitation Agencies

Member, Northern California Society of Environmental Toxicologists and Chemists

Member, SWRCB Nutrient Policy Stakeholder Advisory Committee

As a Senior Executive at LWA, Mr. Grovhoug is responsible for the leadership of the company and the overall quality of technical work performed by the firm. His work for numerous municipal and private clients over the past 34 years at LWA has focused on water quality issues, such as: permitting, policy development, watershed management, TMDLs, offsets and trading. In his frequent role as either Principal-in-Charge or Project Manager, he is responsible for project team leadership and management, budgeting, scheduling, regulatory agency communications, public presentations, and product quality.

Mr. Grovhoug is a registered civil engineer with broad experience in the planning and design of a variety of water management projects. He is also an expert in Clean Water Act and California Water Code regulatory issues, with extensive experience over the past three decades providing a broad range of technical and regulatory policy services to public and private clients. His expertise includes collaborative policy and management plan development working with regulators, municipal, agricultural and non-governmental organizations on a variety of topics, including salinity and nitrate management strategies in surface and ground waters of the Central Valley and the development of a groundwater management zone archetype study in the Alta Irrigation District study area.

Mr. Grovhoug has been actively involved with stakeholder groups participating in the Central Valley Salinity Alternatives for Long-Term Sustainability initiative (CV-SALTS), Delta RMP Steering Committee and Technical Advisory Committee, Central Valley Pyrethroid TMDL, and Delta Nutrient Research Plan Stakeholder and Technical Advisory Group (STAG).

Groundwater & Stakeholder Processes

San Joaquin Valley Drainage Authority, CV-SALTS Central Valley Salt and Nitrate Management Plan development, Initial Conceptual Model (2012-2013)

San Joaquin Valley Drainage Authority, CV-SALTS Central Valley Salt and Nitrate Management Plan development, Alta Irrigation District Groundwater Management Archetype (2014-2015)

San Joaquin Valley Drainage Authority, CV-SALTS Central Valley Salt and Nitrate Management Plan development, Economic and Antidegradation Analysis (2016)

Local Sacramento & Central Valley Experience

Sacramento Regional County Sanitation District, NPDES permit assistance, Lead consultant on NPDES permit issues, compliance strategies, and a wide range of regulatory policy services (1990 to 2015)

Sacramento County Regional Sanitation District, Stakeholder, Technical and Policy support for Nutrient Policy Development, Sacramento-San Joaquin Delta (2013-2015)

Central Valley Clean Water Association, Permitting and Regulatory Advocacy Special Project, Lead consultant working on NPDES permit issues, compliance strategies and regulatory policy development (2004-2015)

Central Valley Clean Water Association, Freshwater Mussels Special Project, NPDES permitting and policy strategies for implementation of USEPA 2013 ammonia criteria (2014-2015)

Central Contra Costa Sanitary District, NPDES permit assistance (2002-2015)

Central Valley Clean Water Association, Technical and Policy Support for Nutrient Policy Development, Inland Surface Waters of California (2012-2015)

Basin Plan Amendments

Central Valley Clean Water Association, Development of Variance Authority and Streamlined Salinity Variance for the Central Valley, Technical support for staff report and Basin Plan amendment (2012-2013)

Sacramento Regional County Sanitation District, Development of Delta Drinking Water Policy and Basin Plan amendment (2002-2013)

East Stanislaus Resource Conservation District, Development of Salinity Objective for Lower San Joaquin River, CV-SALTS Lower San Joaquin River Committee, Technical Support for Basin Plan amendment (2013-2015)

Bay Area Clean Water Agencies, Cyanide Site-specific water quality objective and Shallow Water Discharger Implementation Plan, Technical support to Regional Water Board in development of Basin Plan amendment (2004-2005)

Clean Estuary Partnership, Site-specific Water Quality Objectives for Copper and Nickel for San Francisco Bay north of the Dumbarton Bridge (2002-2004)

Michael Trouchon

Senior Scientist

EDUCATION

M.S., Aquatic Ecology, 1998,
University of California, Davis

B.S., Botany, 1988,
University of California, Davis

YEARS OF EXPERIENCE

With LWA: 19
With other Firms: 6

PROFESSIONAL AFFILIATIONS

Member, WateReuse Association, California Section

Mr. Trouchon has a B.S. in Botany and an M.S. in Aquatic Ecology from the University of California at Davis. Mr. Trouchon has 25 years of experience in the water quality and water resources fields, with multiple assignments that have required the development of data management processes and data management systems to store, analyze, and report a wide variety of environmental data types to various State regulatory agencies. Mr. Trouchon is the Lead Data Management Architect at LWA. He has 22 years of experience designing, building, and managing relational databases for a variety of surface water, stormwater, and wastewater monitoring programs. His experience includes developing relational databases with Microsoft Access and Microsoft Visual Basic. Mr. Trouchon's data management experience also includes the development and implementation of protocols for data reporting, data processing, data validation, and data archiving. He has also led the development of data quality evaluation plans and QA/QC procedures that oversee the data management activities of various wastewater, surface water, stormwater, and agricultural monitoring programs. Mr. Trouchon has significant experience in aiding water quality monitoring programs comply with California Integrated Water Quality System (CIWQS), Surface Water Ambient Monitoring Program (SWAMP), and California Environmental Data Exchange Network (CEDEN) data requirements. Mr. Trouchon is also a specialist in the validation and analysis of environmental and QA/QC water quality data, and water quality standards compliance assessment. In addition, his recent assignments having a groundwater focus include a MUN and AGR beneficial use evaluation for groundwater with development of a Basin Plan Staff Report in support of a Central Valley Basin Plan Amendment (CV BPA), and a salinity variance and case-by-case effluent limit exception request in support of a CV BPA.

Data Management

City of Calistoga Public Works Department, Calistoga, CA (2013 – present), Town of Yountville and California Department of Veterans Affairs, Yountville, CA (2011 – present), *and* City of Sacramento Combined Sewer System, Sacramento, CA. 2010-Present

Developed and currently administer Microsoft Access databases for three municipal wastewater treatment plants. Databases developed to accommodate management and reporting of NPDES compliance monitoring data for each facility's monthly self-monitoring reports. Each application specifically designed to satisfy California Integrated Water Quality System (CIWQS) data reporting requirements for each discharger.

Ventura Countywide Stormwater Quality Management Program, Ventura, CA. 2003-Present

Developed and currently administer CEDEN/SWAMP-comparable Microsoft Access database for Ventura County Watershed Protection District Stormwater Monitoring Program. Developed Data Reporting Protocols, Electronic Data Deliverable (EDD) reporting standards, Data Quality Evaluation Plan (DQEP), and Data Quality Evaluation Standard Operating Procedures for the Program. Perform data validation, data analysis, data quality assessment, water quality objectives compliance evaluation, and preparation of annual compliance monitoring report for Watershed Protection District. Responsibilities also include the training District staff in data management and data analysis procedures.

Fresno Metropolitan Flood Control District, Fresno, CA. 2009-Present

Developed and currently administer CEDEN/SWAMP-comparable Microsoft Access database for Flood Control District needed to manage District's surface water quality monitoring data. Developed data management, data evaluation, and data validation protocols for the District.

Sacramento Valley Water Quality Coalition Monitoring and Reporting Program, Sacramento, CA. 2008-Present

Developed and currently administer CEDEN/SWAMP-comparable Microsoft Access database for the Sacramento Valley Water Quality Coalition needed to meet the requirements of the Central Valley Regional Water Quality Control Board's Waste Discharge Requirements for Irrigated Lands. Perform data validation, data analysis, data quality assessment, and water quality objectives compliance evaluation.

The County Sanitation Districts of Los Angeles County, Los Angeles, CA. 2005-2007

Evaluated Districts' operations and laboratory data management and NPDES reporting systems and processes as a means of providing near-term and long-term data management and reporting improvement strategies to the Districts' Monitoring Section. Evaluated data management and reporting systems of 23 publicly owned treatment works (POTWs) in California to provide Districts with data management and reporting case studies for use in developing a long-range comprehensive plan to upgrade Districts' current data management and reporting system.

Caltrans Monitoring and Water Quality Research Program, Sacramento, CA. 1999-2004

Developed and managed Microsoft Access database for Caltrans Statewide Stormwater Monitoring Program. Database included water quality, sediment, litter and aquatic toxicity data, and featured GIS and advanced statistical analysis tools. Developed data management and evaluation protocols and oversaw implementation of data validation for the Program. Performed data analysis and assisted in preparation of annual data summary report. Intermittently requested to provide data validation and data management technical expertise to Caltrans via the California State University Office of Water Programs.

Sacramento River Coordinated Monitoring Program, Sacramento, CA. 2001-2002; Sacramento River Watershed Program, Sacramento, CA. 1999-2007

Developed and managed Microsoft Access databases for two separate surface water quality monitoring programs. Developed data management and evaluation protocols and oversaw data validation for the programs. Performed data analysis and assisted in preparation of annual monitoring reports.

Work History

Larry Walker Associates, Inc., 1999-Present

California Department of Water Resources, 1996-1999

University of California at Davis, 1992-1995

LARRY WALKER ASSOCIATES

Will Lewis, CPESC, CPSWQ

Senior Scientist

EDUCATION

M.S., Environmental Science and Management, Water Resources Concentration, 2008, University of California, Santa Barbara

B.A., Environmental Studies, 2005, University of San Diego

REGISTRATIONS

Certified Professional in Erosion and Sediment Control (CPESC), No. 6388

Certified Professional in Stormwater Quality (CPSWQ), No. 0735

YEARS OF EXPERIENCE

With LWA: 4
With other Firms: 11

PROFESSIONAL AFFILIATIONS

Member, Water Environment Federal

SPECIALIZED TOOLS

Stormwater Management Model (SWMM)

Hydrologic Simulation Program in Fortran (HSPF)

Load Simulation Program in C++ (LSPC)

HEC-HMS/HEC-RAS/HEC-6

Source Loading and Management Model (WinSLAMM)

ESRI ArcGIS, Spatial Analyst, 3D Analyst, Geostatistical Analyst

GRASS/ERDAS Imagine

Mr. Lewis is a Senior Scientist with LWA focusing on identifying and applying appropriate computational tools to address hydrology, hydrogeology, and water quality management challenges of varying complexity. Mr. Lewis is engaged in a wide array of water resource management work with a focus on developing novel approaches to stormwater modeling as well as surface water-groundwater interactions. Since joining LWA, he has been heavily involved in efforts to comply with multiple separate storm sewer (MS4) permits and TMDLs throughout California.

Calleguas Creek Watershed Implementation Plan, Ventura County, CA. 2014-Present

Responsible for developing an innovative RAA approach to address relevant TMLDs and 303(d) listings on behalf of municipal, wastewater, and agricultural stakeholders. Developed a Load Simulation Program (LSPC) model to simulate hydrology, water quality, and green infrastructure performance to identify and evaluate viable implementation scenarios.

Proposition 218 Stormwater Funding Nexus Study, Confidential Client, CA. 2015-2016

Developed a Stormwater Funding Nexus Study quantifying the benefits that a Stormwater Program operating in southern California provides to water, sewer, and refuse collection enterprise departments to justify an existing funding structure and explore additional funding sources. Parameterized an EPA SWMM model to evaluate the water balance of the area of interest to justify "nexus" assertions such as the volumes infiltrated and recharged that would be available for future use.

Enhanced Watershed Management Program Technical Review, Los Angeles County, CA. 2014-Present

Completed a technical review of Reasonable Assurance Analysis (RAA) approach, modeling methodology, and documentation presented in the Upper Los Angeles River (ULAR), Dominguez Channel (DC), and Upper Santa Clara River (USCR) EWMPs on behalf of the City of Burbank (ULAR), Santa Clarita (USCR), and the City of Los Angeles (DC and ULAR).

Enhanced Watershed Management Program Implementation, Burbank, CA 2013-2014

Developed a transparent and dynamic evaluation matrix to compare potential low-impact development projects in a manner that reflects City goals. Delivered a "living" comparison tool to allow City staff to revise relevant criteria and re-prioritize the project list as incentives and priorities evolve.

Relevant Experience Prior To Larry Walker Associates

Stormwater

Los Angeles Department of Water and Power Stormwater Capture Master Plan, Los Angeles County, CA. 2013-2014

Responsible for carrying out all spatial constraints and BMP opportunities analyses used to establish baseline stormwater capture and future LADWP efforts to enhance stormwater capture under various scenarios using LID/green infrastructure. Established reasonable bounds of retention-oriented BMP implementation within the City of Los Angeles. Spatial processing lead on a small team responsible for developing hydrologic management scenarios using Load Simulation Program in C++ (LSPC) that served as inputs for the Bureau of Reclamation's Groundwater Augmentation Model (GWAM) to simulate hydrogeology, specifically root and vadose zone processes impacting recharge.

Water Replenishment District of Southern California Groundwater Augmentation Study, Los Angeles County, CA. 2010-2014

Responsible for developing, parameterizing, and running a Structural BMP Prioritization and Analysis Tool (SBPAT) model to simulate an array of potential BMP implementation scenarios. Developed all spatial inputs and extracted relevant outputs for use in the parameterization of a Groundwater Augmentation Model (GWAM) consistent with the Bureau of Reclamation's model use guidelines. Developed technical documentation outlining anticipated average annual recharge under various management scenarios for use in a subsequent cost-benefit analysis.

North Santa Monica Bay/Jurisdiction 2/3/Beach Cities EWMPs, Los Angeles County, CA. 2013-2014

Developed conceptual modeling framework to be used in future EWMP's for three large coastal Watershed Management Groups. The proposed modeling framework exclusively uses SBPAT to establish baselines loads, load reduction targets, and loads reduced for each LID/green infrastructure BMP.

Los Angeles River Upper Reach 2 and City of Walnut WMPs, Los Angeles County, CA. 2013-2014

Primary modeler responsible for establishing baseline pollutant loading and target load reductions required to bring receiving water concentrations into compliance using the Load Simulation Program in C++ (LSPC). Carried out multiple iterations of structural BMP modeling using the Structural BMP Analysis and Prioritization Tool (SBPAT) to develop a suite of LID/green infrastructural BMPs acceptable for the Watershed Management Group.

Watershed Management/TMDLs

Ballona Creek TMDL Implementation Plan, Los Angeles County, CA. 2009-2010

Primary stormwater modeler responsible for the quantification of load reductions derived from various structural and non-structural BMPs to bring Ballona Creek into compliance with the bacteria, metals, and trash TMDLs.

Los Angeles River TMDL Implementation Plan, Los Angeles County, CA. 2009-2010

Developed conceptual modeling framework to quantify the stormwater benefits of various stormwater programs within the Los Angeles River Watershed. Provided extensive peer review of modeling carried out by another firm to validate findings.

Work History

Larry Walker Associates, Inc., 2014-present

Geosyntec Consultants, 2007-2011, 2013-2014

DesignFlow Australia, 2011-2013

U.S. Environmental Protection Agency, 2007-2008

U.C. Santa Barbara Institute for Computational Earth Systems Science, 2006-2007

Nautilus Environmental Ecotoxicology Laboratory, 2004-2005

LARRY WALKER ASSOCIATES

Diana Engle, Ph.D.

Senior Scientist

EDUCATION

Ph.D. Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA.

B.S. Biology w. High Honors & High Distinction, University of Michigan, Ann Arbor, MI.

YEARS OF EXPERIENCE

With LWA: 10
Other Pertinent: 15

PROFESSIONAL AFFILIATIONS

Director, Meiners Oaks Water District, 2016-Present

Director, Upper Ventura River Groundwater Agency, 2017-Present

Director, Association of Water Agencies of Ventura County, 2018-Present

Member, CASQA, 2014-Present

Member, Association of California Water Agencies, 2018-Present

Member, Interagency Ecological Program (IEP) POD Contaminant Workteam, 2008-2017

Member, Delta Nutrient Numeric Endpoints Macrophyte Science Work Group, 2015

SPECIALIZED TOOLS

ArcGIS Desktop I. ESRI Redlands, October 2008

ADDITIONAL TRAINING

Federal Wetland Delineation, Wetland Training Institute, San Diego, CA August 2007

Dr. Engle is a Senior Scientist managing LWA's regional office in Ventura, CA. Dr. Engle assists clients in such areas as water quality assessment and monitoring, contaminant source assessment, watershed balances, fate and transport of nutrients and other constituents, aquatic toxicity, algal and food web dynamics, surface- and groundwater interactions, impacts of effluent diversion and reuse, nutrient criteria development, pathogen monitoring and special studies, and other areas of nexus between water quality regulation and watershed science. Dr. Engle provides support on a wide variety of other issues affecting wastewater, stormwater, and agricultural clients related to permit and permit waiver renewals, SGMA, TMDL and SSO compliance, legal actions, jurisdictional matters, points of discharge, water quality policies, and regulatory options for addressing 303(d) listings. Recent projects include salt and nutrient management plans, groundwater monitoring plans, TMDL implementation plans and special studies, continuous monitoring of salts, surface flow, and groundwater recharge, agricultural BMP evaluation and tailwater monitoring, and testimony at Regional Board and State Water Resources Control Board hearings.

Groundwater & Watershed Management

Calleguas Creek Watershed Salt and Nutrient Management Plan, 2016-Ongoing
As Project Manager, currently leading the development of a Salt and Nutrient Management Plan (SNMP) for the groundwater basins underlying the Calleguas Creek Watershed including the Simi Valley, Arroyo Las Posas, Tierra Rejada, Conejo Valley, and Arroyo Santa Rosa, Oxnard Plain, and Pleasant Valley groundwater basins. Project includes calculation of assimilative capacity for TDS, sulfate, chloride, boron and nitrate, and evaluation of projects linking basins together including recycling projects involving six wastewater treatment facilities, regional and distributed groundwater desalters, two aquifer storage and recovery projects, a groundwater recharge project using recycled water, surface water diversions, blending of water for salinity control, stormwater capture and infiltration basins, and a regional brine line.

Surface and Groundwater Interactions in Arroyo Las Posas, 2011-Present
As Project Manager, conducted a two-year study to delineate the losing and gaining reaches of the Arroyo Las Posas and Arroyo Simi, and quantify daily volumes of surface water and groundwater exchanges. Field work included gaging of streams in multiple reaches using customized stilling wells, continuous depth monitors and development of rating curves at twelve stations. Project required a variety of strategies to address a highly dynamic, sandy active channel with limited channel controls. Ongoing work includes wet and dry event water quality sampling, ongoing tracking of the location of the terminus of surface flow, and flow measurements near groundwater basin boundaries. Work is conducted in support of groundwater management and water supply planning in the Calleguas Creek Watershed, on behalf of Calleguas Municipal Water District and the Las Posas Water Users Group.

Review of Groundwater Sustainability Plan for the Pleasant Valley Basin, 2018-Ongoing

As Project Manager, reviewing and commenting on drafts of the Pleasant Valley Basin GSP on behalf of the City of Camarillo. Focus of comments is integration of non-SGMA regulatory requirements (such as SNMPs, TMDLs) into the GSP and the implications of water quality characterizations and sustainability indicators in the GSP on the permitting, allocations, and future operation of a regional desalter.

Calleguas Creek Watershed Salts Balances, 2011-Present
As Project Manager, leads the calculation of annual watershed balances for TDS,

boron, sulfate, and chloride to address interim milestones for load reductions in the Calleguas Creek Watershed Salts TMDL. Work involves the computation of salt loads in imported water supplies, salt loads in extractions of confined groundwater, additions of salt to municipal water supplies, salt loads from pesticide applications, and salt exports through surface stream flows and brine disposal from desalination facilities through a salinity management pipeline (brine line).

County-wide Groundwater Quality Trends Monitoring for Ventura County Agricultural Irrigated Lands Group, 2016- Present
As Project Manager, led the development of a groundwater quality monitoring plan to satisfy new requirements in the 2016 Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Agricultural Lands within the Los Angeles Region. On ongoing basis, managing the annual reporting of nitrate trends in fourteen groundwater basins.

Groundwater Management Practice Evaluation Plan for Ventura County Agricultural Irrigated Lands Group, 2018
As Asst. Project Manager, currently leading development of a workplan to evaluate the effectiveness of agricultural BMPs for managing nitrate contributions from irrigated agriculture to county aquifers.

Real-time Compliance Monitoring of Salt Concentrations and Fluxes in the Calleguas Creek Watershed, 2011-Present
As Project Manager, leads the monitoring program and the reporting activities for the Calleguas Creek Watershed Salts TMDL. Program includes continuous real-time monitoring of salt concentrations and discharge using a watershed-wide network of multi-sensor sondes equipped with telemetry. Concentrations of boron, TDS, sulfate, and chloride are derived using site-specific surrogate relationships between EC and salt constituents, and discharge is derived from continuous time series of depth paired with site-specific rating curves.

City of Ventura OVSD Reuse Feasibility Study, 2014
As Task Lead, participated in a feasibility study for the reuse of effluent from the Ojai Valley Sanitary District (OVSD) WWTP. Responsible for evaluating the implications of diversion of effluent from the perspectives of applicable permits (NPDES, local conditional-use, and recycling permits), TMDL allocations and reopeners, 303(d) listings, and related State and Regional Board activity regarding water recycling.

Camarillo Sanitary District Effluent Diversion Pipeline, 2013
As Project Manager, assisted the Camarillo Sanitary District with their responses to comments on a draft EIR for a pipeline project related to increased use of reclaimed water and cessation of discharge of effluent to surface waters. Work included application of HSPF model output, real-time continuous stream discharge data, in-stream water quality monitoring data, and effluent and groundwater quality data to evaluate the consequences of effluent diversion on in-stream flows and water quality in Conejo and Calleguas Creeks.

MS4 Implementation Plan for the Ventura River Watershed Algae TMDL, 2015
As Project Manager, led the development of an Implementation Plan (IP) for urban stormwater dischargers in the Ventura River Watershed to meet the MS4 allocations for total N and P in the 2012 TMDL for Algae, Eutrophic Conditions, and Nutrients in the Ventura River and Its Tributaries. The IP included GIS-based quantification of load reductions from a proposed suite of structural and programmatic BMPs, identification of representative monitoring sites, elucidation of WLA compliance pathways for wet and dry weather, an adaptive management strategy, and an implementation schedule.

Natural Attenuation Rates of OC Pesticides and PCBs in Calleguas Creek Watershed (2015-2016)
As Assistant Project Manager, led statistical evaluation of several decades of

monitoring data to determine natural attenuation rates of organochlorine pesticides and PCBs in fish tissue and sediment in Calleguas Creek Watershed, and predicted timelines for attainment of TMDL targets. Authored the resulting special study report required by the OC Pesticides and PCBs TMDL for Calleguas Creek.

Ventura River Technical Advisory Group, 2009-2012
As Project Manager, was instrumental in the formation of a technical advisory group (TAG) formed by local agencies in response to the development of the Ventura River Algae TMDL. Was responsible for technical comments, presentations, client support at meetings and negotiations with Los Angeles Regional Board and USEPA, and other regulatory assistance related to the development of the Ventura River Algae TMDL and USEPA Draft Flow TMDL. Clients in the TAG include the Ojai Valley Sanitary District, the Cities of Ventura and Ojai, Ventura County Public Works Department, Ventura County Agricultural Irrigated Lands Group, and the Ventura River Horse and Livestock Coalition.

Ventura River Watershed Nutrient Source Evaluation, 2009
As Assistant Project Manager, conducted a detailed, land-use based assessment of sources of nitrogen and phosphorus in the Ventura River Watershed. Seasonal loadings were quantified from urban areas, national forest, septic tanks, irrigated agricultural land, horses and livestock operations, and WWTP discharges. Work was conducted on behalf of Ojai Valley Sanitary District in support of development of the Ventura River Algae TMDL.

Ventura River Flow TMDL, County of Ventura, CA, 2012-2013

As Task Lead provided extensive comments on the regulatory and compliance implications of the Draft USEPA Ventura River Flow TMDL on behalf of the Ventura River Technical Advisory Group.

Masih Akhbari, Ph.D., P.E.

Project Engineer II

EDUCATION

Ph.D. Civil and Environmental Engineering, 2012, Colorado State University, Fort Collins, CO

M.S., Civil and Environmental Engineering, 2005, Amirkabir University of Technology, Tehran, Iran

B.S., Civil Engineering, 2003, Islamic Azad University

REGISTRATIONS

Professional Engineer, State of Colorado, License No. 0053388

YEARS OF EXPERIENCE

With LWA: Recently Joined
With other Firms: 4

PROFESSIONAL AFFILIATIONS

Member, American Society of Civil Engineers

Member, American Water Resources Association

Member, American Geophysical Union

SPECIALIZED TOOLS

RiverWare, ArcSWAT, WEAP21, WQRRS, RTEMP, Indicators of Hydrologic Alteration (IHA)

MATLAB, Python, VBA, R

ESRI ArcGIS, TSTool

Dr. Masih Akhbari joined LWA in July 2018 as a Project Engineer II and is experienced with interdisciplinary projects that require systemic approaches to plan and manage water supply in the context of environmental concerns, sustainability, and climate change. He has co-authored a textbook on groundwater hydrology and developed multiple conceptual, hydrologic, and integrated models as decision-making support tools to plan and manage water resources. Dr. Akhbari has conducted projects in the State of California, across the United States, and internationally. These projects involved collaboration with decision-makers and stakeholders, facilitation among them, incorporation of social science concepts into the engineering models, managing and analyzing large data sets, conducting hydrologic and statistical analyses, computer programming, and using Geographic Information Systems applications to conduct work.

Experience Prior To Larry Walker Associates

Hydrologic Simulation and Analysis

Hydrologic Hazards Analysis, Tennessee Valley Authority, TN. 2016 to 2018

As the lead RiverWare modeler developed a comprehensive rule-based model for the Tennessee Valley Authority (TVA) to simulate a system of more than 30 reservoirs with interconnected operations. The objective of this project was to create a comprehensive tool that forecasts upcoming hazardous events (i.e., floods).

Forecast System Support, Idaho Power, ID. 2015

Performed double mass analysis of mean areal precipitation and temperature time series and developed Python scripts to automate data preparation. Created more than 10 reservoir simulation models, converted from ResJ models, in RiverWare.

Flood Warning System

Design and Implementation of a Flood Warning Operation System, New York State Canal Corporation, NY 2015

Acquired and verified data, performed time series quality control, used the Interactive Calibration Program (ICP) to calibrate National Weather Service River Forecast System models (i.e., SNOW17 and SAC-SMA), set up input and model configuration files in MIKE CUSTOMIZED, created Python scripts to prepare input files for different models, compared MAP and multi-sensor precipitation estimates data for validation purposes, prepared GIS layers, and performed GIS analysis.

Hydrologic and Statistical Analyses

Data Analysis Support, Tennessee Valley Authority, TN. 2015

Developed a statistical analysis tool in PowerPivot to calculate the annual peak flow, exceedance frequency and rates, moving average with selectable time intervals, and partial duration peak flow.

Applied Statistical Analysis Techniques for Hydro Generation and Runoff, CEATI International. 2015 - 2016

This project was conducted for the Hydropower Operations and Planning Interest Group (HOPIG) at CEATI International, Inc. Acquired information about applied statistical techniques for practical applications of interest to hydropower operators through a literature review and interviews, evaluated the techniques for applicability, feasibility, and transferability, documented their use in real-world applications, summarized surveys taken from HOPIG members, developed customized questions to interview each of the HOPIG members, and participated in the interviews.

Agricultural Water Conservation

Moving Forward on Agricultural Water Conservation in the Colorado River Basin, Department of Agriculture, CO, WY, UT, NM, AZ, NV, and CA. 2014 - 2016

Investigated and documented over 80 relevant case studies to identify the strategies that assist in conserving agricultural water in the Colorado River Basin to increase the security of urban and environmental water supply. Evaluated sociological, economic, and regulatory and legal barriers to provide the conserved water to other users. Participated in or facilitated meetings during which farmers, environmentalists, water lawyers, policy analysts, academic figures, and water conservation districts' staff convened to share their concerns and discussed the ambiguities associated with agricultural water return flow, conservation, and efficiency.

Water-Energy-Food Nexus

The U.S. Perspective on the Water-Energy-Food Nexus, Department of State and U.S. Corps of Engineers Nationwide. 2014

As the lead researcher, prepared a background report to show the status of each sector and to identify challenges and opportunities to implement a nexus approach, with focuses on infrastructure and technology, finance, governance, and partnerships. Organized a workshop about the nexus dialogue with experts from the Department of State, USACE, U.S. Department of Energy's national laboratories, nongovernmental organizations, industry, and academia. Facilitated a working group in the workshop titled *Lessons Learned*, the outcomes of which were presented by the director of the Colorado Water Institute at the 2014 World Water Week in Stockholm, Sweden.

Energy-Water Nexus in the Developing World with a Specific Focus on India and Sub-Saharan Africa, Factor(E) Ventures (a joint venture between Shell Foundation and the Energy Institute at Colorado State University, CO. 2014

As a consultant, evaluated the energy needs of irrigation and other agricultural activities in the developing world, with a specific focus on India and sub-Saharan Africa, determined potential opportunities, challenges, and barriers to implement solutions, and identified practical ways to reduce agricultural energy consumption.

Climate Change

Considering Climate Change in Hydropower Relicensing: A Case Study of the Yuba River Watershed, California Energy Commission, CA. 2012 - 2013

Collected, analyzed, and managed data. Created and calibrated a series of linked models, including a watershed simulation, a reservoir quality simulation, and a stream temperature simulation model to investigate the effects of hydroclimatic changes and hydropower operations on stream temperatures and ecological habitats. Developed Python scripts to link models and run them for the 1950–2100 period on a daily basis. Performed statistical analyses to compare historical and future conditions.

Decision Support and Watershed Planning

Managing Conflicts Over Water Issues in the San Joaquin Watershed, CA. 2010 - 2012

As an interdisciplinary study, integrating hydrologic-environmental-social/institutional aspects of water resources management, this project formed Dr. Akhbari's PhD dissertation at Colorado State University. Developed a decision-making support framework and incorporated it into a conflict management model to manage conflicts in the San Joaquin River watershed. The model included an optimization, a watershed simulation, and a behavioral simulation model, which simulated stakeholders' reactions to management scenarios by employing a sociologic diffusion model. To develop and scale this model, created a questionnaire and administered a survey to a range of agencies and stakeholders in the study area. Used this model to determine the rate of water allocations to agricultural fields, taking into consideration environmental water rights, competing water needs, and institutional interactions.

Methodology for Cost-Based Decisions on Water Main Renewal, Nationwide. 2010

Performed a comprehensive literature review to determine the consequences and risks associated with a main break, weighting factors in order to help set priorities for pipe replacement, maintenance and repair costs, replacement costs, indirect and intangible costs associated with a main break, and optimum year when a pipe should be replaced.

