Project Information Form (PIF)

A. PROJECT INFORMATION

1. Project Title:	Water Supply Vulnerability in Southern Sierra Communities
2. Project Sponsor(s):	
3. Eligible Applicant Type:	Public Agency
4. IRWM Project Region(s):	Southern Sierra

5. Does the project provide benefits directly to a Disadvantaged Communities (DAC) and/or Economically Distressed Areas (EDA) (minimum 75% by population or geography)?

   ☐ Yes ☑ No If yes, please complete D.8 and/or D.9. Show on map if applicable.

6. Is the Project Sponsor a Tribe, or does the project provide benefits to a Tribe (minimum 75% by population or geography) as defined by Proposition 1?

   ☐ Yes ☑ No If yes, please complete D.10. Show on map if applicable.

7. Provide project map. Include location of project, project benefit and/or service area, and other applicable information.

8. Funding Category:

   ☐ DAC Implementation Project

   ☑ General Implementation Project

9. Project Type: Water quality Other:

   Select most applicable project type. See Section II.C. of the 2019 Guidelines for full description of eligible project types. If "Other" is selected, please write in the space provided the proposed project type.

B. SELECTED ELIGIBILITY REQUIREMENTS

1. Will the project be included in the IRWM Plan, that will be adopted prior to anticipated Agreement Execution?

   ☑ Yes ☐ No

2. Does the project address a critical need(s) and/or priority(ies) of the IRWM Region as identified in the IRWM Plan?

   ☑ Yes ☐ No If yes, complete part a:

   a. What IRWM Plan goal(s)/objective(s) does the project address? Identify and explain.

The project addresses 3 goals set forth in the 2019 Southern Sierra IRW: Objective 1b, Goal 2 and Goal 6. Objective 1b: Increase understanding of the water balance and subsurface water resources, by defining the region's natural storage capacity, which currently is not well understood, largely because the groundwater is found in fractured bedrock that is not as easily modeled as a typical alluvial aquifer, and groundwater monitoring is limited. This is addressed by producing data that allows quantification of groundwater residence time and identification of aquifer type and recharge water source(s) - key information for estimating storage capacity and for model calibration. Goal 2 (Protect and improve water quality, including assessing water quality problems of small water systems, studying the impact of septic systems) is addressed by performing analyses of nitrate, arsenic, perchlorate, hexavalent chromium, and uranium. These data also address Statewide Priority 3.2 (Understanding contamination sources enables informed approach to source mitigation or point-of-use remediation) by identifying depth zones or geographic areas where naturally-occuring constituents may be unavoidable requiring point-of-use remediation, or potential sources of diluent water that could bring water into Title 22 compliance. Goal 6 (Protection of Recharge Areas) is addressed

3. Does the project have an expected useful life consistent with Government Code §16727 (generally 15 years)? If not, explain why this requirement is not applicable.

The data and analysis acquired during the project will have applicability beyond 15 years as water sources experience population pressure or changes due to drought and climate change. Models developed in the future can use these data for calibration and/or validation. The data gathered here will provide a baseline for comparison with water quality data examined in the future.

4. Does the project address and/or adapt to the effects of climate change? Does the project address the climate change vulnerabilities assessed in the IRWM Plan?

☑ Yes ☐ No If yes, please explain below.

Although average annual precipitation may not change considerably due to climate change, project increases in temperature and greater interannaul variability (climate 'whiplash') in the region will result in shifts from snow to rain and concentrated runoff, which will lead to lower recharge. This project will identify the fraction of high elevation recharge to wells, and aide in predicting which wells are vulnerable to decreased recharge due to climate change.

5. Does the project contribute to regional water self-reliance?

☑ Yes ☐ No If yes, please explain below.

These wells are already sole water sources in the communities; assessment of well vulnerability (to contamination or changes in recharge) will allow wise allocation of resources for source area protection and water quality monitoring efforts.

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6. Does the project provide a benefit that meets at least one of the Statewide Priorities as defined in the 2019 IRWM Grant Program Guidelines?

   ☑ Yes ☐ No If yes, please identify below.

   7. Provide Safe Water for All Communities

7. Will CEQA be completed within 12 months of Final Award?
   - ☐ Yes
   - ☐ NA, project is exempt under CEQA
   - ☑ NA, not a project under CEQA
   - ☐ NA, project benefits DAC/EDA/Tribe (minimum 75%), or a Tribe is a local project sponsor
   - ☐ No

8. Will all permits necessary to begin construction be acquired within 12 months of Final Award?
   - ☐ Yes
   - ☐ NA, project benefits DAC/EDA/Tribe (minimum 75%), or a Tribe is a local project sponsor
   - ☑ No

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C. WORK PLAN, BUDGET, and SCHEDULE SUMMARY

1. Project Description: Provide a brief project description summarizing major components, objectives, goals, and intended outcomes/benefits (quantitative and qualitative).

The goal of this study is to identify the most vulnerable communities and water systems in Southern Sierra Regional Integrated Water Management area, in terms of water security and water quality. The project objectives are to:
a) Relate well vulnerability to well type and hydrogeology,
b) Quantify contribution of high elevation precipitation to water supply and examine related effects of climate change, and
c) Identify sources of contaminants, including nitrate, arsenic, perchlorate, hexavalent chromium and uranium, in water supply wells.
Approach:
1. Chemical and isotopic fingerprinting of wells to understand source of recharge, residence times and flow paths, of both water and contaminants. Established analytical and interpretive methods using stable isotopes of the water molecule, tritium, and dissolved gases will be interpreted as groundwater residence times, and water source elevations. Combined water quality results will delineate zones of poor quality water and distiguish natural from anthropogenic contaminant sources.
2. Model-data integration of regional scale climate and hydrological variables to evaluate recharge and drought vulnerability related to regional hydrogeology. The PIs will work with water managers and other researchers to develop model input and assess model validity.
The intended outcomes are greater resilience and self-reliance of Southern Sierra communities in terms of water supply.

2. Budget: Provide cost estimates for each Budget Category listed in the table below. (Required for Pre-Application Material Submittal; not required for Final Application Submittal)

Table 1 - Project Budget

	Category	(a) Cost Share: Non-State Fund Source	(b) Requested Grant Amount	(c) Other Cost Share (including other State Sources)	(d) Total Cost
(a)	Project Administration		12,000		12,000
(b)	Land Purchase/ Easement				
(c)	Planning/Design /Engineering /Environmental Documentation	Nine communities, which include DAC areas, were identified by the RWMG as lacking sufficient			
(d)	Construction/ Implementation		153,700	6,300	160,000
(e)	Grand Total (Sum rows (a) through (d) for each		165,700	6,300	172,000

Note: Provide information or other documentation to support the cost estimate in a separate attachment. Identify the source of all cost share and other funds. If other funds are not used, describe efforts to obtain other funding and/or why other funding sources were not used.

Cost chare is from internal research grant from California State University to Jean Moran.

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3. Cost Share Waiver Requested (DAC or EDA)? ☑ Yes ☐ No If yes, continue below:
   Cost Share Waiver Justification: Describe what percentage of the proposed project area encompasses a DAC/EDA, how the community meets the definition of a DAC/EDA, and the need of the DAC/EDA that the project addresses. In order to receive a cost share waiver, the applicant must demonstrate that the project will provide benefits (minimum 25% by population or geography) that address a need of a DAC and/or EDA.

Nine communities, which include DAC areas, were identified by the RWMG as lacking sufficient understanding to adequately address water security:
Auberry (DAC), Prather, Squaw Valley, Dunlap, Badger, Three Rivers, Springville (and EDA and DAC), Posey (DAC), and White River
These nine communities lie at similar elevations along a north-south transect in the Southern Sierra foothills. Variation in climate and geology, and proximity to surface water flows, as well as elevation, are expected to vary in recharge sources and geologic host formations, result in differences in vulnerability.

4. Schedule: Include reasonable estimates of the start and end dates for each Budget Category listed in Table 1 - Project Budget. (Required for Pre-Application Material Submittal; not required for Final Application Submittal)

Table 2 - Project Schedule

	Category	(a) Start Date	(b) End Date
(a)	Direct Project Administration	1/1/2020	12/31/2021
(b)	Land Purchase/Easement		
(c)	Planning/Design/Engineering/Environmental Documentation	1/1/2020	12/31/2021
(d)	Construction/Implementation		

D. OTHER PROJECT INFORMATION

1. Provide a narrative for project justification. If applicable, include references to supporting documentation such as models, studies, engineering reports, etc. Include any other information that supports the justification for this project, including how the project can achieve the claimed level of benefits.

Southern Sierra foothill communities rely on groundwater wells drilled in (a) deep fractured bedrock, (b) shallow alluvium or (c) deep alluvium or weathered bedrock. Each of these well types has distinct characteristics, resulting in varying degrees of vulnerability. There are a number of open questions regarding the sustainability of the water resources including the recharge source(s) of locally pumped groundwater, the contribution of fractured bedrock flow to wells, the sustainable yield of fractured bedrock wells, and the vulnerability of wells to contamination and droughts. Poorly known local hydrogeology is a major factor for well vulnerability. In regions where physical and geologic data are lacking, or where wells are widely spaced, chemical and isotopic data are a good alternative for providing information about hydrostratigraphy, recharge areas, and groundwater flow paths. Deep flow paths and large capture zones in fractured bedrock geology can sustain water supply through prolonged periods of drought, but even deep wells may be vulnerable to lowered yields if contributing zones have a low density of interconnected fractures or if recharge to the capture zone is slow.

Approach:

1. Chemical and isotopic fingerprinting of wells to understand source of recharge, residence times and flow paths, of both water and contaminants
2. Model-data integration of regional scale climate and hydrological variables to evaluate recharge and drought vulnerability related to regional hydrogeology

The two approaches are complementary: Isotopic methods provide a bottom-up view of well vulnerability for individual wells and groups of wells, while the model-data integration provides a top-down assessment of regional hydrogeological constraints, including water sensitivity to annual and decadal changes in water budget components.

Isotopic tracers are a powerful tool for addressing questions regarding the recharge elevation of locally pumped groundwater, the contribution of fractured bedrock flow to wells, the contribution of river recharge to wells, and the vulnerability of wells to contamination and droughts (e.g., Segal et al., 2014; Visser et al., 2018).

In each of the project communities, three wells (representing each well type) will be selected for study. Each well will be sampled for potential constituents of concern (e.g. nitrate, arsenic, perchlorate, uranium, hexavalent chromium) as well as a suite of isotopic and geochemical tracers. These 27 samples will serve as examples for all wells within the management area allowing assessment of which types of well and which communities are most vulnerable.

Segal, D.C., Moran, J.E., Visser, A., Singleton, M.J., and Esser, B.K. (2014) “Seasonal Variation of High Elevation Groundwater Recharge as Indicator of Climate Response”, Journal of Hydrology, v. 519:3129-3141.

Visser, Ate; Moran, Jean; Singleton, Michael; Esser, Bradley. (2018) Importance of river water recharge to the San Joaquin Valley groundwater system. Hydrological Processes

Project Information Form (PIF)

2. Project Benefits Table:

Table 3 - Project Benefits				
Anticipated Useful Life of Project (years):	15+ years			
Primary (Required)				
Type of Benefit Claimed:	Water Supply - Groundwater	**Benefit Units*:**	Other	
Secondary (Optional)				
Type of Benefit Claimed:	Water Quality - Groundwater	**Benefit Units*:**	Other	

Physical Benefits (At project completion or lifetime, as appropriate)		
(a)	**(b)**	**(c)**
Benefit	**Added Physical Benefit Description**	**Quantitative Benefit**
Primary	<15 words maximum>	
Secondary	<15 words maximum>	

Qualitative Benefits (For Decision Support Tools, please describe non-physical benefits.)

The project addresses both water quality and water supply vulnerability. The data will relate groundwater age, water source elevation, and water quality to the local geology. In this manner, the project enables an assessment of the vulnerability of the wells to contamination but also to climate change and possible changes in the amount of pumping.

It could lead to implementation projects like casing off portions of a well if screened over both alluvium and fractured bedrock to bring a well into drinking water compliance, mixing water sources to bring the blended water into compliance, mapping out areas (or depth intervals) to avoid in future drilling, and calibrating or validating hydrologic models.

Comments: [Include narrative on additional benefits, as warranted.]

* DWR may require applicant to convert or modify Benefit Claimed and/or Benefit Units. Where applicable, select one of the following units that corresponds to the benefit claimed:

- For water supply produced, saved, or recycled, enter acre-feet per year (AFY)
- For water quality, enter constituent concentration reduced in mg/L
- For flood damage reduction, enter inundated acres reduced in acres
- For habitat improved, restored or protected, enter habitat restored in acres
- For fishery benefits, enter increased fishery flow rate in cubic feet per second (cfs)
- For species protection, enter number of species benefited

3. Does the proposed project provide benefits to multiple IRWM regions [or funding areas]? If the project is located in another funding area, please provide the information requested in the 2019 Guidelines, Section 1.A.

☑ Yes ☐ No If yes, provide a description of the benefits to the various regions.

The methods applied here, using chemcial and isotopic analyses in areas with low well density and/or low availability of physical and geologic information about groundwater occurrence, could be applied in other, similar areas. The types of wells targeted in the SSIRWM area are abundant in other foothill and mountain communities, but have received little attention from regulators or researchers.

4. Provide a narrative on cost considerations. For example, were other alternatives to achieve the same types and amounts of physical benefits as the proposed project evaluated? Provide a justification as to why the project was selected (e.g., if the proposed project is not the lowest cost alternative, why is it the preferred alternative? Are there any other advantages that the proposed project provides from a cost perspective?)

Existing data such as flows from stream gauges, precipitation records, geologic maps and well logs will be examined in concert with the chemical and isotopic results. However, the proposed synoptic sampling for chemical and isotopic constituents is cost effective compared to acquiring physical data (such as long term water levels from pressure transducers, aquifer parameters from pump tests, lithologic logs and geophysical data from new monitoring wells). As an example, drilling a new well, determining fracture density through geophysical methods, and purchase and maintainence of a pressure transducer would likely amount to at least $10,000, which is greater than the cost per well proposed here.

5. a. Does the project address a contaminant listed in AB 1249?

☑ Yes ☐ No If yes, complete parts b and c:

b. Describe how the project helps address the contamination.

All of the AB 1249 contaminants, along with some additional naturally-occurring contaminants that have been identified in drinking water wells in the region (like Uranium), will be analyzed in the wells sampled for the proposed study. Concentrations will be reported at low limits (below regulatory limits) in order to assess possible sources and patterns of occurrence. Combining AB 1249 contaminant concentrations with information derived from isotopic results will likewise enable interpretation of sources and flow pathways, rather than simple occurrence.

c. Does the project provide safe drinking water to a small disadvantaged community?

☐ Yes ☑ No If yes, provide an explanation on how the project benefits a small disadvantaged community as defined in the 2019 IRWM Guidelines.

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6. Does the project provide safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitary purposes (consistent with AB 685) to meet a specific need(s) of a community?

   ☐ Yes ☑ No If yes, please describe.

7. Does the project employ new or innovative technologies or practices, including decision support tools that support the integration of multiple jurisdictions, including, but not limited to, water supply, flood control, land use, and sanitation?

   ☑ Yes ☐ No If yes, please describe.

Application of isotopic tracers is new to the region, and provides information for water management in areas with insufficient well coverage for development of a flow and transport model. Because groundwater age reflects the integration of flow paths, a great deal of new and unique information can be derived from analyses of groundwater age, coupled with other water quality data, at individual wells.

8. If the project provides benefits (75% by population or geography) to a DAC, explain the need of the DAC and how the project will address the described need. Explain how the area/community meets the definition of a DAC.

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9. If the project provides benefits (75% by population or geography) to an EDA, explain the need of the EDA and how the project will address the described need. Explain how the area/community meets the definition of an EDA.

10. If the project provides benefits (75% by population or geography) to a Tribe or a Tribe is the sponsor of the project, explain the need of the Tribe and how the project will address the described need.

11. Does the project sponsor have legal access rights, easements, or other access capabilities to the property to implement the project?

- ☑ Yes — If yes, please describe.
- ☐ NA — If NA, please describe why physical access to a property is not needed.
- ☐ No — If no, please provide a clear and concise narrative with a schedule to obtain necessary access.

The project requires voluntary participation by well owners; Southern Sierra IRWM stakeholders will collaborate to identify wells and help communicate the value of the project with well owners.

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E. ENVIRONMENTAL

1. Please fill out the CEQA Timeline Table below, if applicable:

Table 4 - CEQA Timeline		
CEQA STEP	**COMPLETE? (y/n)**	**ESTIMATED DATE TO COMPLETE**
Initial Study		
Notice of Preparation		
Draft EIR/MND/ND		
Public Review		
Final EIR/MND/ND		
Adoption of Final EIR/MND/ND		
Notice of Determination		

a. If additional explanation or justification of the timeline is needed, please describe below (optional).

2. Permit Acquisition Plan:

List all permits needed to complete the project. If the project does not provide benefits to a DAC, EDA, or Tribe (min 75%), all permits needed to begin construction must be acquired within 12 months of Final Award.

No.	Type of Permit	Permitting Agency	Date Acquired or Anticipated
1.			
2.			
3.			
4.			
5.			
6.			
n.			

For each permit not yet acquired, describe the following:

No.	a. Actions taken to date (include dates of any key meetings, consultations, submittals, etc.)	b. Any issues or obstacles that may delay acquisition of permit
1.		
2.		
3.		
4.		
5.		
n.		

