Owens Valley Groundwater Basin Water Budget Technical Memorandum

Prepared for
Owens Valley Groundwater Authority

Prepared by

DBS&A
Daniel B. Stephens & Associates, Inc.
a Geo-Logic Company

3916 State Street, Garden Suite
Santa Barbara, CA 93105
www.dbstephens.com
Project #DB18.1418.00

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Certification

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DANIEL B. STEPHENS & ASSOCIATES, INC.

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Name
Title
email
address
city, state zip

DRAFT

Name
Title
email
address
city, state zip

Date signed: **TBD**

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Acronyms and Abbreviations

Acronym	Acronym definition
AB	assembly bill
ADCP	acoustic doppler current profiler
AF	acre-feet
AFY	acre-feet per year
Ag	agriculture
AMI	automated (or advanced) metering infrastructure
amsl	above mean sea level
APN	assessor parcel number
B	boron
BCM	Basin Conceptual Model (USGS)
bgs	below ground surface
BMP	best management practices
BOS	bottom of screen

CA	California
CalGEM	Geologic Energy Management Division (formerly DOGGR)
CASGEM	California statewide groundwater elevation monitoring
CCR	California Code of Regulations
CDPH	California Department of Public Health
CFS	cubic feet per second
CIMIS	California irrigation management information system
Cl	chloride
COC	chemical of concern
CWC	California Water Code
DBS&A	Daniel B. Stephens & Associates, Inc.
DDW	[SWRCB] Division of Drinking Water
DEM	digital elevation model
DOGGR	Division of Oil, Gas, and Geothermal Resources (reorganized as CalGEM)
DPWM	Distributed Parameter Watershed Model
DQO	data quality objective
DTW	depth to water
DWR	[CA] Department of Water Resources
DWUs	downstream water users
EGM96	Earth Gravitational Model of 1996
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ET_0	reference evapotranspiration
FT or ft	feet
GAMA	[USGS] groundwater ambient monitoring & assessment
GIS	geographic information system
GPS	global positioning system
GBUAPCD	Great Basin Unified Air Pollution Control District
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
HASP	health and safety plan
HCM	hydrogeologic conceptual model
Hydrodata	hydrologic data server
ID	identification
IWVWA	Indian Wells Valley Groundwater Authority

JPA	Joint Exercise of Powers Authority
LADWP	Los Angeles Department of Water and Power
LAUWMP	Los Angeles Urban Water Management Plan
LiDAR	light detection and ranging
NCCAG	natural communities commonly associated with groundwater
M&I	municipal and industrial
MCL	maximum contaminant level
MOU	memorandum of understanding
MS4	municipal separate storm sewer system
NAD	North American datum
NAVD88	North American vertical datum of 1988
ND	not detected
NGVD29	national geodetic vertical datum of 1929
NO3	nitrate
NWIS	national water information system
OFR	open file report
OLGDP	Owens Lake Groundwater Development Program
OVGA	Owens Valley Groundwater Authority
PBP	priority basin project
PSI	pounds per square inch
PSW	public-supply well
PVC	polymerizing vinyl chloride
QA	quality assurance
QC	quality control
RASA	regional aquifer-system analysis
RP	reference point (elevation)
RWQCB	[CA] Regional Water Quality Control Board
SAP	sampling and analysis plan
SO4	sulfate
SUM	summation
SWL	static water level
SWN	[CA DWR] state well number
SWRCB	[CA] State Water Resource Control Board
TAF	thousand acre feet
TD	total depth

TDS	total dissolved solids
TFR	total filterable residue
TMDL	total maximum daily load
TNC	The Nature Conservancy
TOS	top of screen
URL	uniform resource locator (web address)
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
WGS84	world geodetic system 1984
WL	water level
WLE	water level elevation
WQ	water quality
WY	water year

1. Introduction

This section provides a quantitative description of the water budget for the Owens Basin, which includes the upland, headwater portions of the basin and the Owens Valley Groundwater Basin itself. California Department of Water Resources (DWR) Groundwater Sustainability Plan (GSP) regulations were used to guide this water budget analysis. Water budgets from previous investigations are summarized. Additionally, the Basin Characterization Model (BCM) (Flint et al, 2013) was used to develop and update the water budget. The DWR Handbook for Water Budget Development (2020) recommends using BCM for basins with no existing models. Los Angeles Department of Water and Power (LADWP) has developed a series of groundwater models based on MODFLOW for some portions of Owens Valley groundwater basin, but OVGA was not granted access to these models and hence BCM was chosen to quantify the water budget.

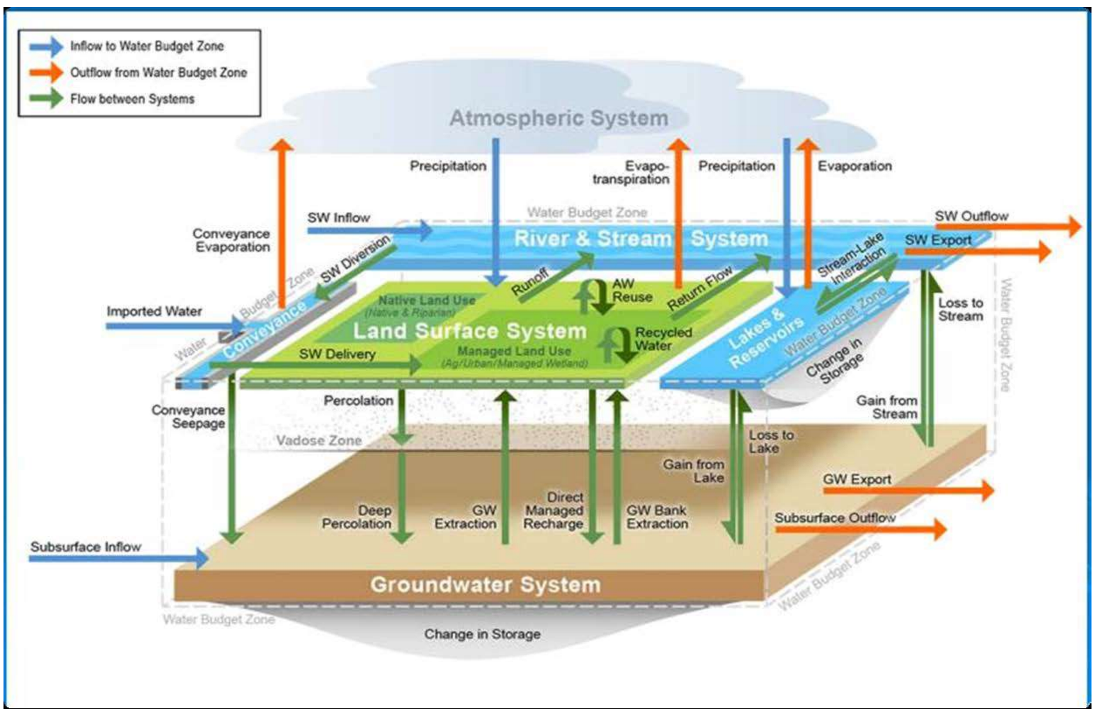

Figure 1-1 Total Water Budget Schematic

BCM is a regional water balance model that mechanistically models the transformation of precipitation into evapotranspiration, infiltration into soils, runoff, or recharge below the root zone (Figure 1-1). The complete basin water budget consists of three primary systems: river and stream; land surface; and groundwater. The interaction between the systems is conceptually shown in Figure 1-1 and illustrates the complexity of those interactions. Integrated surface water – groundwater flow models are the typical tool used to quantify the system interactions.

Figure 1-2 simplifies the BCM into its major components which are used to summarize and compare to other water budgets components and models. Although not depicted, sublimation (direct loss of moisture from snow) is an additional outflow component.

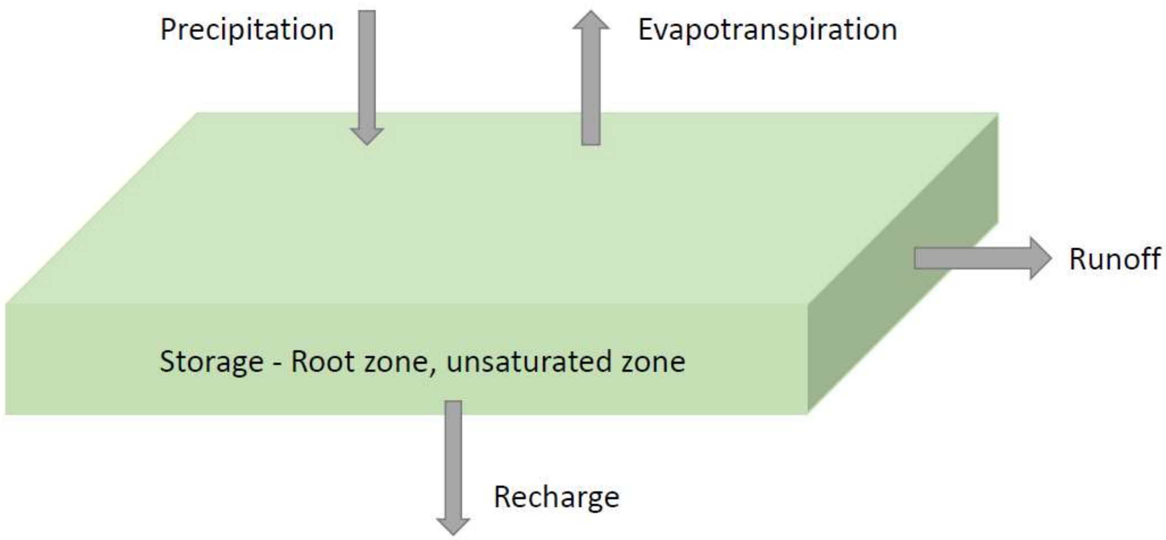

Figure 1-2 Simplified Land System Water Budget Schematic

The BCM is not a groundwater flow model and as such does not quantify groundwater extractions or the subsurface movement of groundwater. It is used in this GSP to comply with DWR's GSP strictures, to give a background estimate of basin-scale water budget components, and to model potential changes related to future climate scenarios.

The Owens Valley Groundwater Basin is somewhat unique in that an extensive network of surface water gauging and groundwater level monitoring has been in place for numerous decades. Results from the BCM are compared to previous water budget estimates, additional modelling, and measured data to provide an order-of-magnitude validation. However, examining long-term groundwater levels trends (as described in GSP Section 3) is the more effective way to judge whether water budget inputs and outflows are balanced (sustainable) in the Owens Valley groundwater basin.

2. Historical and Current Water Budgets

The water budgets for the basin were evaluated using information from previous investigations, as well as the Basin Conceptual Model (Flint et al, 2013). Additionally, a Distributed Parameter Watershed Model (DPWM) was developed for a specific management area (Fish Slough/Tri Valley).

2.1 Previous Investigations

Previous investigations of the Owens Valley Basin have addressed the water budget analytics from differing perspectives. Some have chosen to lump together major components of the water budget while others offered a more detailed itemization of those major components. The periods of record, availability of data, and geographic boundaries of areas included in their analyses are all highly variable.

2.1.1 Owens Basin

Harrington (2016) summarized the water budget for the entire Owens Valley groundwater basin using the water budgets for the Tri-Valley, Owens Valley, and Owens Lake management areas (Table 2-1) to identify some of the regional components of the water budget. In each of the subareas the greatest uncertainty was in the recharge value with the totaled difference being 51,100 acre-feet between the low and high estimates.

Table 2-1 Owens Valley Groundwater Basin Water Budget (Harrington, 2016). All values in acre-feet.

	Recharge	Discharge	
		Pumping	ET, springs and seeps, baseflow to water courses
Tri Valley region	17,000 - 43,000	16,200 - 19,600	5,000[1]
Owens Valley	183,800	98,000[2]	84,000
Owens Lake	29,500 - 55,000	2300[3]	51,400
Subtotal	230,800 - 281,900	116,500 – 119,900	141,400
Total	**220,200 - 271,300[4]**	**251,900 - 260,300**	

[1] 4,400 AFY groundwater discharge at Fish Slough plus 600 AFY discharge in Chalfant Valley.
[2] 78,000 AFY pumping by LADWP plus 10,000 AFY by non-LADWP pumpers, plus 10,000 AFY from flowing wells.
[3] Includes 2,000 AFY for irrigation and 300 AFY for water bottling plant.
[4] 10,600 AFY was subtracted to account for overlap Owens Valley (Danskin, 1998) and Owens Lake (MWH, 2011) study areas.

2.1.2 Owens Valley Management Area

The major historic water budget evaluations in this area (Figure 2.7) came from the USGS multi-year groundwater modeling project (Danskin, 1988) and several studies authored by MWH, long-term Owens Valley consultants for LADWP (Table 2-2).

Table 2-2 Previous Water Budget Evaluations - Owens Valley

Author	Report Year	Water Budget Timeframe
USGS (Danskin)	1988	1935-1970
MWH	Multiple	1985-2009*

Table 2-3 Previous Investigations of Water Budgets - Owens Valley (adapted from Danskin 1998, Table 10).

Component	Average (ac-ft/yr) 1970-84	Low (ac-ft/yr) 1970-84	High (ac-ft/yr) 1970-84
Precipitation	2,000	0	5,000
Evapotranspiration	-72,000	-50,000	-90,000
Tributary streams	103,000	90,000	115,000
Mountain front recharge	26,000	15,000	35,000
Runoff from bedrock outcrops in valley fill	1,000	0	2,000
Reservoirs and lakes	1,000	-5,000	5,000
Canals, ditches, ponds	31,000	15,000	60,000
Irrigation returns and stock water	10,000	5,000	20,000
Pumped and flowing wells	-98,000	-90,000	-110,000
Springs and seeps	-6,000	-4,000	-10,000
Subsurface inflow	4,000	3,000	10,000
Subsurface outflow	-10,000	-5,000	-20,000
Owens River above LA Aqueduct in take			
-Channel seepage	-3,000	0	-20,000
-Spillgates	6,000	3,000	10,000
Owens River below LA Aqueduct intake	-3,000	-1,000	-8,000
Total recharge	**184,000**	**131,000**	**262,000**
Total discharge	**-192,000**	**-155,000**	**-258,000**
Change in groundwater storage	**-8,000**	**-24,000**	**4,000**

These reports suggest a long-term change in groundwater storage equating to about -8,000 ac-ft/yr on average but with a range extending from -24,000 (low) to +4,000 ac-ft/yr (high) for the historic periods of record (Table 2-3). It should be noted that since this historical water budget was computed, the Inyo-LA LTWA has been implemented, resulting in reduce average pumping in the Owens Valley management area and increased surface water application to the Owens Lake.

2.1.3 Fish Slough/Tri-Valley Management Area

The major water budget evaluations in this area came from the technical reports of PWA in the early 1980s, with MHA providing insight in 2001 and Inyo County Water Department in 2016 (Table 2-4). These water budgets were of a more limited scope than for the Owens Valley Management area and, therefore, contain a higher degree of uncertainty.

Table 2-4 Previous Water Budget Evaluations – Fish Slough

Author	Report Year	Water Budget Timeframe
ICWD (Harrington)	2016	General
MHA	2001	General
PWA	1983	1979, 1982
PWA	1980	pre-1980

The water budget for the Fish Slough area lacks information on major components such as groundwater outflow, and therefore, makes the evaluation of the water budget incomplete (Table 2-5).

Table 2-5 Previous Investigations of Water Budgets - Fish Slough

	Low Estimate (acre-ft)	High Estimate (acre-ft)
Precipitation	1,100	1,500
GW Discharge to Springs	4,100	8,400
Surface-Water Outflow	3,100	6,200
GW Pumping	0	0
Phreatophytic ET	500	2,400
Groundwater Outflow	?	?
Total Inflows	**?**	**?**
Total Outflows	**?**	**?**
Change in Storage	**?**	**?**

The previous evaluations of the water budget for the Tri-Valley area are the same ones as the Fish Slough area: PWA, MHA, and ICWD (Table 2-6).

Table 2-6 Previous Water Budget Evaluations - Tri-Valley

Author	Report Year	Water Budget Timeframe
ICWD (Harrington)	2016	General
MHA	2001	General
PWA	1983	1979, 1982
PWA	1980	pre-1980

Table 2-7 provides the low and high water budget estimates for the Tri-Valley area. The change in storage varies from -1,888 ac-ft/yr (low estimate) to as much as 6,418 ac-ft/yr (high estimate). Data from the Tri-Valley area, as described in GSP Section 3.5, is the most limited set in the Owens Valley groundwater basin and the uncertainty in previous water budgets is likely higher than other portions of the basin.

Table 2-7 Previous Investigations of Water Budgets - Tri-Valley (adapted from MHA 2001, Table 5.8)

	Low Estimate (acre-ft)	High Estimate (acre-ft)
Recharge from Precip	0	0
Runoff		
-White Mountains	14,100	25,829
-Benton Range	1,500	1,500
-Bishop Tuff	1,000	1,000
Irrigation Return flows	451	14,700
Surface-water Outflow	0	0
GW Pumping	16,200	19,629
Phreatophytic ET	1,084	3,282
Groundwater Outflow	1,655	13,700
Total Inflows	**17,051**	**43,029**
Total Outflows	**18,939**	**36,611**
Change in Storage	**-1,888**	**6,418**

2.1.4 Owens Lake Management Area

The Owens Lake area has been studies by several investigators starting as early as 1915. A few of those investigators results are summarized below (Table 2-8). LADWP has been conducting extensive additional hydrologic work on the Owens Lake as part of its Master Plan EIR since 2010, but the EIR was unavailable at the time of GSP preparation.

Table 2-8 Previous Water Budget Investigations - Owens Lake Management Area

Author	Report Year	Water Budget Timeframe
Lee	1915	1906-1914
Williams	1969	1937-1960
Lopes	1988	Pre-1988
Wirganowicz	1997	Pre-1997
Schumer	1997	Pre-1997
CDM	2000	Pre-2000
MWH	2013	1971-2012(?)

In 2000, CDM presented more detailed water budget evaluations for the Owens Lake area as part of a groundwater model for the lake area (Table 2-9). Their calibrated water budget depicted the inflows and outflow in balance at about 67,324 ac-ft/yr.

Table 2-9 Calibrated Water Budget (CDM, 2000)

Inflows – AF/yr		Outflows – AF/yr	
Down-Valley Flow	4,184	ET	55,427
		Playa/Brine Pool Evaporation	*29,242*
		Lone Pine Area	*6,140*
		Seep & Spring	*20,045*
Mountain Block Recharge	36,707	Spring and Seep Discharge and Discharge from Flowing Wells	8,318
Inyo	*3,959*		
Coso	*7,321*		
Sierra Nevada	*17,556*		
Deep	*7,871*		
Stream Channel Recharge	7,489	Groundwater Pumped from Wells (includes Lone Pine Pumping)	1,894
Inyo/Coso Range	*1,568*		
Sierra Nevada Range	*5,921*		
Interfluve/Fan Recharge	1,716	Owens River Discharge	1,687
Haiwee Reservoir Subsurface Inflow	3,791		
Centennial Flats Subsurface Inflow	1,095		
Lone Pine Area Recharge	12,342		
Total	**67,324**		**67,326**

Similar to the calibrated water budget, the steady-state water budget shows the total source/sink value at approximately 57,433 ac-ft/yr (Table 2-10).

Table 2-10 Steady-State Water Budget Summary (CDM, 2000)

Budget Element	Steady State Water Budget		
	IN (AF/yr)	OUT (AF/yr)	Net (AF/yr)
Storage	**0**	**0**	**0**
Constant Heads	**8,034**	**(8,761)**	**(727)**
Brine Pool	0	(8,761)	(8,761)
Haiwee Reservoir	8,034	0	8,034
Drains	**0**	**(11,734)**	**(11,734)**
General Heads	**12,840**	**(821)**	**12,019**
Rivers	**16,572**	**(20,537)**	**(3,965)**
Owens River	12,649	(18,703)	(6,054)
Lone Pine Streams	4,106		4,106
Diaz Lake	242	(340)	(98)
Wells	**17,524**	**(2,092)**	**15,432**
Recharge	**2,464**		**2,464**
Evapotranspiration	**0**	**(13,616)**	**(13,616)**
Total Source/Sink	**57,433**	**(57,561)**	**(127)**

2.2 Basin Conceptual Model

The BCM output archived by the USGS at https://ca.water.usgs.gov/projects/reg_hydro/basin-characterization-model.html (accessed, August 2020) were used in the development of the water budget. The BCM's "historical period" for the water budget spans 1986-2016 and the "current period" spans from 2006-2016. The results from the BCM outputs for the various spatial areas described in the subsections of 2.2 and are also totaled and summarized in tabular form in Section 2.3 and Table 2.11.

The BCM is a grid-based model that calculates water balance at each grid at the monthly time step. Numerous grids, each with spatial resolution of 300m x 300m, represent the entire Owens Basin (watershed). The Owens Basin is spatially divided into the headwater basin and the DWR-delineated Owens Valley Groundwater Basin. The headwater areas are primarily high-altitude mountainous areas (e.g. Sierra, White, Inyo ranges) and are where most of the runoff and recharge is generated. The water budget for this spatial area is referred to as the "Contributing

Area." Water budget outputs from the BCM grids within the Owens Valley Groundwater Basin proper are computed and referred to as the "Groundwater Basin."

Figure 2-2 below shows the spatial areas that represent the headwater/contributing area and the groundwater basin area for the Owens Basin in its entirety.

Figure 2-1 Map showing contributing area (headwater) and the groundwater basin for Owens Basin.

2.2.1 Owens Basin Contributing Area

Water budget for the contributing area for the historical and current periods are shown below in Figure 2-3 and Figure 2-4.