Modeling the South Platte River Basin in ArcSWAT, South Platte River Basin, CO 2009 - 2010

Acquired, prepared, and managed hydrological, meteorological, and geographical data to create a comprehensive data inventory to support model development and calibration. Created GIS maps for the South Platte River Basin. Used GIS tools to combine National Agricultural Statistics Service (NASS) and National Land Cover Dataset (NLCD) land use layers with irrigated field maps and to combine soil data sets to fill missing regions in Soil Survey Geographic (SSURGO) by State Soil Geographic (STATSGO) data sets. Set up the South Platte River Basin simulation model in ArcSWAT.

Sefidrood River Water Pollution Prevention, Control, and Reduction, Iran 2007 - 2008

Acquired and prepared data, performed GIS analysis to determine locations of river water quality sampling points, investigated sites, and developed river water sampling plans. Sampled river water, coordinated sampling groups and organized their interactions with laboratories, supervised employees from different disciplines and assigned their tasks, wrote reports, and reviewed reports prepared by other disciplines.

Qualitative and Quantitative Planning and Management of Water Allocation with Emphasis on Conflict Resolution, Iran. 2004 - 2005

Designed and created a system dynamics–based conflict resolution model and linked it to a river water quality simulation model, to determine the optimal agricultural water and waste load allocation policies in the Karkheh River system.

Water Supply Performance Analysis

Retrospective Analysis of Performance of Dual Distribution Systems, National and International. 2010

Created an inventory of cases in which dual systems were implemented across the United States; identified claimed benefits, costs, and risks associated with dual distribution systems; and reviewed evaluations regarding the performance of dual distribution systems across the United States. Determined the extent of using recycled water in other countries, including: Canada, Australia, Japan, Namibia, Israel, United Kingdom, Spain, Germany, and South Africa.

Air Pollution

Master Plan for Air Pollution Control in Abadan City (2005)—

Reviewed reports to estimate pollution load of different air quality variables originated from various sources (i.e., urban, industrial, agricultural, and miscellaneous). Performed a statistical analysis of changes in concentration of different air pollutants. Used results to help create a master plan for air pollution control in Abadan City, southern Iran.

Water Quality and Pollution Source Analysis

Statistical Analysis of Irrigation Ditch Agricultural Contaminant Contribution, Weld County, CO. 2009

To identify how antibiotics from animal feeding operations may be spread through precipitation, located water quality sampling points along the river through GIS analysis. Used an inverse distance weighting approach to perform a geospatial analysis of the number of animals and the amount of domestic wastewater flow upstream of each sampling point. Created GIS maps that illustrated spatial variation of antibiotic concentrations in the study area and the main sources of antibiotic pollution. Performed a statistical analysis to determine the correlation between precipitation and measured antibiotic concentration.

Environmental Impacts Assessment of the Takestan Irrigation and Drainage System, Iran. 2008

Acquired and prepared GIS data, investigated the site, and conducted GIS analysis to determine key water quality sampling locations in the aquifer.

Design of the Karoon Water Quality Monitoring System and Bid Evaluation Assistance, Iran. 2005

This project was conducted for the World Bank. Prepared a review of the existing monitoring program, helped determine potential sites and specifications of local recording options, determined data processing options and hardware requirements, and identified the equipment that was required for continuous monitoring and sampling equipment for physical, chemical, and biological quantities.

Assessment of Water Quality Management in Khuzestan Province, Iran. 2004

This project was also conducted for the World Bank. Diagnosed water quality issues, reviewed existing legislation, and identified gaps in water quality management in the Khuzestan Province in Iran. Performed a literature review to identify water quality issues and provided a review of the existing legislation.

Statistical Analysis of Water Quality Variation in Karoon River and Selection of Water Quality Indicators for the Monitoring System, Iran. 2004

Evaluated the spatial and temporal variations of different water quality variables, calculated the correlation between concentrations of different water quality variables in order to decrease the number of sampling variables, and determined the correlation between river flow rate and concentrations of water quality variables. In addition, estimated the spatial correlation of concentrations of water quality variables to remove redundant stations from the monitoring network, analyzed the results.

Professional Services

Co-advisor, Colorado Water Institute, Co-advised multiple master's and Ph.D. students on their theses and dissertations, 2014-2017.

Review Panelist, Graduate Research Fellowship Program, National Science Foundation, 2017.

Session Chair and Convener, "Global and regional water-food-energy security under changing environments," American Geophysical Union, Fall Meeting, San Francisco, CA, 2015.

Discussion Panelist, "Colorado River Basin Shortage," AWRA Annual Water Resources Management Conference, Denver, CO, 2015.

Facilitator, Short-term Course, "Students in Water Dialogue," Colorado Water Institute, Colorado State University, 2015.

Reviewer, Journal of Water Resources Management (ASCE), Irrigation and Drainage Eng. (ASCE), Hydrologic Engineering (ASCE), American Water Resources Association, Ecology and Society, PLOS ONE, British Journal of Environment and Climate Change

Judge, Outstanding Student Paper Awards, American Geophysical Union, Fall Meeting, San Francisco, CA, 2014.

Organizer, Webinar, "Moving Forward on Agricultural Water Conservation in the Colorado River Basin," Colorado State University, September 3, 2014.

Facilitator, "U.S. Lessons Learned," The Nexus Dialogue on Water Infrastructure Solutions Meeting, Golden, Colorado, June 23-24, 2014.

Publications & Presentations

Books

Karamouz, M., A. Ahmadi, and M. Akhbari, 2011. "Groundwater Hydrology: Engineering, Planning, and Management," CRC Publishing, Boca Raton, FL.

Karamouz, M., A. Ahmadi, and M. Akhbari, 2011. "Solution Manual - Groundwater Hydrology: Engineering, Planning, and Management," CRC Publishing, Boca Raton, FL.

Peer Reviewed Publications

Islami, I., Sadoddin, A., Barani, H., Asgharpour Masoule, A., and M. Akhbari 2018, Analytical Network Process to Prioritize the Influencing Parameters on Local Participation," Industrial Engineering & Management Systems, Vol. 17, Issue 2, Pages 318-326, DOI: 10.7232/iems.2018.17.2.318.

Khaksar, M.A., Monghasemi, S., Akhabri, M., and M. Nikoo (In Review), "Bargaining and Voting in an Agent-based Modeling Framework for Water Resources Conflict Management", Journal of Hydroinformatics.

Islami, I., Sadoddin, A., Asgharpour Masoule, A., and M. Akhbari 2017, "Modeling socio-ecological structure of stakeholders' participation in managing livestock

drinking water using the agent-based approach," Applied Ecology and Environmental Research, DOI: http://dx.doi.org/10.15666/aeer/1503_11731192.

Islami, I., Sadoddin, A., Barani, H., Asgharpour Masoule, A., and M. Akhbari 2016 "investigating seasonal changes of proline, soluble sugars and ion contents in hammada salicornica habitats with various soil conditions in Bafgh area, Yazd Province," Journal of Rangeland, Vol.10, Issue 3—in Farsi.

Farhadi, S., Nikoo, M., Rakhshanderoo, G., Akhbari, M., and M.R. Alizadeh 2016, "An Agent-based-Nash Modeling Framework for Sustainable Groundwater Management: A Case Study," Journal of Agricultural Water Management, DOI: 10.1016/j.agwat.2016.08.018

Akhbari, M. and N. S. Grigg 2015, "Managing Water Resources Conflicts: Modelling Behavior in a Decision Tool," Journal of Water Resources Management, Springer, Volume 29, Issue 14, Page 5201-5216 DOI: 10.1007/s11269-015-1113-9.

Akhbari, M. and N. S. Grigg 2014. "Water Management Tradeoffs between Agriculture and the Environment: A Multiobjective Approach and Application," J. of Irrig. and Drainage Eng., ASCE, Vol. 140, Issue 8, DOI: 10.1061/(ASCE)IR.1943-4774.0000737.

Akhbari, M. and N. S. Grigg 2013. "A Framework for an Agent-Based Model to Manage Water Resources Conflicts," Journal of Water Resources Management, Springer, Vol. 27, Issue 11, pp. 4039-4052, DOI: 10.1007/s11269-013-0394-0.

Karamouz, M., M. Akhbari, and A. Moridi 2011. "Resolving Disputes over Reservoir-River Operation," J. of Irrigation and Drainage Engineering, ASCE, Vol. 137, No. 5, pp. 327-339, DOI: 10.1061/(ASCE)IR.1943-4774.0000292.

Karamouz, M., Kerachian, R., M. Akhbari, and B. Haafez 2009. "Design of river water quality monitoring networks: a case study," J. of Env. Modeling and Assessment, Springers, 14(6), pp. 705-714, DOI: 10.1007/s10666-008-9172-4

Karamouz, M., Kerachian, R., Nikpanah, A. and M. Akhbari 2008. "Management Information System for River Quality Data Analysis, Case Study: Karoon and Dez Rivers," Journal of Iran Water Resources Research, Vol. 4, No. 1, 9-27 (in Farsi).

Karamouz, M., M. Akhbari, R. Kerachian, and A. Moridi 2006. "A System Dynamics-Based Conflict Resolution Model for River Water Quality Management," Iranian Journal of Environmental Health Science and Engineering, Vol 3, No. 3, pages 147-160.

Reports

Akhbari, M., Smith, MLou 2016. "Case Studies Highlighting Challenges and Opportunities for Agricultural Water Conservation in the Colorado River Basin," Colorado Water Institute, Special Report No. 27. Available at: http://cwi.colostate.edu/publications/SR/27.pdf

Akhbari, M., Grigg, N. S., and R. Waskom 2014. "Background Paper for the Nexus Workshop: U.S. Perspective on the Water-Energy-Food Nexus," The Nexus Dialogue on Water Infrastructure Solutions Meeting, Golden, CO, June 23-24, 2014. Available at http://www.cwi.colostate.edu/workshops/NEXUS2014/Background.aspx

Akhbari, M., Childress, A. Averyt, K., Barton, J., Bellamy, B., Belt, R., Chartrand, L., Cohen, M., Gilroy, K., Grigg, N., Harto, C., Holzfaster, J., Kryc, K., Laituri, M., Lineberger, J., MacDonnell, L., Macknick, J., Marshall, Z., Radtke, J., Spang, E., Tellenhuisen, S., Tidwell, V., Waskom, R. 2014. "Report from the U.S. Nexus Workshop — Water, Energy, and Food: Mutual Security through a Nexus Approach," in U.S. Perspective on the Water-Energy-Food Nexus, Colorado Water Institute, Information Series No. 116. Available at: http://www.cwi.colostate.edu/workshops/NEXUS2014/Report.aspx

Waskom R., Akhbari, M., and Grigg, N. S. 2014. "U.S. Perspective on the Water-Energy-Food Nexus," Colorado Water Institute, Information Series No. 116. Available at: http://www.cwi.colostate.edu/workshops/NEXUS2014/Proceedings.aspx

Viers, JH, Rheinheimer, D., Akhbari, M., Peek, R., Yarnell, S., Null, S. 2013. "Considering climate change for hydropower relicensing." Public Interest Energy Research (PIER) Program White Paper. Prepared for the California Energy Commission.

Talks and Presentations (* denotes the presenter)

Akhbari*, M. 2015, "Co-management of Water, Energy, and Food Systems: Where Are We and What Does it Take for Implementation?" 2015 American Geophysical Union Fall Meeting, San Francisco, California. (poster)

Akhbari*, M. and R. Waskom 2015, "Enhancing Water-Energy-Food Security: Primary Challenges and Opportunities," American Water Resources Association (AWRA) Annual Conference on Water Resources.

Akhbari*, M., Smith, MLou and R. Waskom 2015, "Saving Agricultural Water in the Colorado River Basin: Drivers and Challenges," American Water Res. Association (AWRA) Annual Conference on Water Resources.

Akhbari*, M. 2015 (Invited), Systemic Approaches in Planning and Management of Water, Energy, and Food Resources: Employing Agent-Based Modeling as a Supporting Tool, Shiraz University, Shiraz, Iran.

Akhbari*, M., Grigg, N. S., and R. Waskom 2014. "Water-Energy-Food Nexus: Compelling Issues for Geophysical Research," 2014 American Geophysical Union Fall Meeting, San Francisco, California.

Macknick*, J., Waskom, R., Grigg, N.S., Akhbari, M. 2014. "Case Studies and Perspectives on the Water-Energy-Food Nexus in the United States," Symposium on Infrastructure Solutions in the Water-Energy-Food Nexus, Beijing, China.

Waskom*, R., Taylor, P.L., Eckhardt, L., Cabot, P., Smith, MLou, Macilroy, K., Love, H., Akhbari, M., and Kallenberger, J. 2014. "Moving Forward on Agricultural Water Conservation in the Colorado River Basin," National Integrated Water Quality and Agriculture and Food Research Initiative Project Director's Meeting, Washington D.C (poster).

Waskom*, R., Grigg, N.S., Akhbari, M. 2014. "Report from the U.S. — Water Energy Food Nexus Workshop," 2014 World Water Week, Stockholm, Sweden.

Akhbari*, M. (2014), "California Bay-Delta Program," The Nexus Dialogue on Water Infrastructure Solutions Meeting, Golden, Colorado, June 23-24, 2014.

Null*, S.E., Akhbari, M., Ligare, S.T., D. Rheinheimer, D., Peek, R., Yarnell, S.M., and J.H. Viers 2013. "Modeling Climate Change Effects on Stream Temperatures in Regulated Rivers," 2013 American Geophysical Union Fall Meeting, San Francisco, California (poster).

Rheinheimer*, D.E., Akhbari, M., Peek, R., Yarnell, S.M., Null, S.E., Viers, J.H. 2013. "Incorporating climate change in flow regime alteration studies in hydropower licensing." 2013 American Geophysical Union Fall Meeting. San Francisco, CA.

Akhbari*, M., Null, S.E., Viers J.H., and D. Rheinheimer 2012. "A Framework for Incorporating Hydroclimate Variability in Regulated Rivers: Implications for Hydropower Relicensing in California's Yuba River," 2012 American Geophysical Union Fall Meeting, San Francisco, California.

Akhbari*, M. and N. S. Grigg 2011. "Conflicts over Water Quality Management in Sacramento-San Joaquin Delta," AGU Hydrology Days, Colorado State University, Fort Collins, Colorado.

Cowley*, C.T., Akhbari, M. NegahbanAzar, M. Arabi, M. and K. Carlson 2010. "Geospatial Analysis of the Occurrence and Transport of Antibiotics in Irrigation Ditches and the Poudre River in Weld County," AGU Hydrology Days, Colorado State University, Fort Collins, Colorado.

Karamouz, M., M. Akhbari*, R. Kerachian, and A. Moridi 2006. "Conflict Resolution in River Water Quality Management: A System Dynamics Approach," 7th International Conference in Civil Engineering, Tarbiat Modarres University, Tehran, Iran.

Work History

Larry Walker Associates, Inc., July 2018-Present

RTI International (formerly Riverside Technology), 2015-2018

Colorado Water Institute, 2014-2015

Center for Watershed Sciences, UC Davis, 2012-2013

Colorado State University, 2008-2012

Yekom Consulting Engineers, 2007-2008

Water and Environment Research and Development, 2004-2008

Thomas Harter, Ph.D.

Robert M. Hagan Endowed Chair in Water Management and Policy

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EDUCATION

Universität Freiburg, Germany	Physical Geography/Hydrology	Vordiplom, 1985
Universität Freiburg, Germany	Hydrology	Diplom (M.S.), 1989
University of Arizona	Hydrology	Ph.D., 1994
University of Arizona	Postdoctoral Fellow, Hydrology	1994-1995

APPOINTMENTS

2015-present	Professor and Specialist in Cooperative Extension
2007-present	Robert M. Hagan Endowed Chair, Water Management and Policy
2005-2015	Specialist in Cooperative Extension
1999-2005	Associate Specialist in Cooperative Extension
1995-1999	Assistant Specialist in Cooperative Extension

RESEARCH AND PROFESSIONAL EXPERIENCE

Professional Memberships

2014-present	Associate Editor, Journal of Environmental Quality
2014-present	Board of Directors, Water Education Foundation
2008-present	Board of Directors, Groundwater Resources Association
2000-2018	Associate Editor, Vadose Zone Journal
2000-2010	Associate Editor, Water Resources Research
1995-present	Member, American Geophysical Union

HONORS

Since 2007	Robert M. Hagan Endowed Chair for Water Management and Policy
2008	Western Extension Directors' Award of Excellence
2007	Kevin J. Neese Award, Groundwater Resources Association
1991	Harshbarger Fellow, University of Arizona
1985	Fulbright Fellow, University of Arizona

SELECTED SYNERGISTIC ACTIVITIES

2016 and 2010 Lead organizer and chair of the 2010 International Conference on "Toward Sustainable Groundwater in Agriculture: Linking Science and Policy", San Francisco, California, June 2010, http://ag-groundwater.org

2012 Lead author and senior project director, SBX2 1 Nitrate in Drinking Water Study for 2012 Report to the Legislature. Major scientific-technical study and policy analysis for the California legislature, including eight peer-reviewed technical reports (1,300+ pages), a 78-page main report (co-authored by T. Harter and Dr. Jay Lund), an executive summary, and a policy brief. Directed 9 faculty and 16 students and postdocs; organized 3 full-day public workshops, 3 half-day public workshops, 4 full-day state-federal environmental agencies workshops; a year-long seminar discussion series with 16 events featuring invited state and federal agency and stakeholder leaders and representatives; a series of media planning events with public relations planners from 8 state agencies and university institutes; over 50 organized event presentations; development of a website with peak page view rates exceeding 3,000 (over 25,000 page views in the first five months), http://groundwaternitrate.ucdavis.edu; a media campaign with interviews that yielded nearly 400 national newspaper articles, online newsblogs, radio and TV news and feature program broadcasts; nearly 30 invited presentations and briefings to state, national, and international audiences, stakeholder groups, and state leadership (legislative briefing to state assembly members and senators, briefings with the governor's office, individual and executive briefings with heads of seven state agencies – CalEPA, CDPH, CDFA, DPR, DWR, SWRCB, CalNR); and at least four state legislative initiatives during the 2012 legislative session.

2011 Guest Editor, Water Resources Research, Special Issue on "Toward Sustainable Groundwater in Agriculture", http://onlinelibrary.wiley.com/10.1002/(ISSN)1944-7973/specialsection/SGRWTRAGR1

2008 Western Extension Directors' Award of Excellence for outstanding outreach efforts with exceptionally high impact, given to the University of California Cooperative Extension Farm Water Quality Planning Project (State Program Winner), http://extension.oregonstate.edu/weda/secure/files/documents/orginfo/2008WEDAawardofexcellencebooklet.pdf

2007 Kevin J. Neese Award, Groundwater Resources Association of California, for significant accomplishment fostering the understanding, development, and protection and management of groundwater, presented to the University of California Cooperative Extension Groundwater Hydrology Program, directed by Thomas Harter, http://www.grac.org/awards2007.asp

SHORTCOURSES, CLASSES, AND WORKSHOPS DEVELOPED AND TAUGHT

"Principles of Groundwater Flow and Transport Modeling." 3-day course (annually)

"Introduction to Vadose Zone Modeling." 3-day course (irregularly)

"Groundwater, Wells, and Pumps: A Workshop for Growers." 1-day workshop (on demand)

"Drinking Water Source Assessment in Groundwater and Surface Water." 2-day course (annually)

"Introduction to Groundwater and Watershed Hydrology: Monitoring, Assessment and Protection." 2-day course (annually)

"Groundwater Hydrology." Graduate class, UC Davis

"Practice of Groundwater Flow & Transport Modeling. " Graduate class, UC Davis

"The Global Groundwater-Agriculture Nexus" Graduate class, Universitaet Freiburg

PUBLICATIONS (last six years)

Ransom, K.M., A.M. Bell, Q.E. Barber, G. Kourakos, and T.Harter, 2018. A Bayesian approach to infer nitrogen loading rates from crop and land-use types surrounding private wells in the Central Valley, California. Hydrol. Earth Syst. Sci., 22:2739-2758, 2018, doi:10.5194/hess-22-2739-2018.

Foglia, L., J. Neuman, D.G. Tolley, S.B. Orloff, R.L. Snyder, and T. Harter, 2018. Modeling guides groundwater management in a basin with river-aquifer interactions. California Agriculture 72:1, 84-95, http://calag.ucanr.edu/archive/?type=pdf&article=ca.2018a0011

Diamantopoulos, E., J. Simunek, C. Oberdoerster, K. Hammel,B. Jene, T. Schroeder, and T. Harter, 2017. Asessing the potential exposure of groundwater to pesticides: A model comparison. Vadose Zone J. 16(11), 13 pages, doi:10.2136/vzj2017.04.0070.

Harter, T., K. Dzurella, G. Kourakos, A. Hollander, A. Bell, N. Santos, Q. Hart, A.King, J. Quinn, G. Lampinen, D. Liptzin, T. Rosenstock, M. Zhang, G.S. Pettygrove, and T. Tomich, 2017. Nitrogen Fertilizer Loading to Groundwater in the Central Valley. Final Report to the Fertilizer Research Education Program, Projects 11-0301 and 15-0454, California Department of Food and Agriculture and University of California Davis, 325p. http://groundwaternitrate.ucdavis.edu/files/268749.pdf

Ransom, K.M., B.T. Nolan, J.A. Traum, C.C. Faunt, A.M. Bell, J.M. Gronberg, D.C. Wheeler, C.Z. Rosecrans, B.Jurgens, G.E. Schwarz, K. Belitz, S.M. Eberts, G. Kourakos, and T. Harter, 2017. A hybrid machine learning model to predict and visualize nitrate concentration throughout the Central Valley aquifer, California, USA, Science of The Total Environment, Volumes 601–602 (1), p. 1160-1172, doi:10.1016/j.scitotenv.2017.05.192.

Hanak, E., J. Lund, B. Arnold, A. Escriva-Bou, B. Gray, S. Green, T. Harter, R. Howitt, D. MacEwan, J. Medellín-Azuara, P. Moyle, and N. Seavy, 2017. Water Stress and a Changing San Joaquin Valley, Public Policy Institute of California Report, 50p.

Ludington, W.B., T.D. Seher, O. Applegate, X. Li, J.I. Kliegman, C. Langelier, E.R. Atwill, T. Harter, J.L. DeRisi, 2017. Assessing biosynthetic potential of agricultural groundwater through metagenomic sequencing: A diverse anammox community dominates nitrate-rich groundwater. PloS one, 12(4), p.e0174930.

Baram, S., V. Couvreur, T. Harter, M. Read, P.H. Brown, M. Kandelous, D.R. Smart, and J.W. Hopmans, 2016. Estimating Nitrate Leaching to Groundwater from Orchards: Comparing Crop Nitrogen Excess, Deep Vadose Zone Data-Driven Estimates, and HYDRUS Modeling. Vadose Zone J. 15. doi:10.2136/vzj2016.07.0061.

Ransom, K. M., M. N. Grote, A. Deinhart, G. Eppich, C. Kendall, M. E. Sanborn, A. K. Souders, J. Wimpenny, Q.-Z. Yin, M. Young, and T. Harter, 2016. Bayesian nitrate source apportionment to individual groundwater wells in the Central Valley by use of elemental and isotopic tracers, Water Resour. Res., 52, 5577–5597, doi:10.1002/2015WR018523 (open access).

Diamantopoulos, E., W. Durner, T. Harter, Prediction of capillary air-liquid interfacial area vs. saturation function from relationship between capillary pressure and water saturation, Advances in

Water Resources, Volume 97, November 2016, Pages 219-223, ISSN 0309-1708, doi:10.1016/j.advwatres.2016.09.012.

Hafner, S. C., N. Watanabe, . Harter, B. A. Bergamaschi, S. J. Parikh, 2016. Effects of solid-liquid separation and storage on monensin attenuation in dairy waste management systems, Journal of Environmental Management, Volume 190, 1 April 2017, Pages 28-34, ISSN 0301-4797, doi:10.1016/j.jenvman.2016.12.024.

Edwards, E. C., Harter, T., Fogg, G. E., Washburn, B., & Hamad, H. (2016). Assessing the Effectiveness of Drywells as Tools for Stormwater Management and Aquifer Recharge and Their Groundwater Contamination Potential. Journal of Hydrology 539:539-553, doi:10.1016/j.jhydrol.2016.05.059.

Baram S., V. Couvreur, T. Harter, M. Read, P.H. Brown, J.W. Hopmans, D.R. Smart, 2016. Assessment of orchard N losses to groundwater with a vadose zone monitoring network. Agricultural Water Management 172:83-95. doi:10.1016/j.agwat.2016.04.012

Hafner, S.C., T. Harter, and S.J. Parikh, 2016. Evaluation of monensin transport to shallow groundwater after irrigation with dairy lagoon water. J. Env. Qual. 45(2):480-487.doi:10.2134/jeq2015.05.0251

Harter, T., 2015. California's agricultural regions gear up to actively manage groundwater use and protection. California Agriculture 69(3):193-201, doi:10.3733/ca.E.v069n03p193 (open access)

Li, X., E.R. Atwill, E. Antaki, O. Applegate, B. Bergamaschi, R.F. Bond, J. Chase, K.M. Ransom, W. Samuels, N. Watanabe, and T. Harter, 2015. Fecal indicator and pathogenic bacteria and their antibiotic resistance in alluvial groundwater of an irrigated agricultural region with dairies. J. Env. Qual. 44:1435-1447, doi: 10.2134/jeq2015.03.0139 (open access)

Bradford, S.A., J. Schijven, and T. Harter, 2015. Microbial transport and fate in the subsurface environment: Introduction to the special section. J. Env. Qual. 44:1333-1337, doi: 10.2134/jeq2015.07.0375.

Medellin-Azuara, J., D. MacEwan, R.E. Howitt, G. Kourakos, E.C. Dogrul, C.F. Brush, T.N. Kadir, T. Harter, F. Melton, J.R. Lund, 2015. Hydro-economic analysis of groundwater pumping for irrigated agriculture in California's Central Valley, USA. Hydrogeology J., DOI 10.1007/s10040-015-1283-9.

O'Geen, T., M.B.B. Saal, H.E. Dahlke, D.A. Doll, R.B. Elkins, A. Fulton, G.E. Fogg, T. Harter, J.W. Hopmans, C. Ingels, F.J. Niederholzer, S. Sandoval-Solis, P.S. Verdegaal, M. Walkinshaw, 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. California Agriculture 69(2):75-84, doi: 10.3733/ca.v069n02p75.

Mayzelle, M. M., J. H. Viers, J. Medellin-Azuara, and T. Harter, 2015. Economic feasibility of irrigated agricultural land use buffers to reduce groundwater nitrate in rural drinking water sources. Water 7(1):12-37, doi: 10.3390/w7010012 (open access).

Dzurella, K.N., G. S. Pettygrove, A. Fryjoff-Hung, A. Hollander, and T. Harter, 2015. Potential to assess nitrate leaching vulnerability of irrigated cropland. J. Soil and Water Conservation 70(1):63-72, doi: 10.2489/jswc.70.1.63 (open access).

Pasten-Zapata, E., R. Ledesma-Ruiz, T. Harter, A. I. Ramirez, J. Mahlknecht, 2014. Assessment of sources and fate of nitrate in shallow groundwater of an agricultural area by using a multi-tracer approach. Sci. Tot. Environ. 470-471:855-864, doi:10.1016/j.scitotenv.2013.10.043 (open access).

Harter, T. and H. Dahlke, 2014. Out of sight, but not out of mind: California refocuses on groundwater. California Agriculture 68(3):54-55. doi:10.3733/ca.v068n03p54 (open access).

Kourakos, G., and T. Harter, 2014. Parallel simulation of groundwater non-point source pollution using algebraic multigrid preconditioners. Comput. Geosci., doi:10.1007/s10596-014-9430-2.

Rosenstock, T. S., D. Liptzin, K. Dzurella, A. Fryjoff-Hung, A. Hollander, V. Jensen, A. King, G. Kourakos, A. McNally, G. S. Pettygrove, J. Quinn, J. H. Viers, T. P. Tomich, and T. Harter, 2014. Agriculture's contribution to nitrate contamination of Californian groundwater (1945-2005), J. Env. Qual. 43(3):895-907, doi:10.2134/jeq2013.10.0411 (open access).

Harter, T., N. Watanabe, X. Li, E. R. Atwill, and W. Samuels, 2014. Microbial groundwater sampling protocol for fecal-rich environments, Groundwater, doi:10.1111/gwat12222 (open access).

Liang, X. Q., T. Harter, L. Porta, C. van Kessel, and B. A. Linquist, 2014. Nitrate leaching in Californian rice fields: A field- and regional-scale assessment, J. Env. Qual. 43(3):881-894, doi:10.2134/jeq2013.10.0402.

Kourakos, G. and T. Harter, 2014. Vectorized simulation of groundwater flow and streamline transport. Environmental Modelling & Software 52:207-221, doi:10.1016/j.envsoft.2013.10.029.

Foglia, L., A. McNally, and T. Harter, 2013. Coupling a spatio-temporally distributed soil water budget with stream-depletion functions to inform stakeholder-driven management of groundwater-dependent ecosystems. Water Resour. Res. 49:7292-7310, doi:10.1002/wrcr.20555 (open access).

Li, X., N. Watanabe, C. Xiao, T. Harter, B. McCowan, Y. Liu, E. R. Atwill, 2013. Antibiotic-resistant E. coli in surface water and groundwater in dairy operations in Northern California. Environ. Monit. Assess, doi:10.1007/s10661-013-3454-2.

Lockhart, K.M., A. M. King, T. Harter, 2013. Identifying sources of groundwater nitrate contamination in a large alluvial groundwater basin with highly diversified intensive agricultural production. J. Contam. Hydrol. 151:140-154, doi:10.1016/j.jconhyd.2013.05.008.

Harter T. and H. Morel-Seytoux, 2013. Peer Review of the IWFM, MODFLOW and HGS Model

Codes: Potential for Water Management Applications in California's Central Valley and Other Irrigated Groundwater Basins. Final Report, California Water and Environmental Modeling Forum, August 2013, Sacramento, 58 pages. http://www.cwemf.org.