3. Permitting Checklist: This checklist is provided as a courtesy for documentation purposes. Not all permits which may apply are listed. (Required for Pre-Application Material Submittal; not required for Final Application Submittal)

a. Does the project involve any activities that may affect federally or state listed threatened or endangered species or their critical habitat that are known, or have a potential, to occur on-site, in the surrounding area, or in the service area? (i.e. Federal Endangered Species Act Section 7 Consultation and Incidental Take Authorization and Section 10 Incidental Take Permit, California Endangered Species Act Permit, and/or ESA & CESA Consistency Determination)

☐ Yes ☑ No If yes, please explain:

b. Would the proposed project work in, over, or under navigable waters of the US or discharge dredged or fill material in waters of the US? (i.e. Rivers & Harbors Act Section 10 Permit and/or Clean Water Act Section 404 Permit)

☐ Yes ☑ No If yes, please explain:

c. Will the proposed project have the potential to affect historical, archaeological, or cultural resources? (i.e. National Historic Preservation Act and/or State Historic Preservation Officer Consultation)

☐ Yes ☑ No If yes, please explain:

d. Will the proposed project discharge into a water of the US? (i.e. Clean Water Act Section 401 and/or 404 Permit)

☐ Yes ☑ No If yes, please explain:

e. Will the proposed project divert the natural flow of a river, stream, or lake? (i.e. Lake or Streambed Alteration Agreement)

☐ Yes ☑ No If yes, please explain:

f. Will the proposed project change the bed, channel, or bank of a river, stream, or lake? (i.e. Lake or Streambed Alteration Agreement)

☐ Yes ☐ No If yes, please explain:

g. Will the proposed project use any material from the bed, channel, or bank of a river, stream, or lake? (i.e. Lake or Streambed Alteration Agreement)

☐ Yes ☑ No If yes, please explain:

h. Will the proposed project deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it can pass into a river, stream, or lake? (i.e. Lake or Streambed Alteration

☐ Yes ☑ No If yes, please explain:

i. For water supply projects, do you need to obtain a water right? (Water Rights Permit)

☐ Yes ☑ No If yes, please explain:

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j. Is the proposed project within the defined coastal zone? (Coastal Development Permit)

☐ Yes ☑ No If yes, please explain:

Proposal Summary

1. IRWM Region(s): Southern Sierra
2. Funding Area(s):
3. Applicant Name:
4. Eligible Applicant Type:
5. Proposal Title: Water Supply Vulnerability in Southern Sierra Communities
6. Applicant Point of Contact (POC) Information (name, title, organization, phone, email):
7. Provide Proposal Map (show Funding Area and regional boundaries, project location(s) etc.)
8. How does the proposal support the overall intent of IRWM as outlined in Section 1 of the 2019 Guidelines and the IRWM Planning Act (Water Code 10531)? Discuss coordination and/or collaboration within and between agencies, regions, and/or Funding Areas, and any efficiencies or mutual solutions realized.
9. Does the IRWM region(s) include areas that have contamination listed in AB 1249? ☑ Yes ☐ No

Table 1 - Proposal Overview

	Project Title	(a) Funding Category (choose one): DAC	(a) Funding Category (choose one): General	(b) Address Climate Change?	(c) Contribute to regional water self-reliance?	(d) Address AB 1249 Contaminants?	(e) Address Human Right to Water?
(a)	Water Supply	☐	☑	☑	☑	☑	☑
(b)	Project 2	☐	☐	☐	☐	☐	☐
(c)	Project 3	☐	☐	☐	☐	☐	☐
(d)	Project 4	☐	☐	☐	☐	☐	☐
(e)	Project 5	☐	☐	☐	☐	☐	☐
(f)	Project 6	☐	☐	☐	☐	☐	☐
(g)	Project 7	☐	☐	☐	☐	☐	☐
(h)	Project 8	☐	☐	☐	☐	☐	☐
(i)	Project 9	☐	☐	☐	☐	☐	☐
(j)	Project 10	☐	☐	☐	☐	☐	☐
(k)	Project 11	☐	☐	☐	☐	☐	☐
(l)	Project 12	☐	☐	☐	☐	☐	☐
(m)	Project 13	☐	☐	☐	☐	☐	☐
(n)	Project 14	☐	☐	☐	☐	☐	☐
(o)	Project 15	☐	☐	☐	☐	☐	☐

* If no projects in the proposal contribute to regional water self-reliance, provide an attachment explaining why the requirements of Water Code 79741(c) are not applicable to your region(s).

** If the answer to Question 9 was "Yes", but no boxes in column (d) were checked, please provide an attachment to this form explaining why the application did not include such a project(s). Application is not complete unless this justification is provided.

Note: Expand cells and/or tables as necessary to provide complete information on your proposal.

Proposal Summary

Table 2 - Proposal Budget

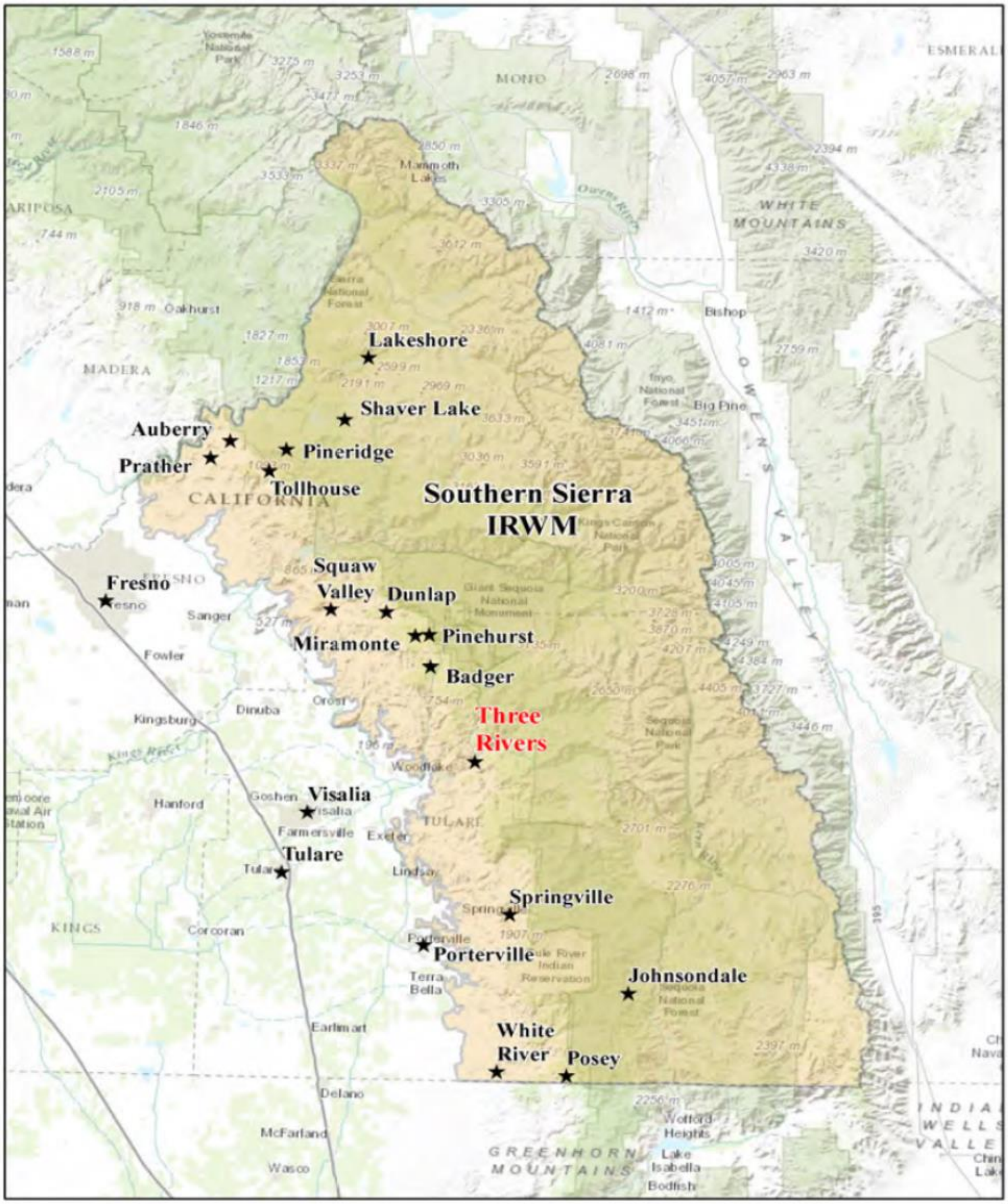
	Project Title	(a) Cost Share: Non-State Fund Source(s)	(b) Requested Grant Amount	(c) Total Cost	(e) Other Cost Share	(f) Cost Share Waiver Requested
(a)	Water Supply		165,700	172,000	6,300	☐
(b)	Project 2					☐
(c)	Project 3					☐
(d)	Project 4					☐
(e)	Project 5					☐
(f)	Project 6					☐
(g)	Project 7					☐
(h)	Project 8					☐
(i)	Project 9					☐
(j)	Project 10					☐
(k)	Project 11					☐
(l)	Project 12					☐
(m)	Project 13					☐
(n)	Project 14					☐
(o)	Project 15					☐
(p)	Proposed Total	0	165700	172000		

Note: Grant administration costs shall not exceed ten percent (10%) of the total requested grant amount, including proposal and project level grant administration costs.

Table 3 - Proposed Schedule

		Start Date	End Date
	Grant Agreement		
(a)	Water Supply Vulnerability in Souther	1/1/2020	12/31/2021
(b)	Project 2		
(c)	Project 3		
(d)	Project 4		
(e)	Project 5		
(f)	Project 6		
(g)	Project 7		
(h)	Project 8		
(i)	Project 9		
(j)	Project 10		
(k)	Project 11		
(l)	Project 12		
(m)	Project 13		
(n)	Project 14		
(o)	Project 15		

Note: Expand cells and/or tables as necessary to provide complete information on your proposal.



Note: Expand cells and/or tables as necessary to provide complete information on your proposal.

Water supply vulnerability in Southern Sierra communities:

An integrated study of water source and water quality

REGIONAL WATER MANAGEMENT GROUP MEETING

6 September 2018
Fresno, California

Jean Moran, California State University – East Bay
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Ate Visser, LLNL
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EAST BAY

LLNL-PRES-756802
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

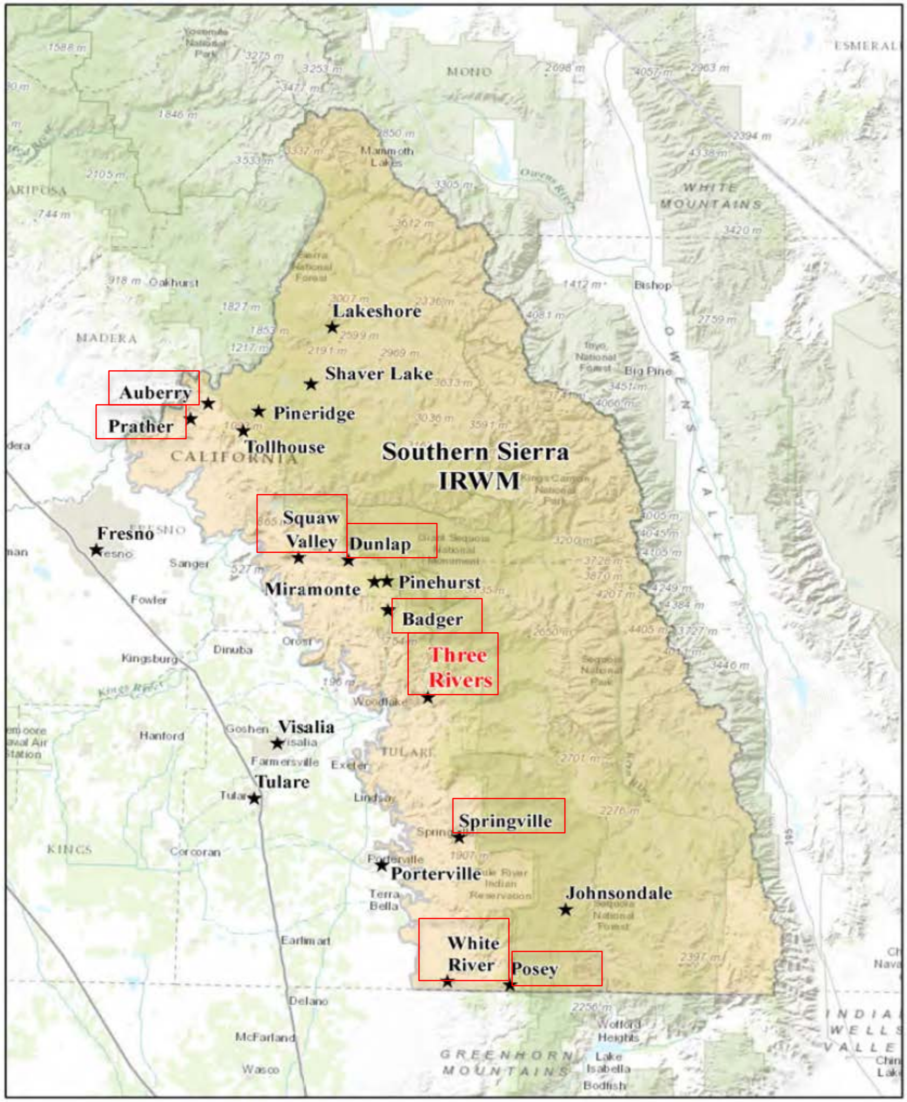
Lawrence Livermore National Laboratory

Goal, Objectives, Approach

- Goal:
  - Characterize vulnerability of water systems in Southern Sierra Integrated Regional Water Management area
    - water supply
    - water quality
- Objectives:
  - Relate well vulnerability to well type and hydrogeology (fracture network vs alluvium)
  - Quantify contribution of high elevation precipitation to water supply
  - Identify sources of contaminants in water supply
- Approach:
  - **Chemical and isotopic fingerprinting** of wells to understand source of recharge, residence times and flow paths, of both water and contaminants
  - Build on previous studies by Suen et al., and USGS
  - **Model-data integration** of regional scale climate and hydrological variables to evaluate recharge and drought vulnerability related to regional hydrogeology

Location, location, location…

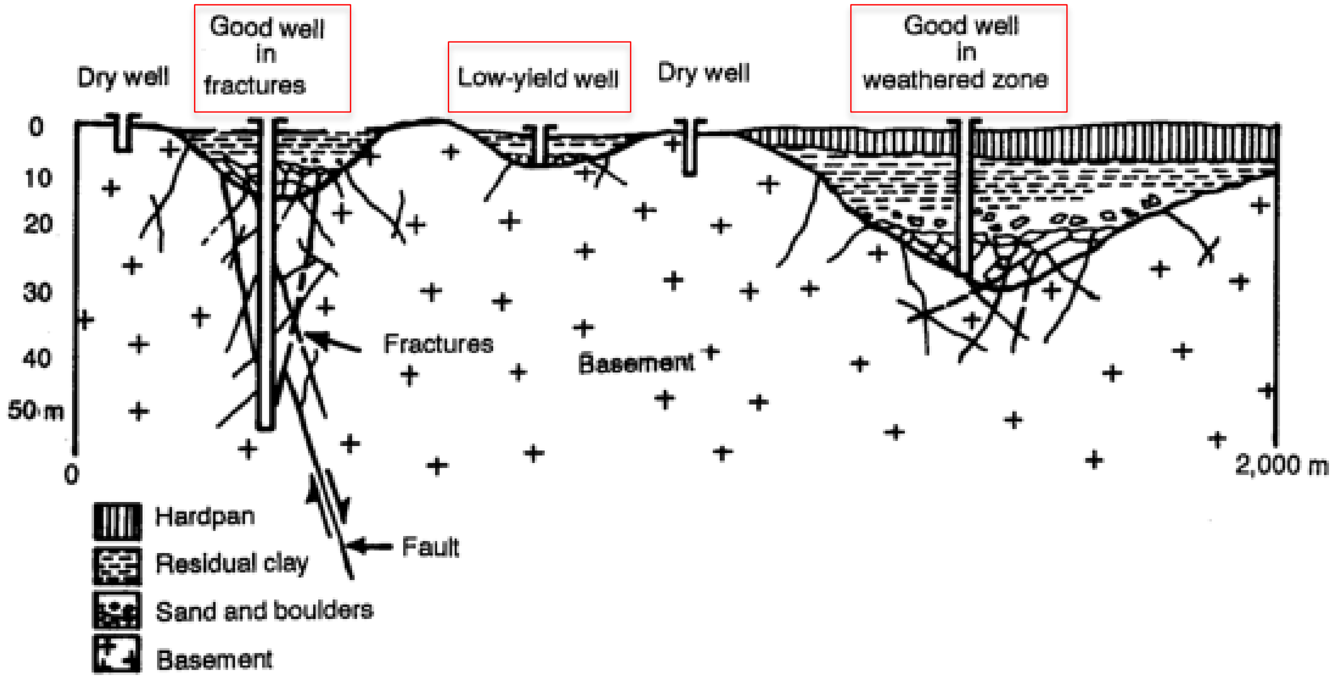
- Nine communities lacking sufficient information to adequately address water security
- Auberry, Prather, Squaw Valley, Dunlap, Badger, Three Rivers, Springville, Posey, and White River
- Similar elevations along a north-south transect in the Southern Sierra foothills
- Climate and geology, proximity to surface water flows, and elevation, are expected to result in differences in vulnerability



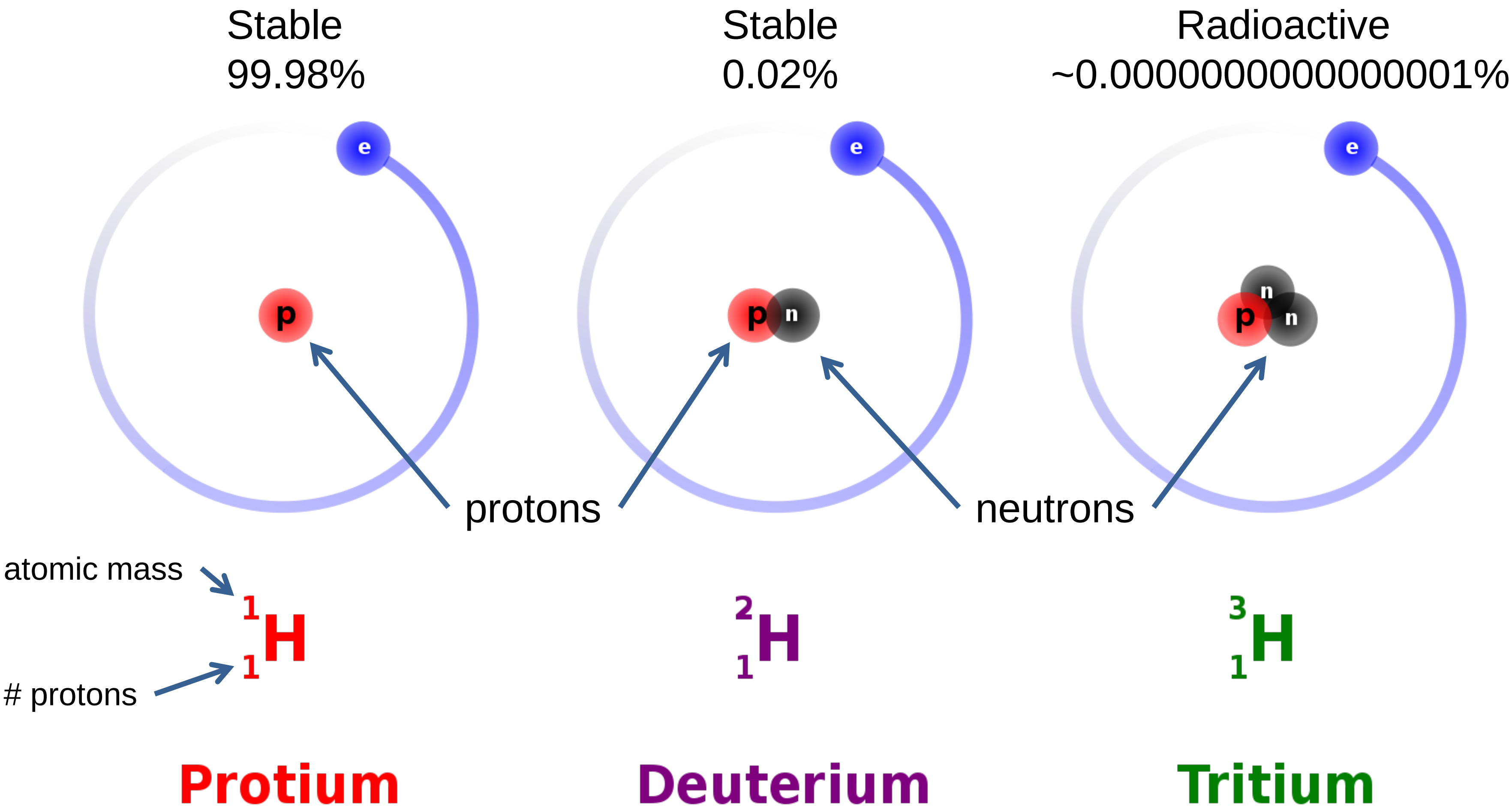
Source: DWR report

Study Design

- Select at least three wells in each community for sampling:
  - — deep fractured bedrock
  - — shallow alluvium
  - — deep alluvium/weathered bedrock
- Relate vulnerability to well type and hydrogeology