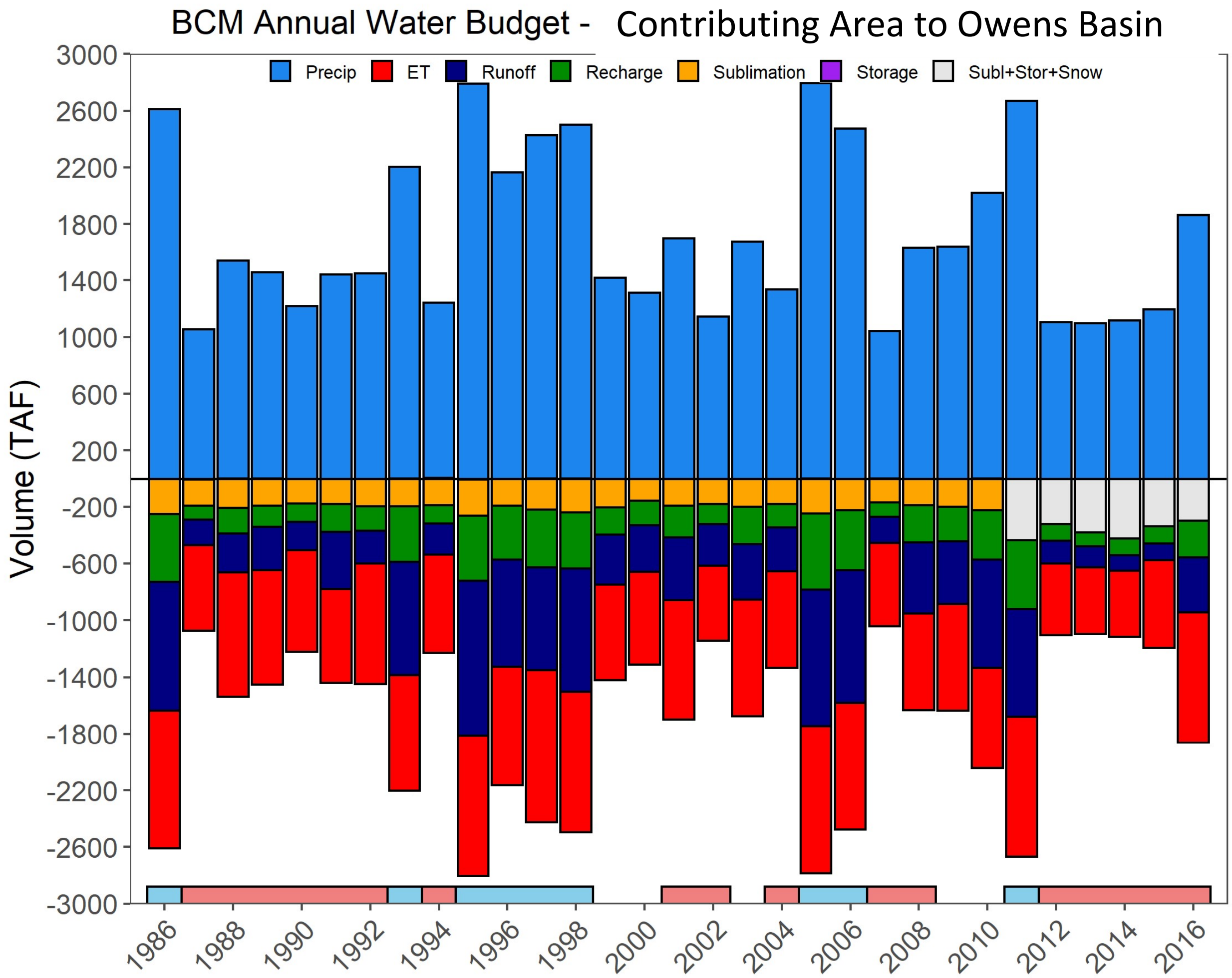

Figure 2-2 Historical water budget for the contributing area (headwater) to the Owens Basin. Wet and dry years shown as blue and red bars at the bottom of the graph.

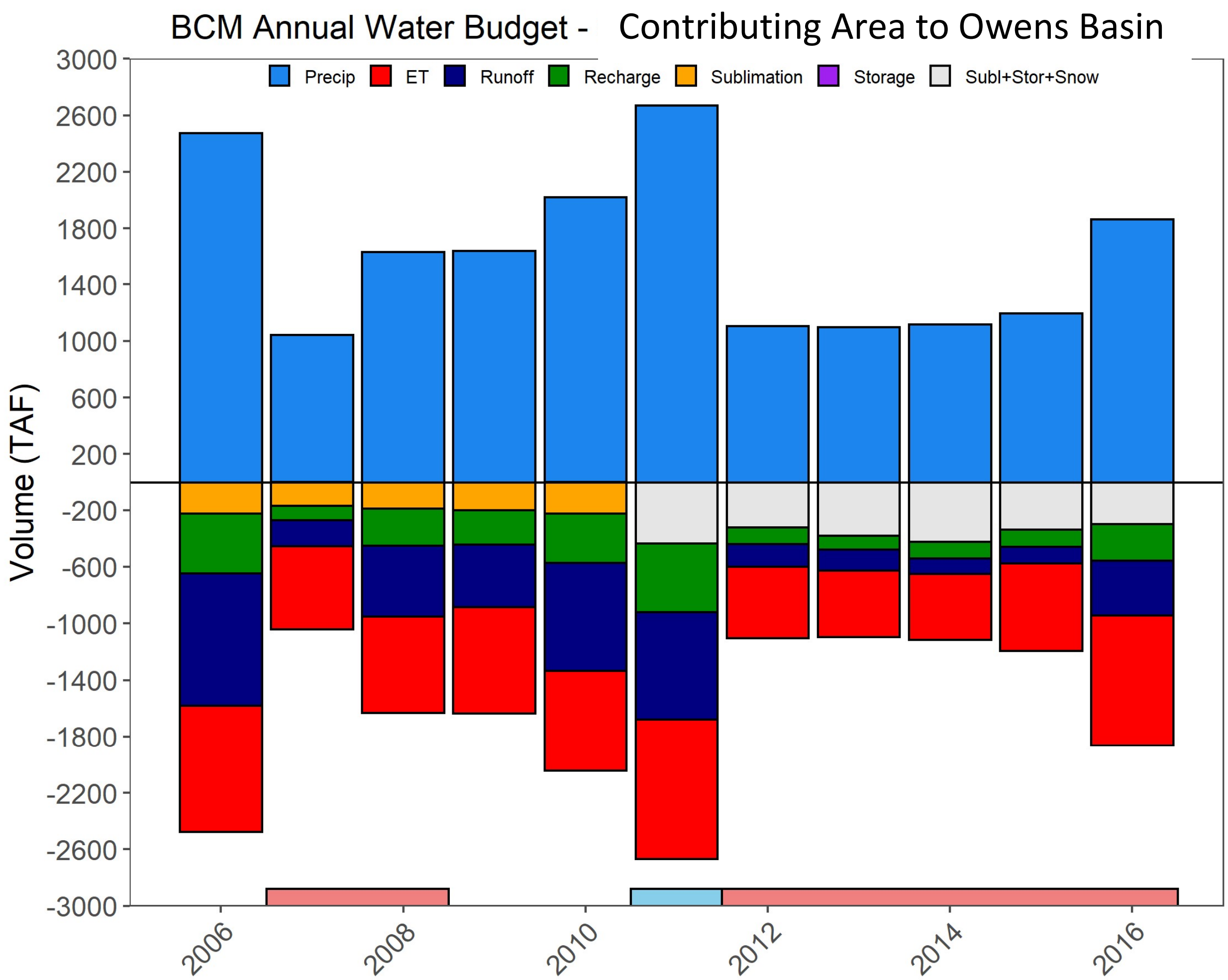

Figure 2-3 Current water budget for the contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

2.2.2 Owens Valley Groundwater Basin

Water budget for the Owens Valley groundwater basin for the historical and current periods are shown below in Figure 2-6 and Figure 2-7

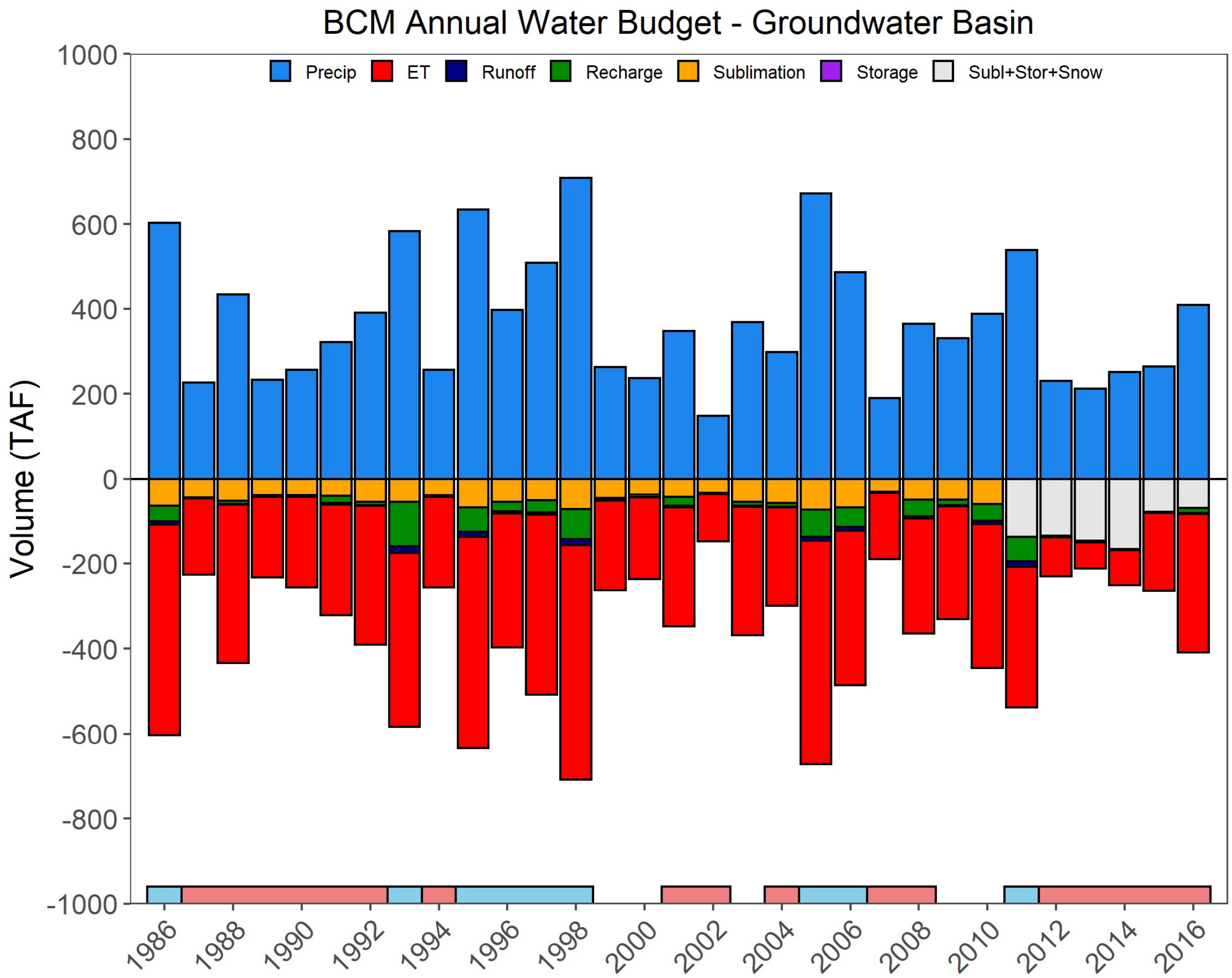

Figure 2-4 Historical water budget for the Owens Valley groundwater basin. Wet and dry years shown as blue and red bars at the bottom of the graph.

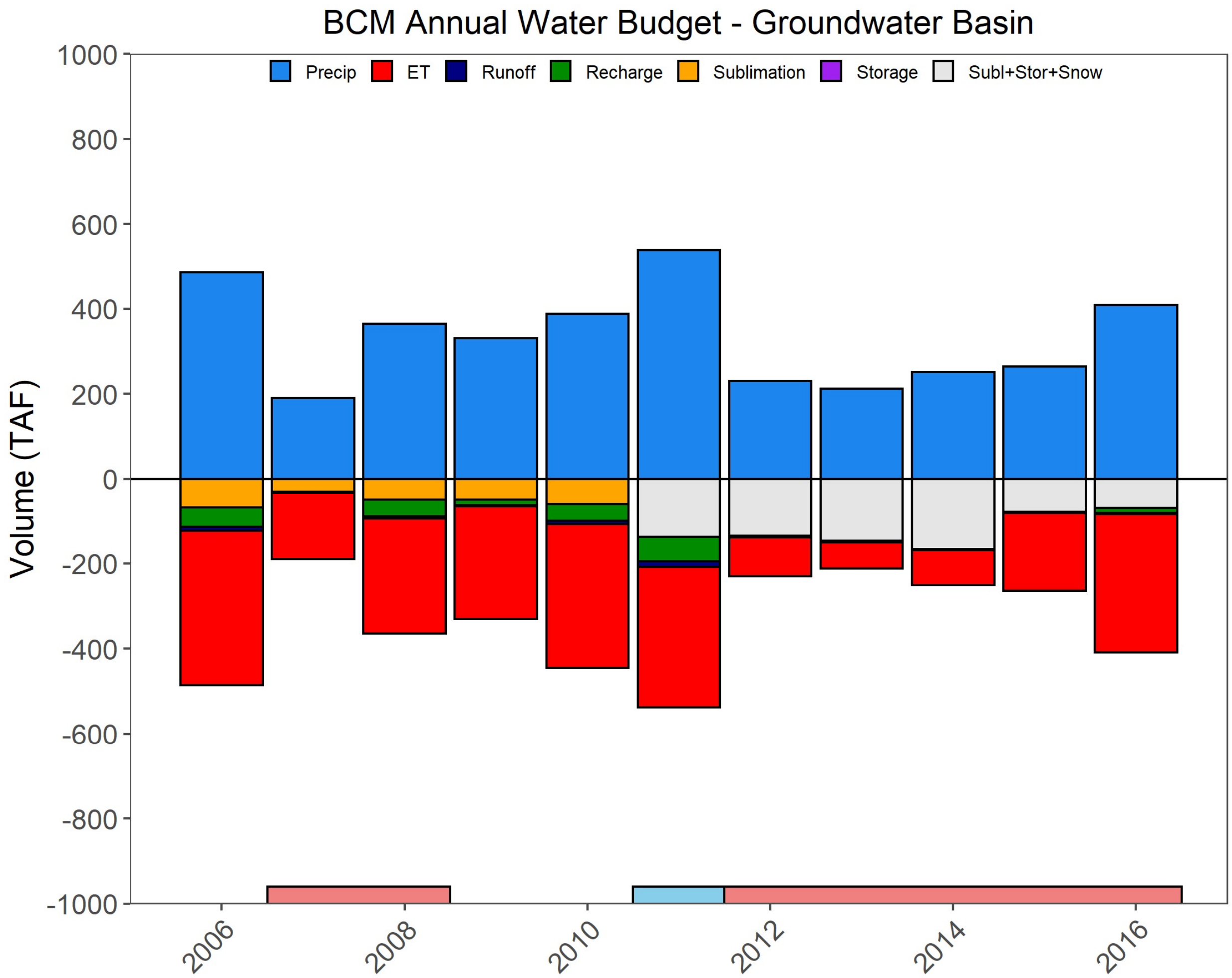

Figure 2-5 Current water budget for the Owens Valley groundwater basin. Wet and dry years shown as blue and red bars at the bottom of the graph.

2.2.3 Management Areas

For the purposes of the GSP, the Owens Basin was divided into three specific management areas: Owens Valley, Fish Slough/Tri Valley, and Owens Lake. Figures 2-7 shows a map of the contributing area and groundwater basin for these three-management areas.

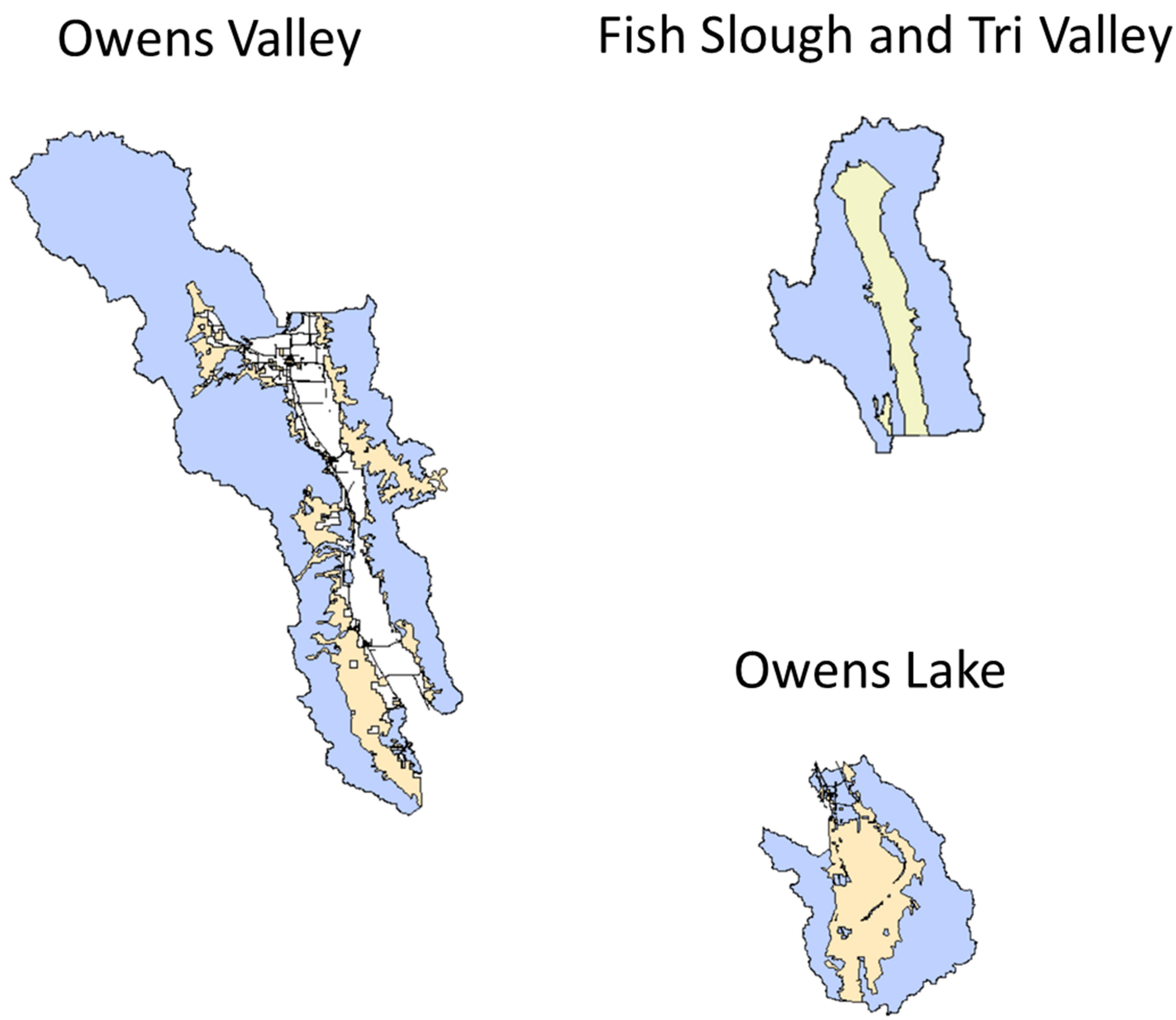

Figure 2-6 Map showing contributing area (headwater) shown in blue and the groundwater basin for the three management areas within the Owens Basin.

2.2.3.1 *Owens Valley Management Area*

The historical and current water budget for the contributing area to the Owens Valley management area is shown in Figure 2-8 and Figure 2-9.