Gold, A., D. Parker, R. Waskom, J. Dobrowolski, M. O'Neill, P. Groffman, and K. Addy with contributing authors:M. Barber, S. Batie, B. Benham, M. Bianchi, T. Blewett, C. Evenson, K. Farrell-Poe, C. Gardner, W. Graham, J. Harrison, T. Harter, J. Kushner, R. Lowrance, J. Lund, R. Mahler, M. McClaron, M. McFarland, D. Osmond, J. Pritchett, L. Prokopy, C. Rock, A. Shober, M. Silitonga, D. Swackhamer, J. Thurston, D. Todey, R. Turco, G. Vellidis, and L.Wright Morton, 2013. Advancing water resource management in agricultural, rural, and urbanizing watersheds: Enhancing university involvement, Journal of Soil and Water Conservation 68(4):337-348, doi:10.2489/jswc.68.4.337.

Medellin, J., T.S. Rosenstock, R.E. Howitt, T. Harter, K.K. Jessoe, K. Dzurella, G.S. Pettygrove, J.R. Lund, 2013. Agro-economic analysis of nitrate crop source reductions. J. Water Resources Planning and Mgmt. 139(5):501-511, doi:10.1061/(ASCE)WR.1943-5452.0000268.

Botros, F.E., Y.S. Onsoy, T.R. Ginn, and T. Harter, 2012. Richards equation-based modeling to estimate flow and nitrate transport in a deep alluvial vadose zone, Vadose Zone Journal Vol. 11(4), doi:10.2136/vzj2011.014 (open access).

Park, Y., E.R. Atwill, L.L. Hou, A.I. Packman, and T. Harter, 2012. Deposition of Cryptosporidium parvum oocysts in porous media: A synthesis of attachment efficiencies measured under varying environmental conditions. Env. Sci. Tech. 46 (17), pp. 9491–9500, doi:10.1021/es300564w (open access).

Kourakos, G., F. Klein, and T. Harter, 2012. A GIS-linked unit response function approach to stochastic groundwater nonpoint source pollution modeling, Models - Repositories of Knowledge, IAHS Publications (Red Book Series #355), 2013. 8 pages.

Bremer, J. and T. Harter, 2012. Domestic wells have high probability of pumping septic tank leachate, Hydrol. Earth Sys. Sci 16:2453-2467, doi:10.5194/hess-16-2453-2012 (open access).

Webster, J.P., S.C. Kover, R.J. Bryson, T. Harter, D.S. Mansell, D.L. Sedlak, 2012. Occurrence of Trenbolone acetate metabolites in simulated confined animal feeding operation (CAFO) runoff, Env. Sci. Tech. 46(7):3803-3810, doi:10.1021/es204529v.

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Kourakos, G., F. Klein, A. Cortis, and T. Harter, 2012, A groundwater nonpoint source pollution modeling framework to evaluate long-term dynamics of pollutant exceedance probabilities in wells and other discharge locations,Water Resour. Res., 48, W00L13, doi:10.1029/2011WR010813.

Harter, T., J. R. Lund, J. Darby, G. E. Fogg, R. Howitt, K. K. Jessoe, G. S. Pettygrove, J. F. Quinn, J. H. Viers, D. B. Boyle, H. E. Canada, N. DeLaMora, K. N. Dzurella, A. Fryjoff-Hung, A. D. Hollander, K. L. Honeycutt, M. W. Jenkins, V. B. Jensen, A. M. King, G. Kourakos, D. Liptzin, E. M. Lopez, M. M. Mayzelle, A. McNally, J. Medellin-Azuara, and T. S. Rosenstock, 2012. Addressing Nitrate in California's Drinking Water With A Focus on Tulare Lake Basin and Salinas Valley Groundwater, Report for the State Water Resources Control Board Report to the Legislature, Center for Watershed Sciences, University of California, Davis, 87p. (open access).

RICHARD C. SLADE, PRESIDENT & PRINCIPAL GROUNDWATER GEOLOGIST

Richard C. Slade & Associates LLC Consulting Groundwater Geologists

HIGHLIGHTS

Education

University of California, Los Angeles, B.A., Geology, January 1966

University of Southern California, M.S., Engineering Geology, 1974

Registrations/Certifications

Professional Geologist, State of California

Certified Engineering Geologist, State of California

Professional Experience

Major fields of hydrogeologic emphasis for Mr. Slade include groundwater resource development (basin-wide studies, and water well design and construction), and aquifer analysis. Principal projects have involved, evaluations of entire groundwater basins, aquifer test analyses, assessment of water quality problems and groundwater degradation, design of water wells for municipal supply, well rehabilitation assessments, monitoring of all phases of water well construction, locating and designing groundwater monitoring networks, and providing expert witness testimony for groundwater litigation. Considerable work has also been performed for numerous vineyards and wineries in both the Central Coast and Northern California regions; types of work have included feasibility studies for determining final locations for new wells, designing new wells, monitoring of the construction of new wells, working with drilling contractors, evaluating down-hole problems (such as sanding) in existing wells, and developing protocol for water well rehabilitation.

Hydrogeologic studies have also involved evaluation of hazardous wastes such as acid mine drainage, leachate from sanitary landfills, and groundwater degradation resulting from leaking underground storage tanks containing various chemicals and organic compounds. Numerous groundwater studies and monitoring projects have involved volatile organics (TCE, PCE, etc.) and subsurface gasoline spills. Hydrogeologic assessments and definition of appropriate mitigation measures for environmental impact analyses have been provided also. Important to Mr. Slade's broad background is the experience gained while being a participant with other geologists on international geologic study tours to Europe, Iceland and Scandinavia, the former Soviet Union, South America, the People's Republic of China, Africa, New Zealand and Australia. Local groundwater and surface water features, large faults and landslides, mines, and oilfields were visited in these countries.

In December 2008, based on the recommendation of the Administrative Committee (the water managers for the cities of Burbank, Glendale, Los Angeles and San Fernando, and the Crescenta Valley Water District), the Superior Court of Los Angeles County selected Mr. Slade as the new Watermaster for the entire Upper Los Angeles River Area (ULARA). Mr. Slade represents only the third Watermaster of ULARA since the date of the original adjudication of the region in January 1979.

Employment History

RICHARD C. SLADE & ASSOCIATES LLC, CONSULTING GROUNDWATER GEOLOGISTS: Independent consulting practice established in 1983 to provide technical, professional, and direct personal services to the groundwater industry. Hydrogeologic projects have included groundwater resource development; locating and designing water wells; assessing potential degradation resulting from hazardous waste sites and sanitary landfills; conducting water level and water quality monitoring from monitoring networks; defining aquifer characteristics from long-term aquifer tests in active wells; observation and monitoring of water well construction; providing expert witness testimony for a variety of groundwater cases; and providing hydrogeologic elements and mitigation measures for environmental assessments.

<u>GEOTECHNICAL CONSULTANTS, INC.</u>: 1970-1983. Joined the firm in 1970 as an engineering geologist and hydrogeologist. Advanced to Associate in 1975. Participated in and supervised geotechnical and hydrogeologic projects of various complexities, from the feasibility level through final design. His investigation and reports have analyzed faults and seismicity, earth materials, and groundwater problems for such facilities as dams, reservoirs, treatment plants, tunnels, industrial and residential buildings, sanitary landfills and groundwater basins. Major experience has involved field mapping, logging of bore holes, monitoring of groundwater observation holes, data analyses, and report writing.

Since 1972, Mr. Slade was the responsible hydrogeologist for several major groundwater basin projects including locating and designing of new wells and well redevelopments, calculations of groundwater in storage, determination of aquifer parameters, and evaluation of dewatering criteria. Several studies utilized emplacement of deep exploratory drill holes, analyses of geologic and geophysical data, and monitoring and analyses of groundwater levels, quality and pollution, and assessment of leachate and gases at existing landfills.

In addition, he conducted and supervised groundwater pollution studies and evaluation of several active and proposed sanitary landfill sites; he has supervised geologic and hydrogeologic studies for the evaluation and abatement of acid mine drainage from a large, inactive sulfur mine; and he has participated in assessing groundwater, geologic, and geotechnical parameters which affect sewer infiltration and inflow.

<u>METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA</u>: Los Angeles, 1967-1970. Performed hydrologic and hydrogeologic studies along pipeline and tunnel routes for State Water Project, conducted field mapping and exploration along tunnel routes, conducted and supervised aquifer tests for calculations of dewatering parameters for tunnel routes and dam sites. Served as Resident Geologist in charge of tunnel mapping and tunnel conditions for the Newhall and Castaic tunnels, excavated by tunnel boring machines.

EARL F. LAPENSEE, SENIOR GROUNDWATER GEOLOGIST/PROJECT MANAGER

Richard C. Slade & Associates, LLC Consulting Groundwater Geologists

HIGHLIGHTS

Education

University of California, Los Angeles, B.S., Geology, 1983

University of California, Riverside, M.S., Geological Sciences, 1986, Trace-element geochemistry specialty

Registrations/Certifications

Certified Hydrologist and Professional Geologist, State of California,

Registered Professional Hydrologist, American Institute of Hydrology (AIH)

California Community College Instructor, June 1986

Professional Experience

Mr. LaPensee has been a Groundwater Geologist/Hydrogeologist with the firm since 1989. Major projects while with the firm have included the hydrogeologic assessment and analysis of groundwater basins in southern and northern California and the exploration for and development of groundwater in those basins. Mr. LaPensee's current focus has been on projects involving the development of groundwater in southern California groundwater basins encompassing the siting, design and technical oversight of construction for municipal- and irrigation-supply water wells. In addition, Mr. LaPensee has also provided technical oversight in the siting, design and testing of aquifer storage and recovery (ASR) wells and groundwater monitoring wells for hazardous waste sites.

Mr. LaPensee utilizes a number of key data elements (driller's and electric logs, water levels and water quality data) on projects to aid in the selection of suitable well sites and test drilling methods; determine depths of well drilling; outline types of testing to be performed in test hole drilling; select suitable types of well casing and other well construction materials; outline appropriate mechanical, chemical, and pumping development methods; define aquifer testing protocol; formulate groundwater sampling methods using accepted protocol for such contaminants as hydrocarbons, metals, and volatile organic compounds (VOCs), and; estimate key aquifer parameters and production capabilities based on the resulting drilling and testing data.

Employment History

RICHARD C. SLADE & ASSOCIATES LLC, CONSULTING GROUNDWATER GEOLOGISTS: August 1989 to present. Employment position is of Senior Groundwater Geologist with major responsibilities as a project manager directed towards groundwater evaluation, exploration, and development projects. The areas of responsibilities in these projects encompass: preparation of proposals and cost estimates for various types of hydrogeologic projects; preparation of technical specifications for new well projects and well rehabilitation; providing technical and administrative oversight of well drilling and rehabilitation, construction, development, and testing activities on well projects; and the preparation and completion of final project reports.

APPLIED GEOSYSTEMS: 1988 to 1989, Project Geologist. Responsibilities encompassed the overview and management of commercial hazardous waste site investigations, including the installation of vadose-zone and groundwater monitoring wells, aquifer testing, and computer data manipulation and modeling of aquifer test data.

ECOLOGY AND ENVIRONMENT: 1987 to 1988. Associate Geologist. Responsibilities encompassed the assessment and investigation of Federal and California Superfund sites (soil and groundwater), including the installation of groundwater monitoring wells, aquifer testing, geophysical surveying (utilizing ground penetrating radar, electro-magnetic, and resistivity methods), and computer processing and modeling of geophysical data.

McKESSON ENVIRONMENTAL SERVICES: 1986 to 1987. Staff Hydrogeologist. Responsibilities encompassed site assessment and investigation (soil and groundwater) of commercial and industrial hazardous waste sites. This included the installation of vadose-zone and groundwater monitoring wells, aquifer testing, and computer processing of geophysical data.

ANTHONY HICKE, SENIOR GROUNDWATER GEOLOGIST/PROJECT MANAGER

Richard C. Slade & Associates, LLC Consulting Groundwater Geologists

HIGHLIGHTS

Education

University of California, Los Angeles. B.S.,Geology (Engineering Geology), 2000

California State University, Los Angeles. In-progress M.S. Hydrogeology,

Registrations/Certifications

Certified Hydrologist and Professional Geologist, State of California, 2006

Professional Experience

Major areas of groundwater work for Mr. Hicke while an employee at Richard C. Slade & Associates, LLC, include project management for numerous groundwater development projects, including well construction projects, groundwater basin evaluations, creation of hydrogeologic conceptual models, and aquifer testing studies throughout California. In addition, Mr. Hicke serves as the lead geologist during the creation, management and utilization of large electronic databases of subsurface geologic data for use in preparing Hydrogeologic Evaluations of California Groundwater basins, and calculation of estimates of underflow and groundwater in storage for those basins. Mr. Hicke is also project manager overseeing preparation of groundwater availability studies for various agricultural clients, as well as the preparation of technical documents intended to support the creation of Environmental Impact Reports (EIRs). Mr. Hicke has many years' experience using the Mapinfo GIS software package to create maps from these data sets, for use in the Hydrogeologic Evaluations. Mr. Hicke also provides technical and administrative oversight during well construction and aquifer testing projects.

Since Mr. Richard Slade's appointment as the Upper Los Angeles River Area Watermaster in December 2008, Mr. Hicke has performed the duties of the Assistant ULARA Watermaster. Mr. Hicke helps to collect and analyze data for the various annual reports and review documents prepared by the Watermaster.

Experience History

RICHARD C. SLADE & ASSOCIATES LLC, CONSULTING GROUNDWATER GEOLOGISTS. October 2001 to present. Duties include: project management and technical analysis for the creation of a hydrogeologic conceptual model for a southern California coastal groundwater basin; estimation and calculation of various hydrogeologic aspects of groundwater basins to support the creation of groundwater budgets, including groundwater in storage, and inflow/outflow of groundwater; management during multi-well design and construction projects in the Central Valley and High Desert areas of California; field monitoring of all elements of the drilling and construction of municipal-supply and irrigation-supply water wells; providing technical and administrative oversight of well drilling, construction, development, and testing activities on production well and monitoring well projects; geologic logging of numerous boreholes in the High Desert areas of southern California, including the pilot boreholes for both production and monitoring wells; field monitoring of water quality and water level data during construction and testing of new water wells; planning and administration of long term aquifer tests, including the utilization of pressure transducers in a variety of hydrogeologic settings; preparation of hydrogeologic feasibility reports for sites throughout California; computer analyses of data and considerable computer work on map and data presentation using a Geographic Information System (GIS). Other significant responsibilities include: collection and analyses of basic groundwater data; computerized analyses of data; computerized mapping and graphics work; and troubleshooting problems with computers and/or with field water level/water quality monitoring equipment.

RALPH STONE AND COMPANY, INC. April 2000 to October 2001. Employment position was as a Staff Geologist with responsibilities that included organization of site investigations, geologic logging of boreholes, data collection, preparing maps and cross sections, and lab testing of soil. Prior work includes numerous seismic hazard (seismically induced landslide and liquefaction) analyses for homes in the Santa Monica Mountains, as well as the cities of Los Angeles, Beverly Hills, Culver City, Malibu, and Santa Monica.

Iris Priestaf, PhD
President

EDUCATION

PhD, Geography, University of California Berkeley, 1983
MA, Geography, University of California Berkeley, 1976
BA, Honors, Geography, University of California Santa Barbara, 1974

PROFESSIONAL SUMMARY

Iris Priestaf, PhD, has more than 30 years' experience in groundwater investigations. She has consulted on numerous projects involving groundwater basin characterization, development, and management. Her expertise in water balance studies has been built on academic training in climatology, meteorology, hydrology, soil science, geomorphology, biogeography, and related disciplines, plus consulting projects across California in a variety of environments and using multiple techniques relevant to the issues at hand. She has worked with numerous water agencies, cities, counties, and private organizations in the preparation of groundwater management plans, urban water management plans, water supply assessments, and environmental documents. Through the Groundwater Committee of the Association of California Water Agencies, she participated actively in planning for the Sustainable Groundwater Management Act (SGMA) and has provided numerous presentations on SGMA. She is now working with various agencies toward SGMA compliance.

Water Supply Availability Study for Indian Wells Valley, Kern County Planning Department
Dr. Priestaf served as Project Manager for the Water Supply Availability Study of Indian Wells Valley in eastern Kern County. Groundwater levels in this arid basin have been declining for decades, but broad agreement on the basin condition and management options has been lacking. Todd Groundwater provided an independent technical review of the hydrogeology and basin yield, an update on groundwater conditions, and recommended management solutions. The process has included a series of stakeholder meetings to gather information, understand concerns, and foster agreement.

SGMA Alternative Plan, Zone 7 Water Agency
In the Sustainable Groundwater Management Act (SGMA) of 2014, Zone 7 was deemed to be an exclusive Groundwater Sustainability Agency (GSA) within its statutory boundaries. SGMA requires GSAs to prepare a Groundwater Sustainability Plan (GSP); alternatively, SGMA allows a functionally equivalent Alternative Plan if such a Plan can demonstrate that groundwater has been managed sustainably for at least ten years. Given its long history of sustainable management, Zone 7 elected to prepare an Alternative Plan. Dr. Priestaf assisted Zone 7 staff,

providing research into wetland issue involving connected groundwater and surface water, writing several sections of the Plan, and serving as peer reviewer and editor. The Alternative Plan was submitted in December 2016, successfully meeting the challenging SGMA deadline.

SGMA Alternative Plan Assistance, Alameda County Water District (ACWD)
Alameda County Water District has successfully managed the Niles Cone Groundwater Basin since 1914, with accomplishments including recovery from historical overdraft and repulsion of brackish water back toward San Francisco Bay. With such a history, ACWD prepared an Alternative Plan for compliance with SGMA. In response to public comments on this Alternative Plan, ACWD took a fresh look at several issues including the characteristics of its northern boundary and its management regarding Groundwater Dependent Ecosystems. Dr. Priestaf worked closely with ACWD staff in analyzing these issues and preparing responses to comments in the context of ACWD's ongoing, adaptive management.

Sustainable Groundwater Management, San Benito County Water District
San Benito County Water District actively manages groundwater resources in the San Juan, Bolsa, and Hollister basins. The District, assisted by Todd Groundwater, prepared an updated groundwater management plan in 2003 and provides regular status reports through its Annual Groundwater Reports. With passage of SGMA in 2014, the District initiated SGMA planning, which has included evaluation of groundwater basin boundaries and planning for complete GSA coverage of the three groundwater basins (which extend into Santa Clara County). As of 2017, the District has become a GSA, has developed an agreement with Santa Clara Valley Water District for GSP development, and has progressed with GSP planning. Todd Groundwater has provided ongoing technical support, including GSP preparation.

Groundwater Management Plan, City of East Palo Alto
Dr. Priestaf served as Project Manager for the Groundwater Management Plan for the City, which long relied solely on imported water. Recognizing the need for water supply reliability and additional supplies, the City embarked on groundwater development and management. Although the City overlies only a portion of a low-priority basin, Dr. Priestaf guided the effort to fulfill plan requirements of the Sustainable Groundwater Management Act (SGMA), including public hearings, stakeholder and agency outreach, description of the physical setting, presentation of maps, definition of management issues, identification of objectives and actions, and development of a monitoring program. The management plan and monitoring program address all of the SGMA sustainability indicators including groundwater levels and storage, saltwater intrusion, groundwater quality, subsidence and surface water-groundwater interactions. The management plan is the first in the San Mateo Plain Groundwater Basin.

Sustainable Groundwater Management, City of Corona
Todd Groundwater prepared the City of Corona groundwater management plan, which was adopted in 2008; Dr. Priestaf served as internal reviewer. She since has advised on subsequent work, including feasibility studies of potential production well sites, assessment of groundwater recharge locations and evaluation of salt loading. Currently Todd Groundwater is assisting the City in compliance with SGMA, including preparation of a successful application to modify local groundwater basin boundaries. This application involved documentation of the local hydrogeology, groundwater agencies, management activities, and explanation of

how the basin boundary changes would enhance groundwater management. Dr. Priestaf provided SGMA advice and internal review.

Technical Support for Sustainable Groundwater Management, City of Paso Robles
Dr. Priestaf has provided groundwater management support to the City of Paso Robles since 1999. This support has included service as an expert witness concerning reservoir releases on downstream recharge and peer review of studies, including the foundational Paso Robles Groundwater Basin Study. Subsequently, she worked with representatives of the County of San Luis Obispo, City, and landowners to support groundwater basin management planning. She managed a groundwater basin update report and a subsequent evaluation of basin-wide pumping. She has assisted the City with preparation of three sequential Urban Water Management Plans and nine water supply assessments, and is currently providing groundwater management support with regard to planning for SGMA compliance.

Groundwater Basin Model Update, Paso Robles
Todd Groundwater teamed to update the numerical model for the Paso Robles groundwater basin. A key feature of the update was extension of the modeling analysis to the watershed, with development of a rainfall-runoff model that was linked to the MODFLOW model. Dr. Priestaf led the Todd team, which was responsible for data collection, water balance analyses including evaluation of groundwater pumping, technical support for modeling, internal peer review of the model, and public outreach.

Independent Analysis of Groundwater Supply, Olympic Valley Groundwater Basin
Dr. Priestaf served as Project Manager for analysis of Olympic Valley basin geometry and water balance and numerical model development. Squaw Valley Ski Corporation is working closely with Squaw Valley Public Service District toward optimization of local well fields for build-out development of Olympic Valley. This work includes independent analysis of the hydrogeology and water balance of the basin, and review of the District's numerical model, including update of the model with recent information, validation of model performance with reference to recent groundwater levels, and collaboration with District consultants for model improvements and application to modeling scenarios. The groundwater supply development has proceeded with successful completion of the EIR in 2016.

Annual Groundwater Report, San Benito County Water District
Dr. Priestaf has served as principal in charge since 2006 for preparation of the Annual Groundwater Report for the San Benito County Water District. This report provides the District and community with a regular update on conditions of the local groundwater basin, including amount of pumping, need for purchase of imported Central Valley Project water, and water charges. The Annual Reports have included triennial updates of groundwater quality conditions and analyses of the basin water balance. Todd also prepared the local Salt and Nutrient Management Plan; Dr. Priestaf served as principal.

Hydrogeologic Assessment of San Mateo Plain Subbasin, San Mateo County
Recognizing the potential importance of local groundwater supply and storage, the County of San Mateo sponsored a comprehensive evaluation of the San Mateo Plain, which underlies a dozen cities, including Menlo Park, Redwood City, and San Mateo. The evaluation—intended

to serve as the technical foundation for future sustainable groundwater management—addresses the hydrogeologic framework, water balance, and water quality; considers governance and management options; and provides a numerical modeling tool. The evaluation is being developed with considerable outreach to local water agencies, stakeholders, and the community. Dr. Priestaf served as groundwater lead, with particular responsibility for the hydrogeology, water balance and water quality investigation, plus community outreach.

Watershed Management and Groundwater Recharge Planning, Sonoma County Water Agency
The Agency developed a watershed management strategy to integrate water supply and flood control projects to 1) reduce flooding through stormwater detention and 2) promote managed aquifer recharge. Dr. Priestaf served as Principal-in-Charge for the Todd effort, which focused on definition of potential areas for managed recharge of stormwater. This initial work was accomplished using GIS data on soils, topography, and geology. Other factors considered included imperviousness; areas of public, protected, and agricultural lands; critical habitat areas; environmental release sites; depth to groundwater; and stream corridors. Areas were defined in terms of natural recharge potential (e.g., promoting recharge through diversion of water to stream channels and swales) and engineered recharge potential, involving engineered recharge basins and recharge wells.

Groundwater Management Program, Northern Cities of San Luis Obispo County
Iris Priestaf was Project Manager for groundwater management activities of the Northern Cities Area (Arroyo Grande, Grover Beach, Oceano and Pismo Beach) of San Luis Obispo County, which uses groundwater, imported water, and Lopez Reservoir supply. Recent work has included a water balance study and preparation of a groundwater monitoring program, consistent with the recent adjudication judgment of the basin. Dr. Priestaf directed preparation of the first two annual reports, which document water supply and demand and describes groundwater conditions, including groundwater pumping, levels and quality, most notably seawater intrusion at the coast.

Groundwater Supply Evaluation and Grant Application Support, Pajaro Sunny Mesa Community Services District
Dr. Priestaf served as principal in charge for the assessment of existing groundwater supply and distribution infrastructure in the Pajaro Sunny Mesa Community Services District (PSMCSD), which includes disadvantaged communities. This work, undertaken as part of the Integrated Regional Watershed Management Plan (IRWMP) for the Pajaro River Watershed, included compilation and review of all available information relevant to local water supply and water quality. This was used to identify possible future capital improvement projects for PSMCSD. PSMCSD management and engineering support identified a new water storage tank as a priority for inclusion in the IRWMP grant application. The Todd team assisted PSMCSD and the grant writer in preparing the grant application, which was successful in funding the new tank so that PSMCSD meets Water and Fire Code requirements for emergency storage. Todd work also supported another successful grant application for a new well for a small disadvantaged community impacted by severe nitrate contamination of shallow wells.

Eugene B. (Gus) Yates, PG, CHG

Senior Hydrologist

EDUCATION

MS, Water Science, University of California Davis, 1985
BA, Geology, Harvard University, 1979

REGISTRATIONS

Professional Geologist California, No. 7178
Certified Hydrogeologist California, No. 740

PROFESSIONAL SUMMARY

Gus Yates is an accomplished hydrogeologist and water resources expert. His 30 years of experience—initially with the USGS and as a consulting hydrogeologist—has been science-based and focused on projects that require critical thinking skills and the application of hydrologic principles and methods. Mr. Yates is technically skilled with the ability to creatively and practically use data in combination with field investigations, computer models, statistics, and traditional analysis methods. He is recognized for his breadth of knowledge in multiple disciplines—including soils, geology, geomorphology, climatology, land use, water use, , vegetation ecology, fisheries biology, and riparian ecology—and for his comprehension of the critical aspects of complex natural hydrologic and water supply systems.

Mr. Yates is an experienced project manager with exceptional communication skills, who has consulted successfully with public agencies, private-sector clients, and non-profit groups in groundwater and surface water hydrology, biohydrology, and water resources management. He is an acknowledged expert in basin yield analysis, groundwater modeling, quantification of groundwater budgets, and evaluation of groundwater flow and quality, and has served as an expert witness in cases regarding groundwater conditions, basin yield, and stream-aquifer interactions.

Water Resources Planning and Management

Evaluation of Groundwater Conditions, Indian Wells Valley, Kern County
Groundwater elevations have been declining for decades in this desert basin, yet a few of the numerous technical reports completed during that period concluded that groundwater yield was ample and that declines were merely local. A recent expansion of irrigated agriculture

renewed fears that overdraft might substantially increase. Working for Kern County Planning Department, Mr. Yates critically reviewed all of the previous studies, completed additional analyses, and methodically refuted the assertions that the basin receives substantial recharge from inter-basin bedrock flow originating in the high Sierra. Local stakeholders held strongly polarized positions regarding the state of the basin, occurrence of overdraft, and the necessity of water and land use management. Substantial progress was achieved through presentations by Mr. Yates, discussion at public workshops, and a clearly-written and accessible report. The basin subsequently was deemed by the California Department of Water Resources as critically overdrafted, and local agencies are collaborating for compliance with the Sustainable Groundwater Management Act.

Groundwater Management and Modeling, San Benito County Water District

For many years Mr. Yates has provided hydrogeologic expertise to the District, which has responsibility for management of groundwater basins in San Benito County, which encompass the Cities of Hollister and San Juan Bautista and intensively farmed areas. The District manages local surface water, imported Central Valley Project Water, groundwater, and recycled water, and currently is planning for compliance with the Sustainable Groundwater Management Act (SGMA). Mr. Yates led the preparation of the District's first AB3030 Groundwater Management Plan, has participated in preparation of the annual groundwater reports, and has also conducted specific investigations. Mr. Yates developed a regional groundwater flow and salinity model for the Hollister basin with MODFLOW and MT3DMS. The model draws on an extensive database of pumping, water-level, and salinity information. With periodic refinements, Mr. Yates has applied the model over the past 10 years to evaluate long-term salinity trends, impacts of wastewater recycling, and alternative conjunctive use strategies to manage water quality and shallow groundwater levels.

Hydrogeologic Characterization of Eastern Turlock Subbasin, Turlock Groundwater Basin Association (TGBA)

Mr. Yates was the hydrologist and lead modeler for a hydrogeologic characterization over 114 square miles in the eastern Turlock Subbasin, focusing on changes in land use, irrigated acreage, and associated impacts to groundwater over time. In order to analyze regional impacts, he updated and applied a basinwide finite-element (FEMFLOW3D) numerical model. He developed input files for FEMFLOW3D for irrigation demand, surface water deliveries, groundwater pumping, and recharge from canal leaks and irrigation return flow. He used a soil-moisture balance approach to estimate irrigation demand and return flow that incorporates root depth, available water capacity and assumed irrigation efficiency. Modeling was used to document changes in groundwater storage over time and to support groundwater management planning by TGBA.

Hydrogeologic Assessment of San Mateo Plain Subbasin, San Mateo County

Recognizing the potential importance of local groundwater supply and storage, the County of San Mateo sponsored a comprehensive evaluation of the San Mateo Plain, a groundwater basin that is highly urbanized but not yet developed significantly for groundwater supply. The evaluation—intended to serve as the technical foundation for future sustainable groundwater management—addresses the hydrogeologic framework, water balance, and water quality; considers governance and management options; and provides a numerical modeling tool. Mr.

Yates served on the hydrogeology team that prepared multiple hydrogeologic cross-sections, identified the bottom of the basin, and evaluated the extent and character of a regional aquitard. He had particular responsibility for development of a water budget.

Independent Review of San Juan Basin Groundwater and Facilities Management Plan, San Juan Basin Authority
In 2014, Mr. Yates provided an independent review of the draft GMP document and a groundwater modeling report. Focusing on key issues and basin strategies, he provided a cogent summary of critical basin characteristics, evaluated water supply options, and addressed specific technical issues regarding recharge, surface water-groundwater interactions, seawater intrusion, and basin yield.

Peer Review of Technical Water Resource Studies, Soquel Creek Water District
Soquel Creek Water District actively manages its groundwater basin along the Santa Cruz County coast. Facing critical management decisions, the District retained Mr. Yates for an independent review of technical studies undertaken to evaluate the groundwater levels needed for prevention of seawater intrusion and to assess the groundwater yield available to the District when it operates the basin to achieve those levels. The 2014 review explored uncertainties in the relationships between pumping, groundwater levels, and yield and provided specific recommendations to reduce uncertainty and to respond with adaptive management.