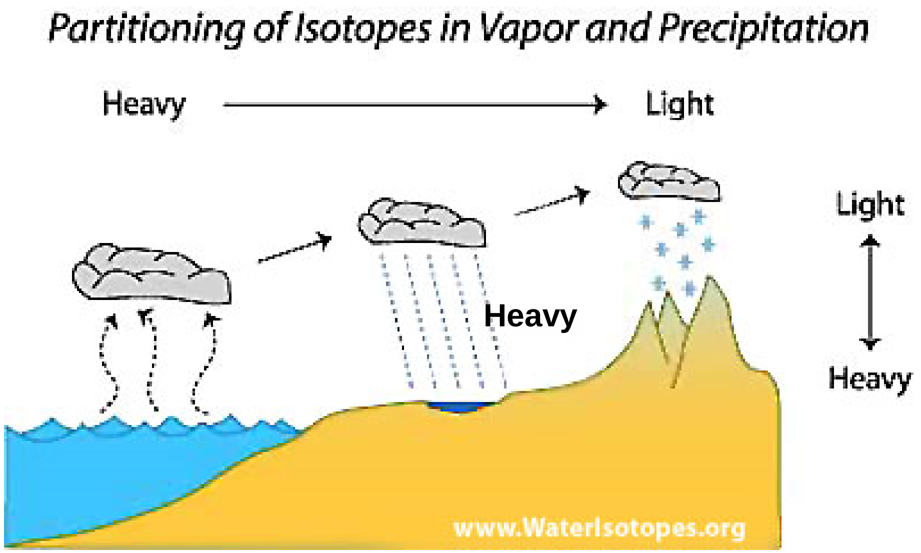


Chemical and isotopic fingerprinting
Isotopes of Hydrogen (for example)

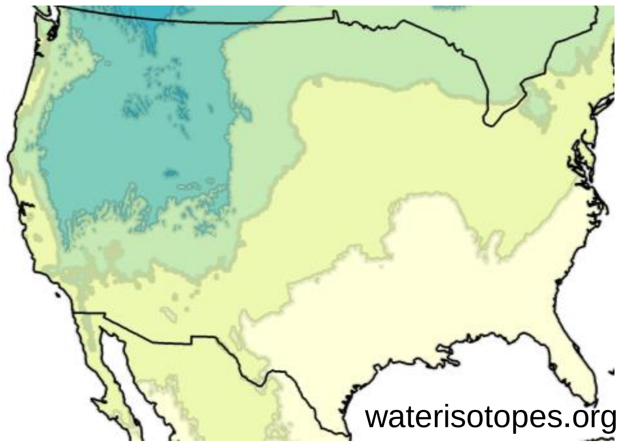


Isotopic tracers for groundwater recharge

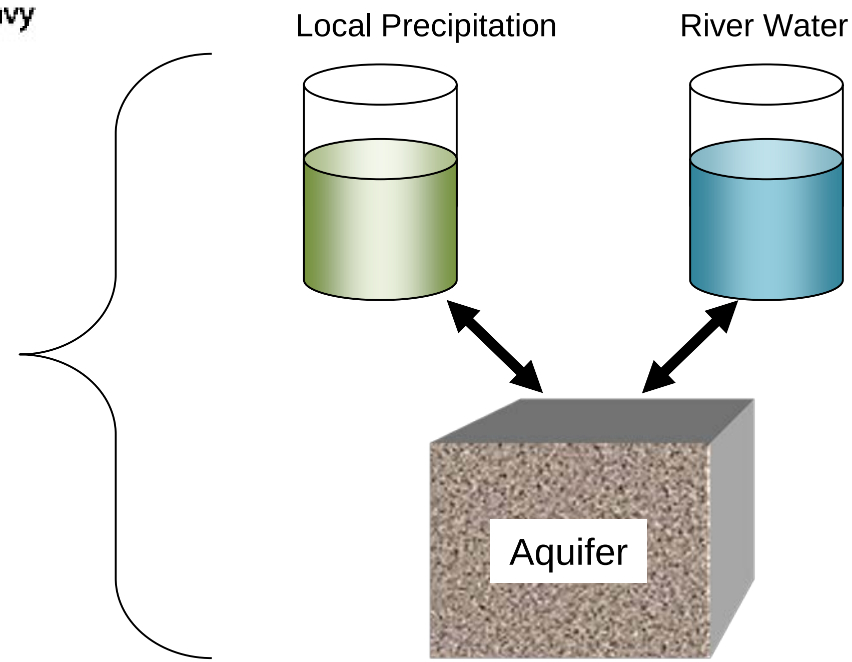
Orographic Effect



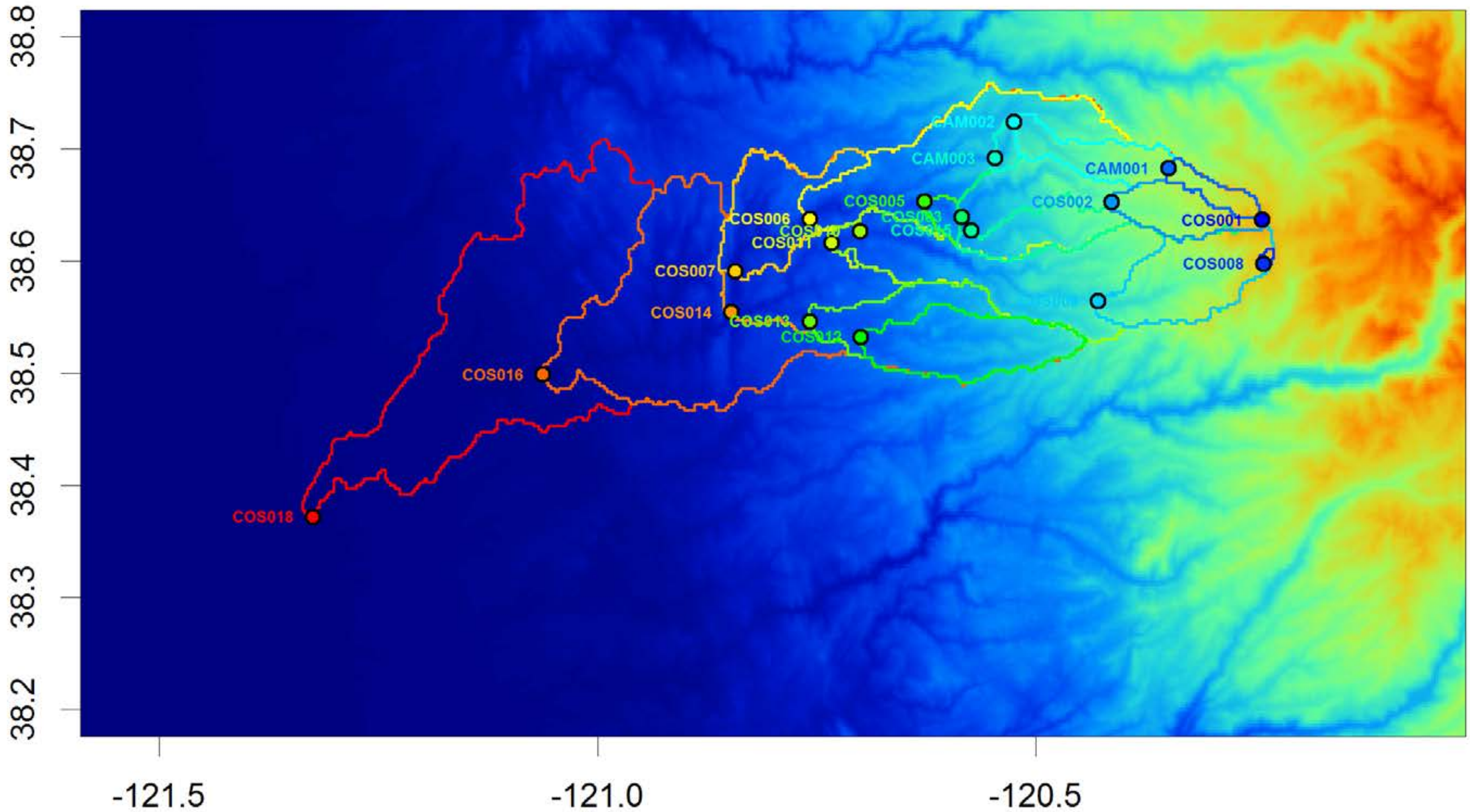
$^2H/^1H$



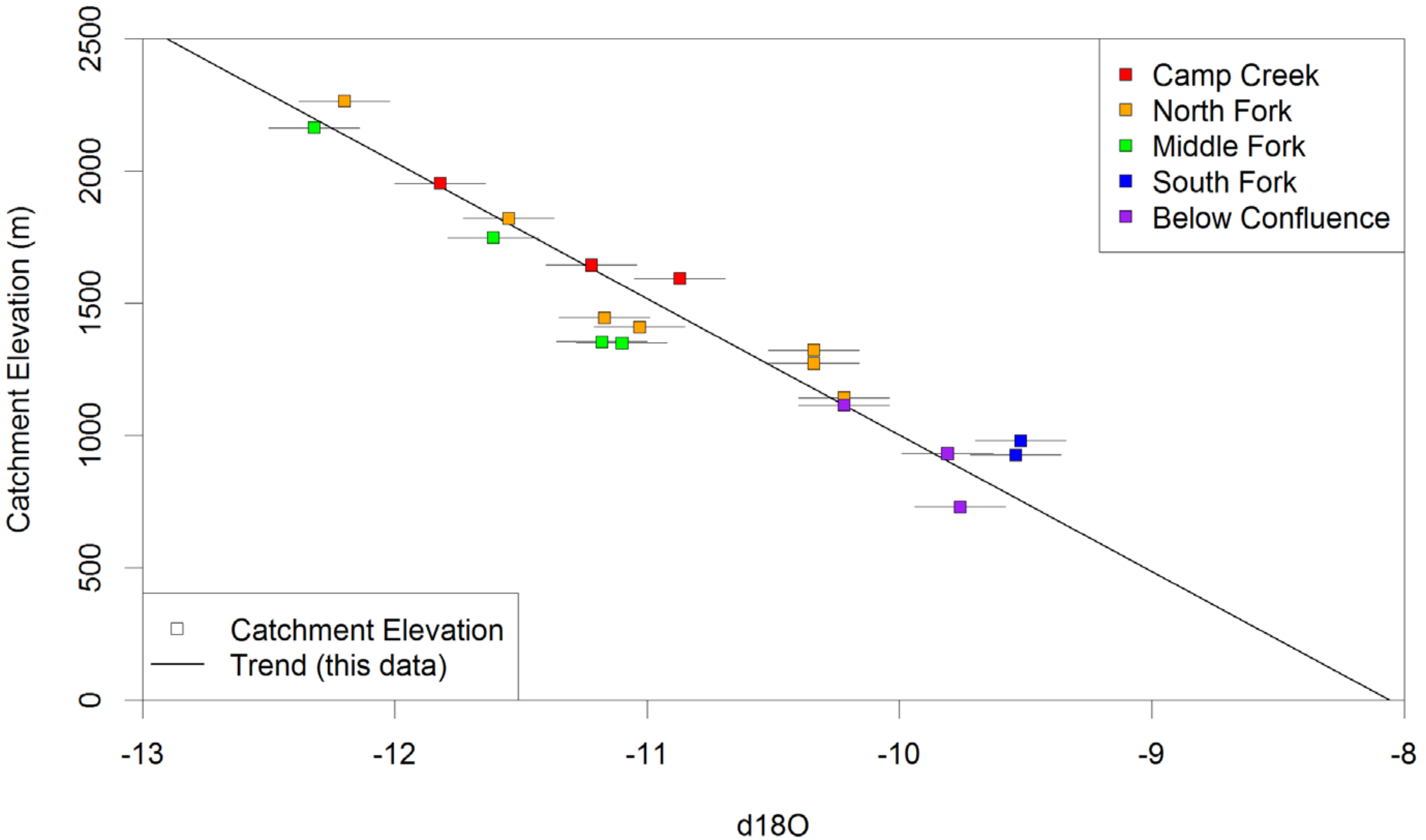
In the absence of a calibrated flow & transport model, an isotopic mixing model can identify and quantify processes associated with the introduction of river water.



Catchment Elevation Example
Cosumnes River – Sample Catchment Areas



Catchment Elevation Example
Isotopic Trend with Elevation



RESEARCH ARTICLE

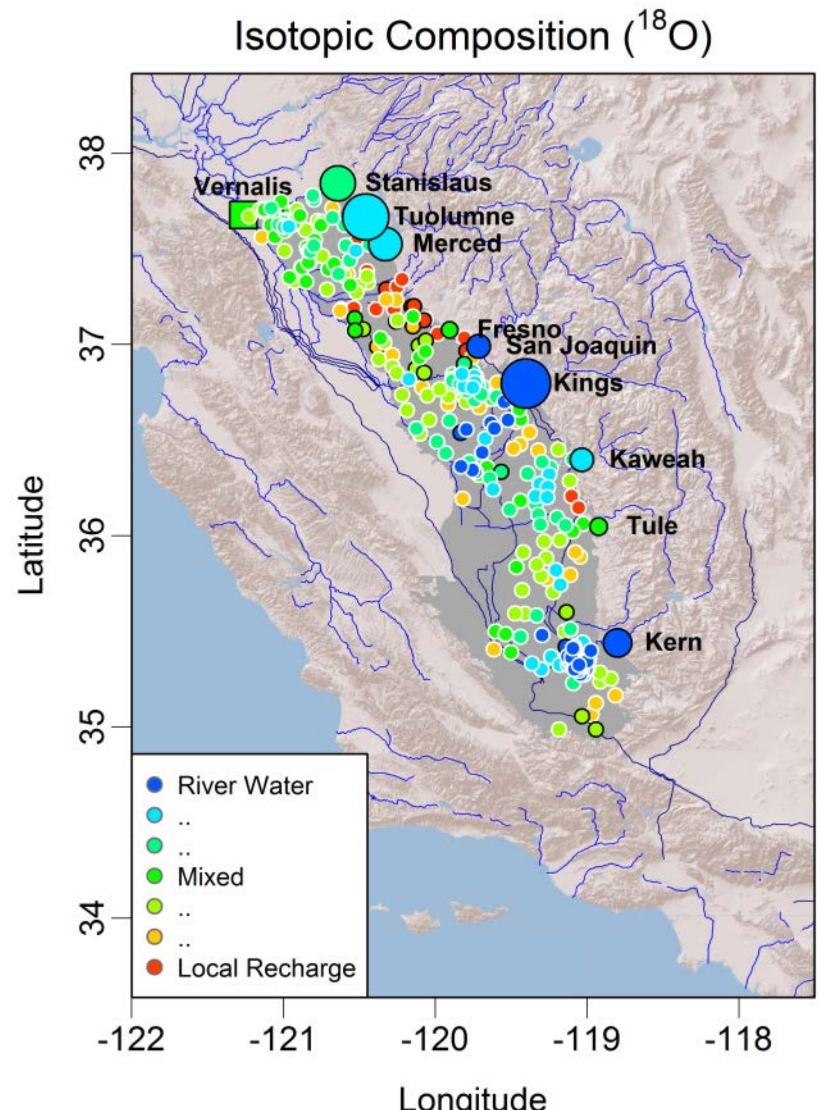
WILEY

Importance of river water recharge to the San Joaquin Valley groundwater system

Ate Visser[1] | Jean E. Moran[2] | Michael J. Singleton[1] | Bradley K. Esser[1]

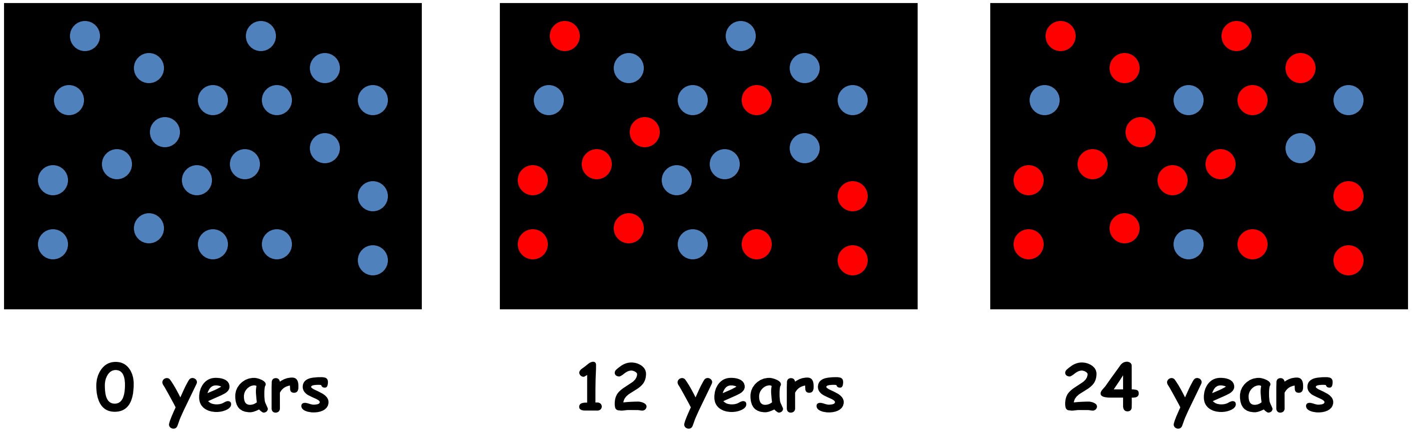
- River water recharge represents 47±4% of modern groundwater in the San Joaquin Valley, but only 26±4% of pre-modern groundwater.
- River water recharges groundwater systems at lower temperatures and with larger water table fluctuations than local precipitation recharge.