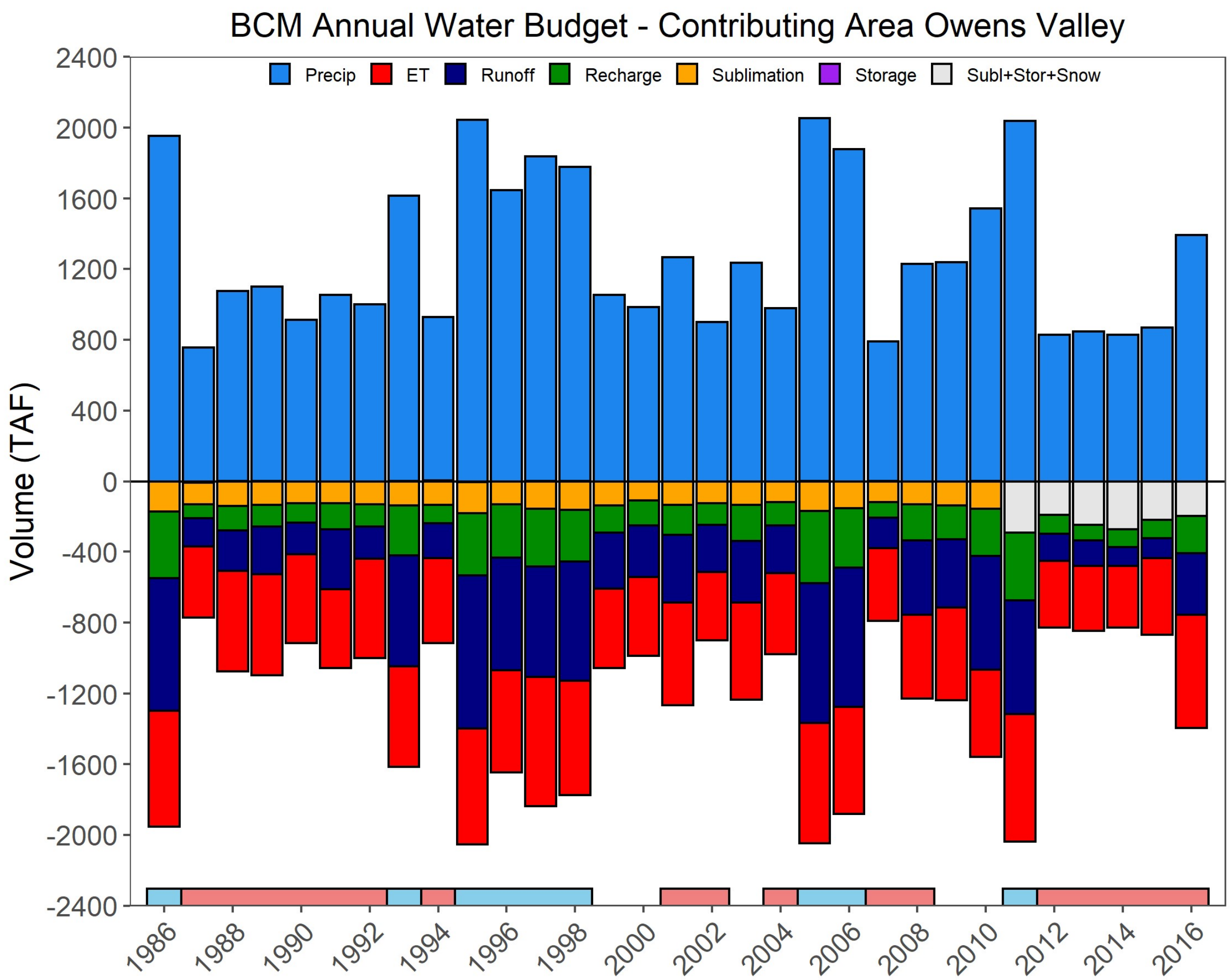

Figure 2-7 Historical water budget for the Owens Valley management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

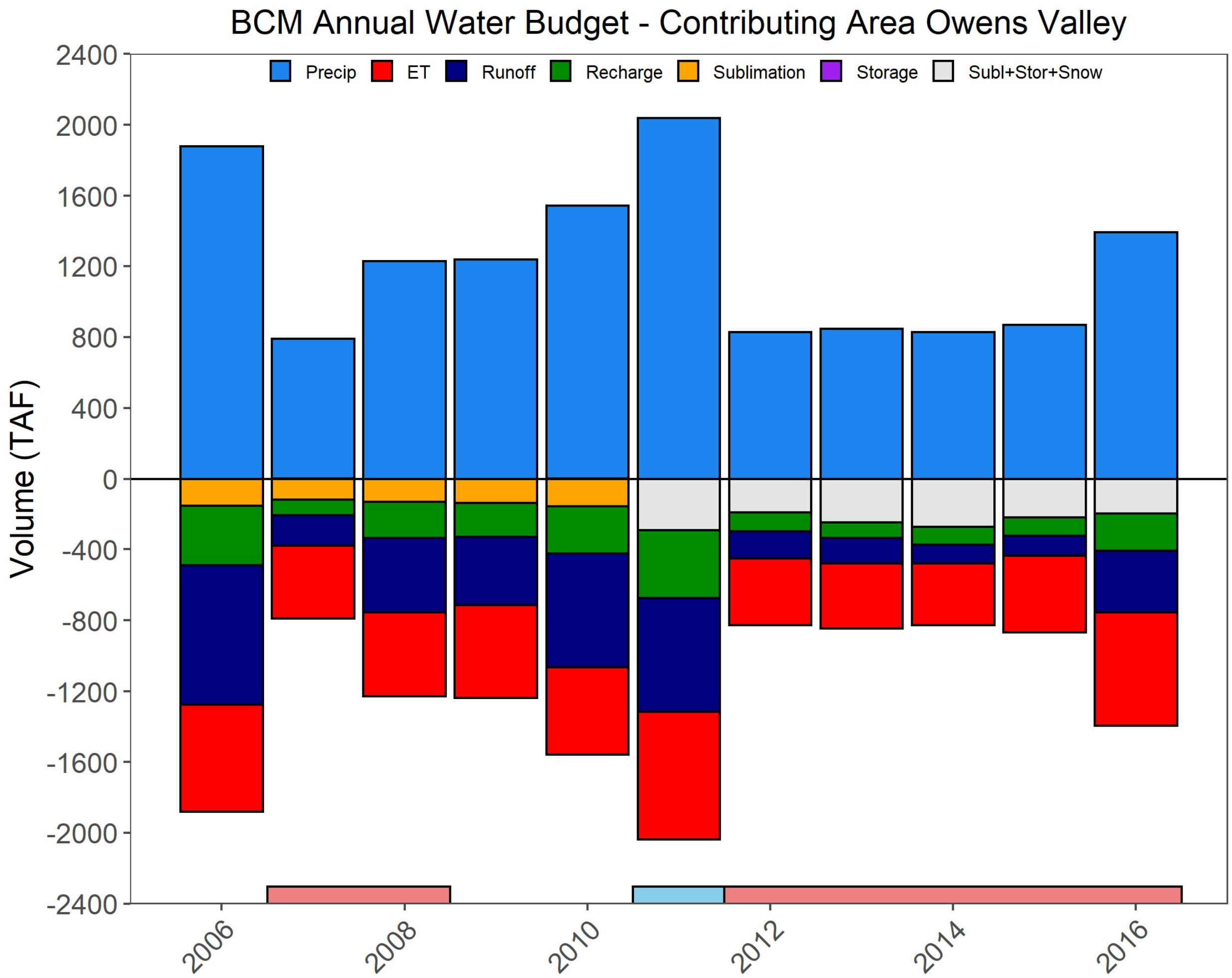

Figure 2-8 Current water budget for the Owens Valley management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

The historical and current water budget for the groundwater basin in the Owens Valley management area is shown in Figure 2-10 and Figure 2-11.

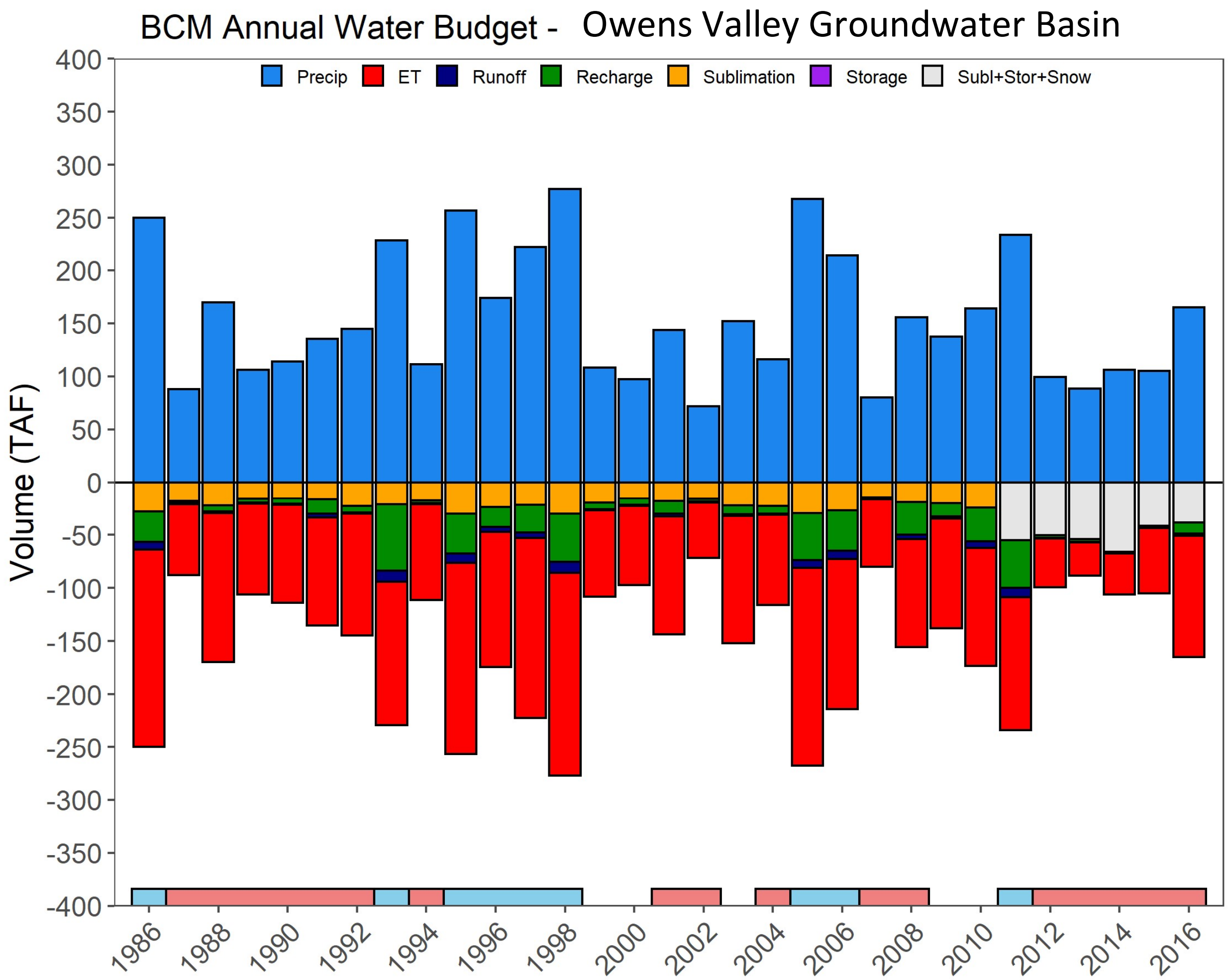

Figure 2-9 Historical water budget for the groundwater basin in the Owens Valley management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

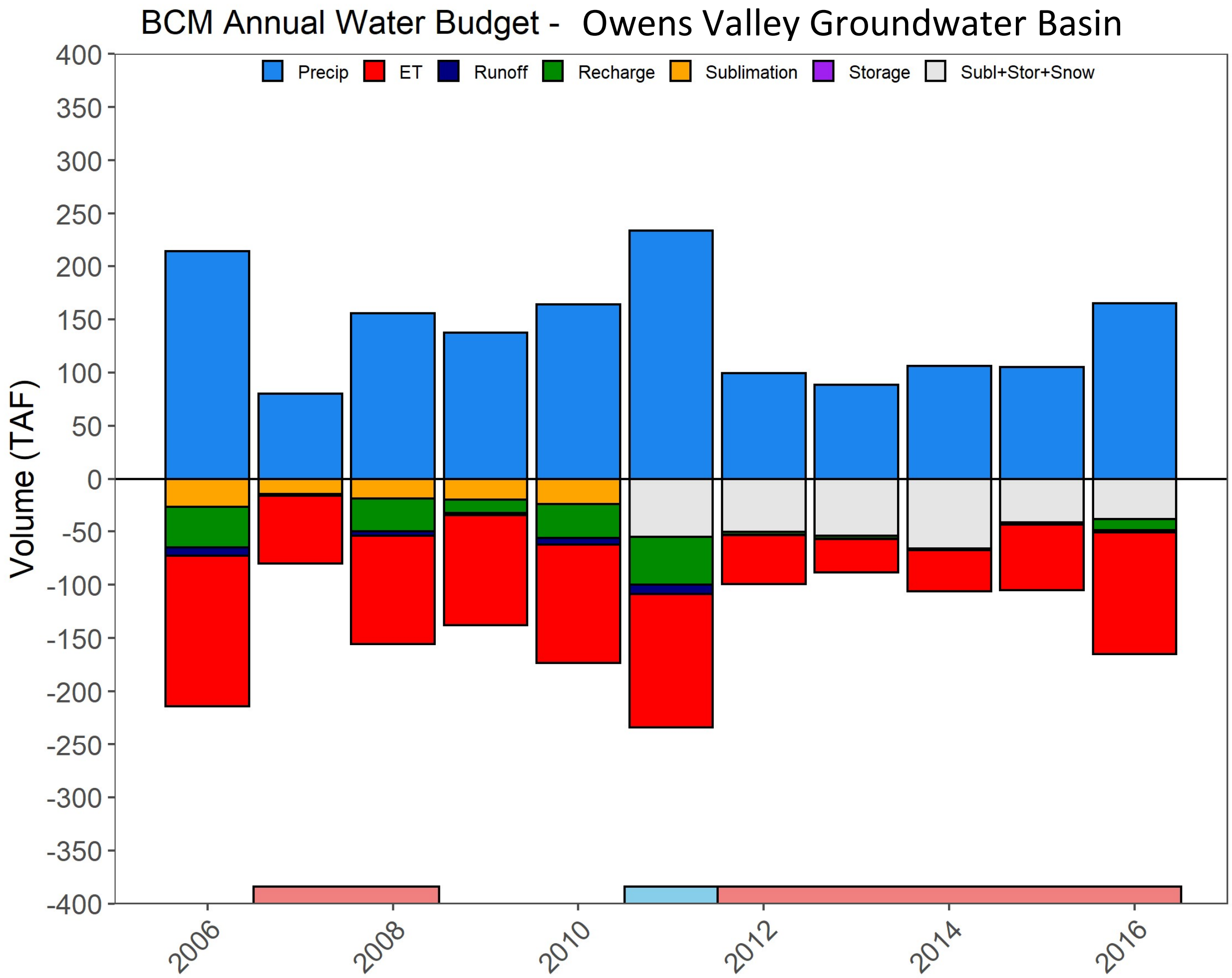

Figure 2-10 Current water budget for the groundwater basin in the Owens Valley management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

2.2.3.2 *Fish Slough/Tri-Valley Management Area*

The historical and current water budget for the contributing area to the Fish Slough/Tri-Valley management area is shown in Figure 2-12 and Figure 2-13.

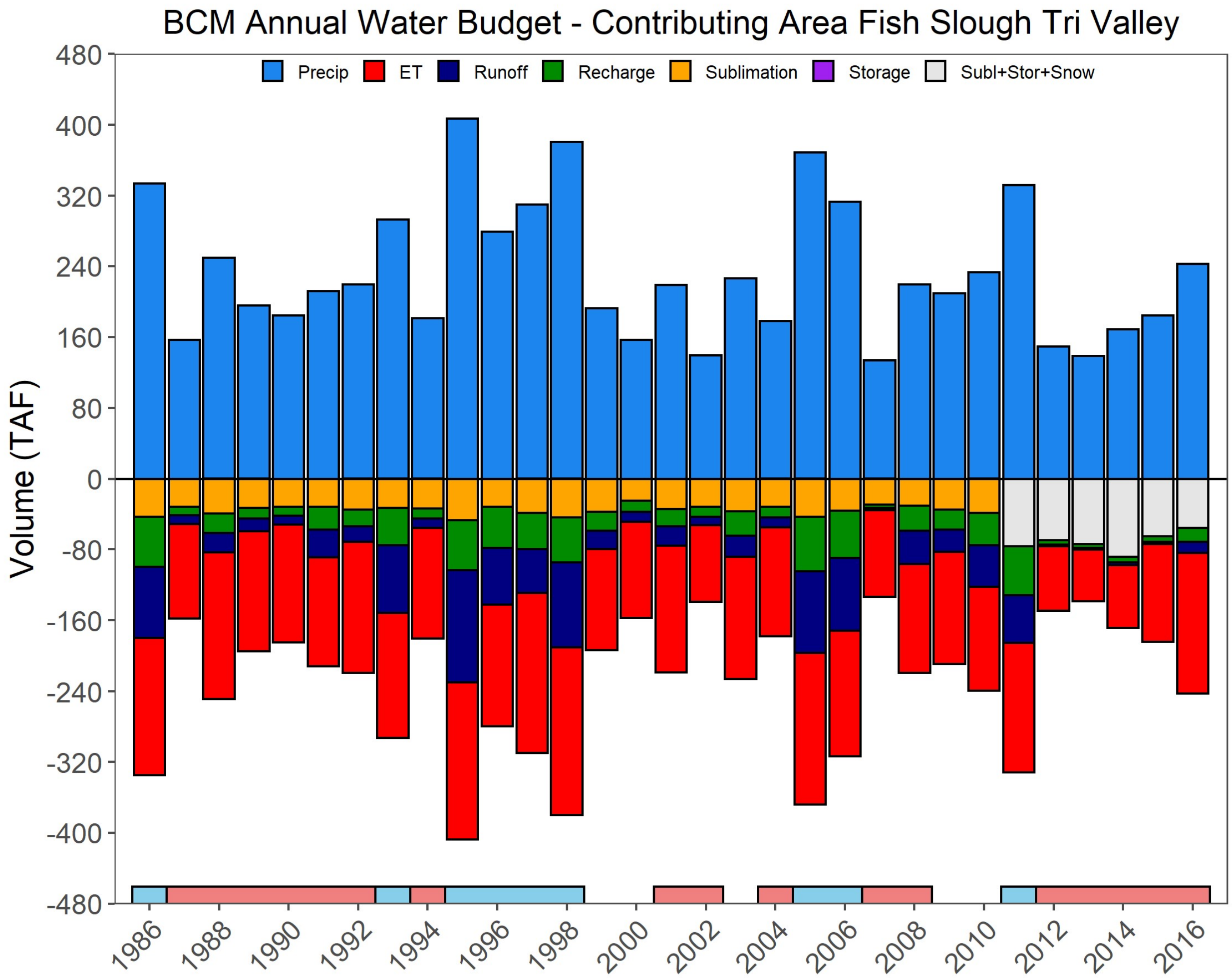

Figure 2-11 Historical water budget for the Fish Slough/Tri-Valley management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

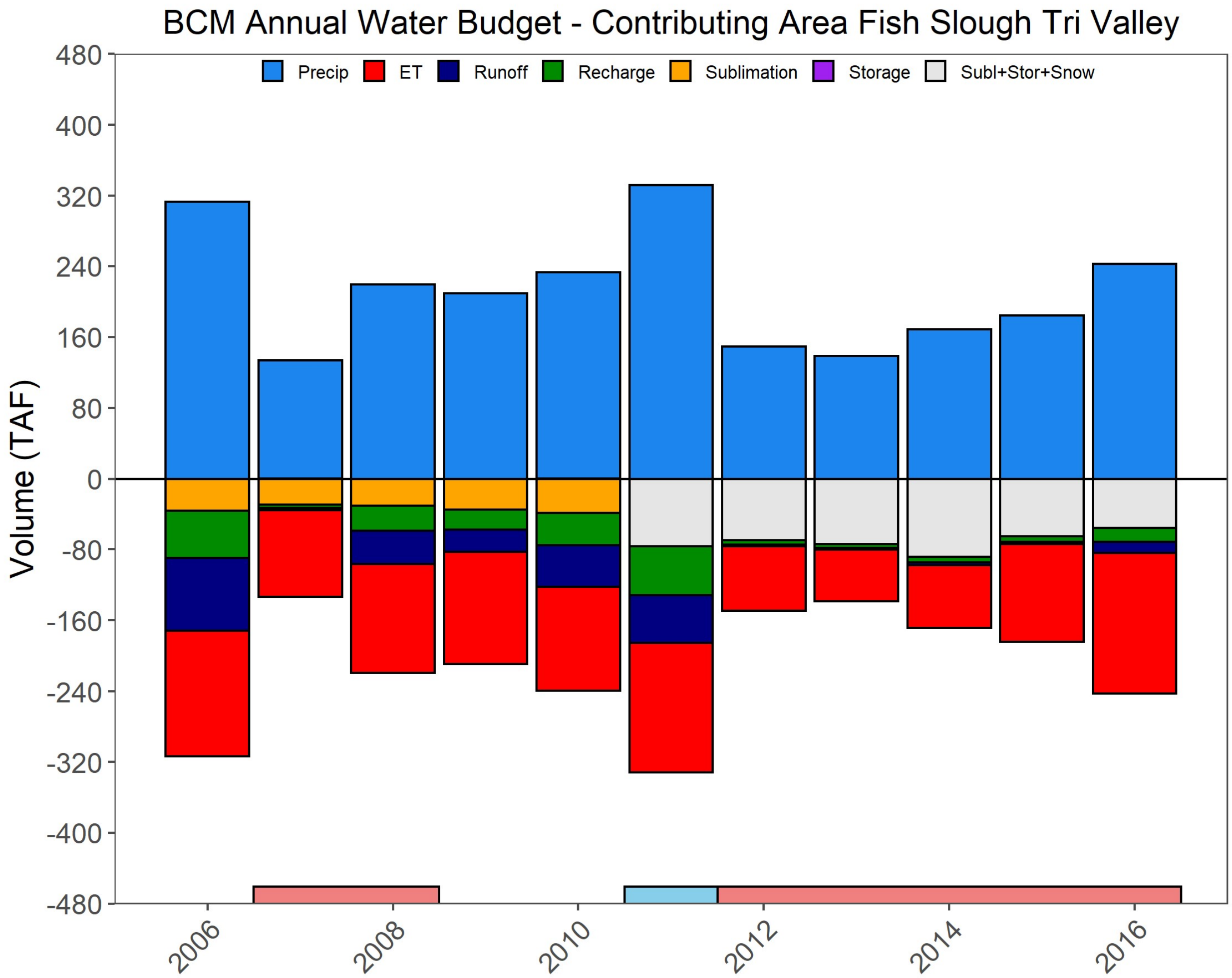

Figure 2-12 Current water budget for the Fish Slough/Tri-Valley management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

The historical and current water budget for the groundwater basin in the Fish Slough/Tri-Valley management area is shown in Figure 2-14 and Figure 2-15.