Peer Review of Basin Plan for the Los Osos Groundwater Basin, Parties to the Adjudication
The Los Osos Basin, located on the San Luis Obispo County coast, is in the process of adjudication, which includes preparation of a Basin Plan. Mr. Yates was retained for a peer review of the Basin Plan focused on the accuracy of technical information, the reasonableness of assumptions and conclusions, and the overall adequacy of recommended measures to address nitrate contamination and seawater intrusion. While acknowledging the usefulness of the Plan and providing specific recommendations, Mr. Yates emphasized the urgency of the seawater intrusion problem and the need to adopt and implement the Basin Plan (including water conservation measures and cost sharing) without delay.

Groundwater Modeling

Groundwater Flow Model of San Antonio Basin, Santa Barbara County
The San Antonio Basin encompasses agriculture (mostly vineyards), rangeland, the town of Los Alamos, and a portion of Vandenberg Air Force Base. Mr. Yates created a MODFLOW model of the San Antonio Basin to improve estimates of long-term water balances and simulate management alternatives. The model helped resolve uncertainty regarding storage depletion from upland wells and valley floor pumping impacts on streamflow. Subsequently, Mr. Yates also helped develop a Salt and Nutrient Management Plan that addressed salt and nutrient loading to the San Antonio basin.

Peer Review of Paso Robles Groundwater Basin Model, San Luis Obispo County
The Paso Robles groundwater basin has undergone rapid development and has experienced significant groundwater level declines, which prompted update of the MODFLOW model. This

model update included not only update through time (to 2011), but also addition of a watershed model to better understand inflow to the basin around its margins and along stream channels. Mr. Yates provided in-depth technical review throughout the process of refining and recalibrating the Paso Robles Groundwater Model; refinement and application of the model was completed in 2016.

Groundwater Flow Modeling for Indirect Potable Reuse near San Jose, Santa Clara County

Santa Clara Valley Water District intensively manages groundwater in the Santa Clara Plain basin to maximize its yield for municipal users while avoiding seawater intrusion from San Francisco Bay. Water levels and pumping are measured at thousands of public and private wells, managed aquifer recharge using imported water and local reservoir storage is accomplished through percolation basins and releases to creek channels. The District is seeking to add recycled water to its sources of recharge, which requires modeling of subsurface travel times and dilution. Two prior basin-scale groundwater flow models each had limitations for this purpose, and Mr. Yates developed a new model designed to answer near-term questions regarding indirect potable reuse while providing long-term value as a superior all-purpose groundwater management tool. Through systematic data analysis and model calibration, it became clear that the basin is highly anisotropic vertically, and that head-dependent boundaries play a relatively minor role in the overall water balance. Consequently, basin yield depends primarily on various recharge flows that are often not well known, particularly ones related to urban hydrology: irrigation return flow, leaks from water and sewer pipes, amplification of rainfall recharge adjacent to disconnected impervious surfaces, etc. By creatively combining disparate data sources, Mr. Yates was able to narrow the range of uncertainty in the recharge terms and obtain a reliable model calibration. The model was then used with confidence to simulate groundwater movement around percolation ponds and injection wells.

Assessment of Potential Impacts of Aggregate Mining, Sonoma County

Mr. Yates was Project Hydrogeologist providing technical support to an EIR addressing potential impacts of aggregate mining along the Russian River. Issues included the adequacy of a MODFLOW groundwater flow model. A Model Review Report documented the sufficiency of the groundwater model and concluded that a revised model was sufficient to evaluate impacts and that the project was unlikely to have significant impacts on groundwater. Intense opposition to the project resulted in a detailed and voluminous Final EIR that clarified the evaluation of impacts on groundwater levels.

Lompoc Basin Modeling and Santa Ynez River Flow Analysis, City of Lompoc

Mr. Yates was the consulting hydrologist for a steelhead passage flow analysis of the Santa Ynez River in Santa Barbara County. Mr. Yates calculated potential base flow depletion from increased groundwater pumping near Lompoc and characterized the impact in terms of timing, duration, and frequency of flows above the fish passage threshold. In related work, Mr. Yates converted an existing finite-element model of the Lompoc Basin to MODFLOW and MT3D. He developed preprocessing programs to allow variable stress period durations based on river flow to better simulate nonlinear river-aquifer interactions.

Appendix C. Fee Schedules

Included in this appendix are the Fee Schedules for the following:

Larry Walker Associates

Richard C. Slade & Associates

Todd Groundwater

LARRY WALKER ASSOCIATES

Rate Schedule
Effective July 1, 2018 – June 30, 2019

PERSONNEL	Rate $/Hour
Project Staff	
Melanie Andreacchi	$ 88
Tina Van Carpels	$ 88
Adriana Stovall	$113
Michelle Benson	$155
Kathryn Walker	$155
Olin Applegate	$170
Katrina Arredondo	$170
Jenny Bayley	$170
Nima Jabbari	$170
Adriel Leon	$170
Amir Mani	$170
Suzanne Brown	$180
Danielle Moss	$180
Jeff Walker	$180
Elizabeth Yin	$180
Bryant Alvarado	$200
Alina Constantinescu	$200
Reni Keane-Dengel	$200
Airy Krich-Brinton	$200
Mike Marson	$200
Steve Maricle	$200
Hope M. Taylor	$200
Senior Staff	
Kristine Corneillie	$232
Diana Engle	$232
Laura Foglia	$232
Gorman Lau	$232
Will Lewis	$232
Shelli St. Clair	$232
Amy Storm	$232
Rachel Warren	$232
Associate	
Denise Conners	$258
Betsy Elzufon	$258
Paul Hartman	$258
Sandy Mathews	$258
Mitch Mysliwiec	$258
Claus Suverkropp	$258
Mike Trouchon	$258
Principal	
Karen Ashby	$283
Brian Laurenson	$283
Chris Minton	$283
Mack Walker	$294
Ashli Cooper Desai	$309
Tom Grovhoug	$309

REIMBURSABLE COSTS

Travel:

Local mileage	Current IRS rate
Transportation	Actual expense
Auto rental	Actual commercial rate
Fares	Actual expense
Room	Actual expense
Subsistence [1]	$48 per day

The rate for each meal as follows: [1]

Breakfast	$ 9
Lunch	$13
Dinner	$21
Incidentals	$ 5

Report Reproduction and Copying:

Actual outside expense	
Per black and white copy, in-house	$0.08
Per color copy, in-house	$0.89
Per binding, in-house	$1.95

Special Postage and Express Mail:

Actual expense

Other Direct Costs:

Actual expense

Daily Equipment Rental Rates:

Single parameter meters & equipment	$ 30
Digital Flow Meter	$ 60
Multi-parameter field meters & sondes	$100
Dye/tracer mapping or residence time	$200
Multi-parameter continuous remote sensing	$ 40

Subcontractors:

Actual expense plus 10% fee

Note: [1] Charged when overnight lodging is required.

Revised 7/05/18

TODD GROUNDWATER

PLANNING • DEVELOPMENT • MANAGEMENT • PROTECTION

SCHEDULE OF CHARGES

Santa Monica Basin GSP

Title	Name	Hourly Rate
Principal Consultant	Iris Priestaf	$ 255
Principal Geologist	Phyllis Stanin	$ 255
Principal Hydrogeologist	Sally McCraven	$ 245
Senior Hydrogeologist	Dan Craig	$ 245
Senior Hydrogeologist	Mike Maley	$ 245
Senior Engineer	Katherine White	$ 235
Senior Hydrologist	Gus Yates	$ 245
Principal Hydrogeologist	Edwin Lin	$ 240
Senior Geochemist	William Motzer	$ 230
Senior Hydrogeologist	Liz Elliott	$ 225
Senior Engineer	Maureen Reilly	$ 225
Senior Hydrogeologist	Chad Taylor	$ 225
Senior Hydrogeologist	Jason Gurdak	$ 210
Associate Geologist	Amber Ritchie	$ 185
Associate Geologist	Brent Johnson	$ 185
CAD/GIS/Graphics	Alain Boutefeu	$ 120
GIS/Drafting Support	Support Staff	$ 110
Clerical	Sheila Gould	$ 115

Travel Time

Travel time will be charged at regular hourly rates.

Litigation, Depositions, and Testimony

Deposition and trial testimony are charged at twice hourly rates.

Outside Services

All services not ordinarily furnished by Todd Groundwater, including printing, subcontracted services, local mileage, travel by common carrier, etc. are billed at cost. Local mileage is billed at the current Federal mileage rate.

SCHEDULE OF CHARGES
Specifically For
Santa Monica Basin GSP Development Project
Valid through December 2021

Professional Services	**Hourly Rates**
Principal Groundwater Geologist	$294.00
Senior Groundwater Geologist	$230.00
Staff Groundwater Geologist	$174.00
Field Geologist/Geologic Logging	$128.00
Clerical, Graphics and GIS Work	$ 92.00
Field Equipment Charges	
Pressure Transducers (water level & barometric pressure monitoring during pumping tests)	$ 50.00/wk
Electric Tape Water Level Probe	$ 25.00/day
Field Water Quality Probe (T, pH, EC)	$ 50.00/day

Litigation, Depositions and Testimony

Depositions and trial testimony are charged at twice the hourly rate (4-hour minimum/day).

Travel Time and Mileage

Travel time for meetings and/or to job sites will be charged at our standard hourly rates. Mileage is charged at the rate of $0.54 per mile.

Administrative Fee

In-house costs for phone, e-mail, fax, regular postage, printing, copying, binding, and records retention, unless otherwise provided for in our project proposal Scope of Services. Administrative Fee = total project labor charges multiplied by 2.5%.

Outside Services

All services not ordinarily furnished by RCS, including subcontracted services (i.e., water quality laboratory testing), delivery services, reproduction and printing, etc, are billed at cost + 15%. Reproduction costs for large format printing, and/or high volume reproduction and binding of hard copy reports performed in-house by RCS staff, will be billed at rates similar to comparable outside services.

Conditions

Invoices are issued at our option on a monthly basis or when the work is completed. A service charge of 1½ % will be payable on any amount not paid within 30 days. Any attorney fees or other costs incurred in collecting delinquent charges shall be paid by the client.

Client will furnish rights-of-way to land as required for field visits and field operations, such as sampling or testing of water wells.

Appendix D. Additional Information

Included in this appendix are the following required documents:

Work Samples

- Foglia, Laura, Harter, Thomas, et al., "Modeling guides groundwater management in a basin with river-aquifer interactions." California Agriculture, 72 (1), 84-95.
- Foglia, Laura, Harter, Thomas, et al., "Coupling a spatiotemporally distributed soil water budget with stream-depletion functions to inform stakeholder-driven management of groundwater-dependent ecosystems." Water Resources Research, 49, 7292-7310.

RESEARCH ARTICLE

Modeling guides groundwater management in a basin with river–aquifer interactions

A Scott Valley study shows gains in understanding seasonal dynamics of groundwater–surface water fluxes as model tools address more complex natural phenomena.

by Laura Foglia, Jakob Neumann, Douglas G. Tolley, Steve B. Orloff, Richard L. Snyder and Thomas Harter

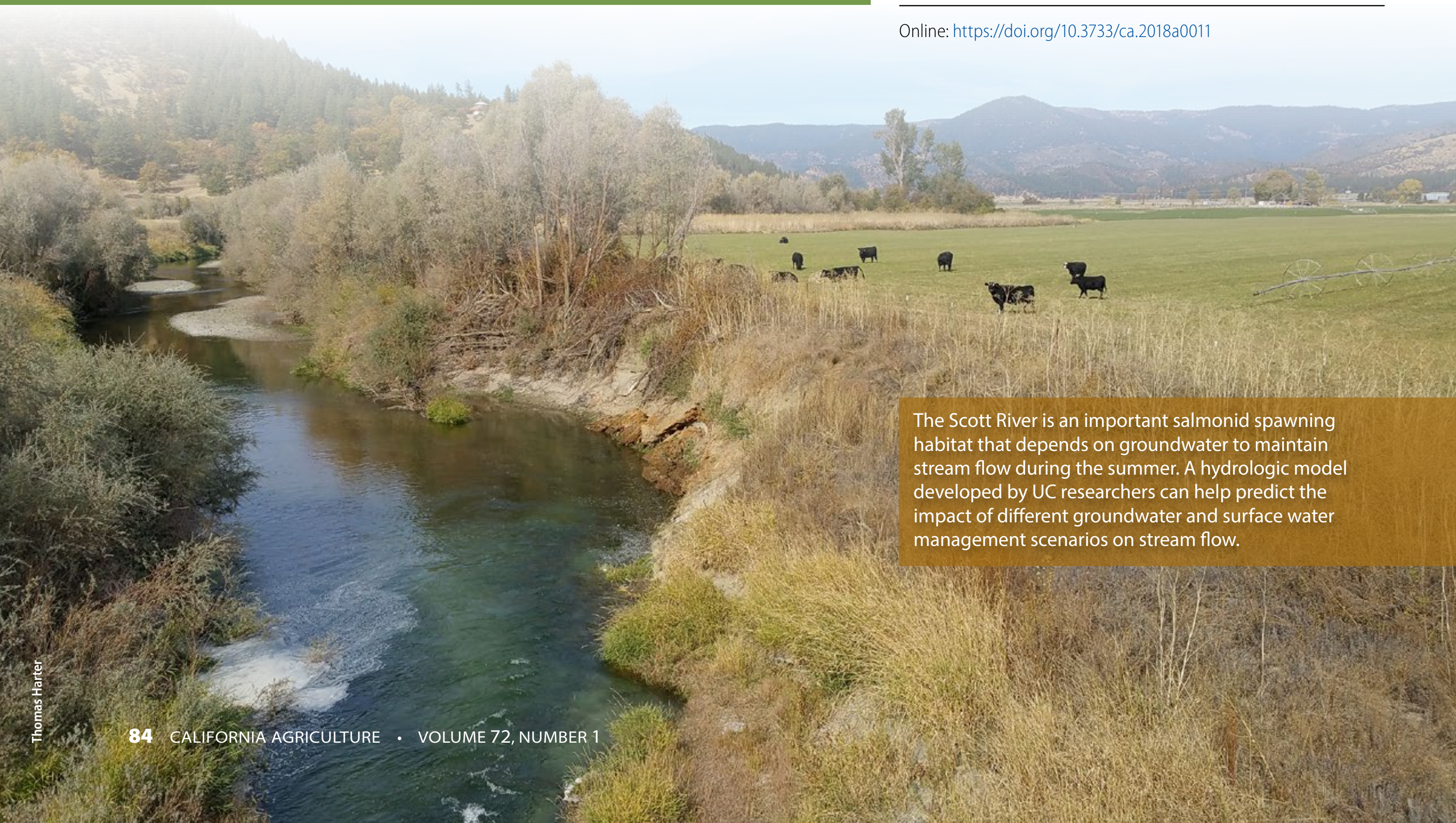
Abstract

The Sustainable Groundwater Management Act (SGMA) of 2014 seeks to maintain groundwater discharge to streams to support environmental goals. In Scott Valley, in Siskiyou County, the Scott River and its tributaries are an important salmonid spawning habitat, and about 10% of average annual Scott River stream flow comes from groundwater. The local groundwater advisory committee is developing groundwater management alternatives that would increase summer and early fall stream flows. We developed a model to provide a framework to evaluate those alternatives. We first created a water budget for the Scott Valley groundwater basin and integrated the detailed, spatiotemporally distributed water budget results into a computer model of the basin that simultaneously accounted for groundwater flow, stream flow and landscape water fluxes. Different conceptual representations (using the MODFLOW RIV package and MODFLOW SFR package) of the stream–aquifer boundary provided significantly different results in the seasonal dynamics of groundwater–surface water fluxes. As groundwater sustainability agencies draw up plans to meet SGMA requirements, they must choose and test simulation tools carefully.

Management of California's water supplies serves diverse goals. Securing the needs of urban and agricultural water customers is a key goal. Meeting environmental health, ecosystem services and stream water quality goals has also been an integral part of many California water management systems. To meet this range of goals, groundwater, soil water and surface water will need to be managed conjunctively, management will likely become more tightly linked with land use and land resources planning and management, and modelling will play a key role in the development of successful and useful management plans.

The 2014 California Sustainable Groundwater Management Act (SGMA) and recent salt- and nitrate-related regulations to protect groundwater quality have put a focus on groundwater resources management, both quality and quantity, particularly in agricultural regions (Harter 2015). They mandate that local agencies pursue groundwater sustainability goals: avoiding long-term groundwater storage depletion, land subsidence,

Online: https://doi.org/10.3733/ca.2018a0011



The Scott River is an important salmonid spawning habitat that depends on groundwater to maintain stream flow during the summer. A hydrologic model developed by UC researchers can help predict the impact of different groundwater and surface water management scenarios on stream flow.

Thomas Harter

seawater intrusion, groundwater management–related water quality degradation, and deterioration of groundwater–surface water interactions.

Particularly important under the SGMA regulations is the interaction between groundwater and surface water: how do groundwater management decisions — by individual landowners or by groundwater sustainability agencies (GSAs) — impact not only beneficial users, but also streams (Zume and Tarhule 2011) and groundwater-dependent ecosystems (GDEs) (Boulton and Hancock 2006; Hatton 1998). Prominent California examples of areas where groundwater–surface water interactions are already addressed include the Napa River in Napa County and the Scott River in Siskiyou County. Both feature important salmonid fish habitat and therefore temperature is a critical issue (Brown et al. 1994; Moyle and Israel 2005); and low or decreased late-summer stream flow over the last half-century has impacted the quantity and quality of fish habitat (Kim and Jain 2010; NCRWQCB 2005; Nehlsen et al. 1991). During drought, portions of these rivers may temporarily dry up. In intermontane Scott Valley, dry sections disconnect lower sections of the stream from tributaries in the headwaters. Summer stream temperatures in the Scott River are affected by groundwater discharge into the streambed and by riparian shading and were being addressed under the federal Clean Water Act (NCRWQCB 2005) before SGMA.

Some measurements can be collected in the field to evaluate groundwater–surface water interactions, but computer models are needed to fully understand groundwater basin flow dynamics and assess impacts to stream flow under future groundwater management scenarios. For example, computer models can show the response of integrated water systems to management decisions such as pumping and intentional recharge. They are expected to play a key role in the implementation of SGMA and regulatory efforts.

Various modeling approaches have been developed for groundwater–surface water interactions (Furman 2008; Harter and Seytoux 2013). These range from analytical or spreadsheet tools (Foglia, McNally, Harter 2013) and coupled or iteratively coupled numerical model codes for computer simulations, such as the MODFLOW river (RIV) package (Harbaugh et al. 2000) and the MODFLOW stream flow routing SFR1 package (Prudic et al. 2004) and SFR2 package (Harbaugh 2005; Niswonger and Prudic 2005), to fully coupled models such as ParFlow (Ashby and Falgout 1996; Kollet and Maxwell 2006) and Hydrogeosphere (Brunner and Simmons 2012).

Fully coupled models provide the physically and mathematically most consistent and complete integration of groundwater, surface water and soil water systems. But they are computationally more expensive and require more parameterization (data input) than iteratively coupled models. In coupled or iteratively coupled models, multiple models are coupled such that one model provides input to the other model and vice versa, sometimes iteratively. Full coupling may not always yield better results (Furman 2008). For some applications, statistical models or analytical tools, which are based on highly simplified concepts and therefore have the least data input requirements and are computationally much less demanding, may be appropriate.


Thomas Harter

Almost 70% of Scott Valley is used for agricultural production, with a nearly even split between alfalfa/grain and pasture.

In Scott Valley, groundwater–surface water interactions are analyzed as part of an action plan to meet temperature TMDL (Total Maximum Daily Load) requirements for the Scott River. Climate change and groundwater pumping for irrigation in the valley have impacted late-summer and early fall stream flows in the Scott River (Drake et al. 2000). The local groundwater advisory committee is developing potential groundwater management scenarios that would increase summer and early fall stream flows. To evaluate those scenarios, we explored three levels of conceptual complexity at which information can be obtained about groundwater–surface water interactions: a water budget approach, a groundwater model with a conceptually simplified stream model (RIV) and a fully coupled groundwater–surface water model (SFR).

Scott Valley study area

Our study area was Scott Valley in northern California. Almost 70% of the valley is used for agricultural production, with a nearly even split between alfalfa/grain and pasture.

Geography and climate

Scott Valley is an intermontane 220-square-kilometer agricultural groundwater basin at an elevation of 2,600 to 3,100 feet in Siskiyou County (fig. 1). The Scott River

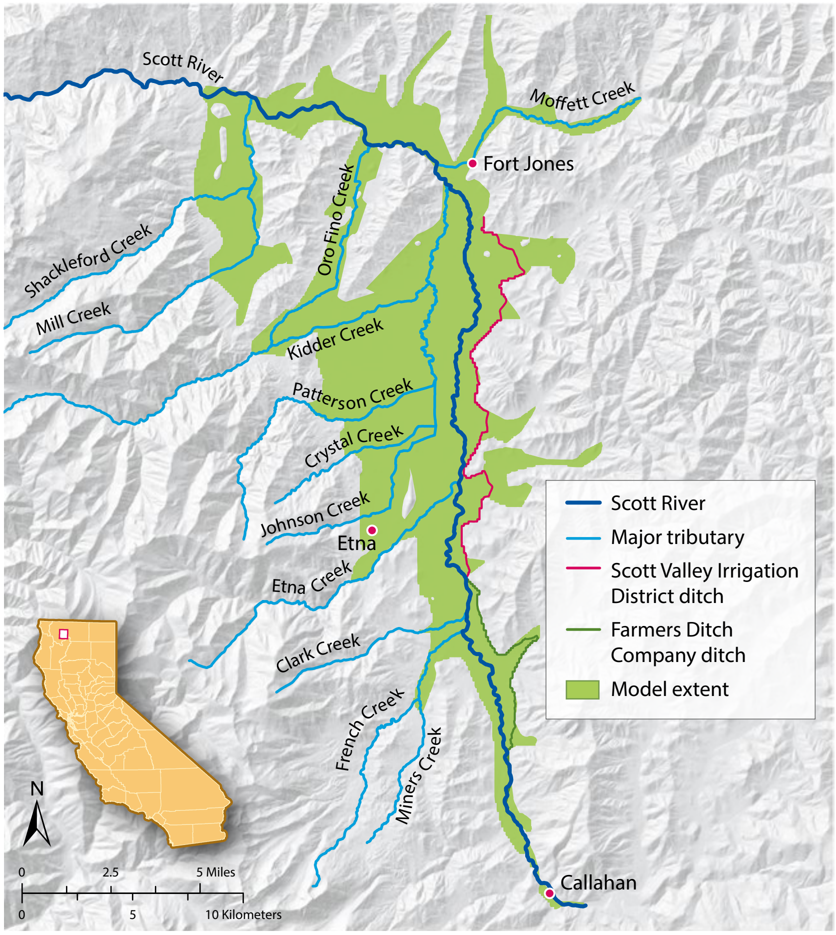


FIG. 1. The boundaries of the groundwater model study in Scott Valley, and its surface waters. The Scott River and its tributaries are an important salmonid spawning habitat, home to native populations of the threatened coho. Source: Model extent derived from Mack (1958) and Soil Survey Geographic Database (SSURGO) data. Projection: North American Datum 1983, UTM Zone 10.

flows from south to north along the east-central and northern portion of the valley. At the valley's northwest corner, the river descends into a gorge before joining the Klamath River several miles below Scott Valley. The Scott River watershed above Scott Valley extends into the surrounding Klamath Mountains to elevations of over 8,500 feet. The river and its tributaries are an important salmonid spawning habitat, home to native populations of the threatened *Oncorhynchus kisutch* (coho).

Scott Valley formed primarily due to movement along an eastward dipping normal fault, with unconsolidated, highly heterogeneous fluvial and alluvial fan deposits forming an alluvial groundwater basin (Mack 1958). Surrounding the valley, the geology is comprised of relatively impermeable bedrock composed of metamorphic and volcanic units, although fractures do yield some water in the form of springs at the margins of the valley and in surrounding upland areas.

Aquifer thickness may be as much as 400 feet in the wide central part of the valley (Mack 1958). However, there is no evidence of sufficiently coarse material to support agricultural groundwater pumping below 250 feet (Foglia, McNally, Harter 2013). The aquifer pinches out at the valley margin.

Climate in the valley is Mediterranean, with 89% of the nearly 500-millimeter average annual precipitation falling between October and April. Daily mean temperatures range from 70°F in July to 32°F in January. Precipitation depths in the surrounding mountains are much higher, and snowmelt is a major source for ephemeral tributaries feeding the Scott River and recharging into the aquifer. Snowmelt dominates Scott River flows through June. During the summer months, flows in the Scott River immediately below the montane valley (USGS gage 11519500 Ft. Jones) can drop to 4 cubic feet per second (cfs), while maximum flows during winter can reach 40,000 cfs. After snowpack storage has been depleted, the Scott River is dependent on discharge from the Scott Valley aquifer to support base flow. In dry years, sections of the Scott River overlying the valley floor become ephemeral.

Land use and irrigation

Land use was surveyed in 2000 (DWR 2000) and further refined using aerial photo analysis and on-the-ground verification through interviews with landowners. A total of 2,119 land use parcels overlie the Scott Valley groundwater basin (fig. 2): 710 parcels (17,400 acres) are alfalfa/grain (an 8-year rotation with, on average, 1 year of grain crop followed by 7 years of alfalfa), 541 parcels (16,600 acres) are pasture, 451 parcels (20,400 acres) belong to land use categories with significant evapotranspiration but no irrigation (e.g., cemeteries, lawns, natural vegetation) and 417 parcels (1,700 acres) represent land uses with no evapotranspiration or irrigation (e.g., residential areas, parking lots, roads, and — most significantly — historic mine tailings).

The year 2000 land use survey by DWR (DWR 2000) also identified the irrigation type associated with each land parcel. About 6,200 acres of cropland were identified as nonirrigated, dry or subirrigated. In Scott Valley, flood, center-pivot sprinkler and wheel-line sprinkler irrigation are used almost exclusively. Over the past 25 years, significant conversion from wheel-line sprinkler (but also from flood irrigation) to center-pivot sprinkler has occurred. For our study, we mapped the location (extent) and year of such irrigation-type conversions to land parcels by reviewing 1990 to 2011 aerial photos.

The beginning of the irrigation season is determined by soil moisture depletion but also by grower peer behavior. Earliest irrigation dates reported by local growers were March 15, March 24 and April 15 for grains, alfalfa and pasture, respectively. Growers irrigate based on soil moisture data, experience, peer behavior and established irrigation practices. The irrigation season typically ends on July 10, Sept. 1 and Oct. 15 for grain, alfalfa and pasture, respectively.

Water sources (identified for each land parcel by the DWR 2000 land use survey and updated through landowner survey) include groundwater, surface water, subirrigated (shallow groundwater table, not actually irrigated), mixed groundwater–surface water, and nonirrigated (dryland farming). Land parcels are distributed across nine subwatersheds associated with the major tributaries and the main stem Scott River. Discharge on these streams into the Scott Valley defines available maximum diversion rates for surface water irrigations. Where surface water is the only source of irrigation, lack of surface water will terminate the irrigation season. Groundwater pumping for a land parcel is from nearby or on-site irrigation wells. Well locations and type for the study area were obtained from DWR well permit records (fig. 2).

Hydrogeology

Within the alluvial groundwater basin of the Scott Valley, Mack (1958) distinguished six subareas (fig. 3). In our work, we also included the mine tailings at the southern end of the alluvial basin, an important hydrogeologic area consisting almost exclusively of reworked boulders from mine dredging operations (Foglia, McNally, Harter 2013).

Aquifer pumping tests were performed to determine hydraulic properties in the main subarea of the valley, along the Scott River corridor. The tests showed that even within hydrogeologic subareas, hydraulic property values vary greatly. Estimates of hydraulic property values were also obtained from literature available for the region (DWR 2000; Mack 1958; SSPA 2012). The ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity was estimated to be 1:10, a relatively high value representing relatively strong vertical connectivity of the coarser sediments.

The aquifer receives recharge from excess rainfall and irrigation but also from streams entering the basin on highly permeable alluvial fans. Groundwater discharge generally occurs through groundwater-dependent wetlands and riparian vegetation, pumping (primarily for irrigation) and discharge to streams, mostly along the valley thalweg.

Modeling tools

We developed the Scott Valley Integrated Hydrologic Model (SVIHM) to (1) provide a tool that integrates a diverse set of data and information within a consistent physical, hydrological framework; (2) estimate water budget components and their seasonal and interannual dynamics in the groundwater, stream and landscape–soil system; (3) better understand the relationship between land use, irrigation, groundwater pumping and stream flow; (4) provide a tool to predict potential impacts on stream flow from future groundwater and surface water management scenarios; and (5) provide an educational and decision-making tool for local stakeholders, regulators and policy- and decision-makers engaged in developing solutions to support and protect groundwater-dependent salmon habitat in the Scott Valley watershed.

For the simulation, we considered the period from October 1991 through September 2011, a period that includes the transformation of the Scott Valley landscape from predominantly sprinkler to significant center-pivot irrigation, a series of wet periods (1996 to 1999, 2006) and dry periods (1991, 2001, 2007 to 2009) and a series of years with potentially higher temperature. We developed several distinct model elements, representing the 1991 to 2011 period of the different hydrologic system components at varying levels of complexity that meet the modeling objectives. These were linked together into the SVIHM:

The upper watershed was represented by a statistical regression model to simulate incoming stream flows in the Scott River and its tributaries from the upper watershed to the valley, which are also used for irrigation. The Scott Valley landscape overlying the groundwater basin was represented by a tipping-bucket-type soil water budget model (SWBM) that simulates daily and monthly landscape-related water fluxes at the land parcel scale (see description above), including irrigation from diversions of surface water inflows to the valley and by groundwater pumping, evapotranspiration and groundwater recharge. Valley groundwater and surface water were simulated using a numerical model capable of simulating groundwater flow dynamics and the groundwater–surface water interface at sufficient detail to guide future data collection and simulate future water management scenarios.