	River Water	Local Recharge
Modern Groundwater	47%	53%
Recharged before 1950	26%	74%



The ^3He from ^3H decay starts to accumulate once the water has become groundwater

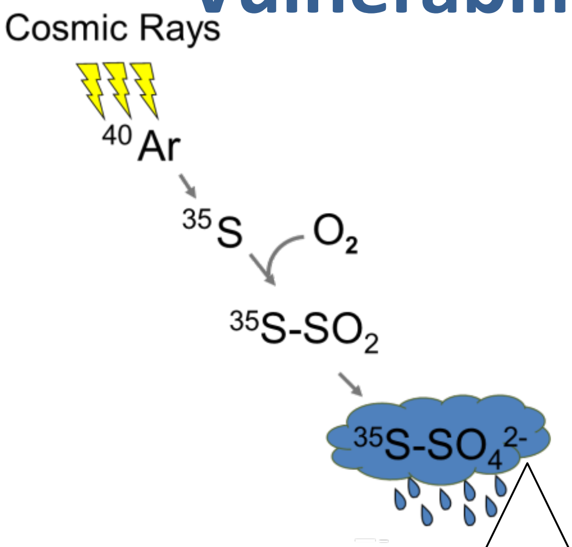
$$^3H \rightarrow {}^3He + e^-$$

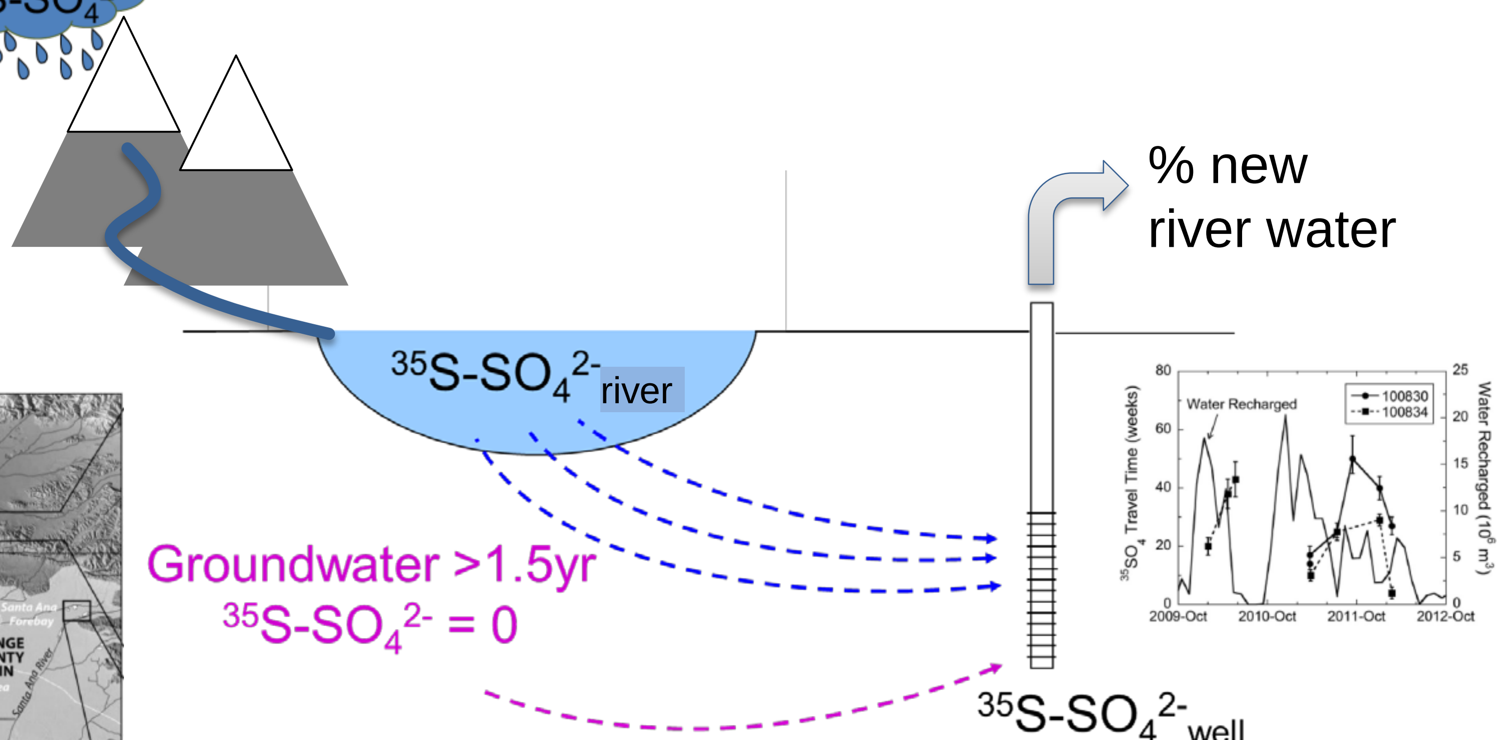


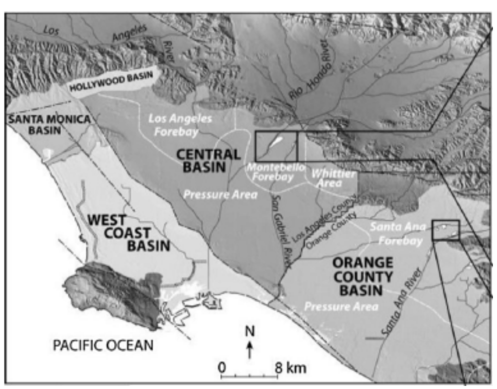
$$\text{Age (years)} = 18 \times \ln(1 + {}^3He / {}^3H)$$

Vulnerability to short flow paths: Sulfur-35

- The 87.5 day half-life of ^{35}S is ideal for investigating groundwater travel times on the <1 year timescale of interest

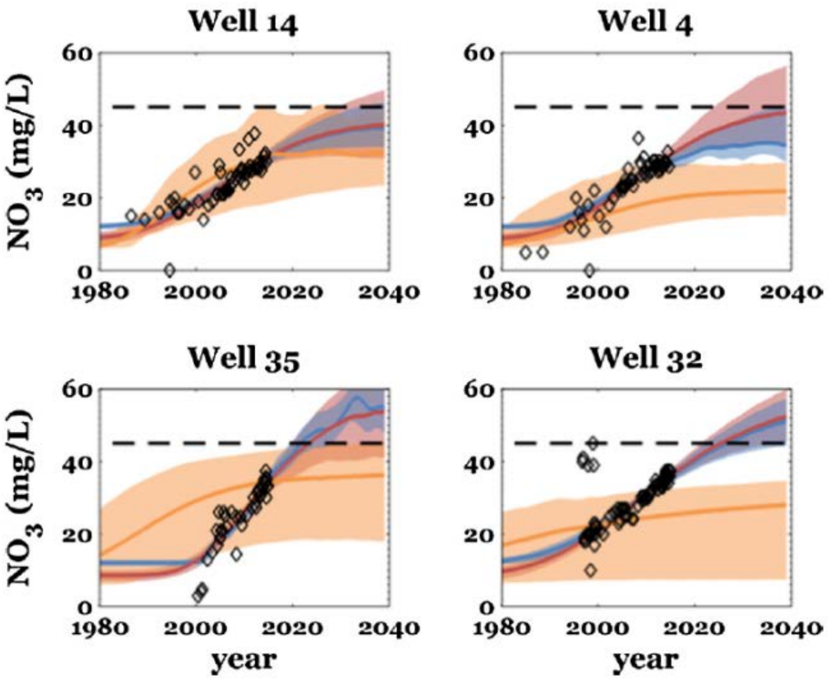






Forecast of well contamination with groundwater age

- Approach:
  - Identify the source of water to water supply wells
  - Link water quality of water supply to groundwater ages
- Benefit:
  - Reliable forecast of water quality and time-scale of management changes



Indicators of fractured bedrock flow

- Naturally occurring **uranium** and **thorium** produce **helium-4**, which accumulates in circulating groundwater

High helium concentrations in fractured bedrock well

Helium in alluvial wells indicates fractured bedrock contribution

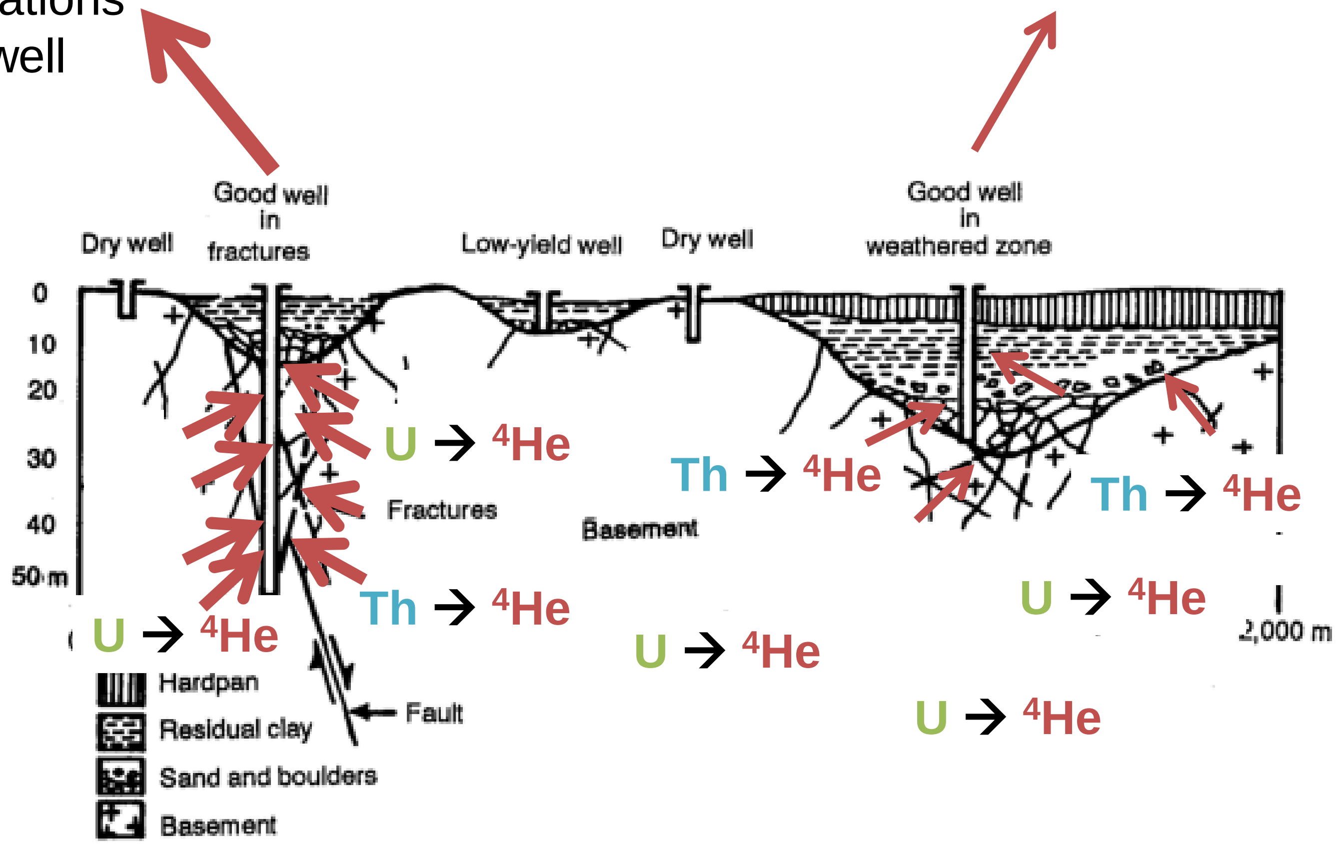


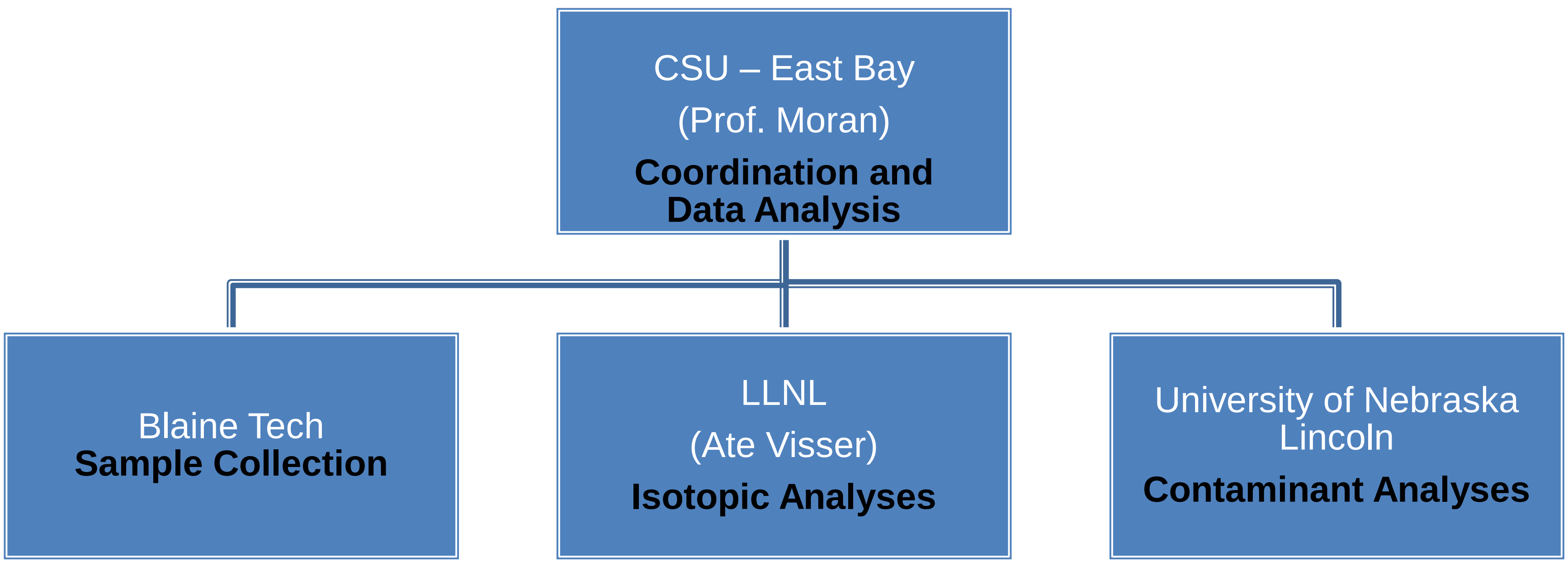
Figure 2-15. Catchment

Summary

- Select 3 wells (different types) in each of the 9 communities
- Sample wells, analyze for:
  - Isotopic tracers of source elevation, residence time, fracture flow
  - Water quality indicators: salinity, nitrate, arsenic, uranium, radon, perchlorate, chrome-VI, others?
- Evaluate data
  - How is vulnerability related to well type?
  - Allow ranking of priorities within systems and among issues
- Integrate data, relate to previous studies
  - DWR Three Rivers study for conceptual model
  - Compliment CSU Fresno (John Suen) studies
  - Use model output from UC Merced climate study
  - Leverage LLNL/UC "Headwaters to Groundwater" project

Organization and Logistics

- Efficient effort: sample wells for both contaminants and tracers
- Combined analysis of water supply quality and quantity
- Unique strengths of team members



Isotopic Tracer Study for Sierra Foothills Water Resource Sustainability

Ate Visser (LLNL), Jean Moran (CSU East Bay), Mohammad Safeeq (UC Merced)

Southern Sierra foothill communities rely on groundwater wells drilled in alluvium or fractured bedrock aquifers. There are a number of open questions regarding the sustainability of the water resources including the recharge elevation of locally pumped groundwater, the contribution of fractured bedrock flow to wells, and the vulnerability of wells to contamination and droughts. Isotopic tracers are a powerful tool for finding answers to these questions:

Topic	Isotopic Tracer (Half-Life)	Application in Sierra Foothills Catchments
Vulnerability of Wells to Contamination	Sulfur-35 (87 days)	Detectable sulfur-35 indicates acute vulnerability to low river stages and vulnerability to contamination. Possibly detectable in summer (low groundwater levels) or late spring (when local rivers are high).
Contribution of Fractured Bedrock Flow	Radiogenic Helium-4	Builds up in groundwater over centuries to millennia from decay of uranium and thorium. Strong signal from granitic fractured rock. Helium-4 in alluvium wells is evidence for fracture flow contributions to alluvium. Fracture flow contribution is quantifiable with end-member samples collected from local fractured bedrock well. Helium-4 in river allows quantification of fracture flow contribution to stream flow.
Water Supply Sustainability	Tritium (12.3 years), Tritium-helium (2-60 years)	Groundwater ages – combined with alluvium thickness – help constrain water balance calculations on recharge rates. Old ages/low tritium confirm long flow paths and sustainable resources. Young ages confirm local recharge and sensitivity to droughts.
Elevation of groundwater recharge	Dissolved noble gases	Noble gas composition in groundwater indicates the elevation and temperature at which recharge took place. Comparison with stable isotopes of water distinguish high elevation recharge from lower elevation recharge of river-sourced water.
	Stable Isotopes (δ^2H and $\delta^{18}O$)	Isotopic composition of precipitation depends on elevation: high elevation rivers are "lighter" while lower elevation recharge is "heavier". Distinguish source of water to wells, i.e., local precipitation vs. high elevation snowmelt/river water.
Groundwater Discharge / Fracture Aquifer	Radon-222 (3.8 days)	Radon accumulates from U/Th decay in ~10 days. Pinpoint groundwater influx in rivers. Indicates influence of river recharge in nearby wells. Complimentary to radiogenic helium-4 in characterizing fractured rock aquifer system.