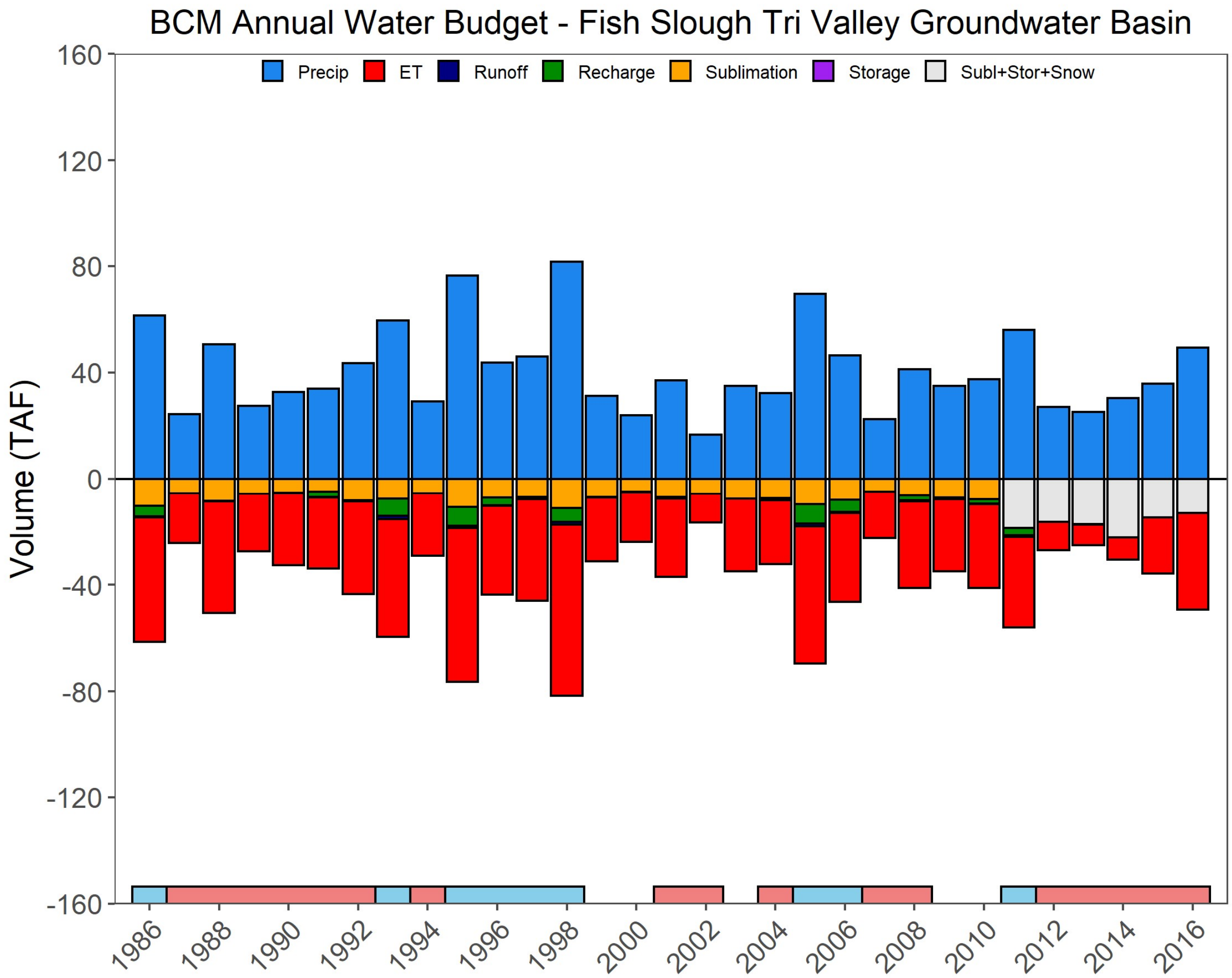

Figure 2-13 Historical water budget for the groundwater basin in the Fish Slough/Tri-Valley management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

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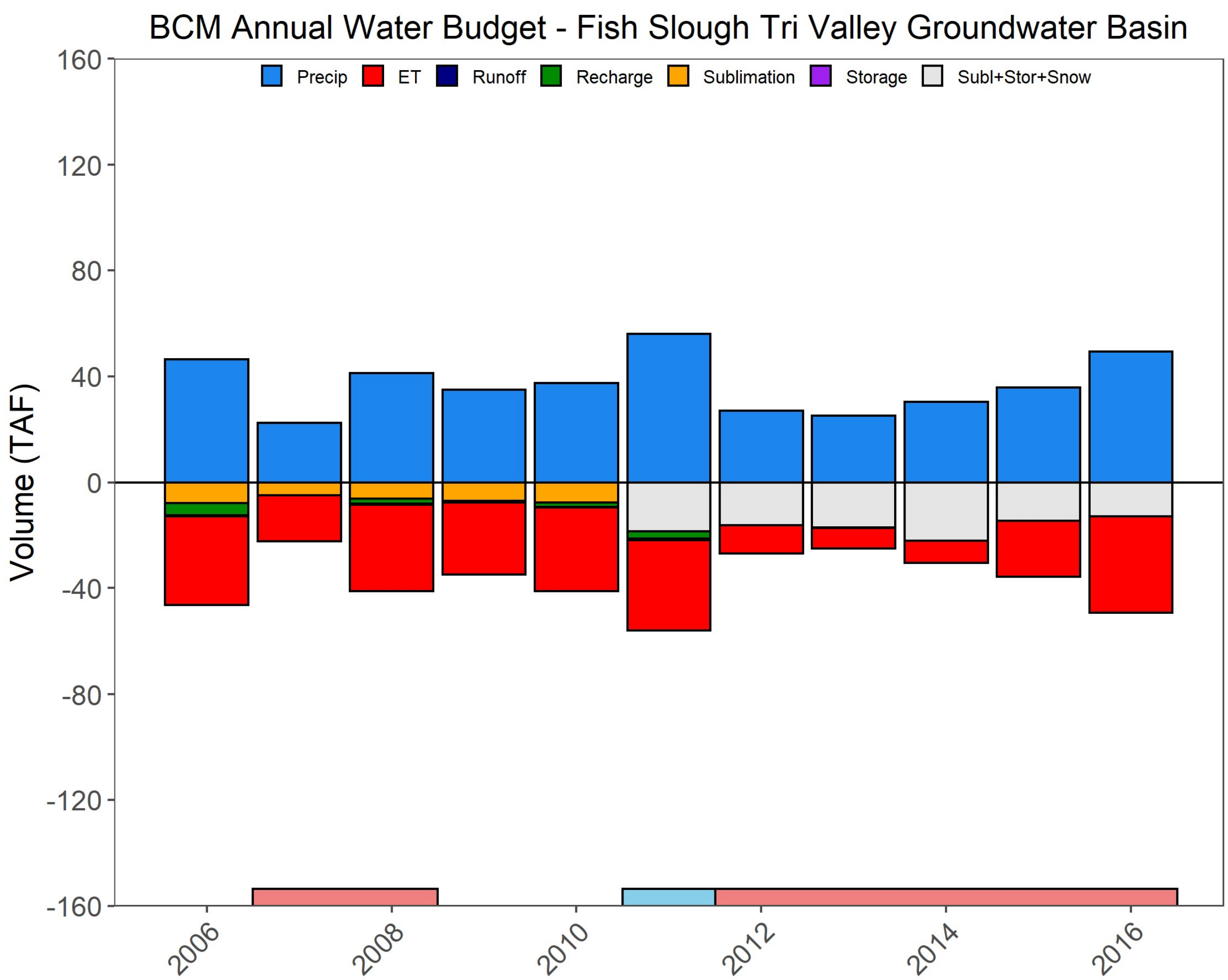

Figure 2-14 Current water budget for the groundwater basin in the Fish Slough and Tri-Valley management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

A Distributed Parameter Watershed Model (DPWM) was also developed for the Fish Slough/Tri-Valley area (attached appendix). The DPWM also models inflows and outflows to the water budget, but uses different parameters as compared to the BCM. The modeling domain for the DPWM was slightly different than the BCM model. Figure 2-16 and Table 2-11 shows an annual water budget from the DPWM for Fish Slough and Tri-Valley. The general agreement between BCM and DPWM for the Fish Slough/Tri Valley management area provides an additional degree of validation.

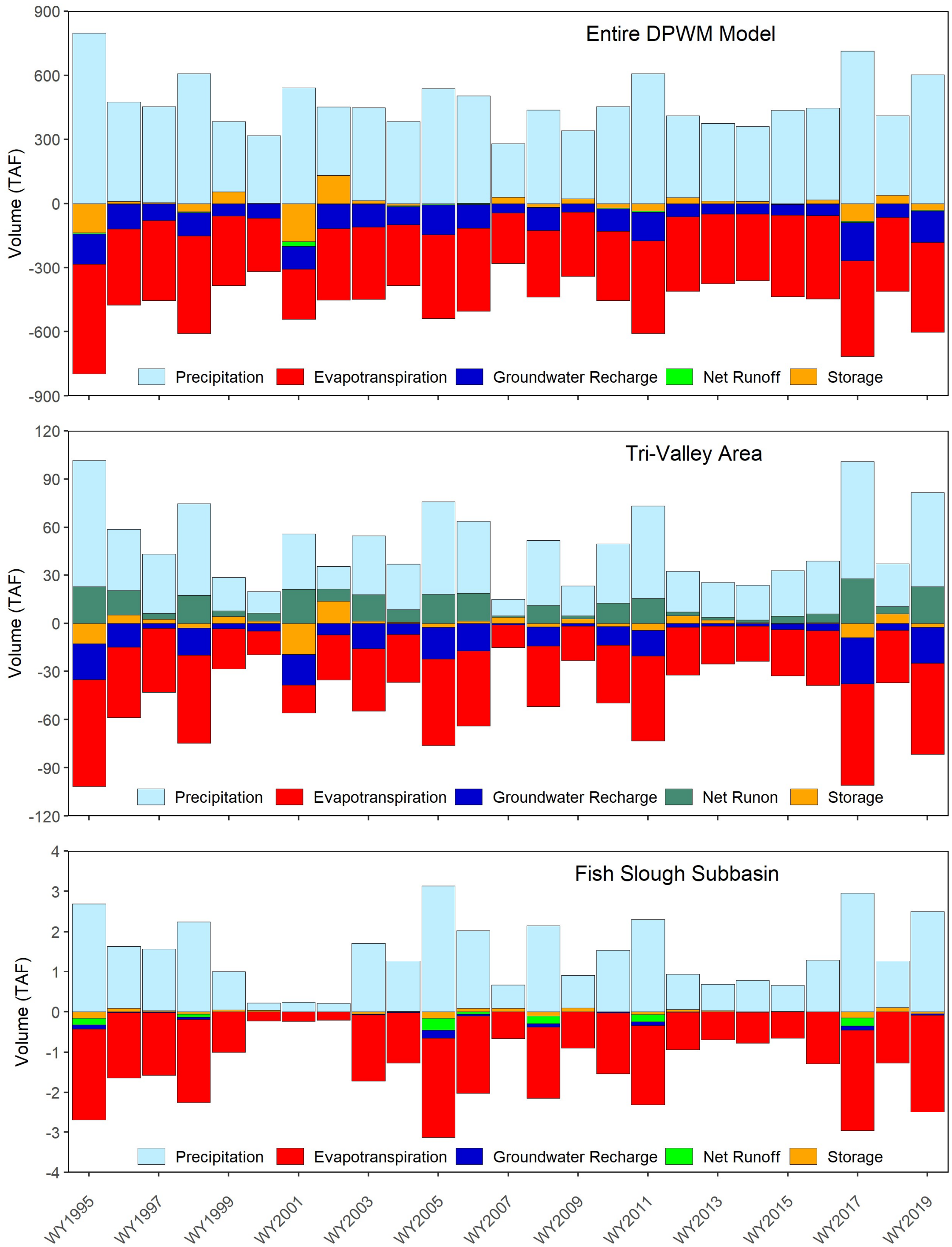

Figure 2-15 DPWM annual water budget for Fish Slough/Tri-Valley

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2.2.3.3 *Owens Lake Management Area*

The historical and current water budget for the contributing area to the Owens Lake management area is shown in Figure 2-17 and Figure 2-18.

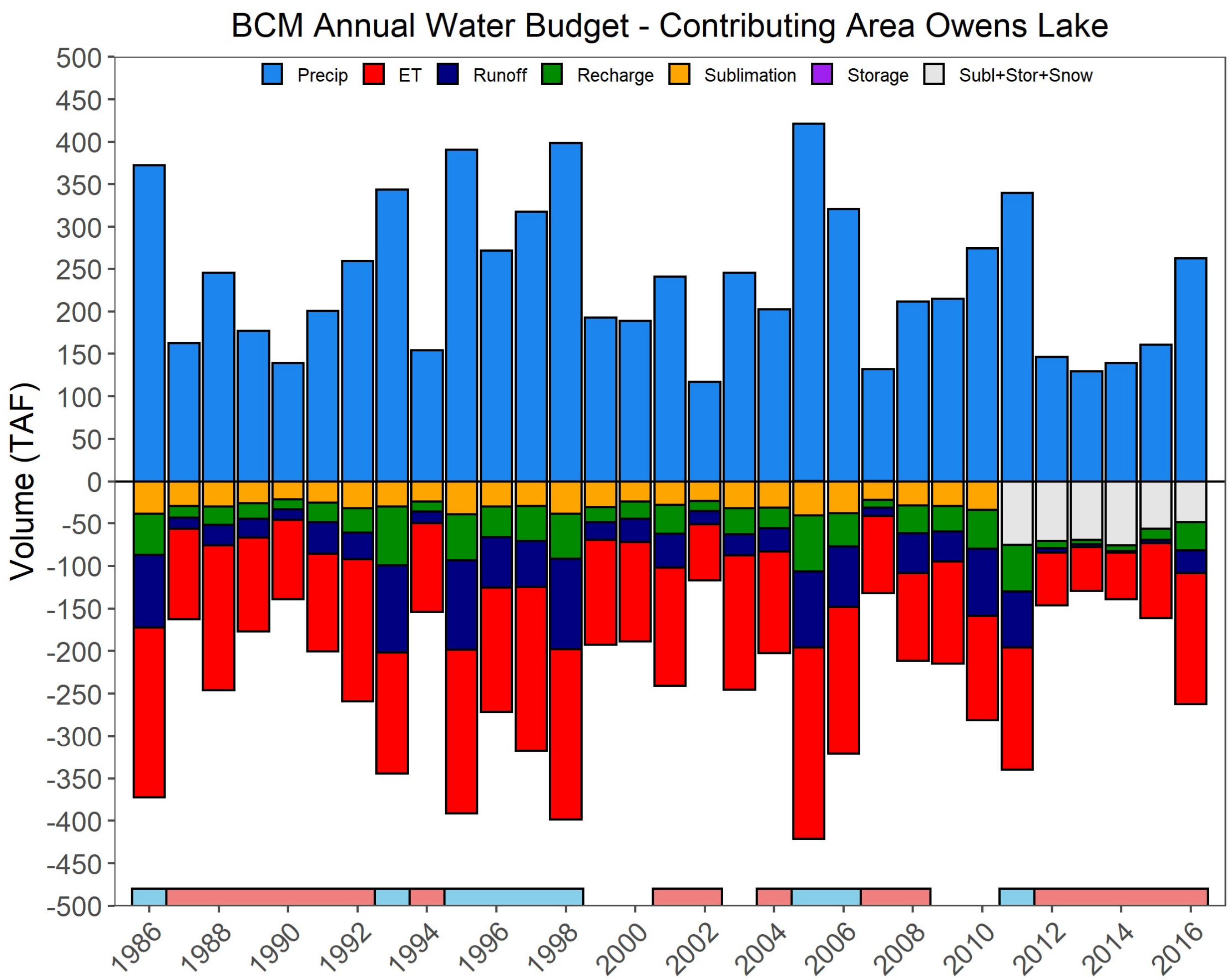

Figure 2-16 Historical water budget for the Owens Lake management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

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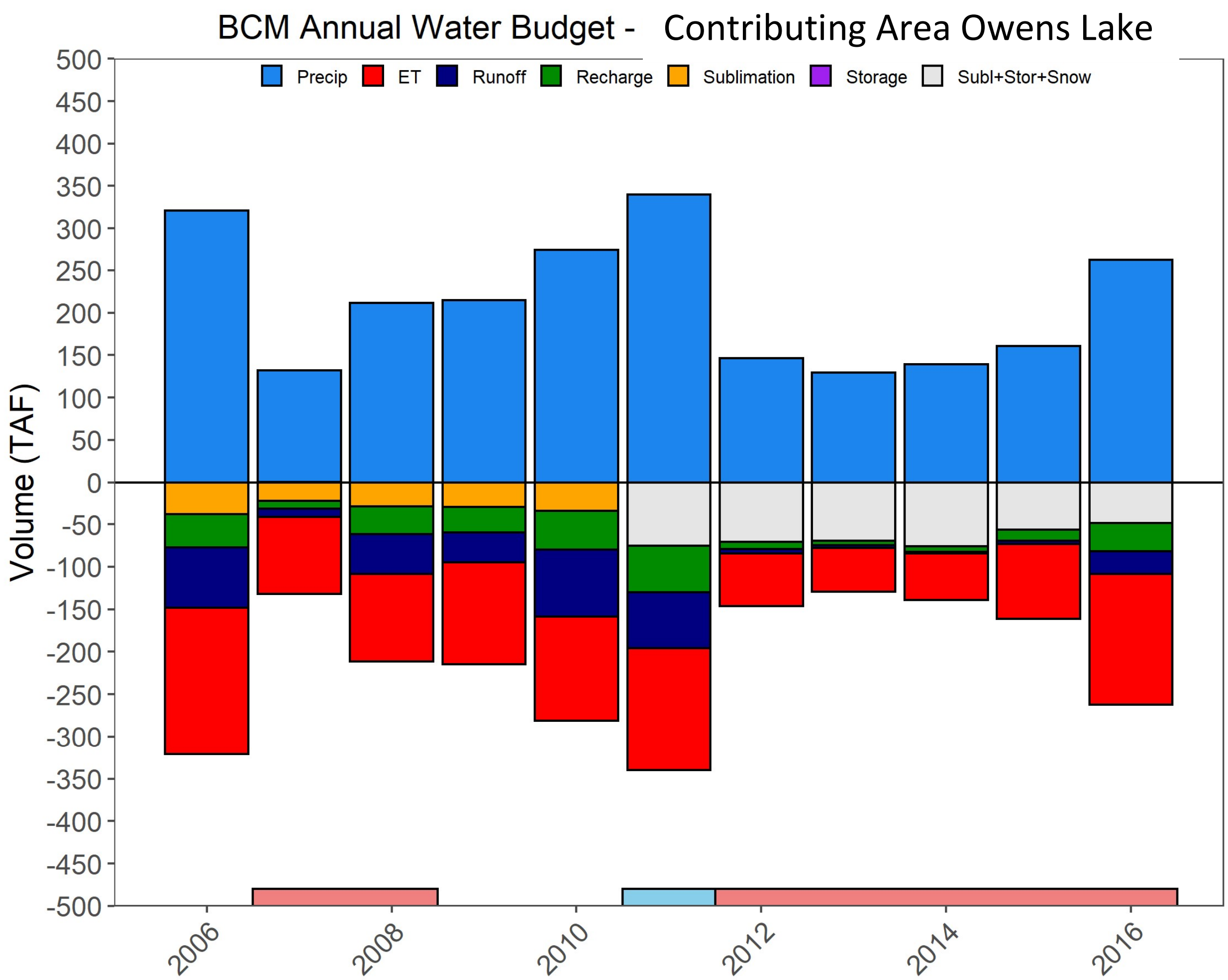

Figure 2-17 Current water budget for the Owens Lake management area contributing area (headwater). Wet and dry years shown as blue and red bars at the bottom of the graph.

The historical and current water budget for the groundwater basin in the Owens Lake management area is shown in Figure 2-19 and Figure 2-20.