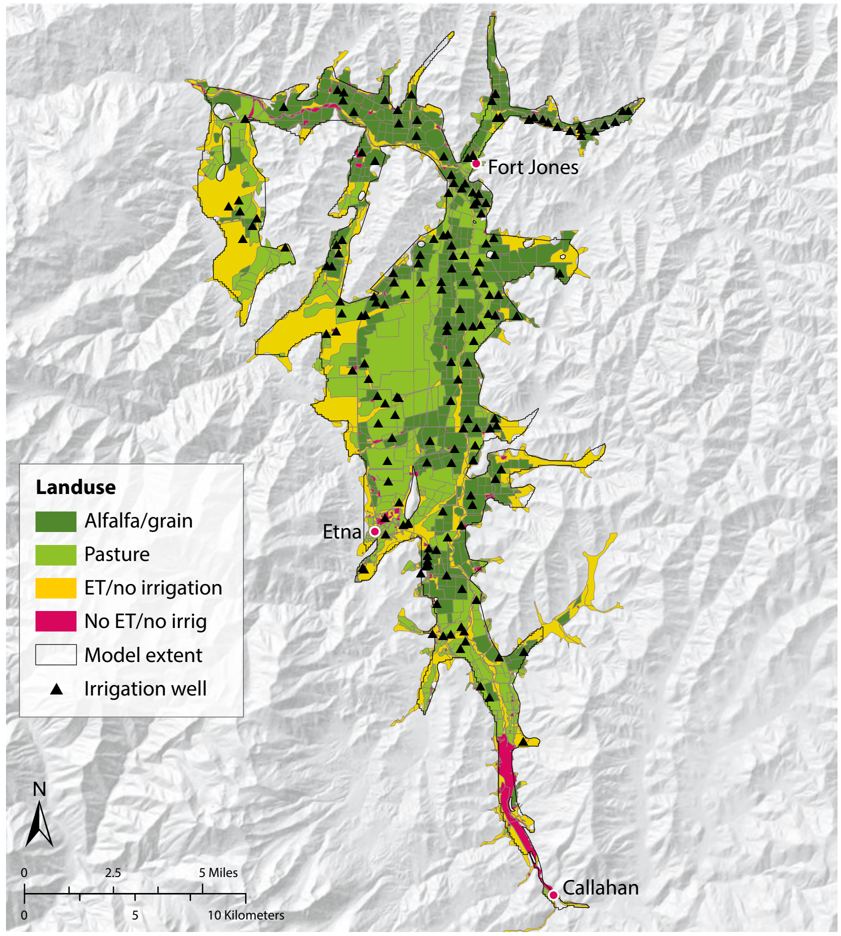


FIG. 2. Land use information and well locations in Scott Valley. ET/no irrigation reflects nonirrigated vegetation, e.g., lawns and riparian vegetation. No ET/no irrigation represents nonvegetated land surfaces including the mine tailings near Callahan. Well location information was obtained from well logs filed with the Department of Water Resources and verified in the field. Source: Model extent derived from Mack (1958) and SSURGO data. Land use polygon data source: DWR (2000). Revised to reflect 2011 land use patterns (GWAC, Groundwater Advisory Committee). Projection: North American Datum 1983, UTM Zone 10.

Upper watershed stream flows

Surface water inflows to Scott Valley from the upper watershed are an important source of irrigation water. During the summer, incoming low flows may limit or terminate surface water diversions for irrigation. This in turn affects groundwater pumping in some crop parcels equipped for dual irrigation (surface and groundwater). Quantitative estimates of surface water inflows are also an important input to simulation of stream flow dynamics (including tributaries) within the valley, where streams are in direct connection with groundwater (the groundwater–surface water interface).

Since only limited stream gauging data were available on inflowing streams, a stream flow regression model was developed (Foglia, McNally, Hall 2013). Several factors were considered in developing the regression model, including precipitation, precipitation history, snowpack, and stream flows at the valley outlet, where the USGS Ft. Jones gage has provided nearly continuous records since the early 1940s. Foglia, McNally, Hall (2013) showed that the latter was the most critical factor to predict available monthly total incoming stream flow measured near the valley margins.

Soil water budget model, SWBM

In California, no water rights permits are issued for groundwater pumping, and wells, including wells in the study area, are largely unmetered. The primary purpose of the soil water budget model (SWBM) was therefore to estimate spatially and temporally varying recharge and pumping across the groundwater basin. A second goal was to quantify crop evapotranspiration (crop ET) and irrigation water use from surface water and from groundwater, and to understand the role of soil water storage. Conceptually, the soil water budget model encompasses the managed and unmanaged landscape including its vegetation and soil root zone and also the managed components of the surface water system (diversions) and of the groundwater system (well pumping).

SWBM does not account for fluxes at the groundwater–stream interface (stream recharge, groundwater discharge to streams) or for evapotranspiration due to root water uptake directly from groundwater by nonirrigated crops or in natural landscapes with a shallow water table. These processes were instead accounted for by the groundwater–surface water models MODFLOW RIV or MODFLOW SFR.

SWBM provided daily estimates of groundwater pumping, groundwater recharge, and evapotranspiration from Oct. 1, 1991, to Sept. 30, 2011, for each of the 2,115 parcels delineated in the land use survey of Scott Valley. Storage routing and mass balance were calculated for each land parcel as

$$\theta_i = \max(0, \theta_{i-1} + Padj_i + AW_i + actualET_i - Recharge_i) \quad (1)$$

$$actualET_i = \min(ET_i, \theta_{i-1} + Padj_i + AW_i) \quad (2)$$

$$Recharge_i = \max(0, \theta_{i-1} + Padj_i + AW_i - actualET_i - WC4_i) \quad (3)$$

where θ_i is the water content at the end of day *i*; $Padj_i$ is the precipitation that infiltrates into the soil and is available for recharge or evapotranspiration on day *i*; AW_i is the applied water (irrigation) amount on day *i*; ET_i is the evapotranspiration on day *i* (computed as the product of the crop coefficient Kc and measured reference ET); $Recharge_i$ is deep percolation to the groundwater below the 1.22 meter (4 foot) deep root zone; and $WC4_i$ is the soil-dependent water holding capacity of the 1.22 meter (4 foot) root zone (Foglia, McNally, Harter 2013).

SWBM approximated growers' irrigation decisions in a simplified fashion: In the model, daily irrigation depths, AW_i, were controlled by crop evapotranspiration depth and effective precipitation, which in turn were computed from daily climate data, using appropriate crop coefficients:

$$AW_i = \frac{(actualET_i - Padj_i)}{\frac{AE}{100}}$$

where *AE* is the water application efficiency, which was assumed to be constant over the growing season. The *AE* values were based on published values (Canessa et al. 2011) adjusted for local conditions: 90% for center-pivot sprinkler, 75% for wheel-line sprinkler and 70% for flood irrigation. The model accounted for the strong relationship between crop evapotranspiration and irrigation, but it did not represent temporal details of the actual irrigation schedule or alfalfa cuttings, as these have negligible impact on variations in groundwater conditions. The model also did not account for delivery losses.

Within the alluvial groundwater basin of the Scott Valley, there are six subareas. In this work, the authors also included the mine tailings at the southern end of the alluvial basin, an important hydrogeologic area consisting almost exclusively of reworked boulders from mine dredging operations.


Thomas Harter

MODFLOW simulations

A water budget model accounts for water fluxes into and out of a groundwater basin, the associated landscape and streams, and it provides some insight into large-scale, regional groundwater–surface water interactions. But integrated groundwater–surface water computer models, such as the MODFLOW packages, are more useful to fully assess and understand groundwater–surface water dynamics that are also driven by human impacts (e.g., pumping).

We used the MODFLOW-2005 code to build the groundwater–surface water model element of SVIHM (Harbaugh 2005). MODFLOW-2005 is a computer-based groundwater–surface water model that simulates groundwater flows and surface water flows by representing the aquifer basin and overlying stream system through discretized blocks (much like the way pixels on a TV screen are a representation of a continuous image). Aquifer and stream properties were defined for each block, which allowed the model to not only take on the actual shape of a groundwater–surface water system but also to represent the internal variability in aquifer and streambed properties that best reflects that actual system.

At the core, the model code solved the equations governing groundwater flow and stream flow, one time step after another. The entire Scott Valley groundwater basin (fig. 1) was discretized into 50-meter-by-50-meter cells, and it was divided into two vertical layers to better capture vertical fluxes associated with groundwater–surface water interactions. Due to the basin geometry, the bottom layer is not laterally expanding as much as the top layer (see supporting information S1 online).

Figure 3 summarizes the boundary conditions used to develop the groundwater model. The model simulates groundwater–surface water interactions along the Scott River, along major tributary streams (Shackleford, Mill, Kidder, Oro Fino, Moffett, Patterson, Etna, Crystal, Johnson, Clark Miner's and French Creeks) and along two major irrigation ditches (Farmers Ditch Company and Scott Valley Irrigation District). These features were simulated using different combinations of the river, stream flow routing (SFR1) and drain (DRN) packages of MODFLOW.

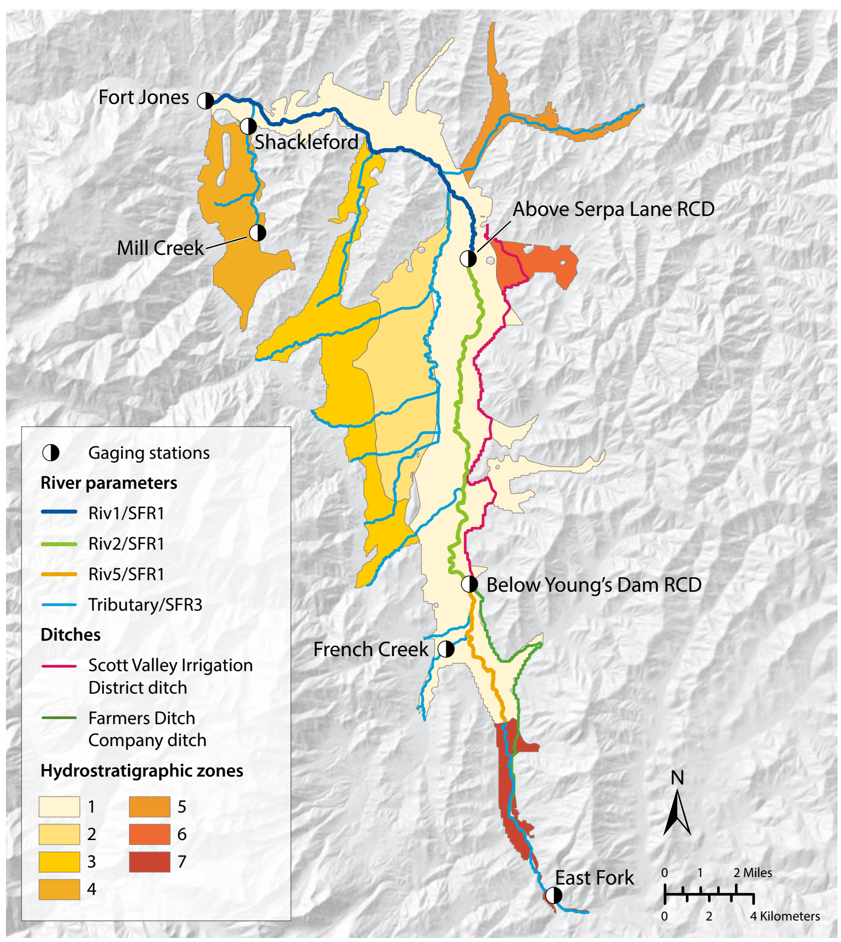
In our study, we developed two versions of SVIHM to represent two levels of conceptual complexities in the simulation of the groundwater–surface water interface. Both used the same algorithm to determine groundwater–surface water exchanges based on water level differences between the stream and groundwater, and as a function of streambed hydraulic conductivity.

In SVIHM-RIV, using the MODFLOW RIV package (Harbaugh 2005), stream water levels were user assigned and might vary in time and space. The advantage of SVIHM-RIV is that it is computationally much less expensive (has a much lower simulation run time) than SVIHM-SFR, since it does not simulate the stream flow system. The computational efficiency is advantageous in model calibration. In Scott Valley, only sparse data were available on stream water levels. As an initial modeling design step, we chose a simple approximation of stream water levels using a constant, average stream depth uniform across the valley at all times.

In SVIHM-SFR, using the MODFLOW SFR package (Prudic et al. 2004), inflows from the upper watershed (obtained from the statistical model of watershed inflows), after irrigation diversions (obtained from SWBM), were physically routed by simulation through the valley's stream system. The simulation computed stream water level as a function of flow rate, stream slope, streambed morphology and stream roughness (Manning's equation). Detailed streambed morphology was available from two LIDAR surveys (SSPA 2012). With SFR, stream flow varied from stream cell to stream cell due to diversions, tributary inflows or groundwater–surface water exchanges. In this way, MODFLOW SFR tracked stream water depth variations in time and along the stream system. It could also estimate the timing and location of stream sections that fell dry.

The land parcel–based output results of SWBM — agricultural groundwater pumping, groundwater recharge and irrigation — were used as input to the MODFLOW RIV and MODFLOW SFR versions of

FIG. 3. Representation of the main characteristic of the modelled area, including boundary conditions, hydraulic conductivity and specific storage as defined by hydrostratigraphic zone, irrigation ditches, stream flow gaging stations and river segments (represented as Riv1, Riv2 and Riv5). Source: Model extent derived from Mack (1958) and Soil Survey Geographic Database (SSURGO) data. Projection: North American Datum 1983, UTM Zone 10.



SVIHM, which simulated the 21-year period using monthly variable boundary conditions (monthly stress periods). Recharge was applied to the top of the highest active cell in the model using the recharge (RCH) package. Evapotranspiration rates were calculated using SWBM for irrigated and for nonirrigated vegetated areas. In addition, in vegetated areas where irrigation water was not applied, additional evapotranspiration from shallow groundwater was calculated within MODFLOW using the evapotranspiration segments (ETS) package (Banta 2000).

Groundwater pumping rates for individual land parcels were assigned to the nearest irrigation well. The sum of groundwater pumping assigned in a given month to a well by SWBM was the input for the MODFLOW well (WEL) package. Surface water irrigations estimated by SWBM were subtracted from the incoming tributary stream flows prior to routing surface water through Scott Valley with MODFLOW. Hydraulic parameters and other relatively uncertain components of the conceptual model were separately evaluated with the numerical model using sensitivity analysis and calibration (Tolley et al., unpublished data).

For SVIHM-RIV, groundwater level measurements across the valley and the net gain or loss in stream flow for three stream reaches along the Scott River were used as calibration targets. For SVIHM-SFR, the same valleywide groundwater level measurements have been included, but flow discharges were calibrated against the time series in the four locations used in the SVIHM-RIV and in the Fort Jones station gaging station, since SVIHM-SFR tracks stream gains and losses for computing stream flows.

Soil water budget calibrated collaboratively

The results of the initial version of SWBM (Foglia, McNally, Harter 2013) were vetted with the Scott Valley Groundwater Advisory Committee, local growers and the UC Cooperative Extension (UCCE) farm advisor. The initial SWBM estimated an average applied irrigation on (mostly sprinkler-) irrigated alfalfa of about 33 inches per year. However, landowners in the valley reported irrigation equipment to be set up for only about 20 to 24 inches per year.
To understand the origin of the discrepancy between simulated and grower-reported irrigation depths, a manual sensitivity analysis was performed with SWBM. SWBM was implemented with varying parameter combinations to quantify the effect these parameters had on water budget results.

To account for the possibility of deficit irrigation and deep soil moisture depletion during the irrigation season, the irrigation model in SWBM (Foglia, McNally, Harter 2013) was modified: Under deficit irrigation, application efficiency is assumed to be 100%, evapotranspiration is assumed to be met by precipitation and applied water but also by soil moisture depletion, where applied water demand is computed from

$$AW_i = \frac{(actualET_i - Padj_i)}{1 + \frac{SMDF}{100}}$$

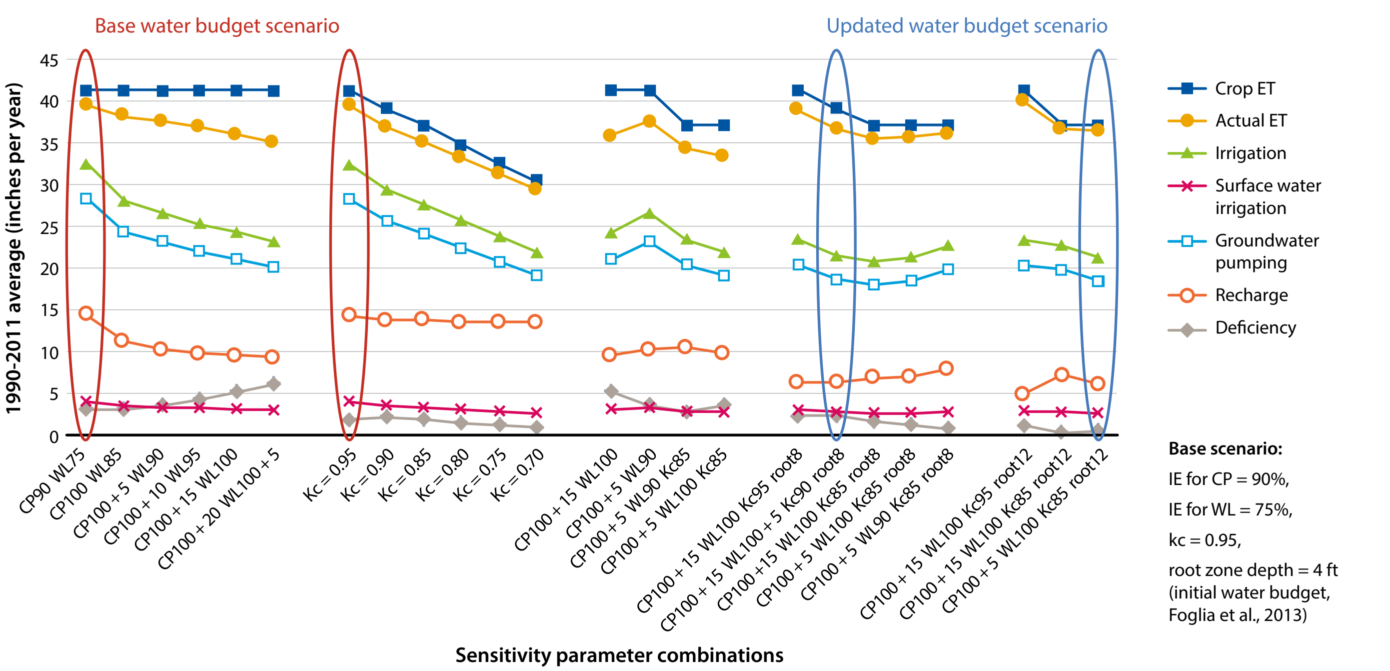


FIG. 4. Sensitivity of the simulated soil water fluxes to application efficiency, soil moisture depletion, root zone depth, and crop evapotranspiration (represented as crop coefficient Kc). For the soil water budget model sensitivity analysis, we adjusted root zone depth, from 4 feet (base value) to 8 feet (root8) and 12 feet (root12); alfalfa crop coefficient, from 0.95 (base value, Kc95) to 0.7; application efficiency for center-pivot from 90% (base value, CP90) to 100% + 20% SMDF (CP100 + 20), and for wheel-line from 75% (base value, WL75) to 100% + 5% SMDF (WL100 + 5); and (for deficit irrigation) the soil moisture depletion fraction (SMDF).

and *SMDF* is the soil moisture depletion fraction, defined as the ratio of soil moisture depletion to applied water during the irrigation season:

$$SMDF = \frac{\sum(\textit{soil moisture depletion}) \\ \textit{during the irrigation season}}{\sum(AW)\ \textit{during the irrigation season}} \times 100\%$$

For the sensitivity analysis, root zone depth, alfalfa crop coefficient (Kc), application efficiency and (for deficit irrigation) SMDF were adjusted (fig. 4).

The scenarios offered several combinations of these parameters that resulted in irrigation amounts of 24 inches or less: Reducing the Kc value led to lower irrigation needs but conflicted with previously measured Kc values (0.95). Increasing application efficiency, increasing the soil moisture depletion fraction for deficit irrigation and increasing root zone depth all led to significant reductions in simulated irrigation without significantly affecting simulated evapotranspiration. It remained unclear which parameter option to choose.

A 3-year field research project was launched in cooperation with local growers to measure evapotranspiration, irrigation water applications and deep soil moisture profiles in eight alfalfa fields distributed across representative locations in Scott Valley. The study established a new, slightly lower Kc value of 0.9. For alfalfa, the soil water profile from 5 feet to 8 feet was found to generally decline in soil water content throughout the irrigation season. Thus, alfalfa was found to be effectively deficit irrigated, that is, the application efficiency was 100%. Experimental results better constrained input choices in SWBM. Using an 8-foot root zone for alfalfa, the new Kc = 0.9 value and soil moisture depletion fractions of 5% for wheel-line irrigation and 15% for center-pivot irrigation (on both alfalfa and grain), the total annual simulated irrigation depth on alfalfa, computed by the adjusted SWBM, averaged 22 inches per year instead of 33 inches per year, corresponding with measured irrigation rates (blue oval in fig. 4).

Aggregated water budget results from this calibrated SWBM provided some important insights into understanding the groundwater–surface water interface dynamics (table 1): The total amount of groundwater pumping (an output from the groundwater account) was equal to about two-thirds of the estimated total landscape recharge (an input to the groundwater account). Since long-term groundwater levels were balanced, the surplus in recharge relative to pumping, 14,000 acre-feet per year, was the net contribution of the landscape to base flow, that is, to the groundwater discharge to the Scott River.

A small portion of the 14,000 acre-feet per year may also contribute to evapotranspiration from groundwater (e.g., riparian vegetation). Note that actual net groundwater discharge to the Scott River is higher, as SWBM does not account for about 44,000 acre-feet per year of mountain-front recharge from tributaries and leakage to groundwater from irrigation ditches (a result obtained from the groundwater–surface water modeling, below). The total amount of net groundwater discharge to streams is only about one-tenth of the much larger Scott River total annual flow, most of which originates from the upper watershed. However, during the low flow period (July/August through September/October) the Scott River outflow from the basin is mostly groundwater dependent, particularly in dry years. Over that period, total stream outflow from the

TABLE 1. Aggregated average annual water budget model results over the 21-year simulation period by land use

	Crop ET*	Actual ET†	Irrigation‡	SW irrigation	GW pumping	Recharge	Area
	Inches per year						*Acres*
Alfalfa	39.2	36.8	21.5	2.8	18.7	6.3	13,893
Grain	16.1	16.1	10.3	1.6	8.7	10.6	1,985
Pasture	38.2	34.8	26.0	20.5	5.5	11.6	11,909
ET/no irrigation	14.0	11.0	0.0	0.0	0.0	10.8	20,383
No ET/no irrigation	0.0	0.0	0.0	0.0	0.0	21.6	1,695
	Acre-feet per year						*Acres*
Alfalfa	45,384	42,065	24,871	3,207	21,665	7,294	13,893
Grain	2,663	2,663	1,707	263	1,444	1,753	1,985
Pasture	37,910	34,536	25,791	20,351	5,440	11,512	11,909
ET/no irrigation	23,780	18,684	—	—	—	18,345	20,383
No ET/no irrigation	—	—	—	—	—	3,051	1,695

Note: All calculations assume that the water table is below the root zone.
* Annual evapotranspiration rate if optimal irrigation was applied year-round.
† May be less than crop evapotranspiration due to discontinued irrigation in late summer (lack of surface water) or fall (no irrigation is typically applied after August).
‡ Includes irrigation with surface water and irrigation with groundwater.
SW = surface water, GW = groundwater.

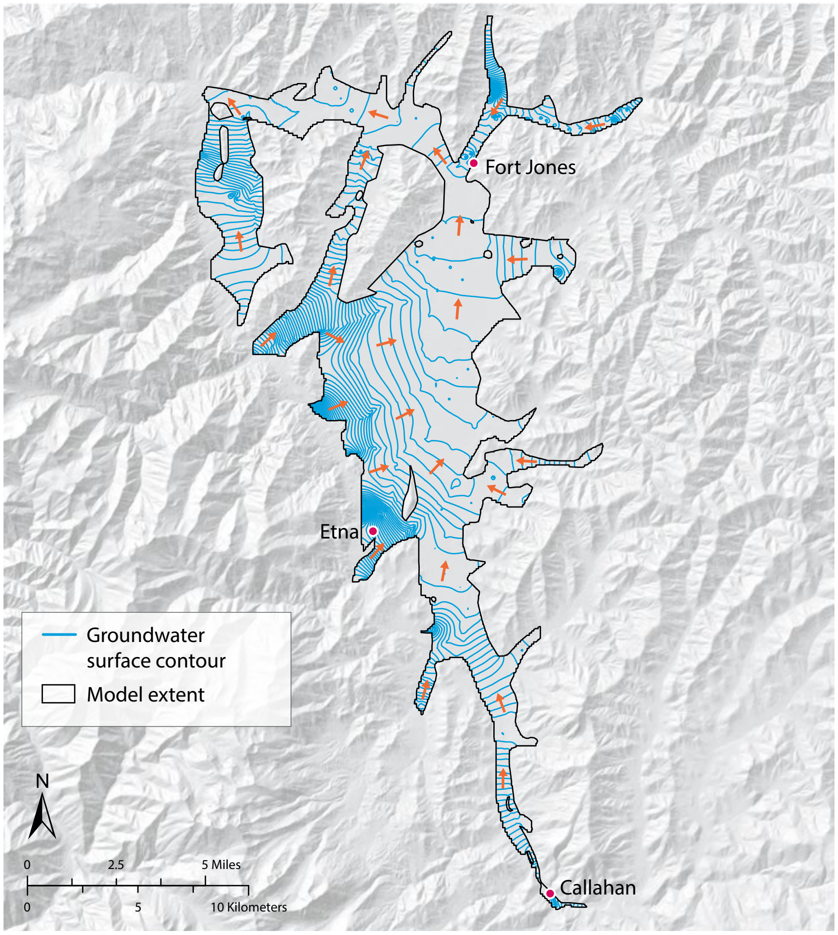


FIG. 5. Groundwater levels and flow direction in August 2001. This is one of the results from the groundwater–surface water model. Other output from the groundwater–surface water model included monthly water levels, groundwater flow directions and amounts, and groundwater–surface water exchanges for water years 1991 to 2011. Arrows indicate the flow direction but are not scaled to groundwater flow velocity. See supporting information S1 for comparison of simulated water levels and flow rates to measured water levels and flow rates. Source: Model extent derived from Mack (1958) and SSURGO data. Projection: North American Datum 1983, UTM Zone 10.

During the low flow period (July/August through September/October) the Scott River outflow from the basin is mostly groundwater dependent, particularly in dry years.

valley may amount to less than 10,000 acre-feet, and in exceptionally dry years (e.g., 2001, 2014, 2015) to less than 2,000 acre-feet. Relative to these flows, landscape recharge contribution to base flow was significant.

SWBM did not account for recharge contributions to groundwater from streams or for the dynamics of groundwater discharge to streams. SWBM also did not provide insight in how those may be affected by groundwater pumping and recharge or by intentional groundwater storage in the basin (a potential future project). For these additional analyses, SWBM must be coupled to a more complex groundwater–surface water model.

Importantly, SWBM was an important tool for outreach and education. That outreach led to initiation of the new field research, results from which improved model development. Refinement of SWBM was made possible through regular interactions between local stakeholders and growers on the groundwater advisory committee, the local UCCE farm advisor, the modeling team and the new field research. The collaboration on the SWBM increased the community's trust of the groundwater–surface water (MODFLOW) model component of SVIHM. (SWBM drives the pumping and recharge condition in the MODFLOW component, which in turn drives the dynamics at the groundwater–surface water interface.)

Water fluxes: RIV versus SFR representations

The groundwater–surface water model component of SVIHM, represented using both the RIV and SFR packages, simulated 21 years of groundwater and stream flow dynamics driven by monthly data of the statistically simulated stream inflows at each tributary from the upper watershed, by pumping in nearly 200 wells and by recharge from over 2,000 land parcels. Output included monthly water levels, groundwater flow directions and amounts, and groundwater–surface water exchanges at the 50-meter scale throughout Scott Valley for water years 1991 to 2011 (fig. 5).

Sensitivity analysis and calibration of the numerical MODFLOW-based groundwater–surface water simulation model were completed to assess model performances and to fine-tune model parameters (supporting information S1 and Tolley et al., unpublished data). These steps were taken to ensure that SVIHM's input and structure yielded simulation results that were consistent with 1991 to 2011 measured water level and long-term stream gauging information on the Scott River.

Groundwater budgets, including groundwater–surface water fluxes, will be one of the critical components evaluated and discussed by groundwater sustainability agencies. It's important to understand how to read the groundwater budget outputs from the conceptually very different RIV and SFR models and how the difference in the model can affect predictions of future scenarios.

SVIHM-RIV and SVIHM-SFR fundamentally differ in the representation of the elevation of the stream's water surface (stream state) — one user defined, one based on a streamflow model. In all other aspects, they are identical. The RIV representation, which lets the user specify stream stage (water level elevation) at each river cell, is an excellent option where water depth in the stream does not vary significantly in time or measurements are available about changes in stream stage at high spatial resolution and where these are not impacted or impacted in known ways under future scenarios of interest. Our very simplified RIV representation (constant, uniform stream water depth) was developed as a simplified conceptual approach to generate a first-order approximation of the groundwater–surface water interface, and we had no stream depth data.

In contrast, in the SFR representation, stream stage is simulated by a stream flow routing model that internally computes stream water levels while preserving water balance within the stream system dynamically. Stream stage at each grid cell is a function of stream flow into the cell, of physical characteristics of the stream available from detailed surveys and of groundwater–surface water fluxes at each grid cell. The SFR representation also accounts for the confluence of streams and for diversions to surface water users, which in turn affect local stream flow rates. When flow is insufficient to support stream flow, the streambed falls dry until either upstream inflow becomes available or groundwater begins to emerge into the streambed due to a higher water table. Given data available for Scott Valley and the dynamics of its stream system, MODFLOW SFR provided a physically more accurate, if computationally more expensive, model representation.

Aquifer water budgets for both the irrigation season (summer) and the nonirrigation season (winter) (fig. 6) showed that exchange of water between surface water and groundwater was about three times larger in SVIHM-RIV than SVIMH-SFR. All other boundary fluxes were identical due to both models having otherwise identical boundary conditions. In figure 6, the exchange between surface water and groundwater is represented in green and labeled "Stream". For all the terms in figure 6, the flow "in" represents the amount of water entering into the aquifer from various sources, while the flow "out" is the flow leaving the aquifer.

The difference between stream recharge (input to the water budget) and groundwater discharge (output from the budget), however, is the same in both models — a net groundwater discharge to the stream of 80 cfs (58,000 acre-feet per year), when averaged over the entire year. This is not coincidental: The net groundwater discharge of 58,000 acre-feet per year is independent from the groundwater–stream connectivity. It is instead entirely driven by the average annual difference between mountain-front recharge (determined by the upper watershed model), ditch losses to groundwater (user input based on measured data) and landscape recharge (SWBM result) on the one hand and groundwater pumping (SWBM result) and evapotranspiration losses from groundwater (MODFLOW result) on the other hand, none of which is a function of the choice of RIV or SFR package. The exception was the MODFLOW simulated evapotranspiration losses from groundwater near streams, which may be affected by the model choice (RIV or SFR).