Geology, Hydrology, Quality of Water, and Water Supply of the Three Rivers Area, California

Prepared for:

Southern Sierra Regional Water Management Group

Prepared by:

State of California
Department of Water Resources
Division of Integrated Regional Water Management
South Central Region Office
Special Investigations and Regional Planning Branch

Contents

Acronyms

µg/L	micrograms per liter
cfs	cubic feet per second
DWR	California Department of Water Resources
EC	specific conductance
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
gpd	gallons per day
IRWM	integrated regional water management
IRWMP	integrated regional water management plan
meq/L	milliequivalents per liter
mg/L	milligrams per liter
msl	mean sea level
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTUs	Nephelometric Turbidity Units
RWMG	regional water management group
SSIRWM	Southern Sierra Integrated Regional Water Management
SSIRWMP	Southern Sierra Integrated Regional Water Management Plan
SSIRWMR	Southern Sierra Integrated Regional Water Management Region
SSRWMG	Southern Sierra Regional Water Management Group
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TON	threshold odor numbers
USGS	U.S. Geological Survey

Executive Summary

This report summarizes a geologic, hydrologic, water quality, and water supply study for the Three Rivers area. The study was performed for the Southern Sierra Regional Water Management Group (SSRWMG) to provide additional information and findings for a portion of the integrated regional water management plan (IRWMP) area. This study could be used as a starting point for similar, more in-depth studies of other portions of the region. The Southern Sierra Integrated Regional Water Management Region (SSIRWMR) is the largest integrated regional water management (IRWM) region, in geographic area, in California. There is little groundwater information readily available from this area, as it largely depends on wells in fractured rock aquifers for its water supply. There are no incorporated cities, and residential areas are clustered around communities such as Auberry, Piedra, Dunlap, Three Rivers, and Springville.

The study area consists of those watersheds that contribute to groundwater recharge and the local water supply of Three Rivers. Nine watersheds have been identified within the Kaweah River watershed, and these are designated as *local watersheds*. Figure 1 shows the Southern Sierra IRWMP area and the Kaweah River watershed. Figure 2 shows the nine watersheds that make up the local watershed group.

Land ownership in the local watersheds is 54 percent government owned and 46 percent privately owned. There are 2,118 private parcels within the study area, with 80 percent being less than 10 acres. Most of the smaller parcels are located next to the Kaweah River and its tributaries. The town of Three Rivers has a population of 2,182 living in 1,018 households (2010 census data). A majority of the government-owned lands are contained in the Sequoia National Forest, Kings Canyon National Park, and Giant Sequoia National Monument.

Two types of aquifers are present: a small, shallow alluvial aquifer along the river bottom and a fractured bedrock aquifer. The rock fracture aquifer consists of an intersecting network of planar breaks in the rock, which in some cases extend for miles and cross watershed boundaries. In the Three Rivers area, the fractures cut across differing geologic units of granitic and metamorphic rock, resulting in a sporadic adverse effect on water quality. Water wells provide nearly all of the drinking water, with surface water and springs providing the remainder. Well yields varied from a low of less than 2 gallons per minute (8 percent of the wells) to more than 100 gallons per minute; 50 percent of the wells had yields greater than 15 gallons per minute. One-third of the wells are less than 100 feet deep. Shallow, low-yielding wells have a greater potential for failure in a drought.

Drinking water is supplied mostly from wells in fractured granitic bedrock. Groundwater recharge results from precipitation and groundwater seepage along the Kaweah River tributaries. Recharge is greatest in the upper watersheds where supply exceeds demand. Recharge is smaller in the lower watersheds; there is little or no recharge in the upper part of each watershed. Residential areas exist primarily in the lower watersheds, and many homes are located adjacent to the river tributaries where groundwater recharge from the river exceeds water supply demand.

Average daily water use per residence is 310 gallons per day (gpd) with seasonal variations, meaning a winter demand of 195 gpd and a summer demand of 480 gpd.

Groundwater in wells is a blend of high-quality surface water and variable-quality groundwater flowing through rock fractures. Water quality varies from high-quality water with a very low mineral content to a few wells containing notably elevated dissolved minerals, such as sulfur or hydrogen sulfide. Groundwater with high levels of these dissolved minerals is related to the underlying bedrock type of the well, typically metamorphic rock.

A summary of this study and its findings and conclusions were presented at a public meeting in Three Rivers on August 15, 2014. The presentation is attached as Appendix E of this report.

Geology, Hydrology, Water Quality, and Water Supply Study of the Three Rivers Area, California

Introduction

The Southern Sierra Integrated Regional Water Management (SSIRWM) region is the largest IRWM in California. It is also one of only two that are completely located within the Sierra Nevada Mountains.

There is little readily available groundwater information available from this area, as it is largely dependent on private wells in fractured rock aquifers for its water supply. There are no incorporated cities, and residential areas are clustered around communities such as Auberry, Piedra, Dunlap, Three Rivers, and Springville.

This report summarizes a geology, hydrology, water quality, and water supply study for the Three Rivers area. The study was performed for the Southern Sierra Regional Water Management Group (SSRWMG) to provide additional information and findings for a portion of the IRWMP area, and could be used as a model for similar, more in-depth studies of other portions of the region. This study is based on available data from the Three Rivers study area, which is defined by nine sub-watersheds located within the Kaweah River watershed.

Background and Purpose

The Southern Sierra Regional Water Management Group is aware that "very little groundwater information is available and accessible for resource planning in the Region where fractured bedrock aquifers serve remote, disadvantaged communities through individual wells and septic tanks." The regional water management group (RWMG) further notes that:

> *Towns such as Three Rivers exemplify the need for more information regarding both groundwater and surface water resources … Groundwater supplies fluctuate seasonally, but amounts and extents are unknown. The area's water quality also fluctuates seasonally, but locally, drinking water must be boiled to be drinkable. Because they, like most other communities in the SSIRWM region, rely on fractured-rock groundwater, it is critical to conduct this study in order to plan for and sustainable manage their groundwater supplies.… The SSRWMG will complete an update to its current IRWMP but lacks funds to conduct fractured-rock groundwater studies in key areas to better understand and thereby manage this resource. … It is unknown if developing a regional groundwater management plan is appropriate for this Region, but additional information and support for the IRWMP will advance groundwater management efforts. SSRWMG recognizes that, at this time, it is not feasible to construct a full groundwater management plan for the entire Region. Thus, the focus of data gathering should be localized compared to the size of the Region because of potentially prohibitive costs and most of the Region does not have traditional groundwater management basins. … Additional information and data would benefit not only Three Rivers or other suitable town and groundwater users, but will also*

serve as a starting point for other geographically similar watersheds and communities to begin to understand and manage the limited groundwater supplies.

In accordance with this SSRWMG statement, the intent of this study was to provide data, methodologies, and findings for the watersheds of the Three Rivers study area, using an approach that could be replicated in other parts of the SSIRWM region.

An initial presentation of this report was provided as an electronic document to the SSWRMG and at a town hall meeting in Three Rivers. This report provides additional information and an explanation of the methods used.

Scope of Work

The study included:

- Meetings with the Southern Sierra RWMG and their consultant, Provost & Pritchard Consulting Group.
- Data collection.
- Well log collection, review, and summaries.
- Creation of a water quality database of public drinking-water supply systems.
- Creation of a geographic information system (GIS) set of maps, data, and databases.
- Calculations for groundwater recharge estimates.
- Public meetings and presentations.
- Report writing.

Regional Setting

The Three Rivers study area is located in the southern Sierra Nevada Mountains within the Southern Sierra Integrated Regional Water Management Plan (SSIRWMP) area. As described by the recently completed SSIRWMP Final Report (Provost & Pritchard Consulting Group 2014):

The Southern Sierra Region covers approximately 6,195 square miles (3,964,800 acres) and includes the foothills and mountain regions of the Kern, Poso, White, Tule, Kaweah, Kings and San Joaquin River watersheds. These watersheds cover the Sierra Nevada portion of Fresno and Tulare counties and a portion of Madera County. The Region is considered appropriate as a RWMG since it has a strong hydrologic basis with borders based on watershed boundaries and the Sierra Nevada crest. The area covered by the Southern Sierra RWMG is coterminous with the area covered by [the] IRWMP.

The Region generally has abundant surface water supplies including several large rivers and scores of creeks and streams. However, most of the surface water rights are held in downstream areas of the Central Valley. Most of the local water users rely on hard rock (typically granitic) wells that have limited ability to hold and transmit groundwater, and typically have low yields. The water budget is not well understood in most of the region.

> *Over 75 percent of the land is administered by State and federal agencies, primarily the US Forest Service and US Park Service. Most of the foothill areas are privately owned and used for agriculture and ranching. The region only has a permanent population of 34,000, but over two million tourists visit the area each year which put demand on water supplies.*

Three Rivers is one of 16 small communities located within the SSIRWMP area and one of six communities located within the Tulare County portion of the area (Figure 3).

Study Area

The study area is located within the watershed of the Upper Kaweah River, consisting of 359,000 acres (561 square miles) of land. The Kaweah River watershed study area consists of two parts: the upper Kaweah River watershed, and the smaller, local watersheds of the Kaweah River that surround the town of Three Rivers (Figure 4).

For the upper Kaweah River watershed, the collected information consisted of available data regarding the water systems that provide public drinking-water supplies for various parts of Sequoia National Park. The data included the:

- Number of water systems and their locations.
- Sources of water to the various systems.
- Types of water sources.
- Water quality and water chemistry data.

For the smaller, local watersheds, the collected data included not only water system and water quality information, but:

- Climate data.
- Climate change.
- River hydrology.
- Geologic setting.
- Population and demographics.
- Land use.
- Land ownership.
- Parcel size.
- Information contained on well logs reviewed as a part of the study.

The smaller, local watersheds that provide drinking water supplies to the Three Rivers area are known as *the nine local watersheds of the Three Rivers area* (Figure 5). Together, the nine watersheds comprise the zone within which most residential areas in the Kaweah River watershed exist, and which provide most of the drinking water supplies for residences; motels and trailer parks; businesses; and public entities, such as schools. The watersheds range in size from 6,000 to nearly 13,000 acres, and in elevation from 700 to 9,250 feet above mean sea level (msl). The nine local watersheds are discussed in greater detail in the following sections.

The nine watersheds, their size, and relationship to the Kaweah River tributaries, are listed on Table 1.

Watershed boundaries were as determined by the California Interagency Watershed Mapping committee. The most current version uses the Calwater 2.2.1 dataset (California Interagency Watershed Mapping Committee 2015).

Regional Geography

The geography and landscape of the region is dominated by the Sierra Nevada Mountain Range. The range is more than 250 miles long and 80 miles wide at its widest point, narrowing to 50 miles wide near Three Rivers. The study area is located on the western slope of the Sierra Mountains, near the southern end of the range. The western slope of the range rises more gently than the abruptly rising eastern slope, resulting in an asymmetric mountain range with its crest nearer to the eastern side. The cause of the asymmetry is faulting along a tilted block. Mountain peaks along the crest range from 11,000 feet to over 14,000 feet. Mount Whitney, with an elevation of 14,505 feet, is the highest summit in the lower 48 states. The granite forming Mount Whitney is part of the Sierra Nevada batholith, a complex of granitic rock bodies that are present throughout much of the Sierra Nevada. The west slope of the mountain is in Sequoia National Park, in Tulare County, about 35 miles east of Three Rivers, marking the eastern limit of the Kaweah River watershed.

Climate

Climate of the San Joaquin Valley and the Sierra Nevada Mountains is largely controlled by the North Pacific High, a semi-permanent high pressure belt that migrates seasonally along the continental west coast. The region has a Mediterranean climate of warm, dry summers and cool, wet winters. The North Pacific High shifts north during the summer and then south during the winter. The summer high pressure condition brings hot, dry summers to the San Joaquin Valley, and temperate conditions to the mountains. The high pressure system moves south and weakens in the winter, allowing onshore movement of winter storm fronts and occasional periods of abundant rain and snow.

Higher elevations and mountain crests receive the most precipitation and experience the most extreme weather. Average precipitation for the western foothill zone is about 30 inches, increasing to 70 to 80 inches at higher elevations. Most of the precipitation falling at higher elevations accumulates as snowfall. The snowpack reaches depths of 10 to 15 feet at altitudes above 7,000 feet. Summer temperatures in the foothills can reach 100 degrees or more, with higher elevations being cooler and more temperate. Additional discussion regarding precipitation and temperature conditions in Three Rivers can be found in the following sections.

Climate Change

The Southern Sierra RWMG recognized the potential impacts that climate change may have on the region, and commissioned the GEOS Institute to prepare climate change projections for the SSIRWMP. The following sections are from their May 2014 report.

> *Broad scale changes in climate are already impacting local conditions across the West and are likely to continue and accelerate in the coming decades. Changes include the timing and availability of water, changes in tree and wildlife species, and changes in wildfire frequency and intensity.*

Local communities will need to plan for such changes in order to continue to provide vital services to local residents and to support the economy. Integrating climate change science into water management planning is one step towards preparing people for climate change.

Overall, managers in the Southern Sierra can expect warmer temperatures, declining snowpack, a dramatic shift in timing for runoff, and shifts in major types of vegetation… Average annual temperature in the Southern Sierra is expected to rise about 4° F by mid-century and 5–7 °F by late century. Summer temperatures are expected to rise slightly more (7–13 °F) than winter temperatures (5–7 °F) by the end of the century… Precipitation projections [show] both increases and decreases in precipitation possible throughout the year. Even with increases, however, drier conditions are expected due to greater evaporation and evapotranspiration.

The hydrograph for runoff is expected to change dramatically, with greater runoff January–April, as precipitation increasingly falls as rain instead of snow, and lower runoff May–September. [Models show] uncertainty in projections, with annual average precipitation that may increase, decrease, or remain similar to historic levels (GEOS Institute 2014).

Based on findings from the climate model projections, the water supply of the Three Rivers area has the potential to be affected. The shift toward a reduced snowpack, a variable rainfall, and an increased number of rain and snow events would increase spring runoff and reduce late season Kaweah River flows. Four of the nine local watersheds contain elevations of 7,000 to 9,000 feet, and a seasonal snowpack in these watersheds has contributed to a prolonged river flow. Accordingly, water systems that rely on surface water could be affected; however, most of the residential properties and water use occurs in lower elevation watersheds and rely on a smaller contribution from melting snow. Groundwater provides most of the water supply for the Three Rivers area, and groundwater recharge from infiltration of precipitation would not be as strongly affected.

Precipitation in the Kaweah River Watershed

There are a relatively large number of precipitation monitoring stations with available data for California. The 25 precipitation stations located in and around the Kaweah River watershed are listed in Table 2. Location of each station is shown on Figure 7. Monitoring agencies included the National Park Service, U.S. Forest Service, Pacific Gas & Electric, Southern California Edison, the U.S. Army Corps of Engineers, and the National Weather Service. Several stations have long monitoring histories and provide data through drought, normal, and wet years. The first station was located in Springville and monitored from 1896 to 1955; the Lemon Cove station has been monitoring since 1899.

Station location with respect to the watershed is also relatively good, with stations located on all sides and at varying elevations. Hyperlinks to the original source data are available on the electronic version of this document and can be found in Table 2.

Figure 6 shows lines of equal precipitation (isohyetals) for the region. Precipitation for the SSIRWM region begins at the edge of the valley or at the base of the foothills as rainfall. Average annual precipitation is 12 inches per year. As would be expected, precipitation increases with increasing elevation. The upper part of the Kaweah River watershed lies on the crest of the Sierra Nevada, where the average annual precipitation is 50 inches and falls as a mix of rain and snow.

For additional information, open the following table and figure:

TABLE
Table 2, Station Data and Average Precipitation.

FIGURE
Figure 7, Location of Precipitation Stations.

Precipitation and Temperature in Three Rivers

Temperature data are provided as background information and as an aid to understanding evaporation and evapotranspiration potential. Precipitation data are used as part of the information necessary to calculate groundwater recharge. Data were obtained from two sources: National Oceanic and Atmospheric Administration (NOAA) and the Western Regional Climate Center. Table 3 provides temperature and precipitation data for Three Rivers (Edison Power House 1) from NOAA for the 1980–2010 period.

Table 4 shows precipitation and temperature data from the Western Regional Climate Center for the Three Rivers weather station located at Edison Power House 2. The average values shown on Table 4 are for the relatively short period of record of 1909–1971. For a longer period of record, actual averages and extremes would be expected to change. For the Three Rivers PH2 station, average high temperature ranged from a low of 58.2 ºF in December to a high of 99 ºF in July. Average low temperature ranged from a low of 33.7 ºF in January to 61.6 ºF in July. A record high of 115 ºF occurred on July 2, 1950, but the hot summer trend continued with a record high for June of 114 ºF and a record high for August of 113 ºF. The record low of 16 ºF occurred on January 7, 1913.

For the Three Rivers PH2 station, the average annual precipitation is 20.6 inches. Precipitation of greater than 0.01 inch per day occurs an average of 52.4 days per year. Winters are cool and wet, with the rainy period extending from December through March, with an average monthly precipitation ranging from 3.0 inches in March to 3.9 inches in January. As indicated above, summers are hot and dry, with the dry period extending from June through August. During the hot summer months, the average precipitation ranges from 0.02 inches to 0.21 inches. Precipitation events can be extreme, with a one-day record maximum precipitation of 8.7 inches, which occurred December 31, 1955. Nevertheless, as described under the atmospheric rivers discussion, the precipitation can be intense and long lasting. The average snowfall is 0.7 inches per year, but does not accumulate from month to month.

For additional information, open the following table and figure:

TABLE
Table 5, Temperature and Precipitation Data for Three Rivers Edison Power House 2.

FIGURE
Figure 8, Monthly Climate Normals (1981–2010) for Three Rivers Edison Power House 1.

Geologic Conditions

The Sierra Nevada Mountains were formed by the uplift and tilting of a block of Earth's crust. It was shaped from the massive forces resulting from the subduction of an oceanic plate sliding underneath the continental plate. The earth's crust in the southern Sierra Nevada consists of several large granitic batholiths. These large pod-shaped features originated as a mix of the shearing and melting of the rocks forming the western edge of the continent and the rocks of the Pacific basin. The rising molten mass of granitic rock intruded into and incorporated overlying oceanic sediments. These sediments consisted of fine-grained sediments originating as erosion from the continental edge, and from streams carrying sediments to the ocean. Portions of the sediments were formed in the ocean and were made up of limestone. These sediments were subjected to heat and pressure from the rising batholiths and became the metamorphic rock now observed in the region. Bedrock, as a result, consists of metamorphic rock and various kinds of now-cooled granite.

As discussed in the following sections, the presence of the various rock types has influenced the quality of groundwater flowing through the now-fractured bedrock.

For additional information, open the following figures:

FIGURES
Figure 9, Regional Geologic Map.
Figure 10, Geologic Map of the Three Rivers Area.

Topography

Topography for the study area consists primarily of foothills or mountains, ranging from 700 to 9,250 feet in elevation. The terrain varies from gently sloping foothills to rugged and steep mountains and canyons. Much of the study area falls into what could be considered the foothill zone (elevations up to 3,500 feet). This land is characterized by small-to-moderate mountains marked with ravines and seasonal streams. The foothills of the lower elevation have a mixed vegetative cover of grassland, and chaparral and oak woodland. The eastern portion of the study area is significantly more mountainous, with elevations often well exceeding 3,500 feet. The land is characterized by steep and rugged mountains, canyons, and bare granite rock faces.