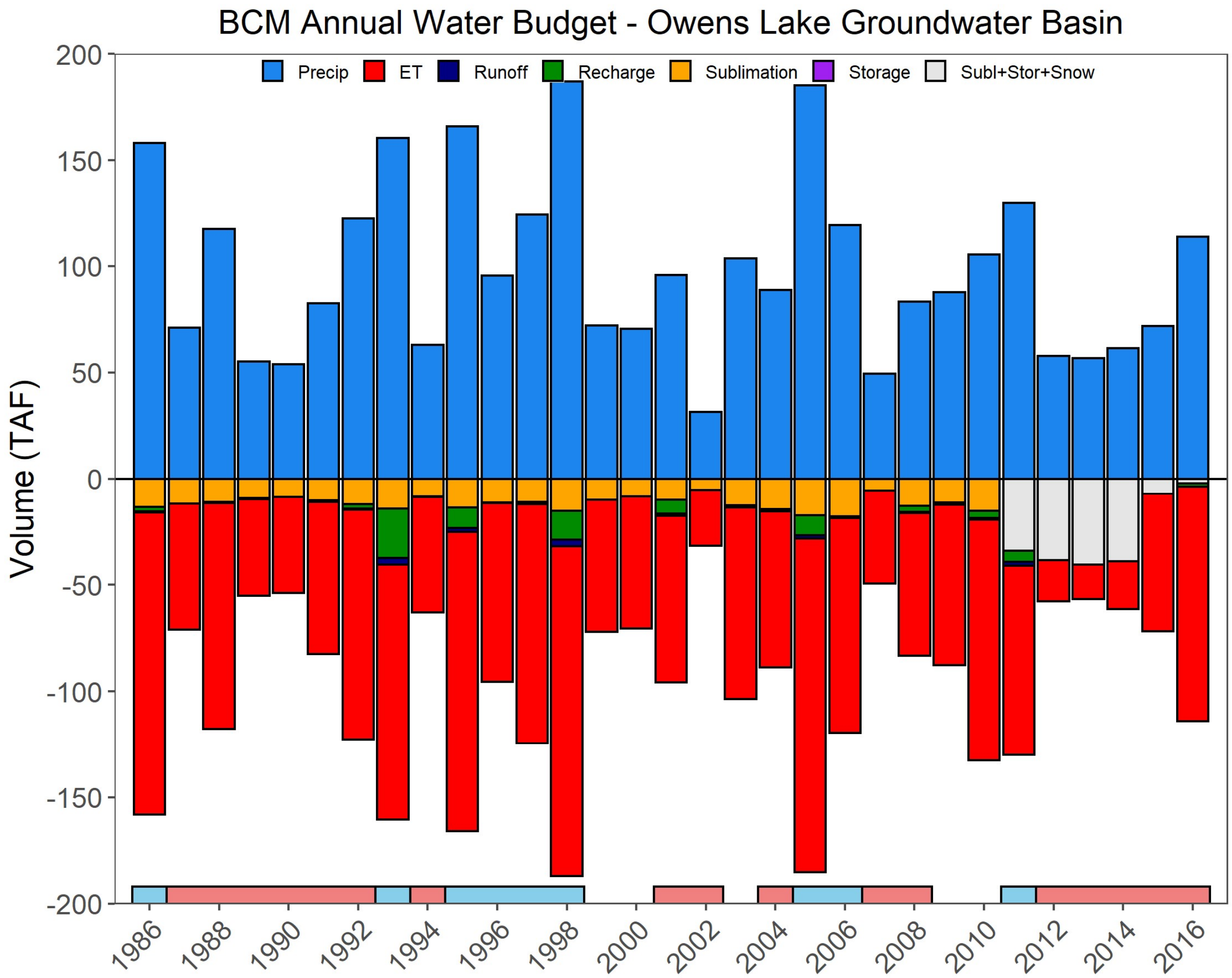

Figure 2-18 Historical water budget for the groundwater basin in the Owens Lake management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

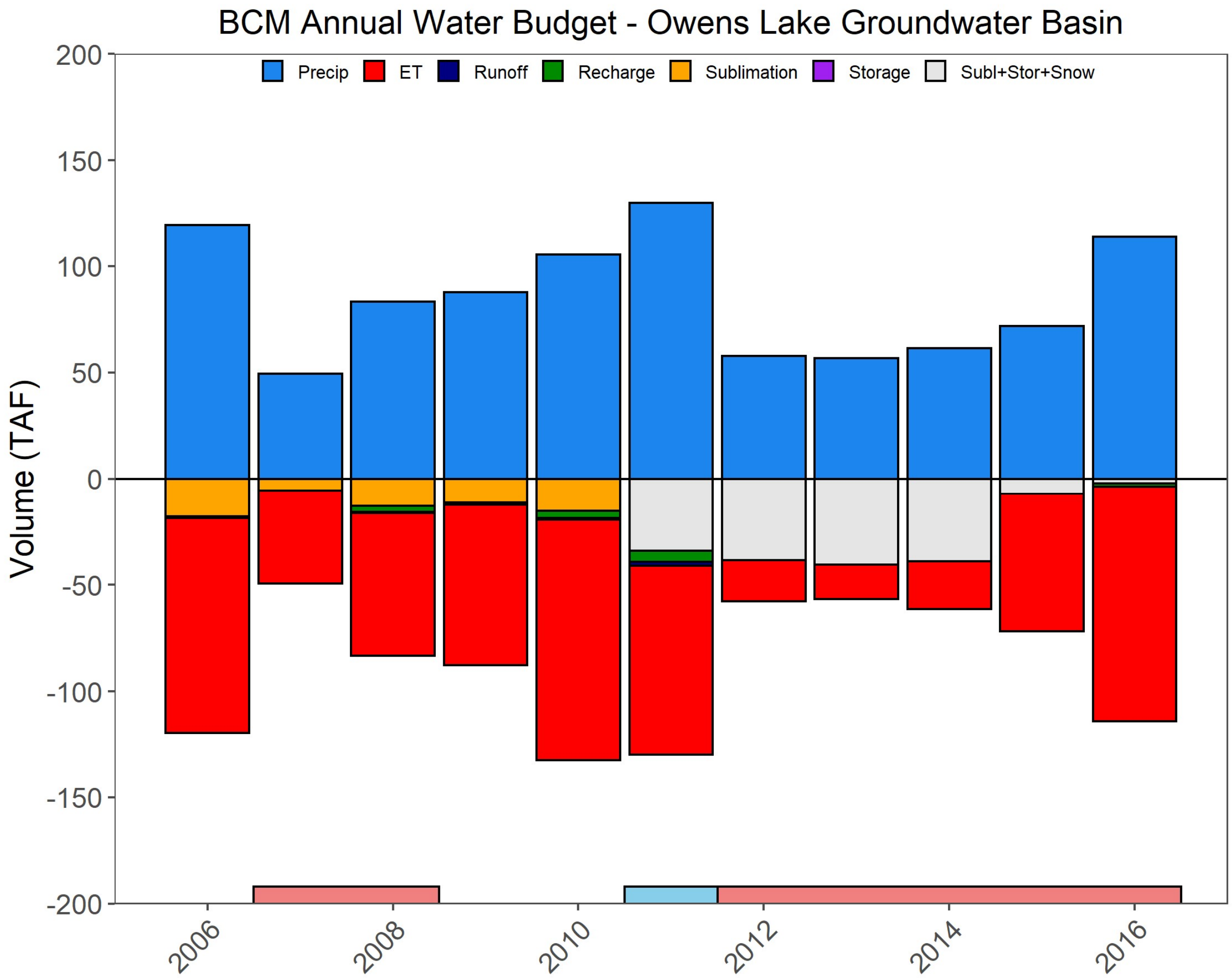

Figure 2-19 Current water budget for the groundwater basin in the Owens Lake management area. Wet and dry years shown as blue and red bars at the bottom of the graph.

2.3 Summary of Current Land System Water Budget

The land system water budgets (BCM & DPWM) are presented in tabular format in Table 2-11 for the current period (2006-2016) for the entire Owens basin and the three management areas described in subsection 2.2.

Table 2-11 Summary of current land system water budget

Average (TAF)	Precip	ET	Runoff	Recharge	Storage
Owens Basin CA	1622	689	410	234	289
Owens GWB	333	224	4	20	85
Owens Valley CA	1225	489	356	188	192
Owens Valley MA	141	85	3	16	36
Fish Slough/Tri-Valley CA	211	111	25	22	54
Fish Slough/Tri-Valley MA	37	24	0	1	12
Fish Slough/Tri-Valley DPWM CA	457	320	3	93	7
Fish Slough/Tri-Valley DPWM MA	38	37	2	11	0
Owens Lake CA	212	106	32	25	49
Owens Lake MA	85	66	0	1	18

CA = Contributing Area; MA = Management Area; GWB = Ground Water Basin; DPWM = Distributed Parameter Watershed Model

3. BCM Corroboration

One method to evaluate the range of accuracy in the BCM results for the Owens Basin is to compare runoff and recharge from the contributing area (headwater basin) entering the Owens Valley groundwater basin to the export of surface water and ground pumping by LADWP. This method is simple to evaluate since the BCM model water budget outputs provide the values of runoff and recharge entering the groundwater basin (after accounting for ET losses) but general in nature as it omits additional outflows such as non-LADWP pumping in the Tri-Valley area and a lesser amount in the Owens Valley and Owens Lake areas. Figure 3-1 shows the annual amount of water pumped by LADWP and Figure 3-2 shows the total export of water from the basin via the LA Aqueduct.

The measured 30-year average LADWP pumping from 1986-2016 was 85 TAF/yr, and the measured 30-year average export of water via the LA Aqueduct was 265 TAF/yr. From the BCM model water budget analysis, the total long- term average runoff entering Owens valley is 414 TAF (versus 265 TAF of export) and the recharge from the contributing area to the groundwater basin is 254 TAF (versus 85 TAF pumping). The BCM estimated runoff and recharge are of a

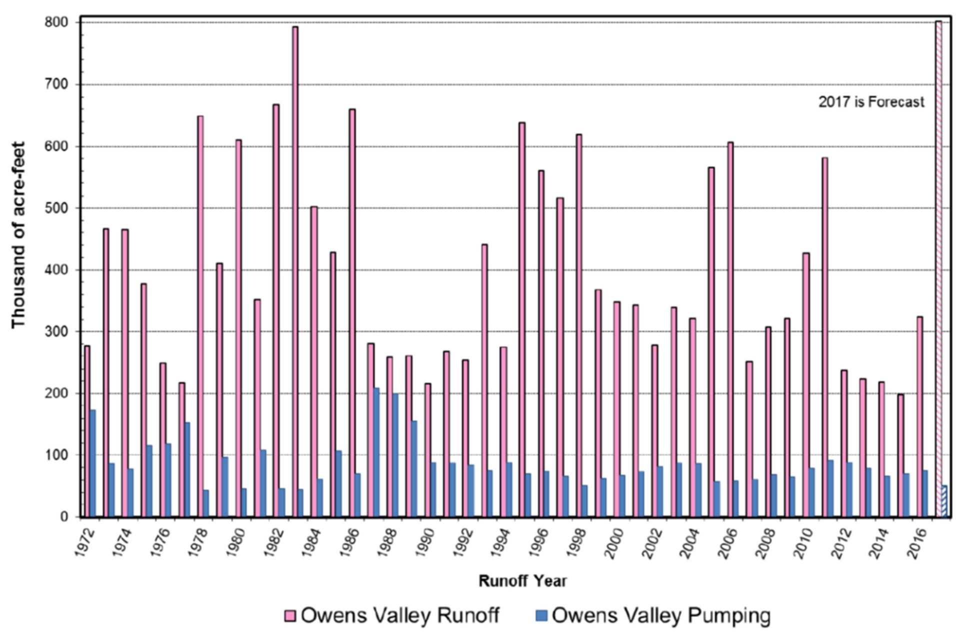

Figure 3-1 Groundwater pumping in Owens Valley. Source 2017 LADWP Annual Report

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similar order of magnitude and higher than the reported LADWP pumping and export of water. This is consistent with the observed groundwater levels on a basin-scale range in the Owens Valley and Owens Lake management areas.

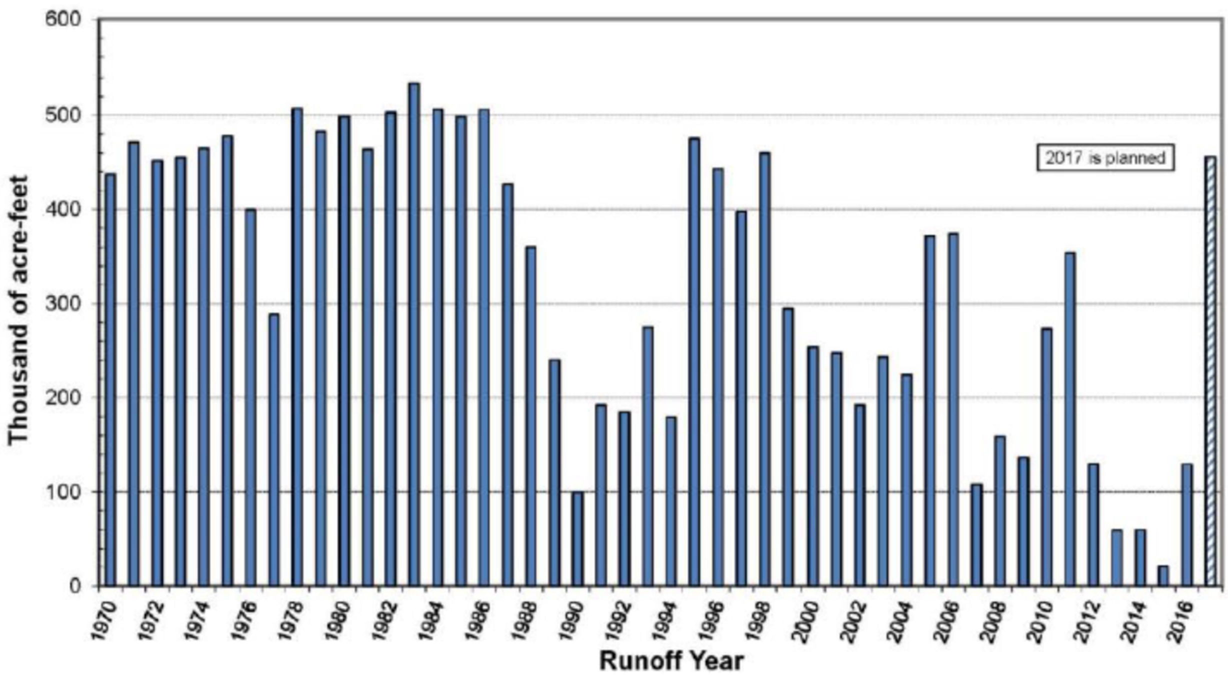

Figure 3-2 Water export from the Owens Basin via the LA Aqueduct. Source: 2017 LADWP Annual report

4. Future Water Balance

DWR future climate change factors for the Owens basin suggest that the temperatures will increase by approximately 2.6 degree F by mid-century and precipitation will increase by 0.3%. The USGS has already made future climate runs using the BCM model for a subset of climate model inputs, CCSM4; CNRM-CM5; GFDL-CM3; MIROC5. For the purpose of this GSP the CCSM4 scenario 8.5 was selected for the Owens Basin to evaluate future water budgets as this scenario showed a similar range in temperature as suggested by DWR.

Figure 4-1 and Table 4-1 shows the future (mid-century) water budget for the contributing area to the groundwater basin. Figure 4-2 and Table 4-2 shows the future water budget for the groundwater basin. Table 4-3 summarizes the future water balance for the entire basin.

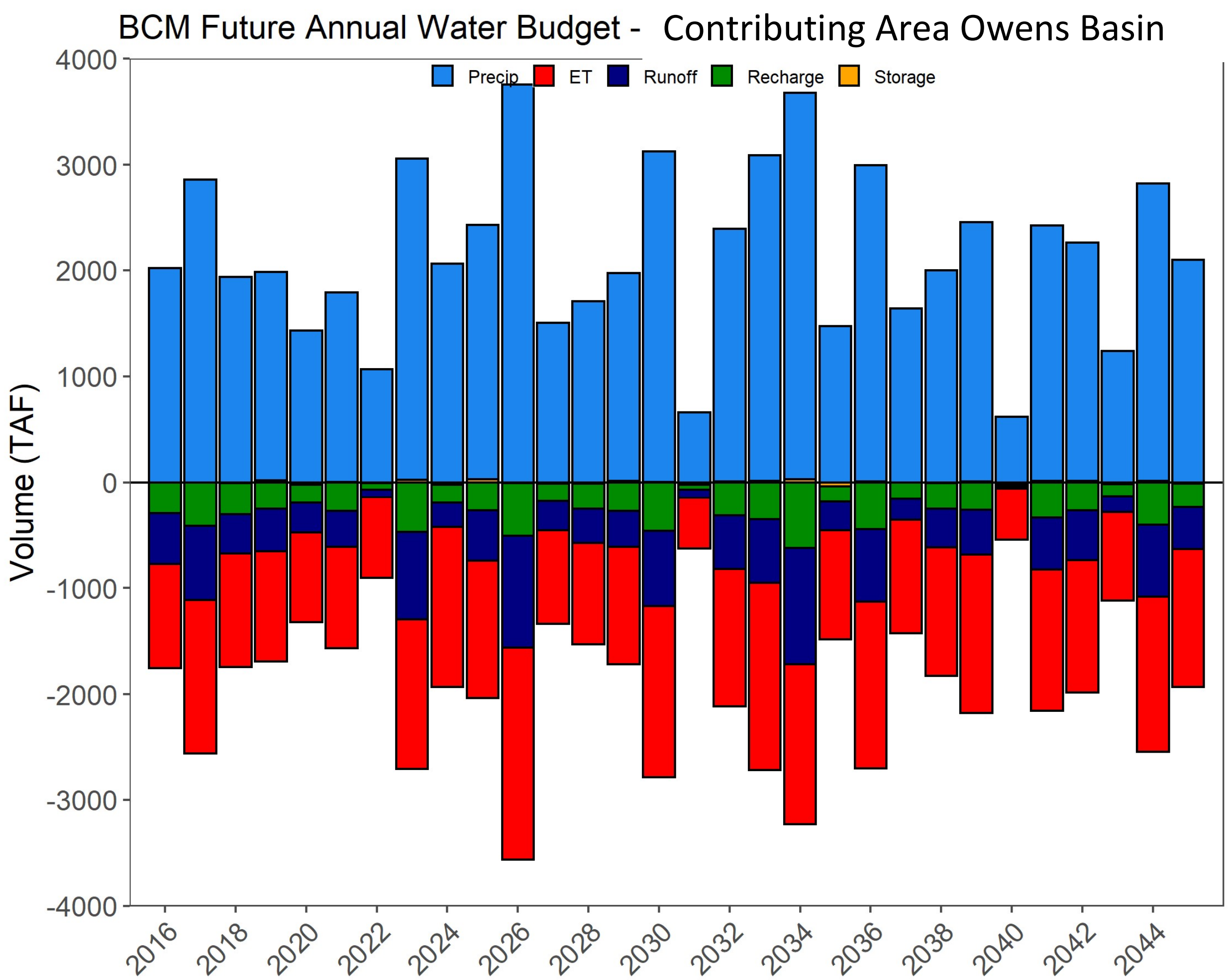

Figure 4-1 Future water budget for the Owens basin contributing area (headwater).

Table 4-1 Future water budget for Owens basin contributing area

Average	Precip	ET	Runoff	Recharge
Historical (TAF/yr)	1719	765	469	252
Future (TAF/yr)	1804	904	443	266
Change (%)	5	18	-6	6

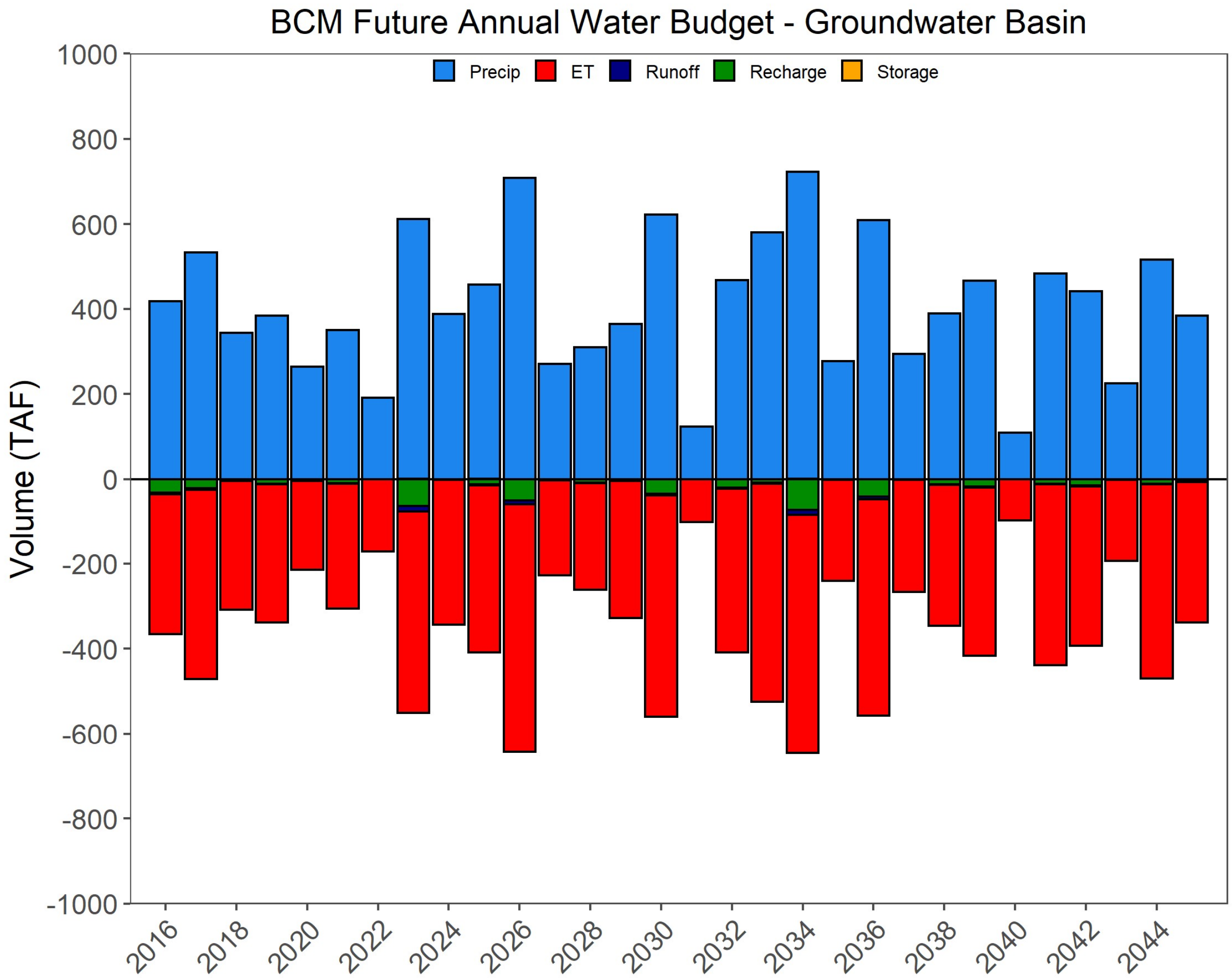

Figure 4-2 Future water budget for the Owens groundwater basin.

Table 4-2 Future water budget for Owens groundwater basin

Average	Precip	ET	Runoff	Recharge
Historical (TAF)	372	282	4	23
Future (TAF)	410	346	3	16
Change(%)	10	23	-25	-30

Table 4-3 Future water budget for entire Owens basin

Average	Precip	ET	Runoff	Recharge
Historical (TAF/yr)	2091	1047	473	275
Future (TAF/yr)	2214	1250	446	282
Change(%)	6%	19%	-6%	3%

5. Summary

- Basin-wide or regional groundwater models were not available to asses Owens Basin water budgets.
- The USGS BCM, per DWR strictures, was used to estimate water budgets for the entire basin and also three management areas.
- The values of recharge estimated by the BCM model are generally comparable to previous estimates, recent modeling efforts, and observed data.
- The future mid-century land system budget shows an increase in precipitation to the contributing area of 5% and 10% to the groundwater basin for an overall increase of 6%.
- Although the precipitation is modelled to increase by 6%, the BCM transfers most of the additional water to evapotranspiration (which increases by 19%) due to increased temperatures. Runoff decreases by 6% with recharge increasing by 3%.

References

California Department of Water Resources (2020). Draft Handbook for Water Budget Development with or without Model.

CDM (2000). Technical Memorandum on the Evaluation Results of LADWP 1999-2001 Pumping Proposal Owens Lake Groundwater Evaluation.

Danskin, W.R. (1988). Preliminary Evaluation of the Hydrogeologic System in Owens Valley, California. U.S. Geological Survey Water-Resources Investigations Report 88-4003.