With SVIHM-SFR, net groundwater discharge (fig. 6, difference between the Stream "in" and the Stream "out") was only slightly smaller over the summer months than over the winter months (about 60 cfs in both seasons). In contrast, with SVIHM-RIV, the net discharge to streams was about 50 cfs in summer but almost 140 cfs in winter. This large seasonal variation was driven by seasonal variations in groundwater storage that operate differently in the SVIHM-RIV model than in the SVIHM-SFR model: Groundwater storage during winter increased in SVIHM-RIV by just 40 cfs, or 15,000 acre-feet per 6 months, half the increase in SVIHM-SFR (80 cfs, or 29,000 acre-feet per 6 months), due to the larger winter net groundwater-to-stream discharge in SVIHM-RIV. By the same token, groundwater storage during summer decreased in SVIHM-RIV by just half of that in SVIHM-SFR due to the much lower net groundwater-to-stream discharge in SVIHM-RIV in summer.

The difference between the simulated fluxes was caused by differences in the stream stage between SVIHM-RIV and SVIHM-SFR. The SVIHM-SFR model relied on measured and estimated stream flow entering the valley, which in turn drove the local and seasonal dynamics of stream stage and the magnitude of groundwater–surface water interaction. Inflows to the valley are highly dynamic and vary strongly between winter and summer. The SVIHM-RIV model with its uniform, constant stream water depth that we chose did not sufficiently capture the spatial and temporal changes in stream flow dynamics. In this simplified representation, the stream became an artificial buffer to groundwater level changes. SVIHM-RIV added recharge from streams during the low flow periods when no exchange occurred in SVIHM-SFR simulations.

When using SVIHM-RIV, it would therefore be important that dry stream sections are properly characterized a priori for simulating future management projects. Also, even in flowing sections of the stream, characterization could be improved by providing

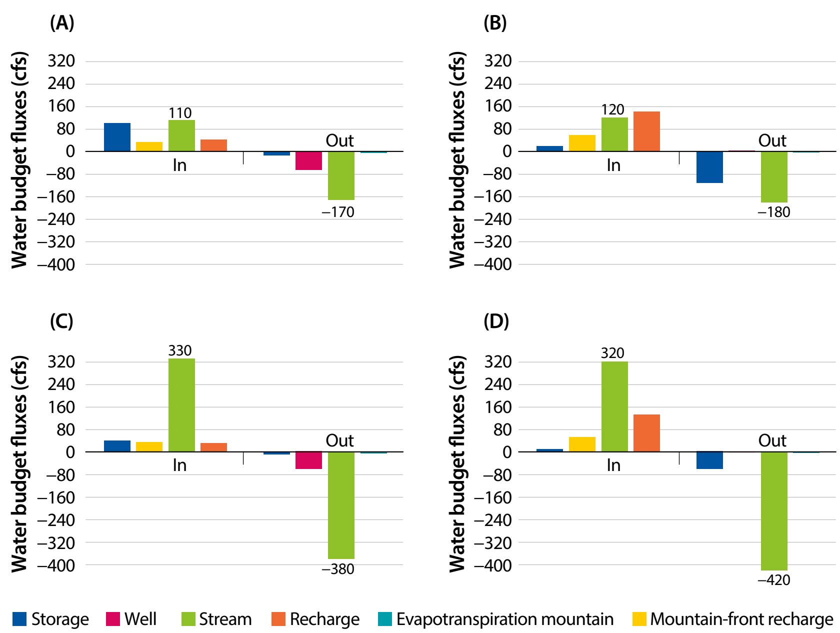


FIG. 6. Water budget results for various seasons and stream models. Markedly different groundwater–surface water fluxes were evident in the results of SFR and RIV models: (A) SFR during summer (the irrigation season, April to Sept), (B) SFR during winter (the nonirrigation season, October to March), (C) RIV during summer and (D) RIV during winter.

Scott Valley Irrigation District diversion and fish ladder. The river and its tributaries are an important salmonid spawning habitat, home to native populations of the threatened *Oncorhynchus kisutch* (coho).

spatially more detailed, seasonally varying water level depth within the stream network as part of the RIV representation. In Scott Valley, however, one of the future scenario modeling goals for which the model will be used is to predict the change in the timing and extent of dry stream sections in response to groundwater management actions. For that purpose, only the SVIHM-SFR approach can be used.

Our Scott Valley study suggests that knowledge of stream stage at high spatial and temporal detail is critical when representing the groundwater–surface water boundary with a RIV approach. More detailed calibration that has been carried out for the SVIHM-SFR model (Tolley et al., unpublished data) demonstrated that the presence of river reaches that become dry during a certain time in the summer was a critical observation to calibrate or validate SVIHM-SFR.

Models for SGMA implementation

Under California's new groundwater governance, groundwater sustainability agencies across the state have to consider the potential impact of new groundwater management measures on groundwater–surface water interaction and specifically on estimating the effect of groundwater management on surface water depletion. Only a groundwater model that also has some representation of streams can provide the spatially and temporally more detailed information on groundwater–surface water exchange that may be required when evaluating individual groundwater management projects and their impacts to stream flow.

As shown in our Scott Valley study, the choice of stream representation will depend on availability of data, data density in space, and data continuity in time for stream flow and stream stage. Depending on implementation, significantly different results may be obtained. The value of the model outcome will increase with better physical representation of the integrated hydrologic system, which in turn is driven by good data availability.

Integrated numerical modeling tools represent and link upper watersheds, the basin soil–landscape systems, the groundwater system and the basin surface water system. These tools will be useful to evaluate groundwater conditions (in SGMA referred to as sustainability indicators) and the benefits of management actions to address undesirable results. Some of these conditions, such as depletion of surface water by groundwater pumping, are otherwise difficult to measure from field data alone.

For the broader audience among groundwater agency stakeholder groups, the important take-away from our work is that numerical groundwater modeling tools are all based on the same mathematical representation of groundwater flow. But other elements of the hydrologic cycle to which a groundwater model must inevitably be linked — for example, the soil–landscape system, including the ways in which urban and agricultural water demands operate; the stream system; and the upper watershed system — are subject to more varied model representations. This variability affects the simulation of groundwater–surface water interface, pumping, recharge from various sources, and flows of surface water and groundwater at the basin boundaries.

Irrigation well in Scott Valley.

As we demonstrated, an integrated model is not only a platform for a unifying, scientifically defensible framework to connect spatially and temporally distributed data of many different kinds and to represent a range of groundwater (and surface water) sustainability indicators. It is also a tool to explore conceptual uncertainties and initiate additional research and data collection to improve representation of the driving elements of groundwater–surface water interactions and other drivers of groundwater dynamics. The integration of various model components also (1) allows representation of fluxes within the basin and between different basins, (2) allows evaluation of the sensitivity of the integrated model to different parameters and observations, (3) facilitates an estimate of the uncertainty in the results (Tolley et al., unpublished data) and (4) supports the design of future management scenarios (not yet implemented here).

Our Scott Valley study shows that models of various complexity (regression model, mass balance model, and numerical dynamic model) can be successfully integrated and provide a useful interface to communicate with and successfully engage stakeholders in developing groundwater sustainability plans. Our results demonstrate the importance for stakeholders to fully understand the conceptual implications of the different assumptions of model development and how these can impact water budgets and management of fluxes between basins. This understanding is fundamental for the successful development of groundwater sustainability plans as required by SGMA. CA

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Coupling a spatiotemporally distributed soil water budget with stream-depletion functions to inform stakeholder-driven management of groundwater-dependent ecosystems

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[1] Groundwater pumping, even if only seasonal, may significantly impact groundwater-dependent ecosystems through increased streamflow depletion, particularly in semiarid and arid regions. The effects are exacerbated, under some conditions, by climate change. In social sciences, the management of groundwater-dependent ecosystems is generally considered a "wicked" problem due to the complexity of affected stakeholder groups, disconnected legal frameworks, and a divergence of policies and science at the cross road between groundwater and surface water, and between ecosystems and water quality. A range of often simplified scientific tools plays an important role in addressing such problems. Here we develop a spatiotemporally distributed soil water budget model that we couple with an analytical model for stream depletion from groundwater pumping to rapidly assess seasonal impacts of groundwater pumping on streamflow during critical low flow periods. We demonstrate the applicability of the tool for the Scott Valley in Northern California, where protected salmon depend on summer streamflow fed by cool groundwater. In this example, simulations suggest that increased recharge in the period immediately preceding the critical low streamflow season, and transfer of groundwater pumping away from the stream are potentially promising tools to address ecosystem concerns, albeit raising difficult infrastructure and water trading issues. In contrast, additional winter recharge at the expense of later spring recharge, whether intentional or driven by climate may reduce summer streamflows. Comparison to existing detailed numerical groundwater model results suggests that the coupled soil water mass balance—stream depletion function approach provides a viable tool for scenario development among stakeholders, to constructively inform the search for potential solutions, and to direct more detailed, complex site-specific feasibility studies. The tool also identifies important field monitoring efforts needed to improve the understanding and quantification of site-specific groundwater-stream interactions.

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1. Introduction

[2] Groundwater-dependent ecosystems (GDEs) located within streams are among several types of GDEs including peats, terrestrial systems, and springs [*Howard and Merrifield*, 2010; *Bertrand et al.*, 2012]. Significant groundwater development can lead to reduction in base flow of nearby rivers and streams. Particularly in Mediterranean and similar semiarid climates, dry, warm periods coincide with the crop growing season supported by irrigation, often with groundwater. Regions in the Western and Central U.S., Mexico, Argentina, North Africa, the Middle East, Southern Europe, Northern India, China, and Southeast Asia are widely affected by use of groundwater with major impacts

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to surface water flows [*Wada et al*., 2010, 2012; *Gleeson et al*., 2010]. Irrigated agricultural systems provide 40% of the world's crop production [*United Nations World Water Development Report*, 2009] with over 100 million ha of land equipped for irrigation with groundwater and an estimated 545 km^3 of extracted water [*Siebert et al*., 2010].

[3] Groundwater management may follow a "safe yield" approach that balances long-term, annual water extraction with groundwater recharge, yet pumping induced decrease of dry season base flow may negatively impact ecoystems [*Sophocleous*, 2000, *Jolly et al*., 2010]. Statistical analyses of long-term precipitation, pumping, and streamflow records, e.g., in the High Plains aquifer system, have been used to show significant linkages between pumping and streamflow depletion [*Burt et al*., 2002; *Wen and Chen*, 2006; *Kustu et al*., 2010]. *Zume and Tarhule* [2008] used a fully three-dimensional groundwater-surface water model to investigate the effects of basin-wide pumping reductions on streamflow depletion in Oklahoma. A similar tool was used, at a much smaller scale, to analyze the hydroecology of mountain meadows fed by groundwater [*Loheide and Gorelick*, 2007]. Significant work has been conducted on optimizing conjunctive use of groundwater and surface water [*Singh*, 2012]. But economic analysis of groundwater-surface water systems does typically not account for hydrologic regimes important to ecosystem services.

[4] Improved implementation of conjunctive use schemes of surface water and groundwater resources are an important step toward improving conditions in GDEs with opportunities for improving the economy of these systems while significantly increasing the resilience to droughts [*Lefkoff and Gorelick*, 1990; *Schoups et al*., 2006; *Bredehoeft*, 2011]. But dynamics at the interface between groundwater and streams and the combined impacts of groundwater abstraction and climate change on streamflow depletion and GDEs are legally unrecognized [*Thompson et al*., 2006] and often ignored by water managers [*Kollet et al*., 2002; *Döll et al*., 2012]. In the United States, where groundwater management is delegated to individual states, water laws largely lack a comprehensive framework for the management of GDEs and even ignore the physical connection of surface water and groundwater [*Harter and Rollins*, 2008; *Nelson*, 2012]. Human modifications of water flows at local, regional, and continental scales interject multiple conflicting objectives into water management including food production and ecosystem services [*Maxwell et al*., 2007]. Climate change promises to incur further shifts with impacts rippling throughout the water network, in unanticipated ways [*Allen et al*., 2004; *Scibek and Allen*, 2006; *Maxwell and Kollet* 2008].

[5] Such "wicked" problems are characterized by a high level of complexity, uncertainty, and conflict [*Von Korff et al*., 2012; *Ker Rault and Jeffrey*, 2008; *Kreuter et al*., 2004; *Freeman*, 2000]. Addressing wicked problems requires new participatory approaches to the decision-making process and an active role of physical/hydrologic sciences in addressing such problems. Scientific understanding of hydrologic systems is advancing rapidly, but developing tools that communicate fundamental scientific understanding to decisions makers and citizens remain a challenge at all scales (global, regional, and local) [*Reid et al*., 2010; *UNESCO*, 2010].

[6] Efforts to address wicked water problems have been or are under development in different regions of the world and at different scales [*Ostrom et al*., 1999; *Sophocleous*, 2002; *Hare et al*., 2003; *Moellenkamp et al*., 2010; *Von Korff*, 2012]. Many include an effort to integrate scientists, decision makers (at the local and regional scale), and regulators within the workflow [*Sophocleous*, 2012]. Often, collaborative solutions to such wicked problems require conceptual representations of the water management system(s) at various levels of complexity.

[7] Simple conceptual models convey fundamental insights into the dynamics of hydrologic systems to non-technical stakeholders. Such models are also useful to develop worst-case/best-case scenarios given the conceptual simplification and data limitation underlying the model. Models representing additional complexity may then be used to further constrain insights into the hydrologic system and predictions of its future state. This process enables a better understanding of water resources and leads to a more informed approach toward developing strategies and scenarios for better water resources management.

[8] In this work, we couple two low order (conceptually and geometrically simple, mass balance based) hydrologic modeling tools to investigate aquifer-stream interactions. Simplified aquifer-stream interaction models to reduce computational costs have been applied in hydro-economic modeling efforts [e.g., *Pulido-Velazquez et al*., 2008], showing that a coupled water budget-stream depletion function analysis may be useful for optimizing groundwater management under ecosystem services constraints. Here we expand the approach to investigate spatiotemporally distributed groundwater management alternatives that may improve GDE conditions in basins with significant but unmeasured groundwater extractions and recharge.

[9] The tool is applied to the Scott Valley groundwater basin, California, to (1) evaluate and demonstrate the fundamental dynamics between landuse, groundwater use, and seasonally low streamflow that is affecting stream temperature [*Caissie*, 2006] and salmonid stream habitat [*Milner et al*., 2012]; (2) evaluate the role of data in understanding the key drivers of potential stream base flow depletion during the dry season in a semiarid, irrigated agricultural region with Mediterranean climate; (3) utilize the tool to cast an overall framework for developing potential groundwater management options and for defining project-specific feasibility work; and (4) employ the tool for education and outreach to diverse stakeholders seeking common, creative solutions. Stakeholders in the Scott Valley include local landowners (farms) and groundwater pumpers, native American tribes dependent on downstream salmon fisheries, environmental groups, as well as local, state, and federal agencies representing often conflicting interests in water rights regulation, water quality control, endangered species protection, and agricultural resources management—thus representing all the ingredients to a "wicked" water management problem.

[10] In the following, we provide further details on the study area and describe the spatiotemporally distributed

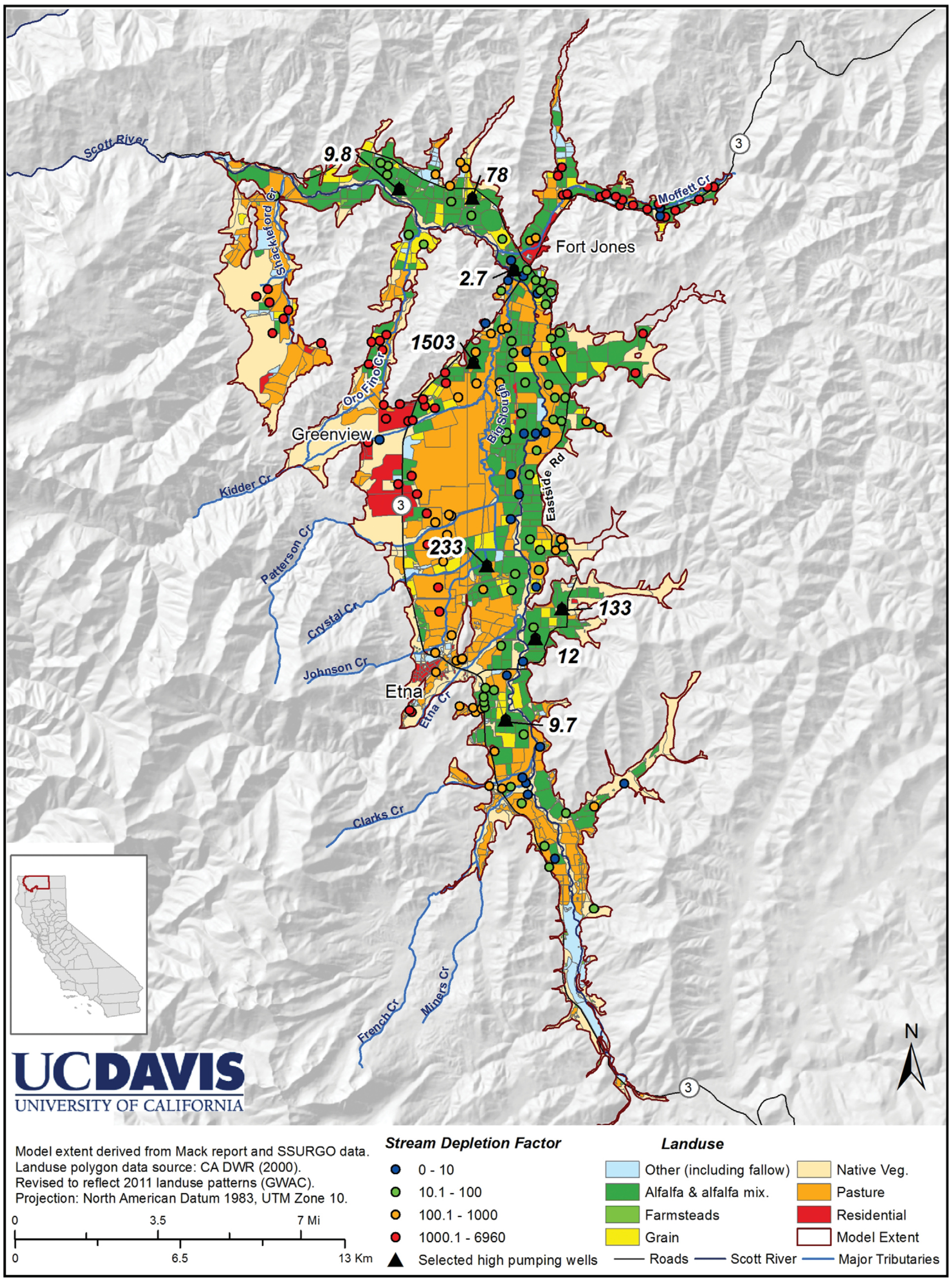


Figure 1. Map of the Scott Valley with the boundaries of the groundwater model study, landuse, and irrigation wells with their stream depletion factor (SDF in days) relative to the main-stem Scott River, calculated as described below. Highlighted are the SDF values of some wells used below for a detailed analysis (also see Table 4).

soil water budget approach and the theory of stream depletion analysis. We use the coupled water budget and stream depletion analysis to explore the role of groundwater pumping in the Scott River Valley with respect to late summer base flow in the Scott River. We then identify broad options for potential alternative water management scenarios to improve summer streamflow as a basis for discussion with stakeholders and for directing the selection and assessment of specific projects including necessary field work and higher level, more complex hydrological modeling efforts.

2. Methods

2.1. Study Basin

[11] The coupled water budget and stream depletion analysis is applied to the 202 km^2 Scott River Valley, Siskiyou County, Northern California. The major landuse is pasture, alfalfa hay, and grain farming (approximately 140 km^2) supported by summer irrigation with stream water and with groundwater. The valley is part of the Klamath Basin watershed straddling the California-Oregon border (Figure 1). The Scott River is one of four undammed

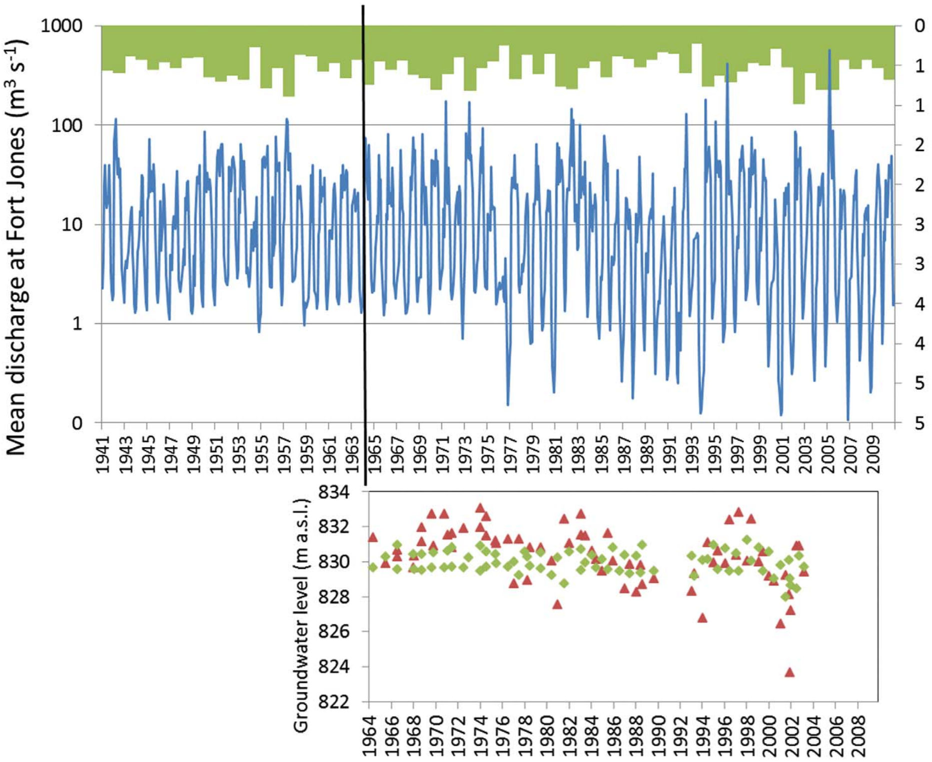


Figure 2. (a) Daily mean discharge (m^3 d^{-1}) of the Scott River recorded at the USGS gauge near Fort Jones. Since the mid-1970s, dry year low flows (1977, early 1990s, 2001, 2007–2008) have been about half an order of magnitude lower than during the 1941–1976 measurement period (1945, 1955). (b) Scott River Valley well levels and precipitation, 1965–2012 [*California Department of Water Resources* (*CDWR*), 2012]. Beginning with the drought-year 1977, summer water levels in some dry years were lower than during the 1964–1976 period.

tributaries to the Klamath River. It provides key spawning habitat for salmonid fish in the Klamath Basin, including *Oncorhynchus tschawytscha* (Chinook salmon) and federally protected threatened *Oncorhynchus kisutch* (Coho salmon). The Scott River has been mapped as medium to high ranking for the presence of base flow-dependent ecosystems [*Howard and Merrifield*, 2010].

[12] Scott Valley overlies an intermontane alluvial basin within the Klamath Mountains Province, created by faulting along its northwestern outlet, and subsequent alluvial deposition during the late Tertiary and Quaternary. The alluvial fill, consisting of gravel, sands, and also silts and clays, may exceed 100 m thickness at the center of the basin and decreases in thickness to the valley margins [*Mack*, 1958]. Groundwater pumping is limited to the upper 60 m of the alluvial fill. Spring groundwater levels, while slightly variable from year to year, have not experienced a long-term decline that would indicate systemic overdraft [*Harter and Hines*, 2008; *S.S. Papadopoulos & Associates (SSPA)*, 2012].

[13] The climate is Mediterranean. Precipitation predominantly occurs during winter and early spring months but is negligible between June and September. Average July temperature is 21°C and average January temperature is 0°C. Total annual rainfall on the valley floor is 500 mm. Mountain ranges surrounding Scott Valley reach elevations of 2500 m with much higher precipitation rates than the valley. Annual runoff from the 1700 km^2 watershed is 560 Mm^3 [*U.S. Geological Survey* (*USGS*), 2012]. Winter flows in the main stem of the Scott River, immediately downstream of the groundwater basin, may exceed 1,000,000 m^3 d^{-1} (400 cfs) during winter months, but are as low as 25,000–125,000 m^3 d^{-1} (10–50 cfs) during the later summer months (July–September) (Figure 2a).

[14] During the dry summer, streamflow in the Scott River system significantly relies on groundwater return flow (base flow) from the alluvial aquifer system underlying Scott Valley. Historic records show that summer base flows in dry years prior to 1977 (1945, 1955) have been higher than during later dry years (1977, early 1990s, 2001, 2009) (Figure 2a). The decrease is generally attributed to climate change [*Drake et al*., 2000], but also to increased groundwater pumping for irrigation [*Van Kirk and Naman*, 2008]. As a result of lower summer/fall base flow, but also due to the lack of widespread riparian vegetation, temperatures in the Scott River may exceed critically high levels during the summer months [*NCRWB*, 2011]. Yet, ecologically necessary minimum flow requirements remain uncertain.

[15] Under regulatory efforts driven by federal *Clean Water Act* [1972] provisions (33 U.S.C. §1251 et seq., 1972, and 40 C.F.R. 130.2), stakeholders have agreed that better knowledge of the hydrology and the alluvial aquifer system is needed to develop a possible array of solutions to water issues and associated problems [*Harter and Hines*, 2008]. Siskiyou County has management jurisdiction over

groundwater and is taking a community-based approach to implementing groundwater management.

[16] Water and groundwater management is also affected by recent enforcement actions under the California Endangered Species Act (CESA; California Fish and Game Code, Sections 2050 et seq.), which allows the State of California to curtail diversions of irrigation water if instream flows are considered critically low with respect to threatened or endangered salmon species in the river system (California Fish and Game Code, Section 5937). Finally, a lawsuit has been brought against the County (as the groundwater management agency) and the State (as the licensor of water rights) to protect groundwater-dependent ecosystems under the so-called Public Trust doctrine [*Hart*, 1996]. If successful, this may give the State an unprecedented legal tool to enforce limits on current groundwater pumping not already controlled under existing adjudications. An existing groundwater adjudication in the Scott Valley, dating to the 1970s, prescribes the amount of groundwater that is reasonably required to irrigate within a groundwater—surface water "interconnected zone" (California Water Code 2500.2) extending approximately 500–1000 m from the main-stem Scott River [*California State Water Resources Control Board* (*CSWRCB*), 1980]. Elsewhere in Scott Valley, as is customary in California, groundwater pumping for overlying uses does not require state permitting [*California Department of Water Resources* (*CDWR*), 2003].

2.2. Soil Water Budget Model

[17] Land use specific water budgets have been used to allow for a better understanding of landuse linkages to groundwater and provide the basis for distributed groundwater-stream models [e.g., *Ruud et al.*, 2004; *Faunt*, 2009; *Chung et al.*, 2010]. In the study area, measurement data on groundwater extraction and recharge do not exist. Hence, a soil water budget model is used to estimate spatially and temporally varying recharge and pumping across the groundwater basin.

[18] The spatial resolution for the analysis is determined by the size of individual fields and other landuse parcels defined in a recent landuse survey [*CDWR*, 2000] that was further refined using aerial photo analysis and on-the-ground verification. A total of 2119 landuse parcels overly the Scott Valley groundwater basin (Figure 1). Of those, 710 parcels (70 km^2) are alfalfa/grain, typically on an 8 year rotation with 1 year of grain crops followed by 7 years of alfalfa, 541 parcels (67 km^2) are pasture, 451 parcels (58 km^2) belong to landuse categories with significant evapotranspiration but no irrigation (e.g., cemeteries, lawns, natural vegetation), and 417 parcels (6.8 km^2) represent landuses with no evapotranspiration or irrigation (e.g., residential, parking lots, roads, and—most significantly—historic mine tailings). For each landuse parcel, the soil water budget is computed with daily time steps [e.g., *Gassman et al.*, 2007] for the period from 1 October 1990 to 30 September 2011, a period that includes several dry years as well as average year and wet year periods.

[19] The soil water budget approach includes the managed components of the surface water system (diversions) and of the groundwater system (extraction), as well as groundwater recharge from managed and unmanaged landuses. The budget does not account for stream recharge or for groundwater discharge downstream resulting from stream recharge upstream. It also does not account for evapotranspiration due to root water uptake from the water table by nonirrigated crops or in natural landscapes with shallow water table. A complete surface watershed or groundwater basin budget requires a more complex, integrated groundwater-surface model.

[20] To compute the soil water budget, each landuse polygon is characterized by a set of properties (attributes) assembled from existing databases, through field work, survey, and by applying spatial analysis within a geographic information system (GIS). The concepts applied represent some simplification over detailed root zone water models, but are commensurate given available data and the overall framework of the approach:

[21] 1. Daily precipitation for 1990–2011 is obtained as the average of records at two rainfall gauges located in the northeast and southern-most portions of the valley floor [*National Oceanographic and Atmospheric Administration (NOAA)*, 2012].

[22] 2. Streamflow for 1990–2011: Daily discharge data for the Scott River downstream of Scott Valley are available from the U.S. Geological Survey [*USGS*, 2012]. Streamflow data on ten tributaries, including the two main stem forks of the Scott River, at locations immediately upstream of the valley floor (i.e., upstream of the groundwater basin) have been collected at various times by local and state agencies. But no long-term records exist. Missing data on tributary inflows into the valley at the upgradient boundaries of the groundwater basin are estimated by performing a regression analysis of measured tributary flow against downstream flow, snowpack, and precipitation as independent variables (see supporting information).

[23] 3. Landuse: Digital land use survey maps for the year 2000 [*CDWR*, 2000] identify individual landuse parcels (polygons) and their landuse. The information was updated and corrected via interviews with landowners (Figure 1). Landuse is then aggregated into four major categories for purposes of computing the soil water budget: (1) Alfalfa/grain rotation in an 8 year cycle (each field is randomly assigned one of the 8 years in the cycle during which it goes into "grain" rotation), (2) pasture, (3) landuse with evapotranspiration but no irrigation (includes natural vegetation, natural high water meadow, misc. deciduous trees, trees), and (4) landuse with no evapotranspiration and no irrigation, but with potential recharge from precipitation via soil moisture storage (barren, commercial, dairy, extractive industry, municipal, industrial, paved, gravel mine tailings, etc).