The western study area's watersheds primarily fall into the foothill elevation range of under 3,500 feet. The watersheds along the North Fork and South Fork of the Kaweah River and the North Side Lake Kaweah watershed all have significant portions of land at lower elevations that fall into this category. The Kaweah River tributaries in these watersheds start at lower elevations in the Sierra and generally do not experience rapid elevation drops when compared with the other forks. The study area's eastern watersheds, the East Fork and Marble Fork, are comprised of land located mostly at higher elevations in the mountains. The rivers in these watersheds drain rapidly from the High Sierra to lower elevations along mostly rough terrain.

Land Use and Population

Land Use

Land use in the watersheds of Three Rivers is 51 percent government owned and 49 percent privately owned. Government ownership is primarily Bureau of Land Management and Sequoia National Park. The eastern half of the watersheds in the Three Rivers area consists of approximately 20,000 acres of government land, including Sequoia National Park, which has an entrance just a few miles from the community of Three Rivers. A substantial portion of the western half of the watersheds is devoted to rangeland used for cattle grazing.

Private land use for the study area consists of five categories: Agriculture, Commercial, Grazing, Residential, and Miscellaneous. (See Table 4 and Figure 11 for more information.) Much of the land is steep and rugged oak woodland or foothills, and is used for rangeland grazing. Most of the area consists of larger parcels, with smaller residential areas occupying only 5 percent of the area. Residential land primarily consists of low density, single family estates and mobile homes generally located adjacent to the Kaweah River.

There is also little land use devoted to the Agricultural, Commercial, or Miscellaneous categories. Much of the commercial business depends on tourism related to the nearby national parks. Commercial properties are near the main roads in the study area. Land use is further detailed by individual watershed in Table 5.

The information on Table 6 is expanded in Table 7, which presents land use in greater detail by showing land by watershed for each of the nine watersheds of the Three Rivers area. For example, government-owned land is 50.6 percent of the total. That said, government-owned land in the Marble Fork of the Kaweah River comprises 99 percent of that watershed, while in the Lower North Fork of the Kaweah it is 6 percent of the total land use. In a similar way, grazing and rangeland varies from a low of less than 1 percent in the Marble Fork of the Kaweah River to a high of 81 percent in the Lake Kaweah watershed. Residential properties vary by less than 1 percent in four of the nine watersheds, including North Fork Kaweah, Marble Fork Kaweah, East Fork Kaweah, and Lower East Fork Kaweah. The highest residential property land use occurs in two of the nine watersheds, with each having more than 10 percent of the land classified as residential. These include North Side Lake Kaweah and Lower South Fork Lake Kaweah.

For additional information, open the following table and figure:

TABLE
Table 7, Land Use of Properties in the Watersheds of the Three Rivers Area.

FIGURE
Figure 12, Private vs. Government Owned Land Use.

Population

According to the U.S. Census Bureau, for the 2010 census, Three Rivers had a population of 2,182 people and 1,312 homes. There were an average of 1.7 people per home (household) compared with the statewide average of 2.7 people per home. The average for the United States is 2.67 people per home. Homes in Three Rivers have a 78-percent occupancy rate, compared with California's 92 percent. There are more owner-occupied homes in Three Rivers than in California as a whole, with 73 percent for Three Rivers and 56 percent for California.

In the study area, there are 16.9 people per square mile. Most of the population is in residential areas of smaller parcels (0.1 to 2 acres) that are located near the Kaweah River's tributaries and the main roads, as seen in Figure 12. The Lower North Fork, Lower South Fork, and North Side of Lake Kaweah watersheds contain most of the study area's residents. The East Fork and Marble Fork watersheds are remote, however, and contain few residents.

Nearly 15 percent of the homes in Three Rivers are seasonal. The area is a popular location for retirement, with 55 percent of homes having residents 50 years of age or older, compared with California's 29 percent. Only 16 percent of homes have residents under the age of 18, compared with California's 34 percent.

For additional information, open the following tables and figures:

TABLES
Table 9, Population of Three Rivers.
Table 10, Demographics of Three Rivers.

FIGURES
Figure 12, Map Showing Location of the Community of Three Rivers — a Census Designated Place.
Figure 13, Private vs. Government Owned Land.

Parcel Size and Distribution

There are 2,118 private parcels within the study area, with 80 percent being less than 10 acres. Most of the smaller parcels are located next to the Kaweah River and its tributaries. Information obtained from the Tulare County Assessor's Office shows that the Three Rivers Study Area contains 2,109 different parcels. Most of these parcels are less than 10 acres, and the smaller parcels are located primarily along the Kaweah River and its tributaries, as seen in Figure 14.

As might be expected, the largest percentage of properties in the watersheds of the Three Rivers area are in the 0.5–2.0-acre size range, and nearly 75 percent are 0.1–5.0-acres in size.

These smaller parcels are grouped adjacent to the Kaweah River and the North Fork and South Fork branches. Residential properties are the primary water users. Water is typically supplied by wells drilled into hard bedrock. Water demand is consequently greatest where higher concentrations of homes are located.

The Tulare County Assessor's parcel map database was used to identify residential properties. While accounting for only a small percentage of the total acreage, residential land accounts for a large majority of the total number of residential parcels of 1,302. Census data for 2010 shows 1,312 housing units in Three Rivers. This is a very close correlation using two different methods to derive the number of homes in the area. The Tulare County Assessor's data is used to estimate the number and distribution of residences across the watersheds and their location within Three Rivers.

For additional information, open the following tables:

TABLES
Table 11, Parcel Size of Properties in the Watersheds of the Three Rivers Area.
Table 12, Parcel Size of Properties by Watershed in Watersheds of the Three Rivers Area.
Table 13, Number of Residences in Watersheds of the Three Rivers Area.

Hydrology

Hydrology of the Kaweah River

The Kaweah river drainage is very short, and the topography climbs rapidly from around 1,000 feet in Three Rivers to between 3,000 and 5,000 feet on the ridgelines of the local watersheds, and continues climbing to 14,000 feet at Mt. Whitney, 50 miles to the east. The Kaweah River is a 58.5 mile-long river (Wikipedia 2016) located in the Southern Sierra Nevada.

The Kaweah River flows southwest to Lake Kaweah and then into the San Joaquin Valley. There are four main tributaries to the Kaweah River (see Figure 15 for location) — the North Fork, Middle Fork, East Fork, and South Fork. Marble Fork is a fifth but smaller fork. The heads of the tributaries approach the upper watershed area of the Great Western Divide. While each fork provides significant surface water contribution to the Kaweah River, the North Fork and South Fork have the greatest concentration of homes, and thus the greatest reliance on water from these river branches. The upper Kaweah River extends from its headwaters in the High Sierra to Terminus Dam. This drains about 561 square miles of the Southern Sierra Nevada.

The Middle Fork is the largest tributary and is considered the main stem of the Kaweah River. It begins at an elevation of about 12,000 feet. The Kaweah River is claimed to be the steepest river in the United States (Sequoia Parks Foundation 2014), dropping 10,000 feet in less than 40 miles. Only a handful of river systems in the United States have descents approaching or even exceeding 10,000 feet. Most of these begin in the Rocky Mountains. Falling into this category are many of the major rivers of the American West, including the Rio Grande, the Colorado, the Platte and Arkansas, and further north, the headwaters of the Missouri and Columbia. Without exception, these rivers that begin in the middle of North America are long. The mountains of the Sierra Nevada have a number of rivers that start at very high altitudes, including the Kaweah, Kern, Kings, San Joaquin, Merced, Tuolumne, and Stanislaus rivers. All other Sierra Nevada rivers are two to three times as long as the Kaweah. The biggest (by flow) and longest branch of the Kaweah is the Middle Fork. The two most significant sources of the Middle Fork are Lone Pine Creek (which starts at Lion Lake, elevation 11,005 feet) and Cliff Creek (which starts at Columbine Lake, elevation 10,970 feet). From these points of origin, it takes the Kaweah about 40 miles to flow to Terminus Dam (base altitude about 500 feet) or about 75 miles to reach the Tulare Lake Basin (altitude about 100 feet). This makes it 20 times steeper than the Colorado River. Photograph 1 shows Hamilton Lake, which is located near the headwaters of the Middle Fork of the Kaweah River.

For additional information, open the following photographs:

PHOTOGRAPHS
Photograph 1, Hamilton Lake at the Headwaters of the Middle Fork of the Kaweah River.
Photograph 2, Kaweah River just before entering Three Rivers.
Photograph 3, Kaweah River from bridge near the center of Three Rivers.
Photograph 4, Kaweah River below confluence with East Fork.
Photograph 5, Kaweah River before confluence with East Fork at Pumpkin Hollow Bridge.

River Flow

There are a number of USGS stream gaging stations on the Kaweah River and its major forks. Several of the gaging stations that monitored pipe flow and diverted water flows were not used. Other gaging locations measured natural river flow and were used in the report. Figure 16 shows the locations of the eight stream gages used in this report; Table 8 lists the gages by station number, period of record, minimum and maximum flow, and river tributary.

Snowmelt feeds small lakes and streams that then converge to form the major forks of the Kaweah River. There are "enormous peak flows in the spring and early summer. Flow shrinks to a trickle by late autumn. Winter rainstorms in lower elevations of the basin can also lead to very high but fleeting peak flows" (Wikipedia 2016). The U.S. Geological Survey (USGS) collects flow information for the upper Kaweah River at a stream gage located below Terminus Dam. Data is available for water years 1962–1990. During this period, the largest recorded flow was 6,000 cubic feet per second (cfs).

Runoff largely depends on watershed size and elevation. Watersheds at lower elevations that receive little snowfall tend to have brief peak-stream flows during and right after rainfall events throughout the rainy season; these streams usually have little to no flow during the dry months. Rivers and streams from larger and higher elevation watersheds normally reach peak flows during the snowmelt runoff period in spring and early summer. These flows can be enormous for a few months, but are usually reduced to a trickle by late summer.

Average annual flow during this period ranged from 104 cfs during dry years to 2,000 cfs during wet years.

There are eight stream gages on the Kaweah River at locations shown on Figure 16 and listed on Table 14. Stream gage data and water flow hydrographs can be found in Appendix A. The stream gages have relatively short monitoring periods, ranging from a maximum duration of 61 years to a minimum duration of six years. The short period of record limits the ability to forecast floods, droughts, and average river flows.

There are two stream gages located near Three Rivers. USGS stream gage 11210500 is located at elevation 611 feet (msl), downstream of Three Rivers and above Lake Kaweah. This location was monitored monthly from May, 1903 to September, 1961. Drainage area above the gage is 519 square miles. The stream gage measures flow from all four main forks of the Kaweah River. During this period, average annual flow was 6,731 cfs. The largest monthly flow was 4,837 cfs, which occurred in June, 1906. The smallest monthly flow was 12.6 cfs, which occurred in September of 1924.

The second stream gage near Three Rivers is USGS gage 11209900, located at elevation 810 feet (msl), upstream of Three Rivers. This location was monitored monthly from October, 1958 to September, 1990.

The drainage area above the gage is 418 square miles. The stream gage measures flow from three of the four main forks of the Kaweah River, but lays upstream of the confluence with the South Fork of the river. During this period, average annual flow was 6,757 cfs. The largest monthly flow was 4,474 cfs, in June of 1983. The smallest monthly flow was 18.5 cfs, in October, 1961.

For additional information, open the following tables:

TABLES
Table 15, River Flow at USGS Stream Gage 11210500, Kaweah River near Three Rivers.
Table 16, River Flow at USGS Stream Gage 11209900, Kaweah River below Three Rivers.

The Impact of Atmospheric River Events on Kaweah River Flow

The large size of the watershed, its steep terrain, and rapid drop in slope combine to produce the potential for significant flood events. The primary cause of floods appears to be a result of large atmospheric rivers and related storm events.

The largest documented event to affect the entire State of California was an 1861–1862 event that lasted 43 days and submerged central California under 20–30 feet of water. A larger atmospheric river hit the Tulare County area in 1867–1868, as a storm that began in mid-November and lasted through December.

The impact of this storm on the Three Rivers area is described below. Atmospheric rivers resulting in flooding have occurred in 1950, 1955, 1966, 1969, 1983, 1986, 1995, 1997, and 2014. Atmospheric rivers capable of producing megafloods have a recurrence interval of 100–200 years (Dettinger, Ingram 2013).

Atmospheric rivers are also known as *drought busters*, with one-third to nearly one-half of all persistent droughts in California ending in flooding resulting from atmospheric rivers (Dettinger 2013).

The following portion of the report relies substantially on information from a 2013 report by John T. Austin, *Floods and Droughts of the Tulare Lake Basin*. During large atmospheric river events, rain and snow can last for considerable periods. As noted by Austin, for a storm that occurred in December, 1867:

> *It had been raining in the Three Rivers area almost steadily for some 41 days, with heavy snows above the 5,000 foot elevation level. All the rivers were very high. The storm caused a large landslide dam on the South Fork of the Kaweah River. From the same source: "This is the largest landslide to have occurred in the national parks in historic time. This event is included in a USGS report of documented historical landslide dams from around the world. "A mass of dirt and vegetation broke loose from near the crest of Dennison Ridge … It swept 21/2 miles down into the canyon of the South Fork of the Kaweah." It was calculated that "350 million board feet of timber came down in that slide … When it came to rest [the landslide] formed a landslide dam that was ½ mile wide and over 400 feet high at its highest point. The South Fork Kaweah was presumably running at flood or near-flood stage because of all the previous rain and snow. It didn't take the river long to fill the temporary reservoir. The dam failed about 1:00 a.m. on December 22, just 25 hours after the slide occurred. The collapse of the landslide dam produced a flood surge about 40 feet deep that rushed down the South Fork Canyon. Joseph Palmer was a homesteader who lived in that canyon, several miles below the slide. "On leaving my cabin in the morning, I found that despite the heavy rain the river was low. From this I knew that a great slide had blocked the canyon above and that later the dam would give way and cause a flood … About 1:30 a.m. I was aroused by a tremendous thundering and rumbling sound … I jumped out of bed, grabbed my clothing, and ran for safety up the mountain side some 200 yards from the river. In a*

few minutes the flood came along with a crest of water some 40 feet in depth that extended across the canyon, carrying with it broken up trees which were crashing end over end in every direction with terrific force and sound." The bursting of the landslide dam at 1:30 a.m. on the morning of December 22 let loose a great flood, and the impounded water spilled and smashed its way down the South Fork Canyon, carrying everything before it, including giant sequoia logs … The flood swept past what is now Three Rivers, 15 miles below the landslide.

A series of four atmospheric river events occurred in November and December, 1950. According to Austin:

> *In Three Rivers, the rain was continuous for 20 hours. Long-time residents of that community could not recall such a heavy downpour… The 1950 flood was so newsworthy that it was written up in at least two issues of the New York Times… Flood crests on the Kings, Kaweah, Tule, and Kern Rivers exceeded all previous records. At the time, this was the biggest flood to occur on those rivers since the 1867-68 flood, an event that occurred before the onset of formal record-keeping. The 1867-68 flood remains the biggest flood to have occurred in historic times in the Tulare Lake Basin… The peak of the 1950 flood began coming through Three Rivers late on the night of November 18 and continued rising into the early morning hours of the 19th… That was the highest flow on that river since record-keeping began in 1910. In the December 1955 and December 1966 floods, the North Fork would experience flows over twice this great." Considerable damage was down to the Three Rivers area, including washed out bridges and roads, homes washed away, and damaged flumes. "So many water systems were contaminated that the county health department set up a program to inoculate all Three Rivers residents against typhoid… One source said that eight bridges in the town had been so badly damaged that they remained impassable." This included losing the "only highway bridge in and out of town, families on the North Fork were isolated from the main part of town because the Upper North Fork Bridge was gone. More than a dozen families on the South Fork Road were also isolated from the main part of town until the three bridges on that road could be replaced.*

There were two atmospheric river events in the winter of 1955–1956. As noted by Austin:

> *In Three Rivers, the various branches of the Kaweah rose steadily all day on December 22 due to the heavy downpour. There was no cause for alarm until shortly after midnight, when the rivers surged up with a thunderous roar and swept everything from their path. Many of the town residents were caught up in the battle to save lives that night." Bridges and roads were washed out. "Water and sand flooded all three of SCE's powerhouses, and all were knocked out of operation… The Three Rivers Motel and Trailer Court was demolished… Many homes were washed away and many others severely damaged. Much livestock was lost… The Highway 198 bridge over the South Fork of the Kaweah River withstood the flood. However, immediately east of that bridge, the mainstem of the Kaweah River overtopped and washed away 1,600 feet of the highway… This washed away five houses and the Dunlap Motel… Almost immediately after the flood, a cable trolley was rigged at the site of the washed-out North Fork Bridge so that people could be pulled back and forth.*

An atmospheric river in December 1966 caused extensive flooding across the region. As noted by Austin:

> *December 1966 was the wettest five days ever at 58 California stations… A total of 42 stations recorded their highest-ever 5-day rainfalls during this storm event. A total of 11 stations reported rainfall totals in excess of a storm with a recurrence interval of 1,000 years… Damage to Three Rivers included bridge and road washouts, damaged homes, damage to the SCE transmission*

lines, and the Three Rivers Golf Course was cut in two by a re-channeling of the mainstem of the Kaweah… The River Isle Trailer Park was located several miles up North Fork Drive… The trailer park was surrounded and overtopped by the 1966 flood, scattering trailers everywhere. Mobile homes stood on end, upside down, and sideways, completely ruined by the water. The situation was so dire that 19 people had to be evacuated by helicopters from Lemoore Naval Air Station… Fifteen-foot waves were reported to have been common the mainstem of the Kaweah River… The American Red Cross launched a major relief operation… Tulare Lake had been dry since about August 14, 1958. It came back to life on December 6, 1966.

Drought

While floods are a dramatic reminder of the destructive power of water, a quieter and longer-lasting disaster can be wrought by long-term droughts. California is now in its fourth year of record-breaking drought. Record-low precipitation and record-low snow surveys provide a measure of the magnitude of the drought. Falling water levels and reduced surface water supplies are two of the resulting impacts. All 58 California counties have now been designated by the federal government as primary natural disaster areas as a result of this drought. According to the U.S. Drought Monitor entry for California (http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA), 48 percent of the state is in a D2 (Severe) or D3 (Extreme) drought, and 44 percent of the state is in a D4 (Exceptional Drought). A statewide drought emergency has been declared (United States Drought Monitor 2016) . Rising temperatures have resulted in an increase in the number of broken temperature records. This warmth reduces the amount of precipitation, increases soil evaporation, and increases the demand for water by vegetation. California's 2015 wildfire season broke records for the number of fires.

California's most significant historical droughts were those that were long lasting and with the driest hydrology. Significant droughts identified by the California Department of Water Resources (DWR) include the six-year drought of 1929–34, the two-year drought of 1976–77, and the six-year drought of 1987–1992. Although the 1976–77 event was brief, 1977 was the driest year to that date.