Danskin, W.R. (1988). Evaluation of the hydrologic system and selected water-management alternatives in the Owens Valley, California. USGS WSP 2370.

Flint, L.E., A.L. Flint, and Stern, M.A. (2013). The basin characterization model – a regional water balance software package. U.S. Geological Survey Techniques and Methods 6-H1, 85 p.

Harrington, R.H. 2007. Development of a groundwater flow model for the Bishop/Laws area. Final report for local groundwater assistance grant agreement no. 4600004129. Inyo County Water Department, April 2007.

Harrington, R.H. (2016), Hydrogeologic Conceptual Model for the Owners Valley Groundwater Basin (6-12), Inyo and Mono Counties. Prepared for submittal to the California Department of Water Resources. Prepared by Inyo County Water Department, Independence, CA

Hollett, K. J., Danskin, W. R., McCaffrey, W. F., & Walti, C. L. (1991). Geology and water resources of Owens Valley, California. U.S. Geological Survey Water-Supply Paper 2370-B.

Inyo County Water Department (2016). Hydrogeologic Conceptual Model for the Owens Valley Groundwater Basin (6-12), Inyo and Mono Counties. Technical Report, 43 pages.

Jayko, A.S., & Fatooh, J. (2010). Fish Slough, a geologic and hydrologic summary, Inyo and Mono Counties, California. USGS administrative report prepared for the BLM Bishop Field Office, 38 pages.

Lee, Charles H. 1912. An Intensive Study of the Water Resources of a Part of the Owens Valley, California. USGS Water Supply Paper 294.

Lee, C.R. (1915). Report on hydrology of Owens Lake basin and the natural soda industry as affected by the Los Angeles Aqueduct diversion.

Lee, Willis T. 1906. Geology and Water Resources of Owens Valley, California. USGS Water-Supply and Irrigation Paper 181.

Lopes, T.J. (1988). Hydrology and Water Budget of Owens Lake, California. Technical Report, 118 pages.

MHA (2001). Task 1 Report: Preliminary Data Collection and Hydrologic Models for the USFilter Tri-Valley Surplus Groundwater Program, Mono County, California. Technical Report, 261 pages.

MWH (2010). Bishop MODFLOW Groundwater Model. Prepared for the City of Los Angeles Department of Water and Power.

MWH (2011). Updated Conceptual Model, Appendix H in Final Report on the Owens Lake Groundwater Evaluation Project, 2012 (revised Jan 7th, 2013)

Montgomery Watson Harza (MWH). 2012. Final Report on the Owens Lake Groundwater Evaluation Project, prepared for the Los Angeles Department of Water and Power, October 2012, revised 01/07/2013.

MWH (2012). Groundwater Model Documentation, Appendix J in Final Report on the Owens Lake Groundwater Evaluation Project, 2012 (revised Jan 7th, 2013)

NOAA National Centers for Environmental information, Climate at a Glance: Statewide Time Series, published January 2020, retrieved on January 28, 2020 from https://www.ncdc.noaa.gov/cag/

PWA (1980). The Hydrology of the Benton, Hammil, and Chalfant Valleys, Mono County, California. Technical Report, 45 pages.

PWA (1983). Water Resources and Their Relationship to Agricultural and Urban Development of Hammil Valley. Technical Report, 54 pages.

Schumer, R. (1997). Extension and Refinement of the Owens Lake Groundwater Basin Numerical Simulation (Master's thesis, University of Nevada Reno).

Williams, D.E. (1969). Preliminary Geohydrologic Study of a Portion of the Owens Valley Ground-Water Reservoir (Doctoral dissertation, New Mexico Institute of Mining and Technology).

Wirganowicz, M. (1997). Numerical Simulation of the Owens Lake Groundwater Basin, California (Master's thesis, University of Nevada Reno).

Preliminary Draft

Distributed Parameter Watershed Model Tri-Valley Area Watershed

Submitted to

Owens Valley Groundwater Authority

Prepared by

DBS&A
Daniel B. Stephens & Associates, Inc.

a Geo-Logic Company

3916 State Street, Suite 1A
Santa Barbara, CA 93105
www.dbstephens.com
Project # DB18.1418.00

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Appendix

1. Introduction and Purpose

Daniel B. Stephens & Associates, Inc. (DBS&A) has completed an estimate of natural groundwater recharge within the Tri-Valley area and Fish Slough subbasin (CA DWR Subbasin Number 6-012.02). Both areas are within the Owen Valley Groundwater Basin (CA DWR Basin Number 6-012). This Report has been prepared for the Owens Valley Groundwater Authority (OVGA) in support of the development of the Owens Valley Groundwater Sustainability Plan (GSP).

The Tri-Valley area is the northern arm of the Owens Valley Groundwater Basin extending to the California and Nevada State Line (Figure 1) and includes the Benton, Chalfant, and Hammil valleys. Fish Slough subbasin is located west of the Tri-Valley area (Figure 1).

The objective of this work is to estimate the amount of natural groundwater recharge that occurs via precipitation or surface water percolation within the Tri-Valley area and Fish Slough subbasin using the Distributed Parameter Watershed Model (DPWM) developed by DBS&A. This model is a spatially discretized "tipping bucket" type soil-water balance model, which evaluates precipitation, evapotranspiration, and resultant percolation through the soil column. The modeling approach includes methods previously applied in similar basin and range locations by the U.S. Geological Survey (USGS) (e.g., Flint and Flint, 2007). A description of the model approach and equations used to estimate different water balance components is explained in Appendix A.

Application of the DPWM allows for mass-conservative quantitative estimates based on site-specific climatological, geologic, soils and vegetation factors. DPWM provides estimates of net infiltration in any basin area that result from mountain front recharge, streamflow infiltration, and infiltration from precipitation at the basin floor. However, DPWM is not a fully-coupled groundwater and surface water model. Water table elevation can rise in some locations (at some times to near land surface), which would then restrict recharge to groundwater. As DPWM does not simulate groundwater flow, it can overestimate recharge in these areas and at those times. Furthermore, it cannot estimate subsurface flows into or out of the basin. Although simulation of groundwater flow would require additional modeling efforts, results obtained from DPWM could be used to quantify some of the required inputs for any future groundwater model developed for the area.

With understanding these limitations of DPWM, it is still a useful tool to estimate the natural recharge from precipitation and streamflow percolation into a basin and is especially useful tool in areas like Tri-Valley where there are insufficient data to determine estimates of recharge within a reasonable level of precision.

2. Study Area and Model Simulation Area

The study area of this report includes the Tri-Valley area and Fish Slough subbasin. The Tri-Valley area consists of unconsolidated alluvial sediments underlying Paleozoic and Mesozoic-age metamorphic and igneous rocks of the Benton Range and White Mountains, respectively. The area is bounded on the west by the Benton Range and Volcanic Tablelands (Bishop Tuff), on the north by the Huntoon Mountains, and on the east by White Mountains (Figure 2). The southern boundary of the project area was delineated based on the approximate discharge point of the project area into Owens River (Figure 2). The climate in Tri-Valley is arid with an average precipitation of approximately 5.5 to 8 inches per year (in/yr) as indicated by Parameter-elevation Regressions on Independent Slopes Model (PRISM) 30-Year average precipitation. In general, as land surface elevation increases above the valley floors, precipitation increases while temperature decreases. Average annual precipitation rates at high elevations along the margins of the watershed exceed 20 in/yr.

Natural recharge in the study area is sourced from precipitation that falls within the watershed defined by the crest of peaks and ridges of the White Mountains, Huntoon Mountains, and Glass Mountain (Figure 2).

The simulated area is approximately 852 square miles with elevations ranging from about 4,100 feet above mean sea level (ft amsl) at the southern end of the modeled area to greater than 14,200 ft amsl at White Mountain Peak (Figure 3).

3. Water Balance Modeling

DBS&A has developed a distributed parameter water balance model (DPWM) code based on the MASSIF model [Sandia National Laboratory, 2007] for Yucca Mountain and similar in concept to water balance models used by the USGS (e.g., Precipitation Runoff Modeling System (PRMS) [Leavesley et al., 1983], INFIL [Hevesi et al., 2003], Basin Characterization Model (BCM) [Flint and Flint, 2007]). The DPWM uses a daily time step over rectangular grid cells. Each cell is assumed to have uniform attributes (e.g., elevation, soil type, vegetation class) across its entire area

DBS&A applied the DPWM code to the simulated watershed (Figure 2). For the purpose of this report, DPWM will be used when referencing the code itself. The application of DPWM to the simulated watershed will be called the Tri-Valley model.

For the Tri-Valley model, the simulated 852 square mile watershed was divided into 78,465 square cells approximately 168 meters by 168 meters (550 feet) on a side. The model generally relies on the widely accepted FAO-56 procedure for computing actual evapotranspiration (AET) from the reference evapotranspiration (ET_0) estimated with the Penman-Monteith method (Allen et al., 1998; Allen et al 2005).

For each cell in the model, the water budget components accounted for include:

- Precipitation
- Runon from upstream cell
- Bare soil evaporation
- Transpiration
- Runoff to downstream cell
- Snow accumulation
- Snow melt
- Snow sublimation
- Soil water storage
- Net infiltration (e.g. recharge to groundwater)

A detailed description of the equations used to estimate each component of the above list is explained in Appendix A.

In DPWM, a bedrock boundary is placed at the bottom of the model cells with shallow soil depths; this boundary will restrict infiltration when the saturated hydraulic conductivity of the bedrock is less than that of the soil. Unlike the USGS BCM model, DPWM accounts for the routing of runoff through the watershed; unlike the MASSIF model, DPWM accounts for flow in washes using a mass balance approach for the area of a wash within a cell.

3.1 Input Data for Tri-Valley Model

One of the advantages of DPWM is that most of the required input data comes from publicly available sources. The inputs for DPWM can be categorized into topography, climate, vegetation, soil, and surface geology data. This section describes the input data for Tri-Valley model.

3.1.1 Topography and Surface Drainage

Topography in the Tri-Valley model was derived from USGS 30-meter Digital Elevation Models (DEM) and values were averaged over the model grid cells. Geographic Information System (GIS) tools were used to estimate slope and azimuth of each grid cell. These data were then used to route surface water flows from one cell to another.

In the Tri-Valley model, washes were classified based on their drainage areas and approximate width of each wash (Figure 3) which was obtained from a review of Google Earth aerial imagery. Internally in DPWM, model cells that contain washes are divided into two cells (a wash cell and an interwash cell), based on the active area of wash within the cell. The total active area of the wash cell is calculated as the length of the wash within the original cell times the width of the wash. The remaining cell area becomes an interwash cell. The soil properties of the wash cells are specified separately in the DPWM input files. The soil depth of the wash cell is assumed to be the same as that of the interwash cell.

3.1.2 Climate

Climate data required for DPWM includes the average spatial distribution of precipitation over the entire watershed and daily total precipitation, maximum daily air temperature, minimum daily air temperature, and average daily wind speed for one or more weather stations within the watershed.

In the Tri-Valley model, PRISM estimates of the mean precipitation for the calendar years 1981-2010 was used for the spatial distribution of precipitation (Figure 4). PRISM 30-year average precipitation interpolates precipitation data of available weather stations in the area and varies precipitation by elevation and accounts for orographic effects (e.g., rain shadows).

Daily climate data collected from the Bishop CIMIS Station (https://cimis.water.ca.gov/) and Benton RAWS station (https://wrcc.dri.edu/wraws/ccaF.html) were used in the Tri-Valley model. These stations have the longest available records and their geographic locations make them more representative of conditions in the Tri-Valley (Figure 4). Based on the coinciding periods of record from both stations, the Tri-Valley water budget was simulated for the 25-year period from October 1, 1994 through September 30, 2019. For days with missing or obviously out of range records (e.g., daily low temperature equal to daily high temperature), daily PRISM data at the location of the stations are used instead of these missed or out-of-range records at the stations.

Figure 5 shows total annual precipitation rates for water years 1995 through 2019 for the Bishop and Benton stations in the Tri-Valley model. In most years during the period of record, the Benton station records higher water year totals than the Bishop station, with 2005 being the most notable exception. Years 2000 through 2002 also provide the largest discrepancy between Bishop and Benton records with Benton's precipitation values at least 15 times greater than Bishop's records for those years. The Benton station is located at an elevation of 5,450 ft amsl in a relatively narrow valley compared to the Bishop station which is located at a lower elevation of 4,180 ft amsl.

In the Tri-Valley model, daily precipitation data are extrapolated from the two weather stations (i.e., Bishop and Benton) to each grid cell in the model using the PRISM 30-year average precipitation distribution and the cell elevation. Temperature data are extrapolated from the Bishop station only. Temperature in the model is assumed to decrease (or increase) by 0.0037 degree Fahrenheit (^{0}F) for every increase (or decrease) in elevation of 1 foot.

Duration of Precipitation Events

In DPWM, when precipitation occurs the daily time step is divided into two periods: (1) the duration of the precipitation event, and (2) the remainder of the day. The water balance is calculated separately for each of the two time steps. In the Tri-Valley model, the precipitation intensity during any precipitation event was assumed to be 0.1 inch per hour and the duration of the event was calculated based on the recorded daily precipitation for that event.

Snow

Precipitation in the model is assumed to occur as snow when the average daily temperature is below freezing. Snow is stored as an equivalent depth of water in the model. The sublimation rate applied is a fraction of the reference evapotranspiration (ET_0). In the Tri-Valley model, a value of 30 percent of ET_0 was used for the snow sublimation rate. This is within the suggested range of 10 to 40 percent of ET_0 [USGS, 2008].

When snow pack is present, the rate of snow melt is determined using the methodology described in the HELP model (Schroeder et al., 1994). In the Tri-Valley model, the rate of snowmelt varies from 2.0 millimeters per day per degree Celsius (mm/d/ºC) on December 21 to 5.2 mm/d/ºC on June 21.

3.1.3 Vegetation

Vegetation types vary considerably within the Tri-Valley model area from desert scrub at the lowest elevations to evergreen forests at higher elevations. The distribution of vegetation classes in the Tri-Valley model (Figure 6) was obtained from digital land cover datasets provided by the GAP/LANDFIRE National Terrestrial Ecosystems 2011 (USGS, 2011). Table 1 summarizes the rooting depths and plant heights assigned to each vegetation class.

Leaf area index (LAI), the ratio of one-sided leaf area over the total land area (L^2/L^2), data are used to calculate actual evapotranspiration (ET) in the Tri-Valley model. DPWM requires monthly LAI values for each model cell. In Tri-Valley model, values of LAI were obtained from datasets published by USGS from the Moderate Resolution Imaging Spectroradiometer (MODIS) (https://lpdaac.usgs.gov/products/mcd15a2hv006/). The data were obtained monthly for the relatively wet water year of 2005 (October 2004 through September 2005) which would provide a conservative upper estimate of vegetation transpiration rates. The pattern of LAI measured by MODIS was also used to determine the phenology for the vegetation associations (initiation of leaves, peak growing season, decline in growth, and dormant season) on a monthly basis.

3.1.4 Soils

Soil texture (e.g., percent sand, silt, and clay) and saturated hydraulic conductivity data for the Tri-Valley model were obtained from the USDA SSURGO database (Soil Survey Staff, 2019). The Rosetta program (Schaap et al., 2001) was used to estimate other soil hydraulic parameters required by DPWM (i.e., residual and saturated water contents, and van Genucthen parameters α and β) based on texture data. Soil type and depth data are presented on Figures 7 and 8, respectively. The SSURGO database reports depth to bedrock (i.e., soil thickness) for depths shallower than 2 meters (approximately 6.6 ft). In the Tri-Valley model, soil thicknesses for cells with deep bedrock (i.e., greater than 6.6 ft) were assumed to be greater than the maximum rooting depth of the predominant vegetation association for these cells.

3.1.5 Geology

Bedrock underlying soils may restrict net infiltration when the saturated hydraulic conductivity of the bedrock is less than the infiltration rate and soils are shallow. In the Tri-Valley model, the distribution of bedrock types (Figure 9) was obtained from geologic maps of California (USGS, 2005) and Nevada (USGS, 2003). The saturated hydraulic conductivities used in the Tri-Valley model at each unit were estimated from literature sources and are listed in Table 2.

4. Results

DPWM uses input topography, climate, vegetation, soil, and geology data to partition input precipitation into evapotranspiration, sublimation, surface runoff, soil-water storage, and net infiltration. For the purpose of this study, net infiltration below the soil thickness of a model cell is considered groundwater recharge.

Annual water budgets for the entire DPWM model, Tri-Valley area, and Fish Slough subbasin (Figure 10) provide a lot of information about general system behavior. Up to nearly 800,000 ac-ft of water passes through the simulated area annually. Except for water year 2001, no net runoff was produced from the entire model domain; all precipitation was partitioned into ET, groundwater recharge, and changes in storage. The runoff observed in 2001 can be explained by a single high-intensity storm during which 75% of the precipitation for that water year fell during a one-day event. This event also explains the significant increase of water in storage (negative storage value) in 2001, followed the next year by a large reduction of water in storage (positive storage value) as the system re-equilibrated. Other years with relatively large storage changes such as 2017-2018 and 2011-2012 follow a similar pattern: a wet year results in filling up of the soil profile (negative storage value) for most of the watershed, followed the next year by a reduction in soil storage (positive storage value) as that additional water in storage is utilized for evapotranspiration by vegetation.

The Tri-Valley area and Fish Slough subbasins exhibited greater interannual variability compared with the entire model, and both showed precipitation volumes were disproportionate to the relative size of the area. For example, the Tri-Valley area accounts for 14% of the total simulated watershed yet only received about 8% of the total precipitation volume. The most apparent difference between the Tri-Valley area and Fish Slough subbasin water budgets, aside from the magnitude of the component values which can be explained by the size discrepancy between the two, was the difference in runon/runoff patterns. The Tri-Valley area budget showed more water entering than leaving as surface flow, resulting in net runon for all years. The opposite pattern was observed for the Fish Slough subbasin, where net runoff was produced but only during wet years (e.g., water years 2005, 2008, and 2011). Very little groundwater recharge is simulated for the Fish Slough subbasin, as most precipitation is utilized by vegetation and converted to evapotranspiration.

Figure 10a shows the average 25-year recharge in the Tri-Valley model while Figures 10b and 10c provide a close-up of simulated recharge within the Tri-Valley area and Fish Slough subbasin, respectively. Simulated average 25-year recharge within the boundaries of Tri-Valley area is 10,563 acre-feet per year (ac-ft/yr) and simulated average recharge within the boundaries of Fish Slough subbasin is 33 ac-ft/yr. Figure 10a shows that only a small portion of the average recharge is simulated at the basin floor of the Tri-Valley area. Most of the estimated 10,563 ac-ft/yr average recharge occurs as either mountain front recharge or streamflow infiltration that is spatially focused along washes. This is expected in most mountainous areas in the southwest (Wilson and Guan, 2004).

Annual simulated recharge volumes in both the Tri-Valley area and Fish Slough subbasin (Figure 11) show a high degree of interannual variability. Recharge in the Tri-Valley area ranges from 1,100 ac-ft/yr in 2007 to approximately 29,000 ac-ft/yr in 2017 (Figure 11). Annual recharge in the Tri-Valley area shows a stronger correlation with annual precipitation at the Benton station compared to the Bishop station (Figure 12). However, we see the opposite for the Fish Slough subbasin, where annual recharge volume is more strongly correlated with precipitation measured at the Bishop station (Figure 12). This is expected for Fish Slough as the subbasin is geographically closer to the Bishop Station. Although precipitation is the only input component of the water budget in the Tri-Valley model, the correlation between simulated annual precipitation and simulated annual recharge is only around 70 to 75 percent. This is because groundwater recharge only occurs when field capacity of the soil is exceeded and gravity drainage can occur. The daily time steps used in DPWM allow the model to take into consideration antecedent soil conditions in addition to precipitation timing and rate. The transient nature of these factors is not considered in the simple plots of the annual correlation of precipitation and recharge.

For the entire watershed, the model shows that, on average, approximately 77 percent of the precipitation water that falls in the watershed is lost to evapotranspiration and snow sublimation (Table 3). The model also indicates that direct precipitation onto the valley floor (36,637 ac-ft/yr) contributes a negligible amount of water to groundwater recharge, as nearly all is lost to ET and snow sublimation (36,485 ac-ft/yr). Simulated streamflow into the Tri Valley area (or surface water runon) is approximately 12,271 ac-ft/yr, while simulated streamflow out of the Tri Valley area (or surface water run-off) is approximately 1,529 ac-ft/yr.

Caution must be exercised when interpreting the surface water runon and runoff values in Table 3 as DPWM does not simulate baseflow portion of streamflows. There is likely negligible baseflow contribution to streams in the Tri-Valley area as evidenced by the lack of exiting surface water features and mapped wetlands. However, the Fish Slough subbasin does appear to have a significant component of groundwater discharge to surface water. Precipitation-runoff simulated by the Tri-Valley model significantly underpredicts observed total runoff from the Fish Slough subbasin (Figure 11). Timing of peaks in observed total runoff appear to be correlated with timing of precipitation-runoff events simulated by the Tri-Valley model. This indicates that a large portion of the observed total runoff from the Fish Slough subbasin is sourced from the groundwater system which is not simulated by DPWM.

Table 3. Average 25 Year Simulated Water Balance Components

Water Balance Component	Average Simulated Volume (ac-ft/yr) Entire Watershed	Average Simulated Volume (ac-ft/yr) Tri-Valley area	Average Simulated Volume (ac-ft/yr) Fish Slough subbasin
Precipitation	457,167	36,637	1,435
Surface water runon from upstream cells	0	12,271	2
Actual Evapotranspiration	319,744	35,465	1,330
Snow Sublimation	34,243	1,020	20
Surface water runoff leaving the area	3,353	1,529	48
Change in storage of the soil	7,174	332	4
Net Infiltration (Recharge)	92,653	10,563	33

5. Discussion and Conclusion

The Tri-Valley region's water budget is the least understood in the Owens Valley Groundwater Basin (OVGB). The water budget in the Owens Lake portion of OVGB and other portions of the Basin underlying Los Angeles Department of Water and Power (LADWP) lands benefit from long record sets and frequent monitoring conducted by LADWP and the Great Basin Air Pollution Control District (Harrington, 2016). Jackson (1993), using the Maxey-Eakon method, estimated an average annual natural recharge in the Tri-Valley area of 1,270 ac-ft/yr. However, he concluded that this method resulted in an unrealistically low estimate and the simple 10 percent of precipitation method (i.e., 13,160 ac-ft/yr) is a better estimate (Harrington, 2016).