[24] 4. Soil type: Digitally mapped soil type information is available from the U.S. Soil Survey Geographic (SSURGO) database [*Natural Resources Conservation Service (NRCS)*, 2012a, 2012b]. Soil type information includes water holding capacities at 0.9 m and 1.5 m depth. For the soil water budget, water holding capacity is computed as the average of these values assuming that average effective root-zone depth for alfalfa is approximately 1.22 m (4 ft) [*Luo et al.*, 1995]. Here we use the same depth for grain and pasture. Each landuse polygon is associated with the soil type present at its centroid location.

[25] 5. Crop coefficients (k_c) and reference ET (ET_0): estimation methods of actual crop ET are primarily designed for

Table 1. Total Areas of Subwatersheds, Total Area for Various Irrigation Types, Total Area for Various Irrigation Water Sources, and Total Area of Landuse, in Square Kilometers[a]

Subwatersheds Name	Area (km^2)	Irrigation Type	Area (km^2)	Water Source	Area (km^2)	Landuse	Area (km^2)
Etna Creek	17	Non-irrigated	75	DRY	14	Water	1
French Creek	2	Flood	44	GW	67	Alfalfa/Grain	71
Kidder Creek	38	Sprinkler	51	MIX	16	Pasture	67
Mill Creek	9	Center Pivot	28	SUB	9	ET/No irrigation	57
Moffett Creek	10	Unknown	4	SW	31	No ET	7
Patterson Creek	16			None/unknown	67		
Scott River	84						
Scott River tailings	14						
Shackleford Creek	12						
Study area total	202	Total	202	Total	202	Total	202

[a]All values represent 2011 conditions. Note that not all areas in the alfalfa/grain and pasture category are irrigated.

irrigation scheduling purposes but are here applied to estimate daily varying actual crop ET (equations (4)–(6)). Daily reference ET is estimated from study area climate data [*Hargreaves and Samani*, 1982; *Snyder et al.*, 2002]. Crop coefficients vary by crop, by stage of crop growth, and by cultural practices. For alfalfa, a crop coefficient of 0.95 was fitted to field data from the study area [*Hanson et al.*, 2011b], since we did not simulate alfalfa cutting dates individually at each field. For grain (variable k_c) and pasture ($k_c = 0.9$), state agricultural extension recommendations were applied [*University of California Cooperative Extention (UCCE)*, 2012].

[26] 6. Irrigation type: The year 2000 landuse survey by CDWR [*CDWR*, 2000] identified the irrigation type associated with each landuse polygon. In the Scott Valley, flood, center pivot sprinkler, and wheel-line sprinkler irrigation are used almost exclusively. Over the past 25 years, significant conversion from wheel-line sprinkler (but also from flood irrigation) to center pivot sprinkler has occurred. The location (extent) and year of such irrigation type conversions are mapped to landuse polygons by reviewing 1990–2011 aerial photos. Total areas for 2011 are shown in Table 1.

[27] 7. Irrigation efficiency is assumed to be a function of irrigation type. It accounts for irrigation nonuniformity and deep percolation losses to below the root zone. Delivery and interception losses are not accounted for. Efficiencies are based on informal surveys of local growers and expertise of local agricultural consultants, although they do not account for unintended underirrigation or deficit irrigation: 90% for center pivot sprinkler, 75% for wheel-line sprinkler, and 70% for flood irrigation (University of California Cooperative Extension (UCCE), personal communication, 2011).

[28] 8. Water source for irrigation: Water source is identified for each landuse polygon by the year 2000 landuse survey [*CDWR*, 2000] and is updated through landowner survey. Water sources include groundwater, surface water, subirrigated (shallow groundwater table), mixed groundwater-surface water, and nonirrigated (dry land farming) (Table 1).

[29] 9. Surface water diversion allocation: Each landuse parcel is associated with one of nine subwatersheds corresponding to the various tributaries to the main stem Scott River (Table 1). Discharge on these tributaries defines available maximum diversion rates (see below).

[30] The soil water budget for each landuse polygon is performed using a storage routing approach with soil water inputs from precipitation and irrigation [e.g., *Neitsch et al.*, 2011]. Adjusted daily precipitation (P_{adj}) is the portion of daily precipitation (P) that infiltrates into the soil and is available for daily evapotranspiration (ET) or recharge [*Allen et al.*, 1998]:

$$P_{adj}(i) = P \quad \text{if } P(i) > 0.2^{*}\text{ET}_0(i) \tag{1a}$$

$$P_{adj}(i) = 0 \quad \text{if } P(i) \le 0.2^{*}\text{ET}_0(i) \tag{1b}$$

where ET_0 (i) is the daily reference evapotranspiration on day i, assumed uniform across the valley floor due to the size of the study area and its level topography. The storage routing mass balance for the 1.22 m thick root zone is then computed as:

$$\theta(i) = \max(0, \theta(i-1) + P_{adj}(i) + \text{Irrig}(i) - \text{actual ET}(i) - \text{Recharge}(i)) \tag{2}$$

$$\text{actual ET}(i) = \min(\text{ET}(i),\ \theta\ (i-1) + P_{adj}(i) + \text{Irrig}(i)) \tag{3}$$

$$\text{Recharge}\ (i) = \max(0,\ \theta\ (i-1) + P_{adj}(i) + \text{Irrig}(i) - \text{actual ET}(i) – \text{WC4}(i)) \tag{4}$$

where $\theta(i)$ is water content at the end of day i, $P_{adj}(i)$ is precipitation on day i, Irrig(i) is irrigation on day i, ET(i) is evapotranspiration on day i, computed from potential ET as: $\text{ET}(i) = \text{ET}_0(i)^{*}k_c(i)$, $k_c(i)$ is crop coefficient, Recharge(i) is deep percolation to groundwater, to below the 1.22 m thick root zone, and WC4 is water holding capacity of the 1.22 m root zone.

[31] Runoff, particularly during the irrigation season, is considered negligible due to the low land surface gradient. The algorithm intrinsically exerts complete mass balance control on each landuse polygon:

$$P_{adj}(i) + \text{Irrig}(i) - \text{actual ET}(i) - \text{Recharge}(i) = \theta(i) - \theta(i-1). \tag{5}$$

[32] Furthermore, we can compute the amount of water deficit relative to optimal growing conditions as follows:

$$\text{Deficiency}(i) = \text{ET}(i) - \text{actual ET}(i). \tag{6}$$

[33] The source of irrigation water, Irrig(i), depends on the water source and landuse specified for an individual landuse polygon. For pasture, irrigation water is most often

exclusively supplied from surface water. Alfalfa/grain landuse polygons are most often irrigated from groundwater. Based on information from stakeholders, alfalfa/grain fields with a surface water source are treated as if equipped for a mixed source.

[34] For mixed sources of irrigation water, the decision process that leads to a landuse polygon switching from surface water irrigation to groundwater irrigation is simulated based on the available surface water supply: if the total surface water irrigation demand within a subwatershed, in a given month, exceeds stream discharge, groundwater is used to make up the landuse polygon-specific difference between surface water available and the irrigation demand. The available surface water is distributed to all polygons designated for use of surface water at equal water depth (water volume proportional to polygon size).

3. Irrigation Scheduling Simulation

[35] Surface water delivery and groundwater pumping rates are driven by daily precipitation and evapotranspiration. Urban and domestic pumping are small in comparison and are here neglected. Irrigation water demand is calculated following FAO guidelines [*Allen et al*., 1998]. The approach computes irrigation timing and demand as a function of climate, soil, crop type, irrigation type, and water source.

3.1. Alfalfa/Grain and Pasture

[36] Alfalfa irrigation in polygon k starts on the first day i after 24 March 24, on which the soil water content has dried to less than 45% of field capacity (*ibid*., Table 22):

$$\theta(i) < (1-0.55)^{*}\mathrm{WC4}(k). \tag{7}$$

[37] 25 March is the earliest reported irrigation date. The last alfalfa irrigation application in Scott Valley typically occurs before 5 September. For the water budget computations, irrigations are assumed to occur daily through 5 September based on perfect farmer foresight of crop water demand.

[38] For grain, the first irrigation on a field k is determined exactly as for alfalfa but the reported earliest starting date is 15 March. The last day of continuous irrigation on grain is assumed to be 10 July, after which the grain crop is harvested.

[39] For pasture, the Scott Valley irrigation season is typically from 15 April to 15 October (184 days). Simulated irrigation is applied daily based on ET demand and irrigation efficiency. However, on pasture that is surface water irrigated (which represents most pasture), no irrigation occurs once surface water supplies become unavailable. For each polygon k and for each day i, the daily irrigation amount is calculated as:

$$\mathrm{Irrig}_k(i) = (\mathrm{Ieff}_k)^{-1*}\big(\mathrm{Max}\big(0,\ \big(\mathrm{ET}_k(i) - P_{\mathrm{adj}}(i)\big) \tag{8}$$

where Ieff_k is the irrigation efficiency in polygon k. We assume that there is no contribution to plant evapotranspiration from groundwater. To the degree that groundwater irrigated areas are subject to direct groundwater uptake by crops, the uptake is implicitly accounted for in the net stress estimated with this approach. It is the difference between estimated groundwater pumping and recharge from polygon k.

3.2. Evapotranspiration (ET) Losses Without Irrigation

[40] The main assumption is that, at all times:

$$\mathrm{Irrig}(i) = 0. \tag{9}$$

[41] In this category, ET computed from the soil water budget model does not include direct ET from groundwater (e.g., wetlands, riparian vegetation).

[42] In the first step, we use the soil water budget model to compute daily ET (on day i):

$$\mathrm{ET}(i) = k_c{}^{*}\mathrm{ET}_0(i) = 0.6^{*}\mathrm{ET}_0(i) \quad \text{subject to}: \ \mathrm{ET}(i) \le \theta(i-1) + P_{\mathrm{adj}}(i). \tag{10}$$

[43] This latter constraint distinguishes this category from an irrigated crop.

3.3. No Irrigation/No ET Category

[44] Landuse categories of this type do not receive irrigation, and they also are not subject to evaporation or evapotranspiration from plants:

$$\mathrm{Irrig}(i) = 0 \ \text{at all times} \tag{11a}$$

$$\mathrm{ET}(i) = 0 \ \text{at all times.} \tag{11b}$$

[45] Given the flat topography of the valley floor, runoff is here considered negligible and recharge is equal to the adjusted precipitation:

$$\mathrm{Recharge}(i) = P_{\mathrm{adj}}(i). \tag{12}$$

4. The Analytical Solution for Stream Depletion

[46] Following *Jenkins* [1968], *Wallace et al*. [1990], and *Bredehoeft* [2011], we simplify the groundwater system and assume a semi-infinite, homogeneous and isotropic aquifer, with transmissivity constant in time and space; recharge to the aquifer is not considered prior to the time of interest, hence the water table is horizontal; the stream is considered to fully penetrate the aquifer; wells also fully penetrate the aquifer; and constant rate pumping starts at time $t = 0$.

[47] Under those assumptions, stream depletion due to pumping is given by *Jenkins* [1968]:

$$\frac{\boldsymbol{q}}{\boldsymbol{Q}} = \boldsymbol{erfc}\left(\frac{\boldsymbol{t_a}}{4\boldsymbol{t}}\right)^{1/2} \quad \boldsymbol{t} < \boldsymbol{t_p} \tag{13}$$

where: $t_a = \frac{a^2 S}{T}$ is the Stream Depletion Factor (SDF) defined by *Jenkins* [1968] and used by *Bredehoeft* [2011]; q is the change in rate of streamflow caused by the well pumping; Q is the rate of pumping; a is the distance of the well from the stream; S is the aquifer storativity and a value of 0.12 is used for the (unconfined) Scott Valley system; T is the aquifer transmissivity; t is time since pumping began; and t_p is the duration of pumping.

[48] The stream depletion after pumping stops at $t = t_p$ is calculated following *Wallace et al*. [1990]:

$$q = Q\left(erfc\left(\frac{t_a}{4t}\right)^{\frac{1}{2}} - erfc\left(\frac{t_a}{4(t-t_p)}\right)^{\frac{1}{2}}\right) \quad t_p \le t < \infty. \tag{14}$$

[49] The rate of stream depletion due to nonsteady, annual cyclical pumping is calculated using (equation (15)) and the principle of superposition. As shown by *Wallace et al*. [1990], for constant t_p and t_d, the stream depletion corresponds to:

$$q = \sum_{i=0}^{N-1} \delta(t - t_d i)\left(Q\ erfc\left(\frac{t_a}{4(t-t_d i)}\right)^{\frac{1}{2}}\right) - \sum_{i=0}^{N-1} \delta(t - t_p - t_d i)\left(Q\ erfc\left(\frac{t_a}{4(t-t_p-t_d i)}\right)^{\frac{1}{2}}\right) \quad 0 \le t < \infty \tag{15}$$

where δ is the unit step function which has a value of 1 when its argument is greater than zero and a value of zero when its argument is equal or less than zero; N is the number of time the pump is turned on; t_d is the interval at which the pattern repeats itself.

5. Coupling Soil Water Budget and Stream Depletion Model

[50] Analytical solutions for simplified stream-aquifer depletion evaluation were originally developed and used for investigations that were lacking today's computer resources. These analytical tools remain attractive, partly because of the computational efficiency and relative ease of implementation, typically with spreadsheets or simple computer programs. More importantly, they are powerful tools that provide fundamental, rigorous theoretical insight into the physical behavior of the groundwater-stream system, even if under highly simplified, hypothetical conditions [*Jenkins*, 1968; *Glover*, 1974; *Wallace et al*., 1990; *Hunt*, 2003; *Bredehoeft and Kendy*, 2008]. In a complex and often misunderstood management system such as the aquifer-stream system, these simplified approaches allow for quickly establishing major operational constraints imposed by basic system variables. Here coupling the water budget model with the analytical solution for stream depletion provides a framework (a) to estimate the magnitude of streamflow depletion and its sensitivity to key system parameters, (b) to implement a benchmark test against an existing numerical model, and (c) to develop management scenarios for discussion and analysis with stakeholders.

[51] The soil water budget model and the streamflow depletion model are coupled, first, by assigning the estimated pumping in each field to its nearest existing well. Active wells in Scott Valley are identified through a review of well drilling permits, GIS analysis, and partial, randomized on-the-ground verification. If multiple wells are located within one landuse polygon, the total pumping is evenly split between wells, while the pumping from a well that is serving multiple polygons is the sum of all daily water needs in the associated fields. Secondly, recharge from each polygon is similarly assigned to the nearest well, but as an injection rate (negative pumping rate). Then, 1990–2011 net daily groundwater pumping rates at each well are computed as the difference between daily groundwater pumping and groundwater recharge assigned to the well.

[52] The distance of each well to the stream is computed as the orthogonal distance from the well to the Scott River, not to the nearest tributary. Here streamflow in the main stem Scott River is the key concern (Figure 1). Transmissivity is obtained from *Mack* [1958] and *SSPA* [2012].

[53] Finally, the superposition principle (equation (15)) is applied to show the effect of transient, combined recharge and pumping on the total streamflow depletion rate along the integrated length of the Scott River within the Scott Valley. We apply each well's average, yearlong net pumping time series cyclically until a dynamic (cyclical) steady state is achieved in annual stream depletion rates. Convergence is considered to be achieved once all wells exhibit less than 1% change in relative depletion on all calendar days. Using the results of the final cyclical year, the 163 wells' computed daily stream depletion (or stream replenishment) rates are summed to obtain a time series of the net total daily stream depletion of the Scott River ("base scenario").

[54] We apply the tool to several additional scenarios to demonstrate the sensitivity of the solution to the SDF parameters, to compare the estimated streamflow impacts from changes in pumping and recharge stress with those obtained with a fully three-dimensional groundwater model, and to outline potential impacts of alternative groundwater management practices that affect timing and amount of additional recharge when additional surface flows are available and the distribution of groundwater pumping.

6. Results and Discussion

6.1. Soil Water Budget

[55] The water budget simulation provides daily soil water fluxes in water years 1991 through 2011, which are aggregated to monthly, yearly and long-term averages. Table 2 summarizes average annual fluxes, by landuse category. The total amount of annual recharge (groundwater system input) from the irrigated landscape is on the order of 46 $Mm^3\ y^{-1}$ (37 thousand acre-feet per year [TAF y^{-1}]). Groundwater pumping (groundwater system output) is about 25% larger, nearly 55 $Mm^3\ y^{-1}$ (44 TAF y^{-1}). Surrounding non-irrigated landuses, including dry land farming and riparian vegetation, contribute 26 $Mm^3\ y^{-1}$ (21 TAF y^{-1}) to basin recharge, mostly from winter precipitation, with 23 $Mm^3\ y^{-1}$ (18 TAF y^{-1}) of water uptake by natural vegetation and dry land crops (not including direct groundwater uptake). The ET demand from natural vegetation and dry land farming (274 mm) is provided through

Table 2. Average Annual Soil Water Fluxes, Water Years 1991–2011, for Irrigated Crops, for Dry Land Farming and Natural Vegetation Areas ("ET noIRR"), and for Areas With No Consumptive Water Use ("noET noIRR")[a]

	Crop ET	Actual ET	Irrigation	SW Irrigation	GW Pumping	Recharge	Deficiency	Area (ha)
mm y⁻¹								
Alfalfa	1068	1018	840	104	736	370	49	5,622
Grain	411	409	358	55	303	467	2	803
Pasture	1017	861	755	528	228	437	155	4820
ET noIRR	284	274				273	10	8240
noET noIRR						547		686
Mm y⁻¹								
Alfalfa	60.0	57.3	47.2	5.8	41.4	20.8	2.8	5622
Grain	3.3	3.3	2.9	0.4	2.4	3.8	0.0	803
Pasture	49.0	41.5	36.4	25.4	11.0	21.1	7.5	4820
ET noIRR	23.4	22.6				22.5	0.8	8240
noET noIRR						3.8		686

[a]"SW": surface water, "GW": groundwater. Deficiency refers to the difference in ET between optimal water supply ("Crop ET") and actual, limited water supply ("Actual ET").

spring precipitation with the dominant source coming from root zone water storage filled during the cold winter rainy season. The nominal deficit in natural vegetation is small, but for this category, recharge and deficit are highly sensitive to the selected k_c (0.6): if k_c values are chosen higher, the deficit is correspondingly higher (due to water availability being limited) with no simulated impact on groundwater; if k_c values are chosen lower, the simulated deficit decreases or disappears and additional groundwater recharge would occur, depending on the annual dynamics of the crop coefficient.

[56] Early spring groundwater levels in the basin do not experience a long-term declining or increasing trend indicating a balanced groundwater budget (Figure 2b). The net surplus of 17.1 $Mm^3\ y^{-1}$ (14 TAF y^{-1}) between recharge and pumping across the basin indicates a net inflow from the groundwater basin to the Scott River. However, the model does not account for annual direct recharge from the stream system to groundwater that is subsequently discharged back to the stream. Both, actual recharge from and groundwater discharge to the stream are likely larger, due to the complex interaction of the groundwater system with streams and tributaries that are not accounted for here. This includes hyporheic zone exchanges due to streambed topography and groundwater-surface water exchanges due to the larger scale streambed and water table variability [e.g., *Wondzell et al*., 2009; *Boano et al*., 2010].

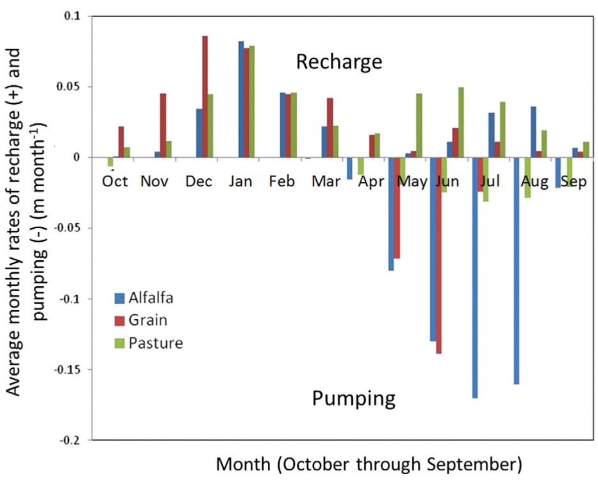


Figure 3. Simulated monthly rates of recharge and pumping (m $month^{-1}$) for each of the three main landuses as calculated with the water budget model.

[57] Irrigation amounts are highest in alfalfa, 840 mm y^{-1}, due to continuous availability of groundwater (736 mm y^{-1} of simulated groundwater pumping) (Table 2). Grains have an early and much shorter cropping season than alfalfa, with lower ET rates and, hence, lower irrigation (358 mm y^{-1}). Pasture, while irrigated much more generously when surface water supplies are available and with crop ET rates comparable to alfalfa (Figure 3), has a lower average annual irrigation rate (755 mm y^{-1}) than alfalfa. This is due to the surface water limitations on this predominantly surface water irrigated crop. Some pasture areas near the western margin of the valley are subject to direct groundwater uptake (not accounted for here).

[58] Average monthly recharge and pumping rates indicate strong seasonal variations. Most pumping occurs during the summer months. Most recharge occurs in the late winter and early spring (Figure 3). On pasture, significant recharge also occurs during the irrigation season due to widespread surface water flooding at rates that are significantly higher than crop water use (relatively lower irrigation efficiency). In August–September, streamflow available for flood irrigation decreases significantly, thus lowering recharge in pasture. Few pasture fields, often wheel-line sprinkler irrigated, switch to groundwater as a water source. Recharge in alfalfa is highest in July and August, when all fields are fully irrigated. Fields in grains (12.5% of the alfalfa/grain cropping area) are fallow after their harvest in July, which causes recharge and pumping in those areas to become nearly negligible after harvest. During the winter months, differences in the amount of recharge between the three landuses reflect varying levels of soil moisture depletion and slight differences in average soil characteristics across each landuse type, in particularly water holding capacity. Although very different in seasonal dynamics (Figure 3), annual average recharge in alfalfa/grain fields and pasture is not dissimilar (Figure 4b). Alfalfa has a simulated average recharge of 370 mm y^{-1},

Table 3. Total Amount of Simulated Irrigation Water Applied to Alfalfa, Grain and Pasture in a Typical Dry (2001) and Typical Wet Year (2003) in mm y^{-1}

	Dry Year		Wet Year	
	Ground Water Applied (mm y^{-1})	Surface Water Applied (mm y^{-1})	Ground Water Applied (mm y^{-1})	Surface Water Applied (mm y^{-1})
Alfalfa	862	50	723	83
Grain	419	29	397	55
Pasture	178	361	167	636
Total	701	326	596	573

about 20% lower than the average grain and pasture recharge of 467 and 437 mm y^{-1}, respectively (Table 3), but significant between-field variability exists due to varying soil water holding capacity.

[59] Few field data exist to confirm the soil water budget results. While simulated ET in alfalfa is consistent with *Hanson et al*. [2011a], the simulated average annual irrigation amounts for alfalfa (840 mm) and grain (358 mm) are found to be significantly higher than reported by growers in the study area: Preliminary field monitoring data for the 2012 irrigation season and interviews with growers on irrigation practices indicate that actual irrigation rates may be on the order of 500–600 mm in alfalfa and 150–200 mm in grain. Lower irrigation rates, when using groundwater for irrigation, may be due to overestimation of ET due to deficit irrigation, direct groundwater uptake by the crop, not accounted for in the model, or due to underestimating root zone depth and, hence, soil moisture storage capacity. Deficit irrigation has been found to lower ET by as much as 55 mm in Scott Valley and up to 200 mm elsewhere [*Hanson et al*., 2011b]. Lower ET would lower the net stress on groundwater. Direct groundwater uptake, where it occurs in groundwater irrigated areas, does not change the simulated net stress to the aquifer obtained from the soil water budget model unless it also affects crop ET. Doubling the water holding capacity (effectively assuming a thicker root zone) reduces simulated irrigation requirements by 3% in alfalfa and only 1% in grain, thus not explaining the discrepancy with observed irrigation rates. New field work was initiated among the study area stakeholders to obtain representative measurements of soil water dynamics, irrigation rates, evapotranspiration and the occurrence of deficit irrigation that can be used in the future to improve soil water budget simulations.

[60] Analysis of the spatial distribution of annual average values over the 21 year period for surface water irrigation, recharge, pumping, and pumping minus recharge (Figure 4) provides useful insight to evaluate the differences in irrigation amount and pumping based on landuse and water source. Some key observations include:

[61] 1. Highest recharge rates (Figure 4b) occur in polygons with pasture as landuse and with groundwater as water source due to relatively low irrigation efficiency and long irrigation season; also in the non-vegetated mine tailings at the southern end of the valley and in areas with very small water holding capacity;

[62] 2. Highest pumping rates occur in the few polygons with pasture as landuse and groundwater as water source

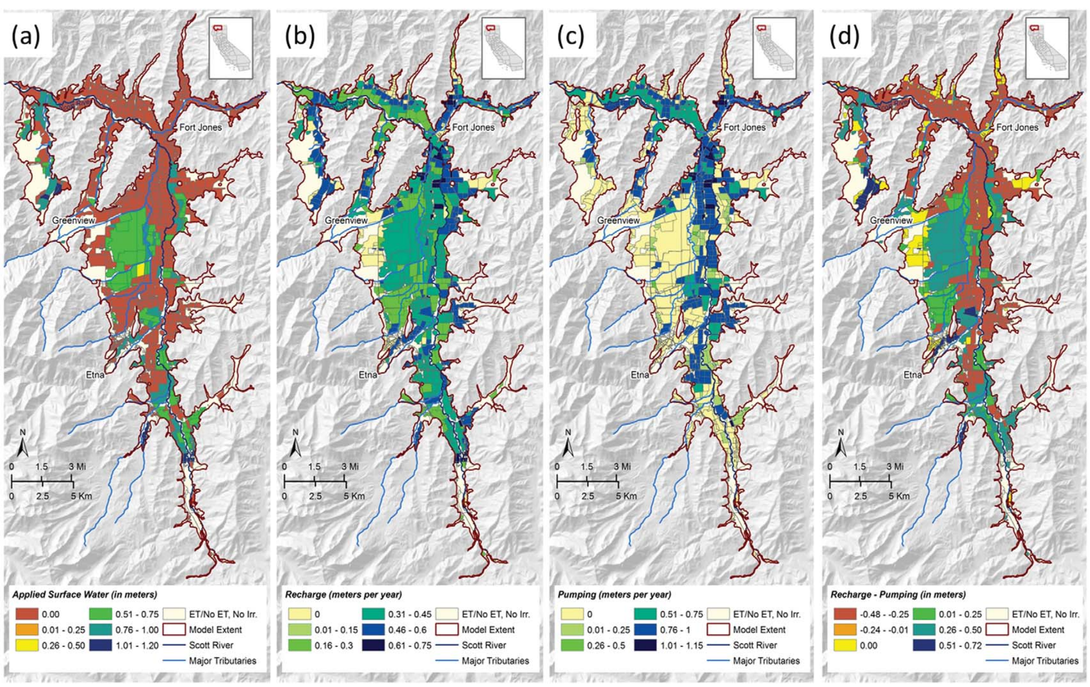


Figure 4. Water budget simulation results: (a) Average annual applied surface water rates (m y^{-1}) in irrigated crops between October 1990 and September 2011; (b) Average annual recharge (m y^{-1}) in irrigated areas between October 1990 and September 2011; (c) Average annual irrigation pumping rates (m y^{-1}) between October 1990 and September 2011; (d) Average annual difference between recharge (positive) and pumping (negative) (m y^{-1}) in irrigated areas between October 1990 and September 2011.

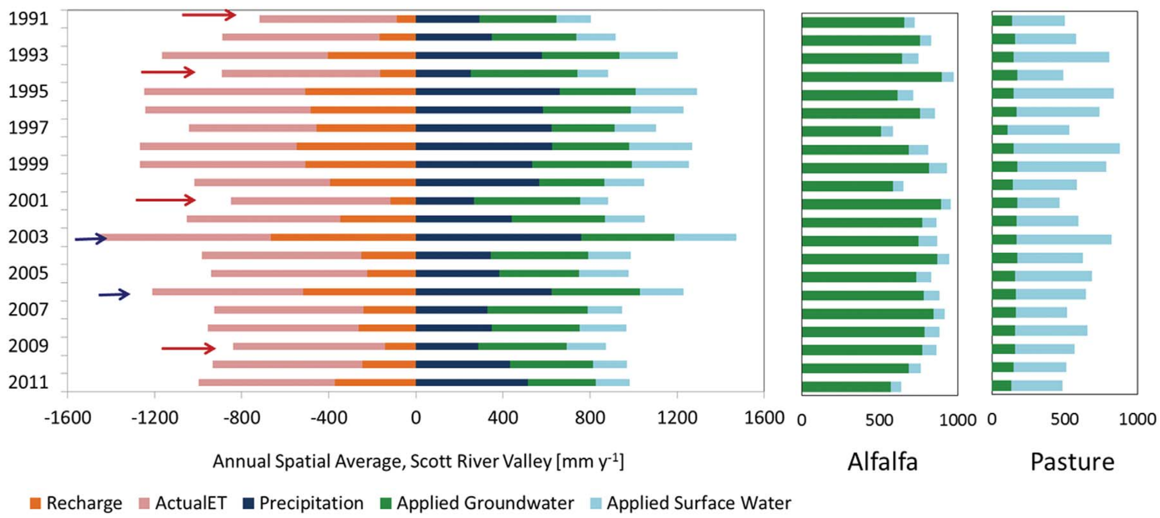


Figure 5. (a) Annual soil root zone water budget (mm y^{-1}), area-weighted average for the alfalfa/grain and pasture area in the Scott Valley. Input to the root zone shown as positive values (precipitation, applied groundwater and applied surface water). Outputs from the root zone are shown as negative values (actual ET and recharge). Annual applied surface water and annual applied groundwater (mm y^{-1}) for (b) alfalfa/grain and (c) pasture, area-weighted average over all alfalfa/grain landuse polygons in the project area. Critically dry years are highlighted in red and wet years are highlighted in blue.