The State Water Resources Control Board (SWRCB) has established California River Water Year Indices for several hydrologic basins, including the San Joaquin Valley. The Water Year Index is based on the unimpaired combined flow of four rivers: the Stanislaus, Tuolumne, Merced, and San Joaquin. The Kaweah River and the Tulare Lake Basin receive less precipitation and runoff than the San Joaquin River. There is no comparable index for the watersheds of the Kaweah River, so the San Joaquin Valley index is used for a relative comparison.

The indices classify the amount of water originating in a basin into five types: Wet, Above Normal, Below Normal, Dry, and Critical. For the 1901–2015 period, there have been 59 Wet to Above Normal years, 18 Below Normal years, and 38 Dry to Critical years. As of 2015, there was four years of drought. For most years, wet and dry years occur in randomly alternating intervals lasting one to two years; however, for the 1901–2015 period, there has been a boom and bust cycle of droughts and floods. During this 114-year period, there were six time periods with droughts of three-to-six years in duration (Table 17).

Austin summarized the droughts that occurred in the Central Valley over the much longer time period of 1566–1900. The determination of droughts and drought length were made based on tree-ring reconstructions, Tulare Lake elevations, and settler accounts.

Based on this information, droughts have typical durations of two to four years. For the 449 years represented by the 1566–2015 period, there have been 21 occurrences of droughts lasting two to four years, three occurrences of droughts lasting five to six years, and two occurrences in which droughts exceeded six years in duration, for a total of 132 years of drought (30 percent of the time). Methods used to identify drought periods for the 1566–1900 period shown on Table 18 are based on data which is more difficult to attain than that for the modern era, and this period likely represents only notable droughts. The notable droughts identified for the 1566–1900 period may be a measure of the probability of recurrence of future notable droughts — droughts that are long lasting, severe, and occur across broader areas of the state.

The Effect of Droughts as Assessed by River Gages

As described above, there are eight USGS stream gages on the Kaweah River that provide data for this report. Table 19 below shows the minimum river flow conditions that occurred on any date during the period of record. Two of the gages, 11208730 and 11210000 (Table 20), lie on river tributaries at locations where there are few or no homes. A third, 11209500, lies on the upper portion of the North Fork of the Kaweah River where there are few homes. These stream gages provide only a general indication of stream flow conditions.

The period of record for each of the stream gage locations is short; none of them exceed 100 years, and some are as low as six and 13 years. This is an inadequate duration from which to draw more than general conclusions. Table 19 represents known low flow conditions on the Kaweah River. A longer duration record would likely show lower minimum flows or zero flow conditions at other stream gage locations and at other locations along the Kaweah River.

Many of the area's residences are located along the main branch of the Kaweah River in and near Three Rivers. There are two stream gages located near Three Rivers, one near and one below the community.

The two stream gages indicate that the Kaweah River through Three Rivers has not been dry during any of the measuring periods. Conversations with local residents from Three Rivers also indicate that the river has not been dry in living memory.

Impact of the Drought on Water Wells

Tulare County collects reports on wells going dry within the county boundaries during the current drought cycle. Many private wells have been reported as dry or as having water quality problems resulting from declining water levels, but all of the reported wells have been from the valley floor and none have been from the foothills or the mountains. The dry wells appear to occur in clusters, and no explanation has been offered as to why. Nevertheless, the clusters are likely the result of local geologic and hydrologic conditions, as well as proximity to surface water features.

For additional information on Kaweah River hydrology and river flow, open the following tables and figures:

TABLES
Table 15, River Flow for Stream Gage 11210500, Kaweah River near Three Rivers.
Table 16, River Flow for Stream Gage 11209900, Kaweah River below Three Rivers.
Table 21, Water Year Index, San Joaquin Valley Hydrologic Basin.

FIGURES
Figure 17, Hydrograph for Stream Gage 11210500, Kaweah River above Lake Kaweah.
Figure 18, Hydrograph for Stream Gage 11209900, Kaweah River at Three Rivers.
Figure 19, San Joaquin Valley Water Year Index.
Figure 20, Stream Gages near Three Rivers, Lowest River Flow.
Figure 21, Dry Wells Reported to Tulare County.

Groundwater

Groundwater Hydrology

Precipitation from Pacific Ocean storms or from summer orographic storms in the watershed either evaporates, occurs as runoff to the Kaweah River as described previously, or infiltrates the ground surface into an underlying network of rock fractures. Groundwater occurs both in the fractured bedrock and in unconsolidated river bottom sediments of the Kaweah River. Groundwater flow is generally to the southwest, from areas of recharge in the mountains and along the Kaweah River to areas of discharge.

Alluvial Aquifer

Riverbed sediments and a shallow decomposed granite layer have formed an alluvial aquifer in a narrow band along the Kaweah River. It has an observable width of a few tens of feet to a few hundred feet. It also has a variable thickness. It is thinnest where the river is steep and cascading down resistant bedrock. It is thickest where the stream gradient gentles and widens along straight stretches between river bends. There are one or more radial (wagon wheel) wells located adjacent to the river, with shallow radials that extend under the riverbed, capturing poorly filtered water.

Bedrock Aquifer

Crystalline bedrock is nearly impermeable, as movement of water through the rocks depends completely on the presence of fractures in the rock. Groundwater percolates downward through soil and weathered rock into the fractured bedrock. The thin soil mantle that overlays the bedrock can be either large or extensive, and by itself does not yield significant quantities of water to wells. But the layer does aid in recharge by providing temporary storage of precipitation. Moisture in seasonally saturated soil migrates into rock fractures and then into the bedrock aquifer.

The bedrock has been fractured, in part, into an identifiable network of fractures. The fractures appear in two major groups. One is a northwest-to-southeast trending group and the other, at an approximate right angle, is a northeast-to-southwest trending group. Other fractures and fracture orientations are present, but these are the dominant fractures. Fracture spacing is variable, with smaller fractures spaced a few feet apart, and the larger fractures spaced hundreds of feet apart. Hard rock has greater decomposition rates along fractures as a result of breaking rock. Greater decomposition has resulted in higher erosion rates and the formation of depressions along the fractures. The broken and weathered rock has also produced a higher rate of soil formation. As a result, larger fractures can be identified on aerial photographs by linear depressions and more vigorous plant growth. The aerial photo (Figure 23) is from the Sierra Nevada, east of Three Rivers. Rock fractures are relatively easy to identify because of the contrast between the bare ground and the highly vegetated rock fractures. The northwest-to-southeast fracture set and the northeast-to-southwest fracture set are clearly visible in this photo. The fractures often extend for miles. Although a single fracture is highlighted on the air photo, many others can be seen.

Some areas have groups of rock fractures that are tightly spaced, have larger openings, or that extend to greater depths. Fracture groups have been observed to cross drainage basins, and can appear as large linear features, such as river bottom valleys. Where present, they have the potential to provide a more abundant and more dependable water supply. High-yielding wells encounter fractures of this kind. Where the large fracture groups intersect (usually at nearly right angles), well yields are the highest.

The land around Three Rivers has been more heavily weathered, and there is a more well-developed soil cover. As a result, the regional rock fractures do not present as well on an aerial photo. Where the rock is well exposed, the fracture pattern becomes more discernible, as in the aerial photo (Figure 24) that shows North Fork Drive. A northwest-trending fracture zone has formed a linear valley along the North Fork of the Kaweah River. Broken and fractured rock is visible, showing both this trend and a secondary northeast-to-southwest set of fractures.

The water supply for Three Rivers depends largely on water wells. The ability of a well to produce water is influenced by well construction, well depth, age of the well, and the presence of water-bearing fractures. Water supply for Three Rivers depends on groundwater recharge, which is discussed in the subsequent sections.

For additional information, open the following figure and photographs:

FIGURE
Figure 22, The Hydrologic Cycle and Groundwater.

PHOTOGRAPHS
Photograph 7, Example of Rock Fractures (Bristol, England).
Photograph 8, Example Groundwater Flow along a Fracture (Maine, U.S.).

Information from Water Well Logs

When drilling a water well, the drilling company is required to submit a well completion report (well log) to DWR that contains information about the location of the well, type of well, its purpose, subsurface materials encountered, the date of drilling, well construction information, notes about materials encountered, and estimated pumping rate. A search for private well logs that have been filed with DWR shows a total of 486 wells in the watersheds of the Three Rivers area.

Using the location information from the well logs, 439 private wells were identified as having adequate information to locate them within a given watershed, and also within a given township and section number. Of the 439 wells, 238 were located with high confidence. That is, the wells could be identified within a few hundred feet or so of their actual location. An additional 201 wells could only be located to within the nearest one-quarter to one-half mile. There are also 15 public drinking-water systems that rely on wells. These wells had high location accuracy. Some of the watersheds had as few as one or two wells identified from the DWR well-log database. Others had as many as 138 (this information is summarized in Table 22). Wells located within Sequoia National Park were not included in the well-log count.

Wells with useful location information were plotted on a map. It is apparent that most wells are near the Kaweah River or one of its tributaries. The largest number of residential properties is located there, and it is where the parcels are the smallest. Water demand would be greatest where there is a high concentration of residences with wells.

The number, location, and distribution of wells in the watersheds were used to provide an indication of whether the wells were preferentially located along the Kaweah River or were more or less evenly distributed across a watershed. Previously discussed census data indicated the numbers of residents and occupied housing. Number and size of parcels from Tulare County also show the distribution, density, and location of parcels of land in the area. Table 22 shows a total of 1,273 residences (based on Tulare County data). This agrees with the 2010 census data that indicate there are 1,331 occupied residences in the Three Rivers Area. Yet, there are significantly fewer wells than there are parcels. After accounting for public drinking-water supply wells with multiple connections providing water to approximately 399 homes, there are a total of about 874 wells in the watersheds of the Three Rivers area. Of the total number, there remain approximately 435 wells that have very poor location information or that do not have well logs on file with DWR.

Nearly 40 percent of the wells are in the North Side Lake Kaweah watershed. Lower North Fork, Lake Kaweah, and Lower South Fork watersheds contain 55 percent of the remaining wells. This means that four of the watersheds contain 95 percent of the homes and wells, and that water demand is by far the greatest in these four watersheds. The number of wells per square mile (section of land) is a further indication of the concentration of residential properties and water wells, as shown in Figure 27. As many as 55 wells have been identified in a single section of land. Since this is based on well-log identification information, the actual number of wells in this section could be 75 or more.

Information from the well logs commonly shows well depth. A review of the well logs shows that 481 of the 486 wells with well logs provided the driller’s statement of well depth (Figure 28). As discussed above, deeper wells have greater odds of encountering rock fractures, and these rock fractures contribute to a more reliable water supply.

About one-third of the wells are 100–250 feet deep; another third are 250–500 feet deep. It remains that nearly one-quarter of the wells are shallow, less than 100 feet deep. That said, shallow wells located along a river bottom and tapping into fractures hydraulically connected to a river would generally be more reliable than wells that are not located next to a river and/or do not have hydraulic connectivity to a river. Shallow wells in hydraulic connection with a river, though they have greater reliability, would also have greater potential for contamination from surface water.

Information from the well logs sometimes shows estimated well yield. A review shows that 214 of the 486 wells with well logs provided the drillers' estimate of well yield (Figure 29). The drillers' yield estimates were generally based on air pressure tests after completing well construction, but before any well development. An air pressure test involves lowering the drill string (without the drill bit) to near the bottom of the borehole, sending compressed air down the borehole, then measuring well production. Compressed air tests typically take from less than an hour to several hours. The driller estimates the well's yield by using a stop watch and a 5-gallon bucket. Well construction is then completed and a pump and pressure tank installed. Experience shows that well yield estimates by this method commonly show production that is two to four times higher than the actual long-term well yield.

For additional information, open the following table, figures, and appendix:

TABLES
Table 23, Distribution of Wells — Watersheds of the Three Rivers Area.

FIGURES
Figure 25, Well Types.
Figure 26, Well Locations in the Watersheds of the Three Rivers Area.
Figure 27, Number of Wells per section in the Watersheds of the Three Rivers Area.
Figure 30, Hydrologic Cycle.

APPENDICES
Appendix D, Private Water Wells — Well Log Information Three Rivers Area.

Water Systems

A water system consists of a water source and all of the components necessary to convey that water for use. Water systems vary in source and scope, and scale by demand and location. The community of Three Rivers does not have a public water system for all of its residents, but water is provided by a variety of entities, including:

- A small public water system (ID #1).
- Small commercial water systems for a golf course; service stations; restaurants; motels; other business enterprises; and public facilities, such as schools and a library.
- Mutual water companies providing public drinking-water supplies.
- Individual residential properties generally consisting of a single well.

Individual Water Supply Systems

Private domestic systems are small systems owned by an individual and used for residential use. Most of the single-family homes with an individual water supply have a single well and storage tank. These water systems are generally untreated, as there are no requirements to meet State or federal drinking-water standards when used for a single-family residence. Treatment, if it occurs, is only because of poor water quality or personal preference. Use is for potable water supplies and landscape irrigation. The number of private water wells was estimated earlier in this report.

Public Drinking-Water Supply Systems

A public water supply is any water system that has at least 15 service connections, or regularly supplies at least 25 individuals (U.S. Environmental Protection Agency 2015). Typically, water would be supplied by wells and/or surface water sources. These systems may require treatment and regular testing of the potable water supply, and must meet safe drinking-water standards set by the U.S. Environmental Protection Agency (EPA) and the State of California. Small public systems serving broad areas are often cost prohibitive for low-density communities, such as Three Rivers.

Twenty-three private water systems in the watersheds of the Three Rivers area are classified as public drinking-water supplies. Seven of these provide water for residential use, and the remainder consists of small public or commercial properties, such as the Three Rivers Library, motels, restaurants, and service stations. The residential water systems are typically small, having 19–105 service connections, and serve a population of 19–300. There are several small commercial properties similar to those found in the study area, but which are not classified as public drinking-water systems. No information was collected for those systems. They normally provide potable water for use by employees and customers, and may provide landscape irrigation water. Water sources for the water systems come primarily from wells drilled into fractured bedrock (77 percent), with some systems relying on spring water (3 percent) and others on intakes from the Kaweah River (21 percent).

Eleven of the 23 private systems have more than one source of supply. Often this is a new well replacing an older well, but some systems have some combination of one or more wells, springs, or intakes from the Kaweah River.

There are an additional eight public drinking-water systems located within the Kaweah River Watershed of Sequoia National Park. While most of these are located in the upper reaches of the Kaweah River Watershed, the Ash Mountain entrance to the park is located within the local watersheds of the Three Rivers area. Water sources for the water systems come primarily from surface water intakes on the Kaweah River (53 percent), wells drilled into fractured bedrock (33 percent), and spring water (13 percent). The water is primarily for potable use for tourists and park employees, with some limited landscaping use.

Four of the eight public drinking-water systems have more than one source of supply. This is commonly a combination of one or more wells, springs, or intakes from the Kaweah River.

For additional information, open the following tables, figures, and appendices:

TABLES
Table 24, Water System Information for Public Drinking-Water Systems — Three Rivers Area.
Table 25, Water System Information for Public Drinking-Water Systems — Sequoia National Park.

FIGURES
Figure 31, Public Water-Supply Wells in the Kaweah River Watershed.
Figure 32, Public Water-Supply Wells in the Three Rivers Area.

APPENDICES
Appendix A, Table A1, Public Drinking-Water Systems — Three Rivers Area.
Appendix B, Table B1, Public Drinking-Water Systems — Sequoia National Park.

Water Quality

For the water quality discussion in this section, data was collected regarding:

- Individual water wells based on well log information. Analyses of portions of this data have been previously presented in this report. This section also contains additional data analyses and assessments of water quality, based on notes contained in the well logs.
- Private water systems located in the watersheds of the Three Rivers area classified as public drinking-water supplies by the SWRCB. Analyses of portions of this data were previously presented in this report. This section also contains additional data analyses and a discussion of water quality, based on water quality sampling and analytical testing.
- Sequoia National Park water systems. Analyses of portions of this data were previously presented in this report. This section also contains additional data analyses and a discussion of water quality, based on water quality sampling and analytical testing.

The SWRCB maintains a database of water system information for public drinking-water supplies. The database contains records of analytical test results for all public drinking-water supply systems in California. Information about each water system includes the name of the water system; number of water sources; type of water source (groundwater, spring, or surface water); name and address of operator; number of connections; population served; and number of violations, if any. The database also contains records of analytical test results for four separate sampling periods: 1974–1999, 2000–2005, 2006–2010, and
2011–2015. A search of the database identified the known water systems, and a summary of water source information, analytical test results, and date of testing was created for each.

For public drinking-water systems in the Three Rivers area, 3,880 analytical test results have been tabulated and summarized. For public drinking-water systems in the Kaweah River watershed, located in Sequoia National Park, 4,005 analytical test results have been tabulated and summarized. The following sections provide these findings. As previously discussed, the analytical test results are samples from wells, springs, and surface water intakes. Although no attempt has been made to enumerate the number of analytical tests for each type of water source, it is apparent that the number of analytical tests is in proportion to the number and type of water sources. For the Three Rivers area, most of the test results represent groundwater. For Sequoia National Park, most of the test results represent surface water. Previous sections of this report discussed the relative proportions of water source types for each of the two areas.

Surface Water Quality

Streams flowing through the upper Kaweah River watershed drain the western slopes of the Sierra Nevada. The dominance of granitic rock and the amount of undeveloped and protected portions of the watershed in Sequoia National Park results in good quality surface water. Information collected regarding surface water quality of the Kaweah River comes from testing water samples from public drinking-water supplies. The SWRCB Drinking Water Program has required periodic sampling and analytical testing of public drinking-water supplies. This has included groundwater from wells, groundwater from springs, groundwater under the influence of surface water from radial wells with radials extending underneath the river, and surface water from intakes on the river.

As discussed above, there are 23 public drinking-water systems in the watersheds of the Three Rivers area. Five of these systems utilize surface water. The SWRCB-required sampling of public water supplies includes analytical tests from 1974 through 2014, the last date for which data was searched. The number and types of testing performed varied significantly from system to system and from year to year. The possible analyses included Title 22 organics; general mineral; general physical; nitrate; and radiological constituents, such as uranium, radium, and gross alpha. The test results are provided in Appendix A. A review of the results shows that no sample test exceeded primary drinking-water standards; however, a single sample exceeded the secondary drinking-water standard for manganese. The standard for manganese is 50 milligrams per liter (mg/L) and test results showed 81 mg/L. Manganese may cause staining in clothing and other materials. As might be expected, the Kaweah River through Three Rivers provides high-quality surface water.