Assuming that all streamflow that was not diverted for agricultural use was recharged to groundwater, Phillip Williams & Associates (PWA, 1980) estimated that recharge in the Tri-Valley area from the White Mountains is 14,100 ac-ft/yr. They estimated that total recharge into Tri-

Valley from precipitation and streamflows (i.e., components considered in DPWM) is 16,600 ac-ft/yr. The estimated 25-year average of recharge into Tri-Valley area from DPWM results (10,563 ac-ft/yr) is less than the PWA (1980) estimate. However, it is not clear what period of time PWA used to estimate the recharge value. DPWM results (Figure 11) show that in some years, the simulated recharge is significantly higher than the PWA estimate.

MHA (2001) discussed the PWA (1980) recharge estimates and noted that in PWA's water budget, inflow and outflow are equal which connotes that the groundwater system was in balance. This is contrary to groundwater level data gathered during the same time period which showed declining water levels (MHA, 2001). This could also indicate that PWA may have overestimated recharge in the Tri-Valley Area.

While DPWM allows for mass-conservative quantitative estimates of recharge based on site-specific climatological, geologic, soils and vegetation factors, it is also important to understand the limitations of the model not simulating the groundwater system. As such, DPWM cannot directly estimate either groundwater underflow to a basin or baseflow into a stream. While this does not appear to be a significant limitation for the Tri-Valley area, groundwater appears to be a significant contributor to the water budget of the Fish Slough subbasin. This groundwater must be derived from somewhere upgradient, which includes the Tri-Valley area among possible sources. A groundwater model or groundwater budget analysis is needed to further quantify the water balance components for the entire hydrologic system.

References

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. *Crop evapotranspiration guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper 56, Rome, Italy.

Allen, R.G., I.A. Walter, R.L. Elliott, T. Howell, D. Itenfisu, and M. Jensen. 2005. The ASCE standardized reference evapotranspiration equation. American Society of Civil Engineers, Reston, Virginia.

Flint, A. and L. Flint. 2007. Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah. USGS Scientific Investigations Report 2007-5099.

Harrington, 2016. Hydrogeologic Conceptual Model for the Owens Valley Groundwater Basin (6-12), Inyo and Mono Counties.

Hevesi, J.A., A.L. Flint, and L.E. Flint. 2003. Simulation of net infiltration and potential recharge using a distributed-parameter watershed model of the Death Valley Region, Nevada and California. USGS Water-Resources Investigations Report 03-4090.

Jackson, R.J., Reconnaissance Estimate of Natural Groundwater Recharge to the California Section of the Tri Valley Region, Mono County, California, 1993, Inyo County Water Department Technical Note 93-3.

Leavesley, G.H., R.W. Lichty, B.M. Troutman, and L.G. Saindon. 1983. Precipitation-runoff modeling system: User’s manual. USGS Water-Resources Investigations Report 83-4238, 207 p.

MHA Environmental Consulting Inc., TEAM Engineering and Management Inc., Mark Bagley, EMRICO, Don Sada, and Sage and Associates, 2001, Task 1 Report – Preliminary Data Collection and Hydrologic Models, Prepared for the US Filter Tri Valley Groundwater Surplus Program, Mono County, California.

Sandia National Laboratory, 2007. Simulation of Net Infiltration for Present-Day and Potential Future Climates. Yucca Mountain Project. MDL-NBS-HS-000023 REV 01.

Schaap, M.G., F.J. Leij, and M. Th. van Genuchten, 2001. Rosetta: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. Journal of Hydrology, 251:163-176.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton. 1994. The hydrologic evaluation of landfill performance (HELP) model: Engineering documentation for version 3. U.S. Environmental Protection Agency Office of Research and Development, Washington, DC. September 1994. EPA/600/R-94/168b.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at https://sdmdataaccess.sc.egov.usda.gov. Accessed [10/15/2019]

U.S. Geological Survey, 2003. Spatial Digital Database for the Geologic Map of Nevada: U.S. Geological Survey Open File Report 03-66.

U.S. Geological Survey, 2005. Preliminary integrated geologic map databases for the United States. Western States: California, Nevada, Arizona, Washington, Oregon, Idaho, and Utah. U.S. Geological Survey Open File Report 2005-1305.

U.S. Geological Survey, 2008, Documentation of computer program INFIL3.0—A distributed parameter watershed model to estimate net infiltration below the root zone: U.S. Geological Survey Scientific Investigations Report 2008–5006, 98 p.

U.S. Geological Survey, 2011, Gap Analysis Program, 20160513, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey, https://doi.org/10.5066/F7ZS2TM0

Wilson, J.L. and H. Guan. 2004. Mountain-block hydrology and mountain-front recharge. In Hogan, J.F., F.M. Philips, and B.R. Scanlon (eds.), Groundwater recharge in a desert environment: the southwestern United States. Water Science and Applications Series, Vol. 9. American Geophysical Union, Washington, D.C.

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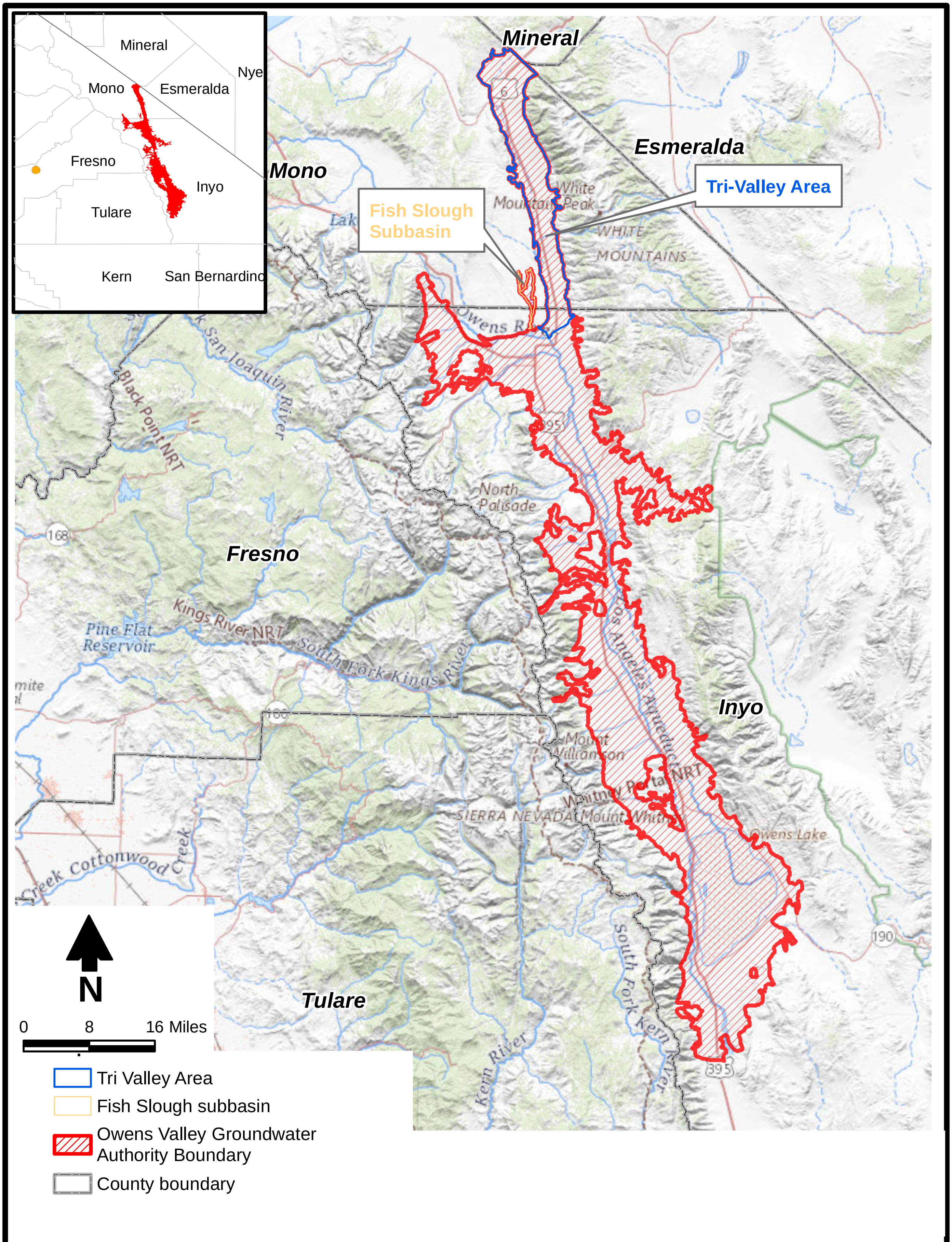

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OWENS VALLEY GSP
Owens Valley Groundwater Basin

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JN DB18.1418

Figure 1

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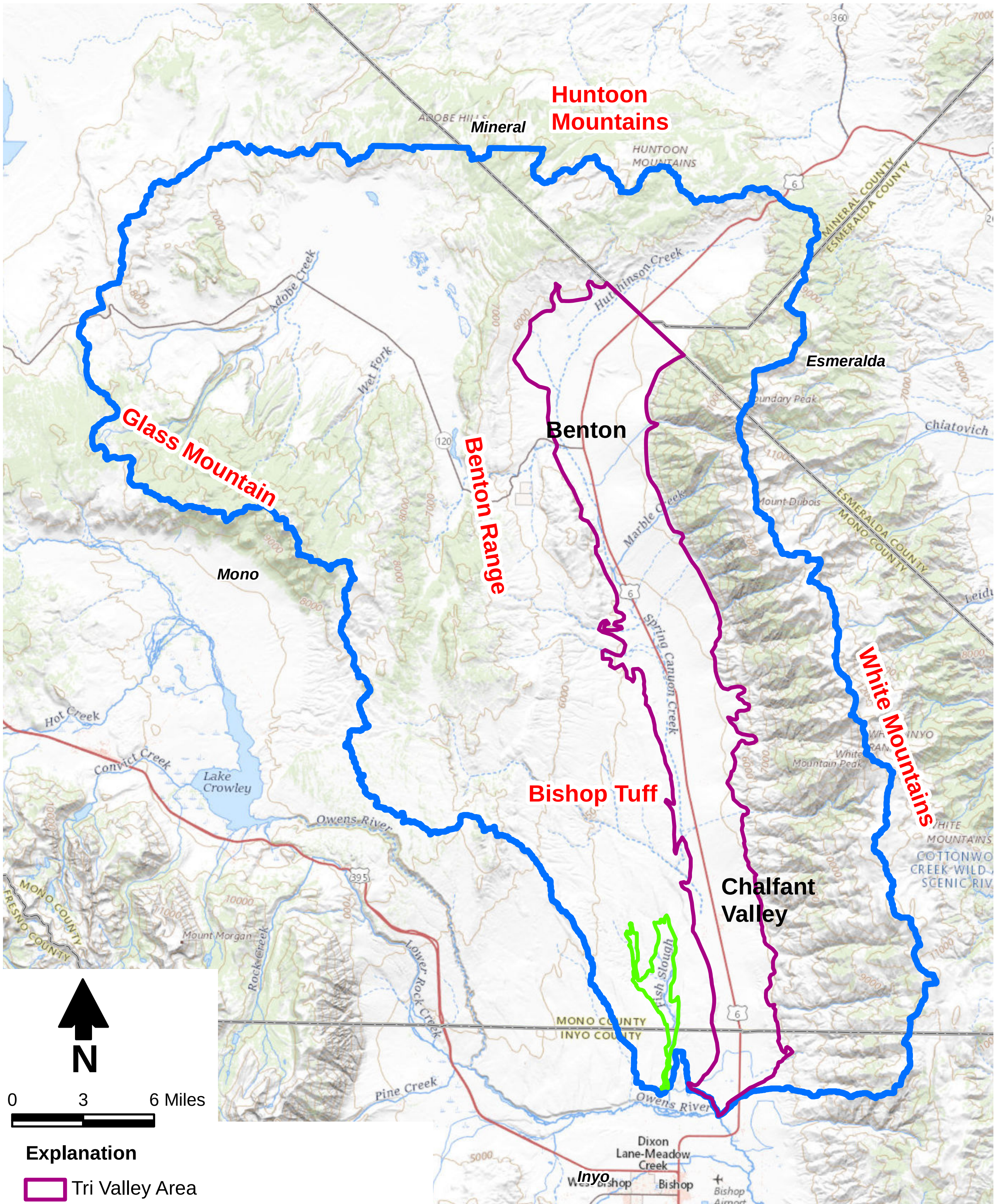

Explanation

- Tri Valley Area
- Fish Slough subbasin
- Simulated watershed
- County boundary

OWENS VALLEY GSP

Tri Valley Area and Simulated Watershed

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12/5/2019
JN DB18.1418

Figure 2

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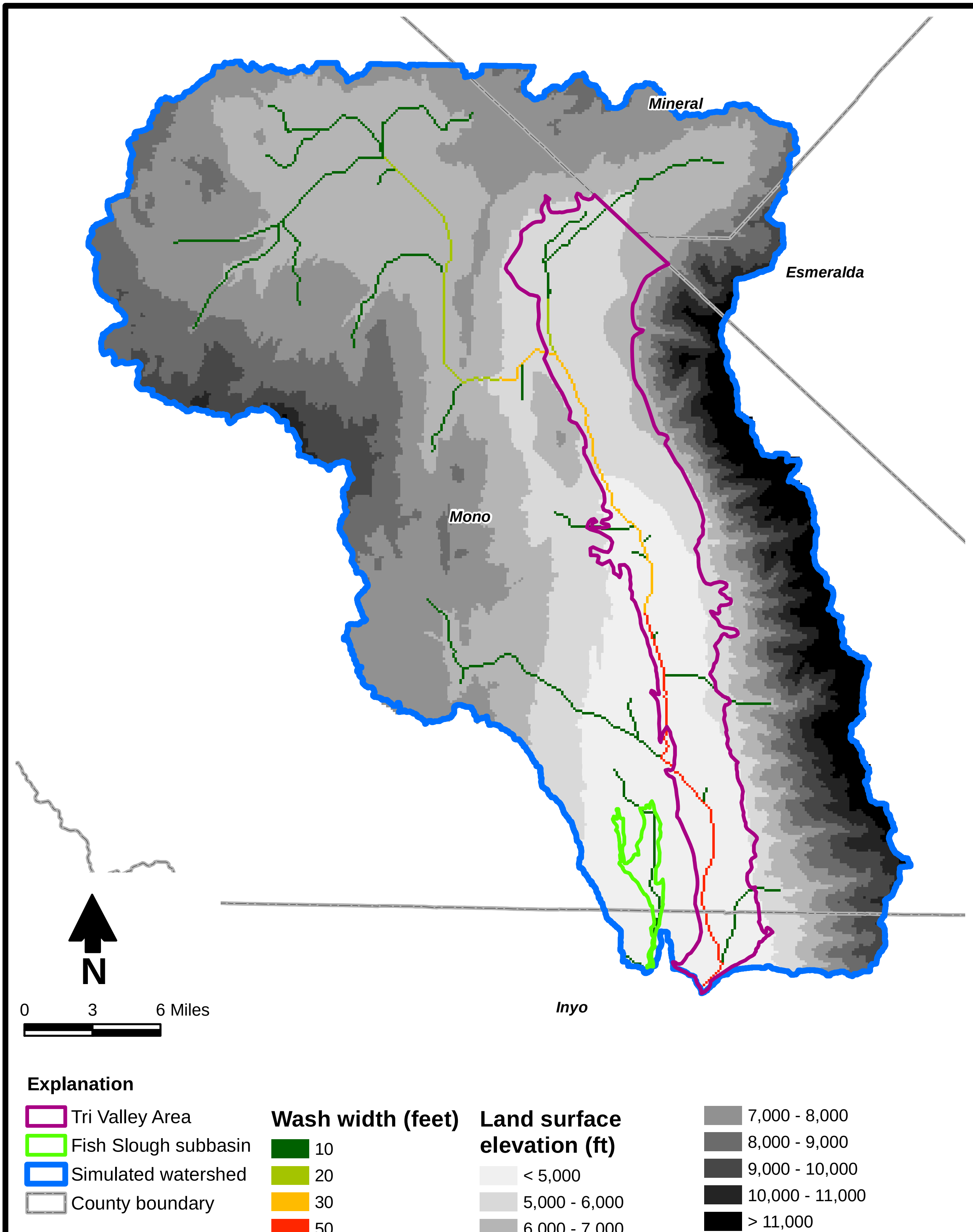

OWENS VALLEY GSP

Elevations and Wash Widths within Tri-Valley Model

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JN DB18.1418

Figure 3

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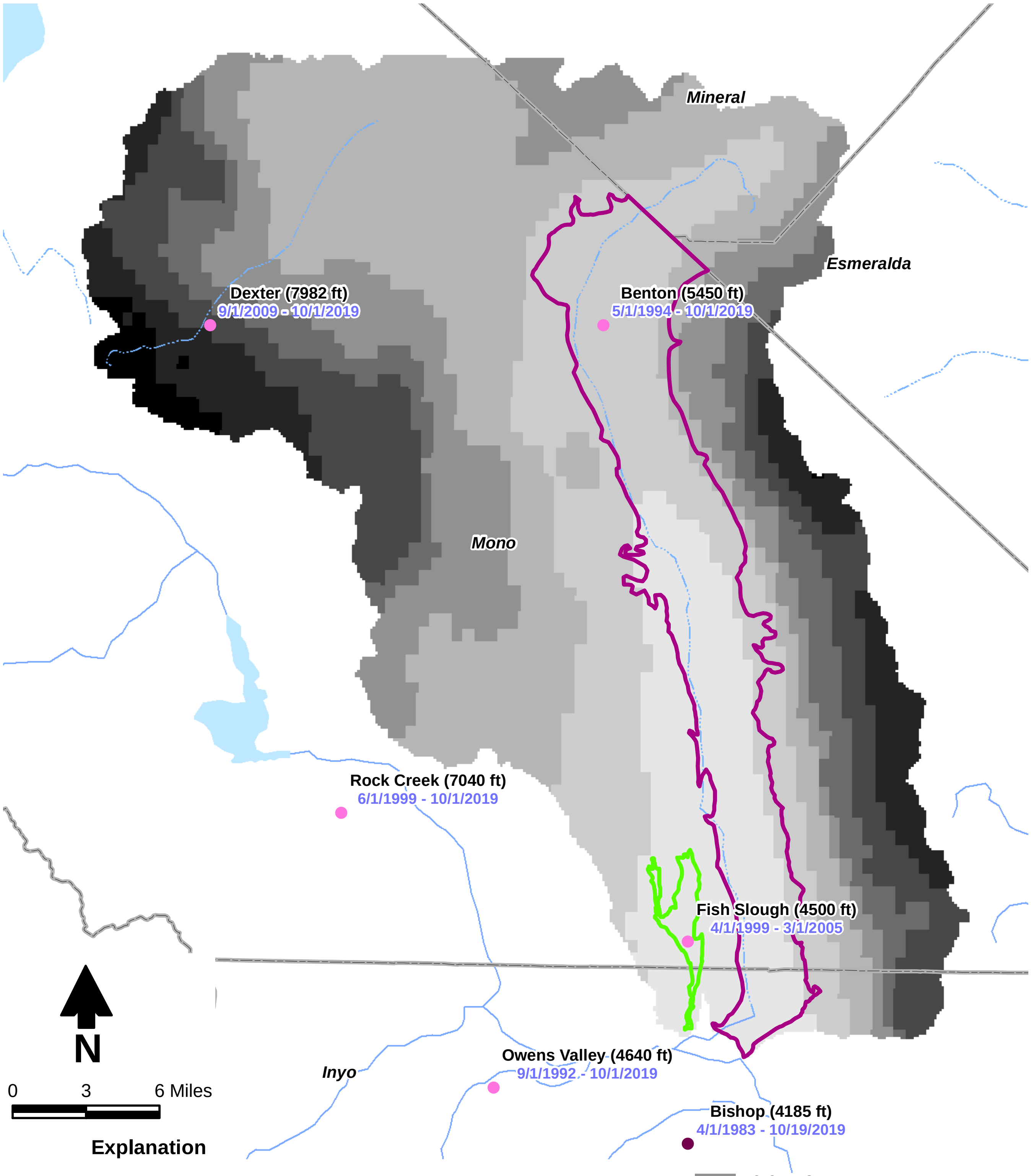

Explanation

Weather station (Elevation ft)
- CIMIS
- RAWS
- Tri Valley Area
- Fish Slough subbasin
- County boundary

Average Precipitation (in/yr)
- < 6.0
- 6.0 - 8.0
- 8.0 - 10.0
- 10.0 - 12.5
- 12.5 - 15.0
- 15.0 - 20.0
- 20.0 - 25.0
- 25.0 - 26.6