(Figure 4c): this can be explained by the fact that pasture has the longest irrigation season. In polygons with groundwater as water source, the estimated irrigation rate is equal to the estimated pumping rate and it is not limited by (surface) water availability;

[63] 3. The lowest recharge rates occur in polygons that correspond to dry land farming or natural vegetation. They rely on precipitation as water source for plants, which are effective at extracting available moisture;

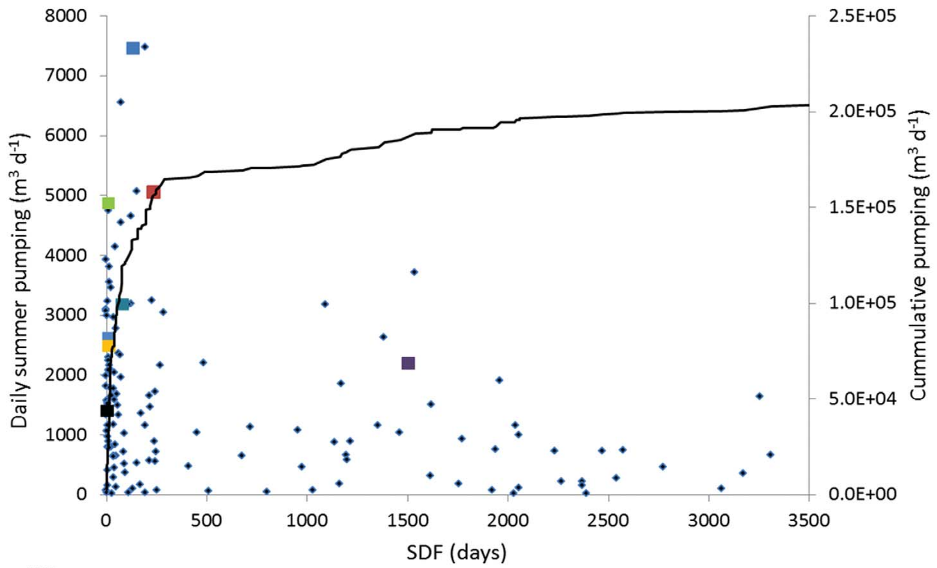
[64] 4. Since irrigation is driven by ET and irrigation efficiency, there is no water deficiency during the irrigation season. The water deficiency shown in Table 2 occurs mostly in the months immediately following the end of the irrigation season (September, October, and November) and prior to winter dormancy. In practice, much higher deficiencies may occur in wheel-line and center pivot sprinkler irrigated crops, as possibly indicated by preliminary data on field irrigation rates.

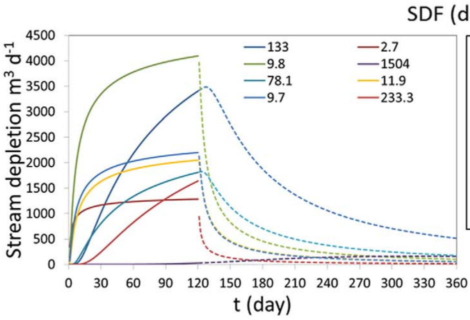
[65] Significant differences in water flows are found between dry years and wet years (Figure 5 and Table 3). Valley wide recharge to groundwater is significantly lower in dry years (as little as 100 mm y^{-1}) than in wet years (over 600 mm y^{-1}). Low recharge in dry years is mostly due to lack of streamflow from the surrounding watershed and, hence, lower amounts of applied surface water (Table 3). Dry year surface water irrigation is only 60% of wet year surface water irrigation. Changes in groundwater pumping due to dry year conditions are relatively small when compared to the large reductions in surface water irrigation, as is common in semiarid regions [*Ruud et al.*, 2004]. Dry years, therefore, significantly affect the agricultural productivity of the Scott Valley with most impact focused on pasture areas (Figure 5c).

[66] Simulated groundwater use in alfalfa, on average, is about 16% higher in dry years than in wet years. Higher groundwater use in dry years is driven mostly by higher evapotranspiration from alfalfa/grain landuses early in the growing season, demanding a higher irrigation amount. Less importantly here, higher groundwater use in dry years is also due to limited surface water availability on those fields equipped to switch from surface water to groundwater (Figure 5b). Groundwater irrigated pasture land is the exception (Figure 5c). The amount of applied groundwater, driven by spring precipitation, ET, and soil moisture availability, varies within a limited range throughout the 21 year period because there are no significant differences in the

Table 4. Summary of the Data on the Eight Wells Selected for the Analysis (for Location, See Figure 3)

SDF (d)	Polygon	HK (m/d)	Storage Coefficient	Aquifer Thickness (m)	Transmissivity (m^2/d)	Distance From the River (m)	Daily Pumping (m^3/d)
2.7	595	45	0.12	45.4	2042	215	1400
9.7	88	45	0.12	40.5	1821	385	2620
9.8	46	45	0.12	44.7	2013	405	4870
12	414	45	0.12	44.7	2013	446	2490
78	226	45	0.12	42.3	1905	1114	3180
133	103	45	0.12	39.6	1782	1407	7460
233	617	12	0.12	66.8	801	1248	5060
1503	1728	12	0.12	32.5	390	2211	2200





	# wells	%	total pumping	%
SDF < 10 d	34	24	67,566	33
10d < SDF < 1000 d	83	59	126,815	61
SDF > 1000 d	24	17	13,164	6

Figure 6. Daily cumulative summer pumping as a function of the stream depletion function (SDF, blue dots) for all 163 wells (Figure 1). For eight wells shown in larger colored squares, the graph on the lower left shows simulated stream depletion over 1 year, assuming 120 days of constant pumping and 240 days without pumping (in corresponding colors). Solid lines represent the pumping period and dashed line the subsequent period without pumping. The eight wells are labeled by their SDF (d) (also see Figure 1 for location).

length of the irrigation season between different years. Where the water source is groundwater, irrigation continues for the entire irrigation season, unaffected by surface water availability. This does not account for grower responses to climate, such as increasing/decreasing deficit irrigation.

6.2. Scott River Stream Depletion Dynamics

[67] The stream depletion factor, t_a [SDF; *Jenkins*, 1968] associated with each of the 163 wells identified (Figure 1) varies from less than 1 day to over 3600 days. High SDF values lead to slow stream depletion and vice versa. The SDF increases (stream depletion slows down) with increasing aquifer storage coefficient and distance. But the SDF decreases (stream depletion occurs more rapidly) with higher transmissivity between the well and the stream (equation (13)). Distance, varying over orders of magnitude from few meters to several kilometers is the key controlling variable for the variability of the SDF across Scott Valley. In contrast, the storage coefficient, here assumed constant, has been found to vary within a relatively narrow range throughout most of the valley (7–15%) [*Mack*, 1958]. Regional hydraulic conductivity varies by about half an order of magnitude between subareas, significantly influencing SDF. Hydraulic conductivity has been estimated from short-term pump tests to evaluate the specific capacity of wells, typically performed during well construction [*Mack*, 1958; *SSPA*, 2012]. Accuracy of these estimates may be limited, as they reflect local conditions in the immediate vicinity of the well, rather than effective conditions. However, total (integrated) stream depletion in the Scott River is less sensitive to random errors of local transmissivity estimates than to systematic under or overestimation of transmissivity across multiple wells, especially those with small SDF. This suggests that further field evaluation of hydraulic conductivity is needed, particularly near high capacity wells in close proximity to the river.

[68] Spatial distributions of crop type and the SDF values show some similarities: alfalfa/grain fields are concentrated in the vicinity of the Scott River, where well capacity is likely higher due to coarser and thicker sediments with higher aquifer transmissivity and with low SDF (Figure 6, equation (13)). Pasture fields are often located away from the Scott River in areas with higher SDF (Figure 1), and are irrigated with surface water from tributaries emanating off the surrounding canyons.

[69] Considering stream depletion due to average seasonal pumping at eight selected wells with a wide range of

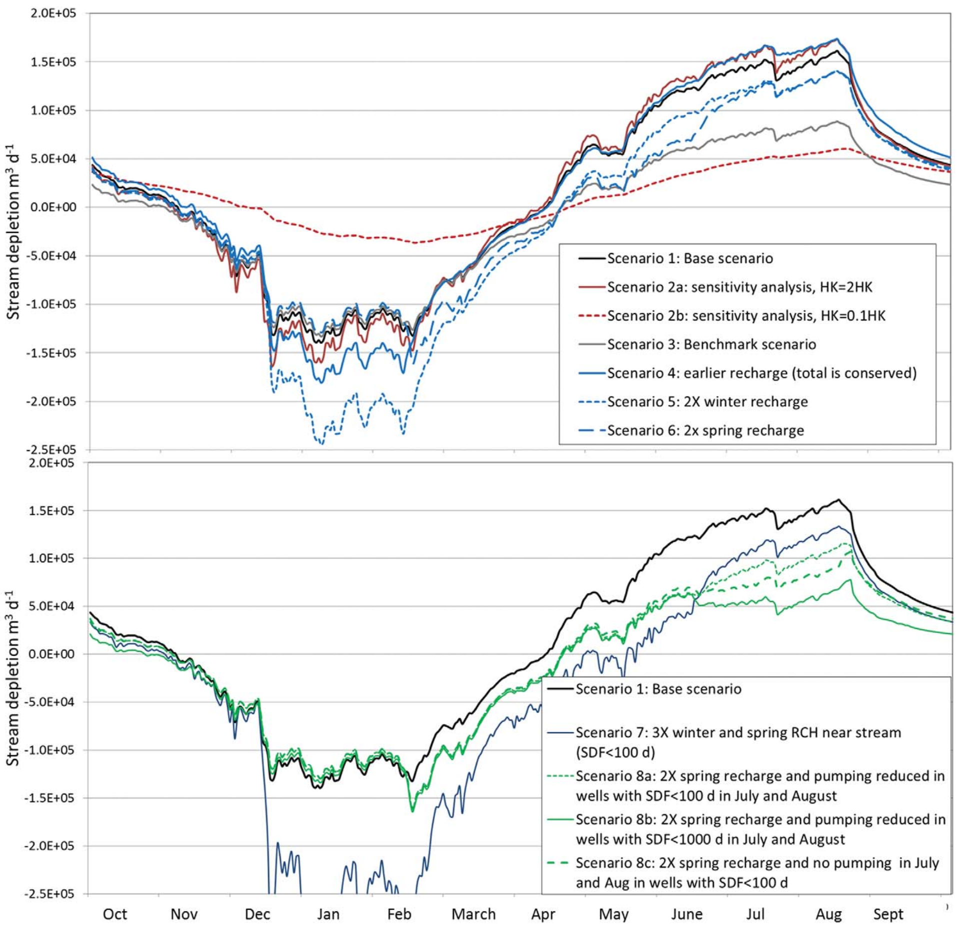


Figure 7. Simulated total daily stream depletion of the Scott River in response to 1991–2001 average daily varying net stress (pumping minus recharge), spatially distributed across the Scott Valley. Results represent a cyclical, dynamic equilibrium. Absolute stream depletion values are subject to significant uncertainty due to parameter uncertainty (compare Scenarios 1, 2a, 2b) and the simplicity of the conceptual approach, but relative changes in stream depletion over time and between management scenarios (Scenarios 3–8) provide guidance on the magnitude of stream depletion changes affected by managed changes in recharge and pumping. Note: 100,000 m^3 d^{-1} corresponds to approximately 40 cfs.

SDF values (Table 4) indicates that wells with very small SDF (<10), lead to measurable stream depletion within hours to few days after the onset of pumping. About half of the full depletion effect occurs within approximately one week. Within 2 months, the stream is affected at 90% of the full depletion rate (Figure 6). For SDFs on the order of 100, significant effects on stream depletion are observable within less than 1 month and increasing impacts occur throughout the 4 month pumping season. Only wells with SDF $>$ 1000, have limited effect on stream depletion during the 4 month pumping season. Climate variability would therefore exacerbate stream depletion: dry years lead to more stream depletion during the later summer months due to reduced basin-wide spring and summer recharge (total runoff in the Scott River, e.g., in 2009, was less than 45% of average), while groundwater pumping to support crop irrigation remains unchanged or maybe even somewhat higher than in average or wet years due to increased crop ET.

[70] Wells with SDF of less than 10 days represent 24% of all wells, but 33% of the total pumping. This is consistent with the alluvial hydrogeology of the valley, which dictates that larger capacity wells are located closer to the river, where aquifer thickness is large and sediments are coarsest. For the same reason, wells with an SDF of over 1000 days represent less than one-fifth of all wells (17%) delivering merely one-twentieth (6%) of the total pumpage (Figure 6).

[71] Cyclical simulations based on average daily pumping rates converge to a dynamic steady state only after 20 years, due to the long-term effects of wells with high SDF on stream depletion. The CPU time for computing 20 years of stream depletion due to daily varying net pumping stresses across 163 wells and for performing the convolution is 470 s (0.13 h) on a PC with Intel(R) Core^{TM} i7–3520M CPU @ 2.90GHz and 64-bit operating system. In comparison, a fully integrated, three-dimensional numerical hydrological model with sufficient resolution to resolve individual landuse parcels requires about 8 h using monthly stresses for 21 years on the same platform.

[72] For the base scenario, the maximum total stream replenishment (negative depletion) in the study area occurs

from mid-December through mid-February, at approximately 125,000 m^3 d^{-1} (50 cfs), while the largest stream depletion occurs in August, at approximately 150,000 m^3 d^{-1} (60 cfs) (Figure 7). The latter represents slightly more than one-third of the simulated peak groundwater pumping rate, nearly 400,000 m^3 d^{-1} (160 cfs) in July.

[73] Summed over the entire year, the stream depletion model, which assumes an infinite aquifer, yields a small net annual stream depletion despite the water budget of the study area showing more recharge than pumping (Table 2). Due to the high streamflows during November through June (in excess of 250,000 m^3 d^{-1} [100 cfs]), stream depletion is here only of concern during the summer period. During that period, existing winter and spring recharge is not sufficient to offset summer groundwater pumping effects on stream depletion due to the large number of wells with SDF $\ll$ 1000 days and especially those with SDF $<$ 10 days.

[74] If the selected transmissivity values for the base scenario consistently underestimated actual aquifer transmissivity by a factor 2, actual stream depletion during the critical period in July and August would be about 9200 m^3 d^{-1} (3.8 cfs) more than estimated with the base scenario (Figure 7, Scenario 2a). Similarly, if actual transmissivity in the Scott Valley consistently were only half of the values assumed for the base scenario, actual stream depletion due to the same stresses would be 9200 m^3 d^{-1} (3.8 cfs) lower than in the base scenario (not shown). The transmissivity term in (13) is an effective transmissivity for the flow between a well and the stream. If the aquifer is heterogeneous or flow paths are constricted, especially near the stream, the lowest transmissivity values along the flow path between a well and a stream would dominate the effective value. If such factors reduced the effective field transmissivity between Scott River and wells to 10% of that assumed in the base scenario, actual stream depletion in July and August would be about 80,000 m^3 d^{-1} (33 cfs) less than in the simulated base scenario. This shows that estimated stream depletion is highly sensitive to actual hydraulic conductivity and flow configuration, especially near the stream.

[75] To understand the accuracy of predictions based on equation (15), *Sophocleous et al*. [1995] analyzed the predictive accuracy of the *Glover* [1954] stream-aquifer analytical solution with a numerical groundwater flow model. Across a range of aquifer conditions, assumptions in the analytical solution were tested, e.g., by removing the hydraulic equilibrium conditions. Generally, the analytical solution overestimated stream depletion suggesting that the analytical solution approach leads to a relatively conservative assessment in guiding decisions about water rights administration. A rank of the importance of the various assumptions involved in the derivation of the analytical solution was presented and the three most significant factors were: (1) streambed clogging, as quantified by streambed-aquifer hydraulic conductivity contrast, (2) degree of stream partial penetration, and (3) aquifer heterogeneity. Aquifer width, not considered by the SDF, has also been demonstrated to be important [*Miller et al*., 2007].

[76] Streambed clogging or low streambed hydraulic conductivities (relative to the aquifer) may be addressed by applying the method of additional seepage resistance [*Sophocleous et al*., 1995] to raise the SDF value. In our study area, it is unlikely to play an overriding role due to the absence of fine materials in the streambed and frequent scouring and redeposition of streambed materials during the high flow season. The effect of partial well penetration on stream depletion has also been shown to be small [ibid].

[77] The range of maximum stream depletion obtained from this sensitivity analysis (54,000–143,000 m^3 d^{-1} (22–55 cfs)) provides a coarse approximation of possible actual stream depletion in July and August given the pumping and recharge distribution simulated for the Scott Valley. This range would be proportionally lower, if actual ET, especially in alfalfa, will be shown to be lower in the Scott Valley than simulated here, due, e.g., to deficit irrigation.

[78] A benchmark test (Scenario 3) is used to perform an independent assessment of the order of accuracy provided by this simplified stream depletion analysis, when used to provide predictions of changes in stream depletion due to certain changes in pumping and recharge. For the benchmark test, results of the coupled water budget-stream depletion model are compared against a third-party fully 3-D, numerical, cyclical steady-state groundwater model that represents year 2000 conditions in groundwater pumping and recharge. The spatial distribution of pumping and recharge is qualitatively similar to that of our soil water budget model, but not identical [*SSPA*, 2012]. The numerical model simulates a partially penetrating streambed and its streambed hydraulic conductivity has been calibrated against measurements of well water levels. Aquifer hydraulic conductivities vary across the valley, but are of similar magnitude in both models (7–45 m d^{-1}). For the benchmark test, basin-wide net groundwater extraction (pumping minus recharge) is reduced by approximately equivalent amounts, 12.0 Mm^3 y^{-1} (13.5 cfs) in the numerical model, and 14 Mm^3 y^{-1} (15.7 cfs) in the analytical model. The resulting late summer reduction in streamflow (July–September) depletion reported for the numerical groundwater model is 39,000 m^3 d^{-1} (16 cfs). The corresponding reduction estimated with our simple analytical model is 50,000 m^3 d^{-1} (21 cfs). The analytical model results, while exceeding the numerical estimates by 25%, are sufficiently consistent with the numerical results to consider this tool useful for evaluating broad options for pumping and recharge that can guide preliminary planning for alternative groundwater management practices to evaluate.

6.3. Groundwater Management Scenarios

[79] With surface water storage not available at the scale required for agricultural water use in the basin, the groundwater basin is the *de facto* storage basin to hold water from winter and spring recharge for irrigation water use during the summer. As in other semiarid and arid basins, groundwater is a key local water management instrument to extend the cropping season beyond that possible without power pumps, especially in dry years.

[80] The water budget model indicates that there are broad opportunities to redistribute surface water available during the wetter periods of the year for irrigation water use during the dry season. Alternative management practices may include those affecting groundwater recharge, practices affecting groundwater pumping, or both. In the

past, changes in recharge have occurred due to changes in landuse, and due to changes in irrigation efficiency and methods in the Scott Valley. Given the soil water budget results, switching from mostly flood irrigation to wheel-line sprinkler irrigation between the 1950s and the 1970s had a significant impact on the timing and amount of recharge. It also incentivized the much increased use of groundwater since pumps were needed to pressurize wheel-line sprinklers and, later, center pivot sprinklers (introduced during the late 1990s and 2000s). *Van Kirk and Naman* [2008] suggested considering the difference in irrigation efficiency between flood irrigation and sprinkler irrigation.

[81] Management scenarios 4 to 7 highlight potential benefits to stream depletion during the critical summer months by managing groundwater recharge during seasons with high streamflow. Scenario 4 illustrates the effect of recharge timing, while keeping the total annual recharge amount the same as in the base scenario: recharge timing is moved from spring and early summer months to January–February, a difference that may occur naturally between individual years due to interannual climate variability. Having recharge occur earlier in the year, albeit at the same total amount, increases stream depletion in July and August by nearly 10% (by 15,000 $m^3\ d^{-1}$, 6 cfs) over the base scenario (Figure 7). In contrast, hypothetically doubling the amount of (already high) recharge in January–February while keeping recharge during other months identical to that in the base scenario (Scenario 5) reduces July and August stream depletion by 16,000 $m^3\ d^{-1}$ (7 cfs) (Figure 7). Additional recharge in January and February would not significantly interfere with agronomic practices as crops are dormant, if aquifer storage capacity is available.

[82] Stronger reduction in streamflow depletion may be expected when increasing the amount of recharge closer to the period of high stress in July and August. Indeed, doubling recharge in March through June rather than in January and February (Scenario 6) substantially decreases stream depletion (relative to Scenario 5) during the months with additional recharge (by as much as 30,000 $m^3\ d^{-1}$, 12 cfs), but 3–4 weeks after the additional recharge seizes, there are no observable differences between Scenarios 5 and 6 (Figure 7).

[83] Tripling the amount of recharge during the entire first half of the year, but only in areas near the Scott River (SDF < 100 d, Figure 1), yields large stream replenishment (negative depletion) for most of the winter months and into May (Scenario 7), much longer than in the base scenario. Also, through much of July and August, stream depletion is much lower than in the base scenario and never reaches base scenario levels. Although additional recharge in this scenario occurs only near the Scott River and ends on July 1, stream depletion is consistently smaller (by 8000 $m^3\ d^{-1}$, 4 cfs) in July and August when compared to Scenario 6. A significant delay in the onset of strong stream depletion could benefit other streamflow management scenarios that rely on the enhancement of instream flows: later onset of stream depletion would result in shorter periods where additional instream flow requirements are needed. Later spring recharge (April–June) could therefore provide a particularly important management tool to limit stream depletion during the critical period of July and August. Additional surface water could be obtained through acquisition of surface water rights from the valley margin (where a discontinuation of recharge during the summer months has no detrimental effect on Scott River flow), or by creating an external surface or subsurface storage capacity [*Schneider*, 2010].

[84] Groundwater management options may not only include additional recharge, but also altered groundwater pumping patterns. These scenarios are designed following the classification of SDF values by *Bredehoeft and Kendy* [2008]:

[85] 1. Wells with SDF > 1000 d (17% of the wells, Figures 1 and 6, representing 6% of the total pumping) present the most interesting pool of wells for the design of mitigation strategies. Significant recharge occurring in the areas between the wells and the stream during the spring months is sufficient to offset potential long term, delayed stream depletion from pumping during the summer months.

[86] 2. Wells with 10 d < SDF < 1000 d (59% of the wells, Figures 1 and 6, representing 61% of the total pumping) represent the most uncertain situation. The pumping causes significant seasonal fluctuations. Different patterns of streamflow depletion can be produced depending on the SDF value, which is subject to uncertainty due to varying aquifer properties and boundary conditions not considered in the analytical model. For example, a combination of significant additional late spring and early summer recharge, switching from groundwater pumping to surface water irrigation or increasing already ongoing surface water irrigation, while streamflows are high, may significantly dampen effects of summer pumping from these wells. In the Scott Valley case, more detailed analysis using a numerical groundwater-surface water model and additional data collection will further guide specific future decision making.

[87] 3. Wells with SDF < 10 d (24% of the wells, Figures 1 and 6, representing 33% of the total pumping) have quick impact on streamflows and produce large annual fluctuations in stream depletion. Pumping may be offset by additional streamflow, which would require additional surface water rights. Pumping may also be offset by groundwater transfers that replace groundwater pumping from wells with SDF < 10 d with groundwater pumping from wells with SDF $\gg$ 100 d, at least during the most impacted season (July–August).

[88] Scenarios 8a–8c investigate potential benefits obtained by jointly managing groundwater recharge and groundwater pumping. Increased recharge during spring and early summer delays the onset of significant stream depletion, while the translocation of pumping away from the river during the sensitive summer period mutes the groundwater stresses that impact streamflow most immediately. A 50% reduction of July and August pumping in the wells closest to the river (SDF < 100 d, Figure 1), and replenishment of that water by additional pumping (1.6 fold) outside that zone (Scenario 8a) would potentially yield reductions in July and August streamflow depletion of 42,000 $m^3\ d^{-1}$ (17 cfs). Expanding to a hypothetical 75% reduction of pumping in the zone with SDF < 1000 d (Figure 1), yields additional July and August streamflow reductions of another 37,000 $m^3\ d^{-1}$ (16 cfs) when compared to Scenario 8a (Figure 7, Scenario 8b). Alternatively, an additional streamflow depletion of 12,000 $m^3\ d^{-1}$ (5 cfs), when compared to Scenario 8a, are obtained when

completely replacing groundwater pumping in the zone with SDF < 100 d and providing that irrigation water by transporting additional groundwater pumping from outside that zone to those fields (Scenario 8c). The latter two scenarios are hypothetical designs to estimate the magnitude of possible reductions in streamflow depletion. But Scenarios 8b and 8c would impose unachievable pumping requirements on outlying areas (3.5 fold and 2.3 fold pumping increases, respectively). Reductions in streamflow depletion achieved by these scenarios therefore reflect unrealistic goals.

[89] The scenario analysis indicates that both, recharge alone and the combination of recharge and selective changes in groundwater pumping patterns yield some reductions in streamflow depletion, which is here hypothesized to yield equivalently larger instream flows. The magnitude of the simulated reductions in streamflow depletion is significant. Potential streamflow increases are on the same order as current summer flow rates in the Scott River, which sometimes fall below 24,000 $m^3\ d^{-1}$ (10 cfs) suggesting that measurable gains in streamflow can be made. Stream temperature modeling indicates that a 50% increase of these low summer streamflows may substantially reduce the extent of Scott River reaches that are above 25°C, considered lethal for salmon habitat [*North Coast Regional Water Quality Control Board (NCRWQCB)*, 2005]. Flow increases also create opportunities for creating additional local habitat.

[90] Regulatory agencies have not defined numeric objectives regarding streamflow, largely because streamflow management to protect salmonid habitat via groundwater management remains an emerging research arena [*Malcolm et al*., 2012; *Milner et al*., 2012]. Salmonid ecosystem responses to streamflow are highly variable and confounded by other factors. Local investigations of flow impacts and solutions were identified as most promising [*Milner et al*., 2012]. In the case of managing the salmonid GDE in Scott Valley, regulators envision a broad range of measures and assessments across hydrologic and ecological disciplines [*NCRWQCB*, 2007].

[91] All scenarios are based on average monthly 1991–2011 recharge and pumping conditions. Other scenarios that could be considered with this tool may account for climate variability, the transient effects of consecutive dry or wet years, as have occurred in the recent past, and artificial aquifer recharge (AR) and aquifer storage and recovery (ASR) projects [*Nelson*, 2011; *Sophocleous*, 2012]. Scenarios may include sensitivity analysis to parameters in the soil water budget model. And the analytical stream depletion model can also be implemented as a fully transient, long-term impact analysis model.

[92] The scenarios presented here are purposefully designed to mimic relatively simple, extreme management cases. While not considered accurate and subject to significant uncertainty, such scenarios enable scientists and stakeholders to better understand the relationship between management outcome (the amount of reduction in stream depletion) and the associated magnitude of specific management changes needed to affect the outcome (change in pumping and recharge operations). Such scenarios may also enhance the interaction between stakeholders and scientists [*Margerum*, 2008]. For example, the scenario analysis has prompted stakeholders to identify large tracts of alfalfa that have suitable infrastructure to use a combination of in lieu recharge (switching from groundwater pumping to surface water irrigation) and increased recharge via lowering irrigation efficiencies, during spring months while streamflows are high. Stakeholders are further considering to reintroduce beaver dams as a way to increase recharge to groundwater in the immediate vicinity of the stream, while also creating potential salmonid habitat improvements.

[93] Other issues and limitations will need to be considered in the process: Implementation of programs to translocate summer pumping toward the valley margins would require further feasibility analysis with a hydraulic groundwater model to assess the limitations imposed, for example, by the aquifer geometry and heterogeneity, with often lower transmissivity near the valley margins. The scenarios also sketch out potential routes for an assessment of legal and political issues related to transferring groundwater across property boundaries, and applying surface water to increase groundwater recharge. The economic feasibility of such management strategies would further require an assessment of infrastructure needs and costs to install the required groundwater pumping capacity and distribution system.

[94] The approach presented here identifies important groundwater management options that warrant additional analyses including the design of useful scenarios to be simulated with a fully developed numerical groundwater-surface water model [*Sophocleous*, 1995; *Neupauer and Cronin*, 2010]. The approach must therefore be considered as only one of a broader range of tools that support monitoring and assessment programs and adaptive management of groundwater-dependent streamflows under complex conditions and at multiple scales. One potential option that warrants further research is the application of this computationally efficient methodology in automated multiobjective groundwater management optimization that considers various management constraints and uncertainties. Such an application would be particularly relevant because future groundwater management in systems like the study area typically consists of a portfolio of multiple management options that optimize for economic cost, political acceptability, and desired ecologic outcome within the hydrologic constraints of the basin.

7. Conclusion

[95] The modeling approach presented here, a combination of a spatiotemporally distributed soil water budget model and an analytical streamflow depletion model, represents a powerful, computationally efficient, while conceptually simple means to effectively integrate science into a social network watershed process driven by legal and policy decisions. The tool has been applied to the Scott Valley watershed in Northern California, a groundwater-dependent ecosystem that relies on sufficient groundwater discharge into the stream during July–September. The estimation of spatiotemporally distributed recharge and pumping stresses with the soil water budget model allowed us to develop and implement a range of groundwater management scenarios to broadly bracket options that can serve as catalyst to direct stakeholder discussions, and to

demonstrate the potential range of beneficial impacts from groundwater management on stream depletion. The scenarios provide significant insights into spatial and temporal scales of measures and potential venues needed to mitigate existing conflicts between stakeholders representing local farms and those representing downstream fisheries:

[96] 1. Increased groundwater storage of winter and spring streamflow, especially near the Scott River, may significantly decrease the impact of the pumping season on streamflow depletion during the critical summer period.

[97] 2. Groundwater pumping effects in August and July could be further mitigated by transferring groundwater pumping in the most sensitive areas to wells that are some distance away from the Scott River. This would require water trading and transport infrastructure. But the analysis also identified significant limitations on the amount of stream depletion reduction that can realistically be expected.

[98] 3. Addressing uncertainty about the effective hydraulic conductivity between the stream and the aquifer due to geologic heterogeneity, due to geomorphologic complexity, and the unknown complexity of the flow field between groundwater and the stream is critical to better quantify actual stream depletion impacts. We also found that the soil water budget significantly overestimates currently reported farm irrigation rates in center pivot and wheel-line sprinkler systems, possibly due to significant, but unreported deficit irrigation. Sensitivity analysis yields a measure of uncertainty. More importantly it provides direction for critical field measurement programs and the design of more complex hydrologic models for site-specific assessment and feasibility studies of specific recharge and pumping management projects.

[99] The approach has broad merit in the initial phases of a stakeholder driven process to address groundwater-stream interactions through groundwater management, to identify broad areas of potentially feasible projects, and to convey information on the scope of potential projects and expected outcomes. The approach may possibly also be applicable, e.g., for computationally demanding complex management systems optimization applications. Further research on such applications is warranted. The approach is not intended as a tool to provide accurate, quantitative answers for site-specific assessments. Some of its components, especially in the soil water budget, can be significantly improved (e.g., by addressing ditch and canal losses, potential winter runoff, deficit irrigation and reduced ET).

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