There are eight public drinking-water systems in Sequoia National Park that are also within the Kaweah River watershed. Five of these systems utilize surface water as classified by the SWRCB. The SWRCB-required sampling of public water supplies includes analytical tests from 1974 through 2014, the last date for which data was searched. The number and types of testing performed varied significantly from system to system and from year to year. The possible analyses included Title 22 organics; general mineral; general physical; nitrate; and radiological constituents, such as uranium, radium, and gross alpha. The test results are provided in Appendix B. A review of the test results shows that a single sample from National Park Service (NPS) Wolverton exceeded the drinking water standard for Total Trihalomethanes. The standard is 80 micrograms per liter (µg/L), and the test result was 130 µg/L. NPS Ash Mountain also had one water sample that exceeded the primary drinking-water standard of 60 ug/L for Haloacetic Acids and 80 µg/L for Total Trihalomethanes. The test results were 120 µg/L and 150 µg/L, respectively. These test results may be outliers, as there does not seem to be a consistent exceedance. Six tests exceeded one or more of the secondary drinking-water standards for turbidity, color, or odor threshold. Exceedances were sporadic. Four of the six tests were exceedances for color. The standard for color is 15 color units, and test results varied from 20 to 25. The standard for odor is 3 threshold odor numbers (TON) and a single sample showed a test result of 4 TON. One test exceeded the standard of 5 Nephelometric Turbidity Units (NTUs) for turbidity by having a test result of 8.4 NTU. The Kaweah River in Sequoia National Park has high-quality water, with the possible exception of color.

Groundwater Quality

Groundwater from water wells drilled in fractured bedrock is the primary source of water for both individual systems and private water systems classified as public drinking-water supply. For public drinking-water systems, water from wells comprises 81 percent of the sources, springs comprise 3 percent of the sources, and surface water sources comprise the remaining 16 percent. Stated another way, the sampled sources for the 23 water systems consist of 30 active and inactive wells, one spring, and six surface water intakes from the Kaweah River.

For the 23 private water systems in the Three Rivers area classified as public drinking-water supplies, the SWRCB Drinking Water Program has required periodic source water sampling and analytical (chemical) testing. Nineteen of these systems utilize groundwater from water wells. The well sampling required by the SWRCB includes analytical tests from 1974 through 2014, the last date for which data was searched. The number and types of testing performed varied significantly from system to system and from year to year. The possible analyses included Title 22 organics; general mineral; general physical; nitrate; and radiological constituents, such as uranium, radium, and gross alpha. The test results are provided in Appendix A. A review of the results showed that two of the water systems had primary drinking-water standard exceedances for arsenic, and three water systems had exceedances for uranium and gross alpha. These exceedances may be a result of the wells drawing water from fractured granitic bedrock. It is not uncommon for wells completed in granite to experience problems from these constituents. In addition, two water systems had periodic exceedances for nitrate. There were very few secondary drinking-water standards exceedances. Three water systems had samples with exceedances for manganese, two had samples with color standard exceedances, and a single water system had samples with exceedances for iron.

Public drinking-water supplies for Sequoia National Park within the Kaweah River watershed rely primarily on surface water. Four of the eight water systems utilize groundwater supplied by wells. The four water systems have five active or inactive wells. The well sampling required by the SWRCB includes analytical tests from 1974 through 2014, the last date for which data was searched. The number and types of testing performed varied significantly from system to system and from year to year. The possible analyses included Title 22 organics; general mineral; general physical; nitrate; and radiological constituents, such as uranium, radium, and gross alpha. Test results are provided in Appendix B. A review of the tests showed generally high-quality water. None of the samples had exceedances for primary drinking-water constituents. Three of the water systems had secondary drinking-water standards exceedances for color, turbidity, iron, or manganese.

Groundwater Quality Information from Well Logs

The well log review of the 486 well logs identified in the Three Rivers area showed that for 10 of the well logs, the well driller noted an issue with water quality. The comments made note of high salt content, using phrases such as “Water very salty,” “Hydrogen sulfide,” “Sulfur water,” or “Considerable hydrogen sulfide and salt.” The 10 wells represent 2 percent of the well logs. The actual number of wells affected by salt or sulfur is unknown but probably higher than what is represented by notations on well logs.

The wells are present at locations along the main branch of the Kaweah River. There does not appear to be a pattern to their occurrence. Plotting salt and/or sulfur well locations on the geologic map suggests that some of the wells may be correlated with an underlying bedrock of limestone or metamorphic rock. Other wells do not appear to have a correlation with a rock type. In other regions of the Sierra Nevada, salt, sulfur, and high-temperature wells have been identified adjacent to ancient and inactive faults. The faults appear to act as conduits and sources of origin for the poor-quality water. It is not known if the wells are located on or adjacent to such a feature, but no known mapped faults are present.

For additional information, open the following tables, figures, and appendices:

TABLES
Table 26, Public Drinking-Water System with Water Quality Information — Three Rivers Area.
Table 27, Public Drinking-Water System Water Quality Information — Sequoia National Park.

FIGURES
Figure 33, Wells with Salt or Sulfur Noted on Well Log.

APPENDICES
Appendix A, Public Water-Supply Systems in Watersheds of the Three Rivers Area.
Appendix B, Public Water-Supply Systems in Kaweah River Watershed in Sequoia National Park.

Water Chemistry Comparisons and Water Sources

To better understand the origin of the water supply for wells in the Three Rivers area, an assessment was made of the source of water to wells, whether primarily from recharge from the Kaweah River, groundwater flowing through fractures in the bedrock, or a mixture of the two. The method used is commonly referred to as the Piper Graphical Method, created in 1953 by Arthur M. Piper of the U.S. Geological Survey. This method compares proportions of cations and anions expressed in concentrations of milliequivalents per liter (meq/L). The cations include calcium, magnesium, potassium, and sodium. The anions include bicarbonate, chloride, and sulfate. This method also uses either total dissolved solids (TDS) or specific conductance (EC) as a criterion.

Sufficient analytical tests are available only for public drinking-water systems; no private water-well samples from individual homes are represented in the following discussion. The SWRCB database of water systems and test results, described previously, were searched for available analyses containing all of the required constituents necessary for a Piper diagram analysis. For the 23 public drinking-water systems in the watersheds of the Three Rivers area, only seven systems with 16 water sources had sufficient data available. These include 14 groundwater (water well) and two surface water sources. For the eight public drinking-water systems in Sequoia National Park, all eight had sufficient data available for 16 water sources. These include seven groundwater (water well) and nine surface water sources. This means that there are a total of 32 source waters (wells plus surface water) available for Piper diagram analyses, including 21 for groundwater and 11 for surface water. No water tests for springs were available. There are a total of 137 water sample analyses having the required Piper diagram constituents, consisting of 37 water samples from the Three Rivers area and 100 water samples from Sequoia National Park.

Groundwater and surface water from the upper watershed of the Kaweah River, for the most part, has a very low dissolved-solids content. That water is essentially snowmelt. The results of analytical tests for several constituents were so low, they came in below laboratory instrument detection levels. It was not possible to identify the relative concentrations and proportions of cations and anions. This resulted in 40 of 100 of the Sequoia National Park water samples not being used in the Piper diagram and water chemistry discussion.

A Piper diagram provides a graphical method to compare and correlate water samples from various sources. Figure 35 shows the water sample analytical test results for Sequoia National Park and the Three Rivers area plotted on a Piper diagram. There are three Piper diagrams shown on this figure. The top portion shows a Piper diagram for groundwater and surface water source samples from Sequoia National Park. The middle portion shows a Piper diagram for groundwater and surface water source samples from the Three Rivers area. The bottom portion shows a combined graph. Each Piper diagram has three fields, two triangular fields for plotting cations and anions, and a third diamond-shaped field for plotting projections of both cations and anions. The location of the percentage of each of the constituents of the cations and anions are plotted on their respective triangular fields. The locations are then projected up into the diamond-shaped field. The intersection of the two projections is the plotting location for the particular constituent. The size or diameter of the symbol for the water sample is proportional to its TDS; larger symbols indicate a higher dissolved-solids (salt) content.

Comparing the Figure 35 Piper diagram test results with the Piper diagram water types (Figure 34) shows that there are two dominant water types: a calcium bicarbonate type and a sodium chloride type. Water originating from the watershed of the Kaweah River in Sequoia National Park has notably low dissolved-solids content. The symbol size on the graph of Figure 35 is proportionately small. This water is dominantly a calcium bicarbonate type.

Surface water in the Kaweah River watershed from Sequoia National Park, down and through Three Rivers, is a high-quality, low-dissolved-solids water of the calcium bicarbonate type. Precipitation, as rain and snowfall, is the source of this water. Infiltration into the underlying fractured bedrock, either from percolation through the soil or from the Kaweah River, is the source of groundwater. Groundwater flow through the fractures is slow, allowing for mineral dissolution and an increase in dissolved solids. The type of rock, whether granitic or metamorphic, determines the types of minerals that come into contact with the groundwater.

Water source samples from the Three Rivers area show the two dominant water types and indicate calcium carbonate surface-water sources blending with groundwater from areas of bedrock containing relatively high concentrations of sodium chloride. The water samples were obtained from public drinking-water supplies and are unlikely to include the extremes of saltwater noted on the well logs. The arrows shown on Figure 35 indicate the mixing of the two, calcium bicarbonate water with low dissolved solids mixing with sodium chloride water with higher dissolved solids.

Public drinking-water supplies use both surface water and groundwater to provide water of an acceptable quality, and water sample analyses can ensure this higher-quality water. Water chemistry and the water quality samples described in this and preceding sections do not include the possible extremes of sodium chloride, salt, and hydrogen sulfide water (noted on the well logs and suggested by the Piper diagram analyses) that existing or future private wells may encounter.

For additional information, open the following tables, figure, and appendices:

TABLES
Table 28, Piper Diagram Analytical Test Results, mg/L, and TDS Check.
Table 29, Piper Diagram Analytical Test Results, meq/L, and Balance Check.
Table 30, Piper Diagram Analytical Test Results, Percentage Reacting Values.

FIGURE
Figure 35, Piper Diagrams.

APPENDICES
Appendix C, General Mineral Analyses for Piper Diagrams.
Appendix C, Table C1, General Mineral Analyses for Piper Diagrams – Three Rivers Area.
Appendix C, Table C2, General Mineral Analyses for Piper Diagrams – Sequoia National Park.

Water Supply

Most of the local water supply originates as precipitation on the Kaweah River watershed. The majority is lost as a result of evaporation and evapotranspiration, with the remainder flowing downstream in the Kaweah River or infiltrating into the subsurface to recharge groundwater. Public water supplies rely on surface water from the Kaweah River for 16 percent of the total demand. Groundwater provides the remaining 81 percent of the water supply through water wells, plus an additional 3 percent from spring water.

Groundwater Recharge

There are several methods available to estimate groundwater recharge. Bedinger (1987) provides an annotated bibliography of references from worldwide studies. The Crippen method (1965) was created for use in the mountain basins of Southern California, and is locationally suitable for use in the Three Rivers Area. The Crippen method uses precipitation as the starting point, then incorporates losses resulting from evaporation and evapotranspiration, mountain basin physiography (steepness and elevation), climatic conditions (frequency of occurrence and magnitude of storm events), and geologic factors (soil and weathered bedrock thickness, root zone thickness, soil type, and rock type). Each of these factors is included in Figure 36, a summary graph of precipitation contrasted with groundwater recharge.

Precipitation was generally described in a previous section of this report. Precipitation does not fall uniformly across the watershed, but increases with increasing elevation. For purposes of calculation, the precipitation isohyetal map (Figure 6) has been divided into several bands of average precipitation (Figure 37), with the smallest band having a range of precipitation between 12.5 and 15.5 inches and an average precipitation of 14 inches.

The bands increase in steps of 4–10 inches, with the top band having a range of precipitation of 50–60 inches, resulting in an average of 55 inches for the top band. The precipitation bands' intersections with the nine watersheds of the Kaweah River are shown on Figure 37. Each band cuts across only a portion of each watershed. Groundwater recharge for each precipitation band within each watershed is calculated using Figure 36 (Crippen 1965).

Summing the recharge for each band in each basin provides an estimate of groundwater recharge. This is summarized on Table 32 and Table 33.

For example, the Middle Fork Tributary of the Kaweah River has two watersheds: Marble Fork and North Side Lake Kaweah. Marble Fork has an area of 8,512 acres, and North Side Lake Kaweah has an area of 11,326 acres.

There are five precipitation bands crossing the watersheds, beginning with 18 inches at the lowest elevation and ending with 35 inches at the highest.

Referring to the map on Figure 37, the highest part of the watershed consists of a 2,351 acre portion intercepted by the 35-inch average precipitation band. Using the Crippen method, it was determined that this precipitation would yield about 13.5 inches of recharge, or across this portion of Marble Fork, 2,645 acre-feet of groundwater. Performing the same calculation for the remaining two portions of the Marble Fork watershed would yield an estimated groundwater recharge of 5,544 acre-feet. Table 32 provides a short summary of estimated groundwater recharge for each of the four tributaries and nine watersheds. Table 33 shows additional detail regarding calculation of groundwater recharge.

Estimated groundwater recharge calculations are based on average precipitation conditions. Successive years of below-normal precipitation produces dryer soil conditions, greater relative evaporation, and lower infiltration. There is also a significant variation shown on Figure 36, particularly for lower precipitation values. Although the average graph value for precipitation of 20 inches suggests a groundwater recharge of two inches, the lower band of the graph suggests it could be half or less of this estimate.

Groundwater recharge would not be expected to be uniform across a given watershed. Steeper slopes provide greater runoff, north-facing slopes generally have thicker soil profiles and a lower evapotranspiration rate, and areas of shallow rock produce greater runoff and less infiltration. Other factors would apply. The calculated number is an average for the entire watershed.

For additional information, open the following tables:

TABLES
Table 31, Precipitation in Bands, Watersheds of the Three Rivers Area.
Table 33, Groundwater Recharge in Watersheds of the Three Rivers Area.

Water Use

Water demand or water use in the Three Rivers area was estimated using EPA guidelines and water use data provided by Yosemite Lakes Park. This is a residential community in the Sierra Nevada foothills of Madera County, which has a similar population, demography, reliance on groundwater from hard rock wells, and use of septic tanks for sewage disposal.

Average Residential Water Use

According to the EPA Water Sense website (https://www3.epa.gov/watersense/our_water/water_use_today.html), the average American family uses more than 300 gallons of water per day per home. According to the EPA, "roughly 70 percent of this use occurs indoors. Nationally, outdoor water use accounts for 30 percent of household use, yet it can be much higher in drier parts of the country and in more water-intensive landscapes. For example, the arid West has some of the highest per-capita residential water use because of landscape irrigation." The "How Much Water Do We Use?" pie chart on the EPA website shows the distribution of indoor water use (United States Environmental Protection Agency 2015).

Information from Yosemite Lakes Park shows 1,893 housing units. Water is supplied by a community owned and operated water utility company. Each home has a water meter that is read monthly.

The average daily use, on an annual basis, is essentially the same as that provided by the EPA. Nevertheless, the monthly water-use numbers show, as might be expected, that summer use is much higher than winter and early spring use. Outdoor landscaping at Yosemite Lakes Park is minimal, and homes with landscaping are typically of the low-maintenance type; there are few or no lawns.

The average peak summer water use of 484 gallons per day occurs in July. The average minimum winter or early spring low of 188 gallons per day occurs in April. The summer water use is double that of winter use.

The summer high water use coincides with low water availability. The Kaweah River would be running at a minimum, and groundwater levels would be expected to decline to seasonal lows.

Water Use Within Each Watershed

As discussed in previous sections, residences are not evenly distributed, but are instead concentrated along the main branch of the Kaweah River near the valley floor and in four of the nine watersheds. Some watersheds are occupied by as few as four homes, and others by as many as 494. Four watersheds have a combined total of 1,193 residences, while another four watersheds have a total of 39 residences. As discussed in the previous section, average residential water use is 310 gallons per day, or 113,500 gallons per year.

Table 35 was prepared using the number of residences per watershed and the water use per watershed. Water use is as low as 1.4 acre-feet per year in the North Fork of the Kaweah River, and as high as 171.6 acre-feet per year for the North Side Lake Kaweah watershed. Table 35 was prepared using the metric of 310 gallons per day per residence.

For additional information, open the following table and figure:

TABLE
Table 34, Residential Water Use in Yosemite Lakes Park, 2014.

FIGURE
Figure 38, Residential Water Use in Gallons per Residence per Day.

Water Balance

The difference between the amount of groundwater recharge a watershed receives and the amount of groundwater that is removed by pumping provides an indication of whether the watershed is in balance, in deficit, or has a surplus. Previous sections of this report have provided estimates of groundwater use and groundwater pumping by watershed and by Kaweah River tributary. Comparing the two provides data necessary for Table 36.

The water balance for each watershed and for each river tributary shows a significant surplus in each of the watersheds and for the Three Rivers area as a whole. As discussed above, the most dependable groundwater supply will be in the lower parts of each drainage, adjacent to the Kaweah River. Most of the water supply is provided by wells, and most of the wells are located near the Kaweah River, indicating that for most of the homes, under average climate conditions, there appears to be an adequate water supply. Also, as discussed previously, for shallow wells and wells located higher on the watershed, the water supply would be less dependable. For wells located in or near zones of poor-quality water, even though the quantity of water may appear adequate, the quality of water may make it unusable. The valleys forming the lower parts of the watersheds have, in part, resulted from enhanced erosion along the rock fractures, and the bedrock has a greater number and size of fractures along the valley floors. Wells near or along these rock fractures would have a higher probability of encountering a water-bearing fracture.

On the other hand, periods of extended drought, such as the current four-year drought, would produce a water balance significantly different than that shown above. Taking this into consideration, Table 36 is based on average precipitation. Dry years, such as 2014 and 2015, would show a negative water balance. This stresses the importance of the Kaweah River as a recharge source, benefitting those wells located near the river.

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Photograph Credits

Photograph 1. Hamilton Lake at the headwaters of the Middle Fork of the Kaweah River.
Source: Wikipedia. Photo by Jane S. Richardson.

Photograph 2. Kaweah River just before entering Three Rivers.
Source: GeoffreyGlass.com

Photograph 3. Kaweah River from bridge near the center of Three Rivers.
Source: GeoffreyGlass.com

Photograph 4. Kaweah River below confluence with East Fork.
Geographic coordinates: 36.4777, -118.845.
Source: Google Earth. Photo by Chris Sanfino

Photograph 5. Kaweah River before confluence with East Fork at Pumpkin Hollow Bridge.
Geographic coordinates: 36.4793, -118.839.
Source: Google Earth. Photo by Fluzao.

Photograph 6. Flood on the Kaweah River, January 2, 1997.
Source: Austin. 2013. *Floods and Droughts of the Tulare Lake Region*. Photo by Tony Caprio.

Photograph 7. Example of Rock Fractures.
(Bristol, England). Source: Stanford University.

Photograph 8. Example Groundwater Flow along a Fracture.
(Maine, U.S.). Source: State of Maine.