OWENS VALLEY GSP

PRISM 30-Year Average Precipitation and Location of Weather Stations

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Figure 4

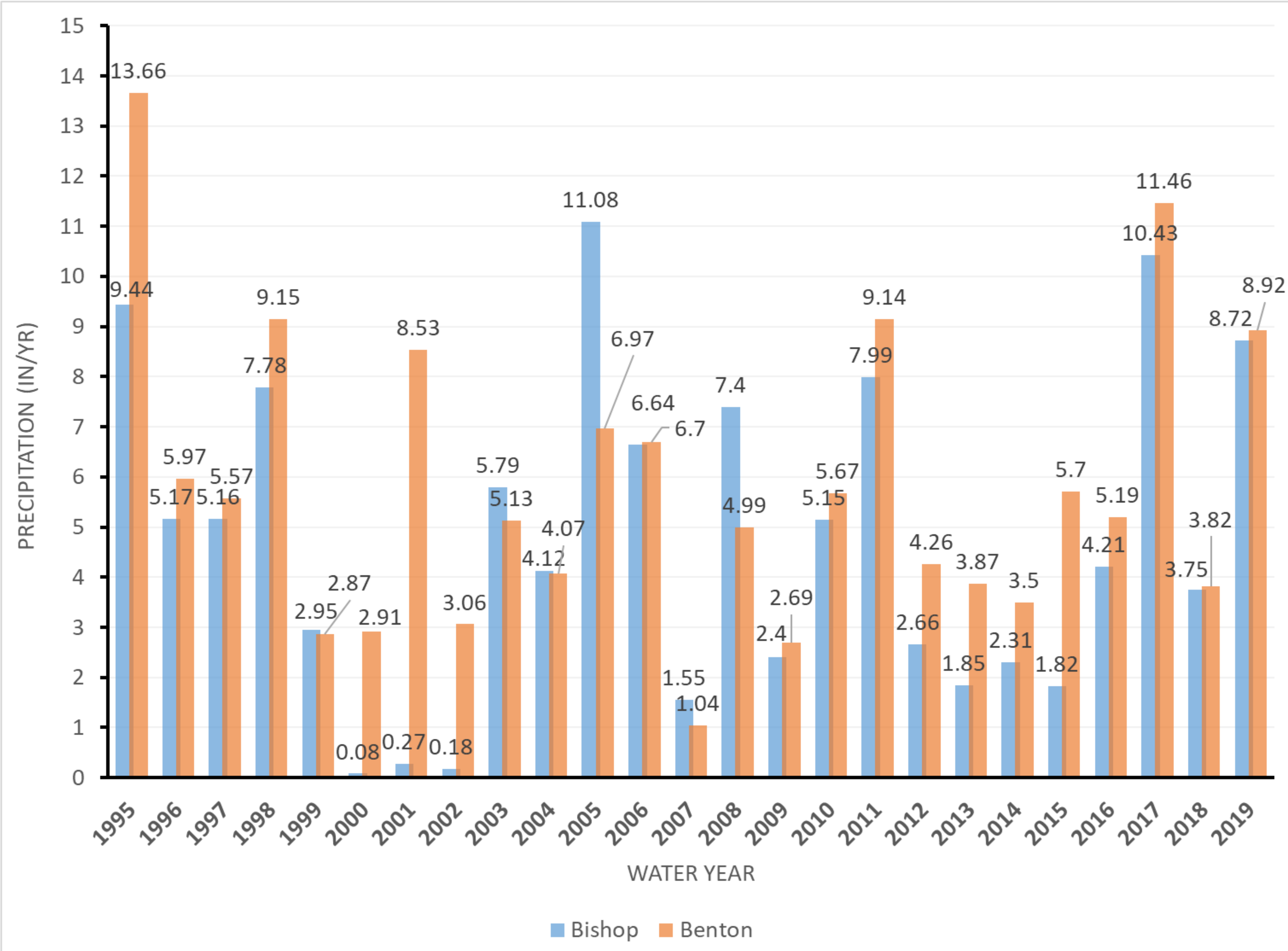

Figure 5. Annual Precipitation at Bishop and Benton Stations

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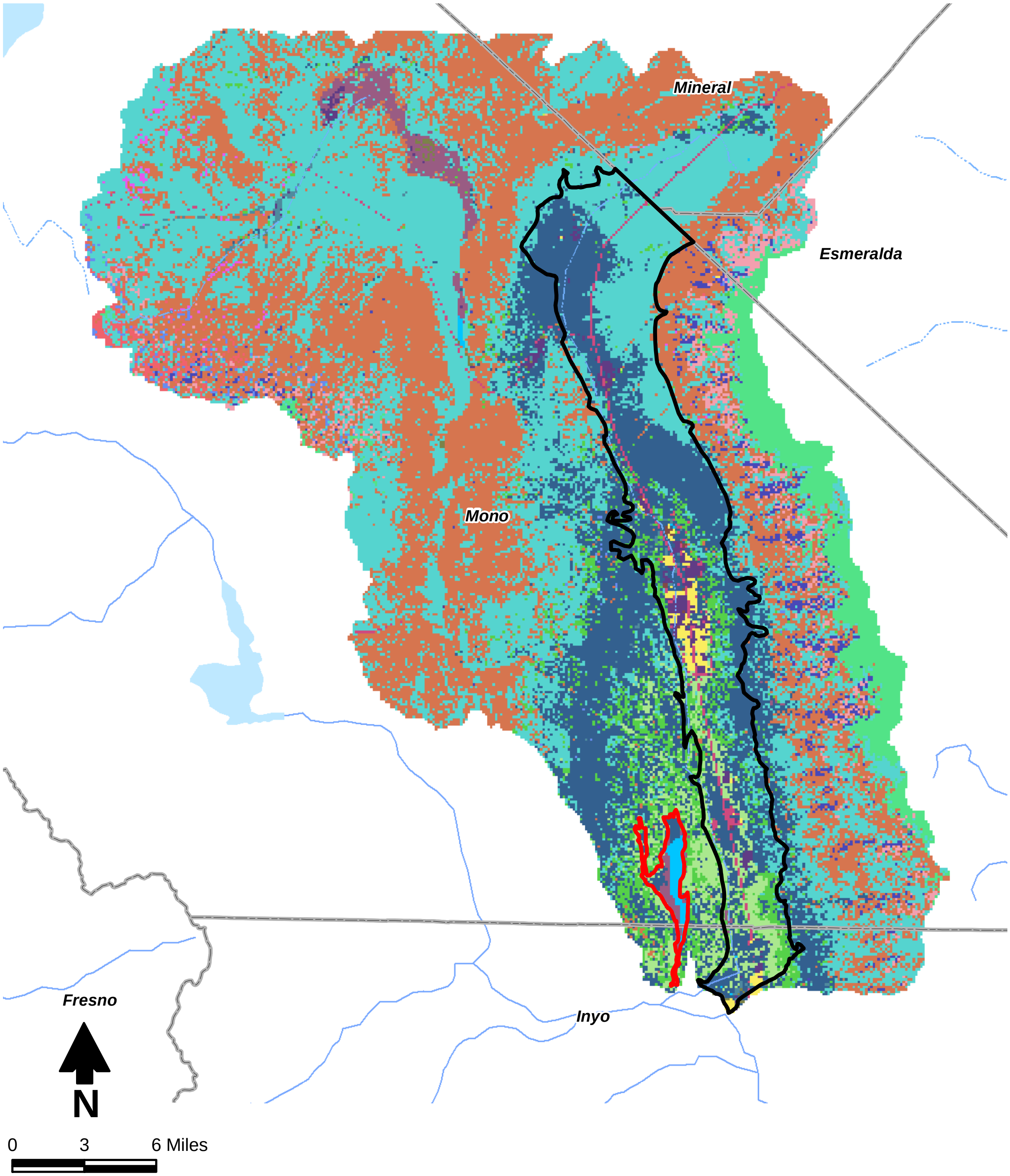

Explanation

- Tri Valley Area
- Fish Slough subbasin
- County boundary

Expalanation of Each Color Symbol is in Figure 6b

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OWENS VALLEY GSP

Vegetation Covergae within Tri-Valley Model

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Figure 6a

PRELIMINARY SUBJECT TO REVISION
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Vegetation code

- Arid West Interior Freswater Marsh
- Cool Interior Chaparral
- Developed & Urban
- Great Basin Saltbush Scrub
- Great Basin-Intermountain Dry Shrubland & Grassland
- Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland
- Herbaceous Agricultural Vegetation
- Intermountain Basins Cliff, Scree & Badlands Sparse Vegetation
- Intermountain Singleleaf Pinyon - Utah Juniper - Western Juniper Woodland
- Introduced & Semi Natural Vegetation
- Mojave-Sonoran Semi-Desert Scrub
- Pasture & Hay Field Crop
- Recently Disturbed or Modified
- Rocky Mountain Subalpine-High Montane Conifer Forest
- Rocky Mountain-Great Basin Montane Riparian Forest
- Rocky Mountain-Vancouverian Subalpine-High Montane Mesic Meadow
- Southern Rocky Mountain & Colorado Plateau Two-needle Pinyon - One-seed Juniper Woodland
- Southern Rocky Mountain Lower Montane Forest
- Southern Vancouverian Montane-Foothill Forest
- Vancouverian Alpine Tundra
- Vancouverian Subalpine Forest
- Warm & Cool Desert Alkali-Saline marsh, Playa & Shrubland
- Western North American Montane-Subalpine Marsh, Wet Meadow & Shrubland
- Western North American Temperate Cliff, Scree & Rock Vegetation
- Open Water

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OWENS VALLEY GSP
Vegetation Codes

Figure 6b

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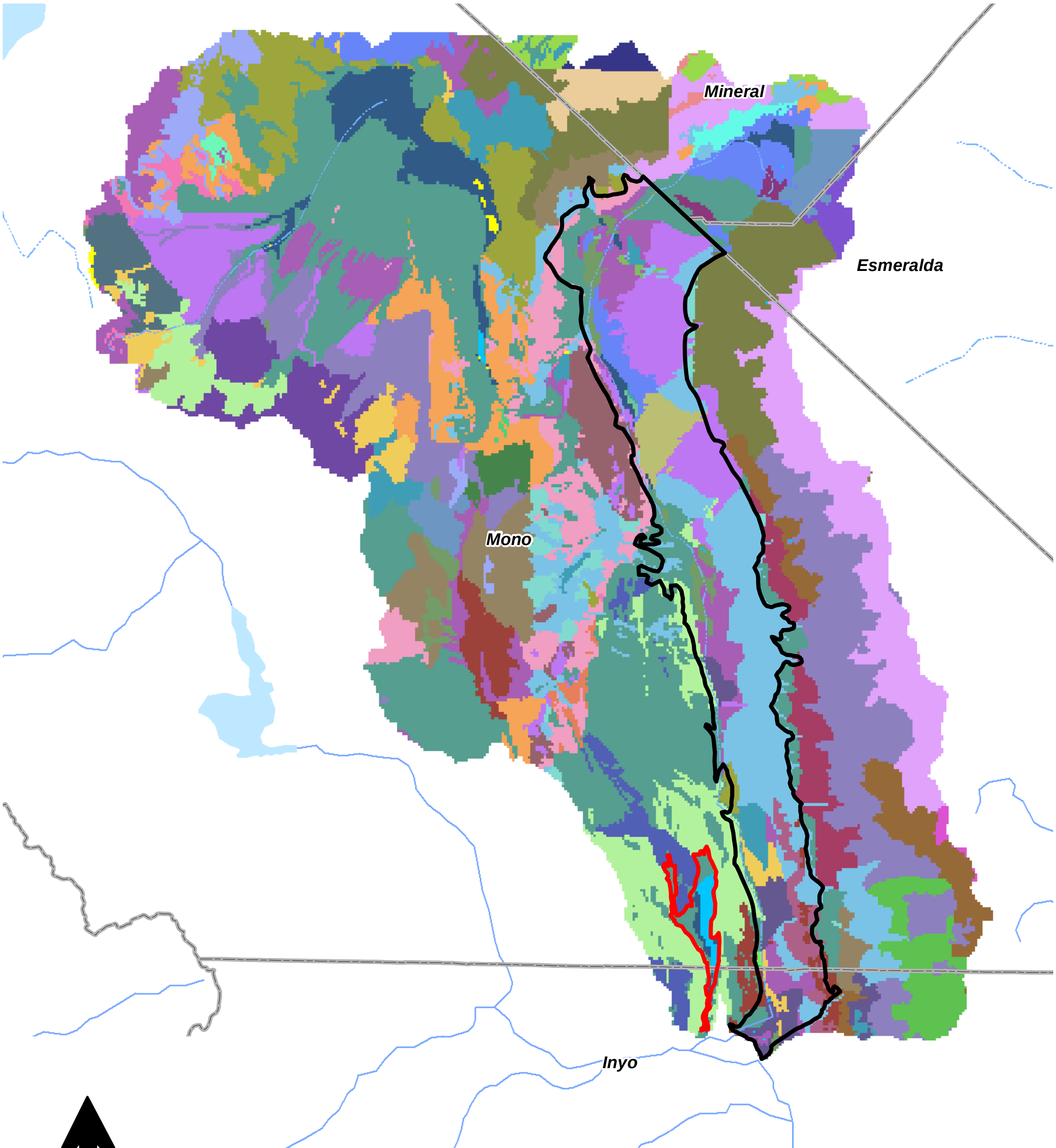

Expalanation of Each Color Symbol is in Figure 7b

Explanation

Tri Valley Area

Fish Slough subbasin

County boundary

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OWENS VALLEY GSP

Soil Coverage within Tri-Valley Model

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1/30/2020
JN DB18.1418

Figure 7a

Soil Type

Bedrock
Bouldery loamy coarse sand
Bouldery loamy sand
Coarse sand
Cobbly loam
Cobbly loamy sand
Extremely cobbly loamy sand
Extremely gravelly loam
Extremely gravelly loamy sand
Extremely gravelly sandy loam
Extremely stony sandy loam
Fine sandy loam
Gravelly coarse sand
Gravelly coarse sandy loam
Gravelly fine sandy loam
Gravelly loam
Gravelly loamy coarse sand
Gravelly loamy fine sand
Gravelly loamy sand
Gravelly sand
Gravelly sandy loam
Loam
Loamy coarse sand
Loamy fine sand
Loamy sand
Mucky loam
Sand
Sandy loam
Stony fine sandy loam
Stony loamy sand
Stony sandy loam
Unknown
Unweathered bedrock
Variable
Very bouldery
Very bouldery coarse sandy loam
Very cobbly loam
Very cobbly loamy fine sand
Very cobbly loamy sand
Very cobbly sandy loam
Very gravelly clay loam
Very gravelly fine sandy loam
Very gravelly loamy sand
Very gravelly sandy loam
Very stony ashy sandy loam
Very stony loam
Very stony loamy fine sand
Very stony sandy loam
Water

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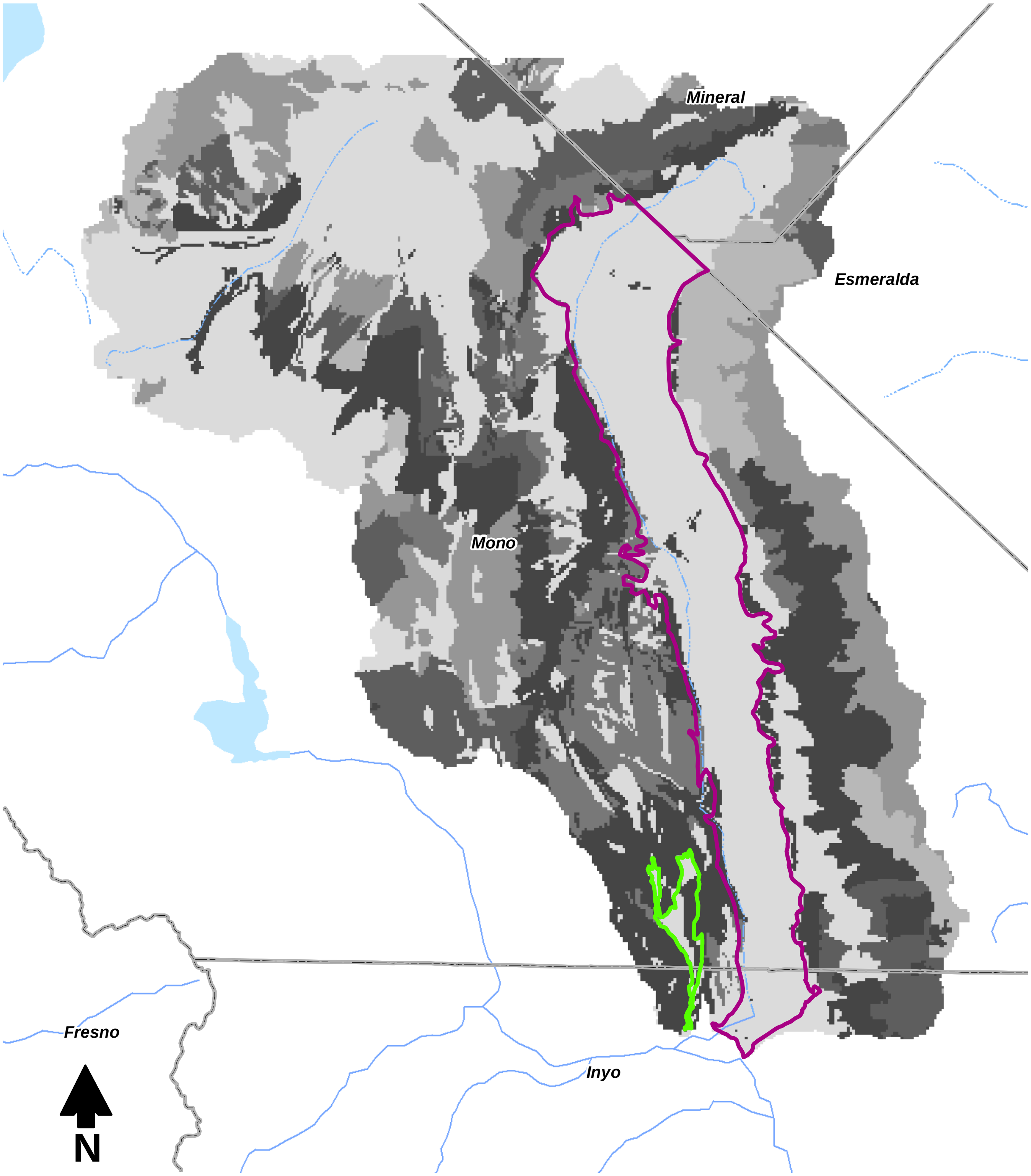

Explanation

Tri Valley Area
Fish Slough subbasin
County boundary

Soil thickness (ft)

0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
> 5

OWENS VALLEY GSP

Soil Thickness within Tri-Valley Model

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Figure 8

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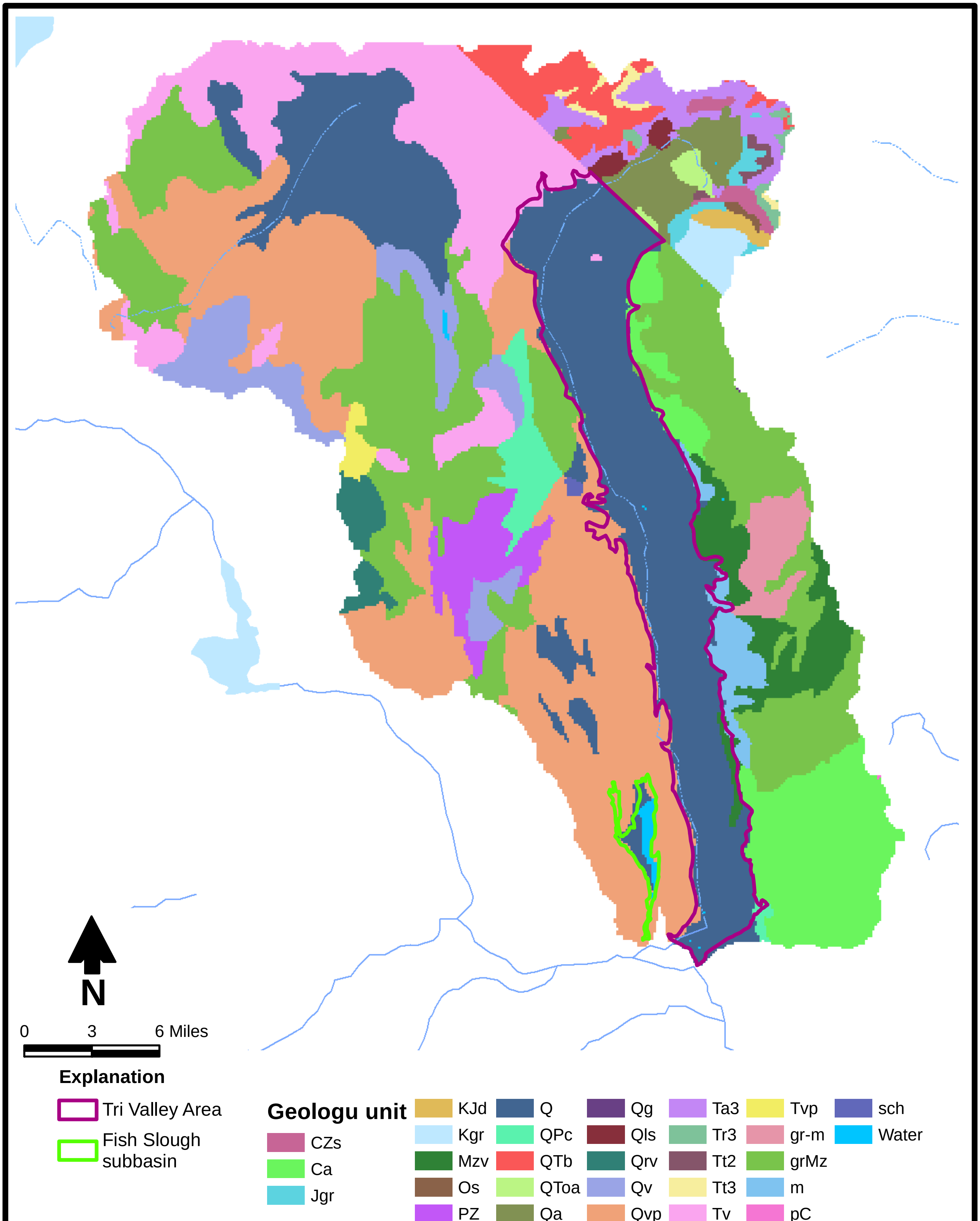

OWENS VALLEY GSP

Surface Geology within Tri-Valley Model

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Figure 9

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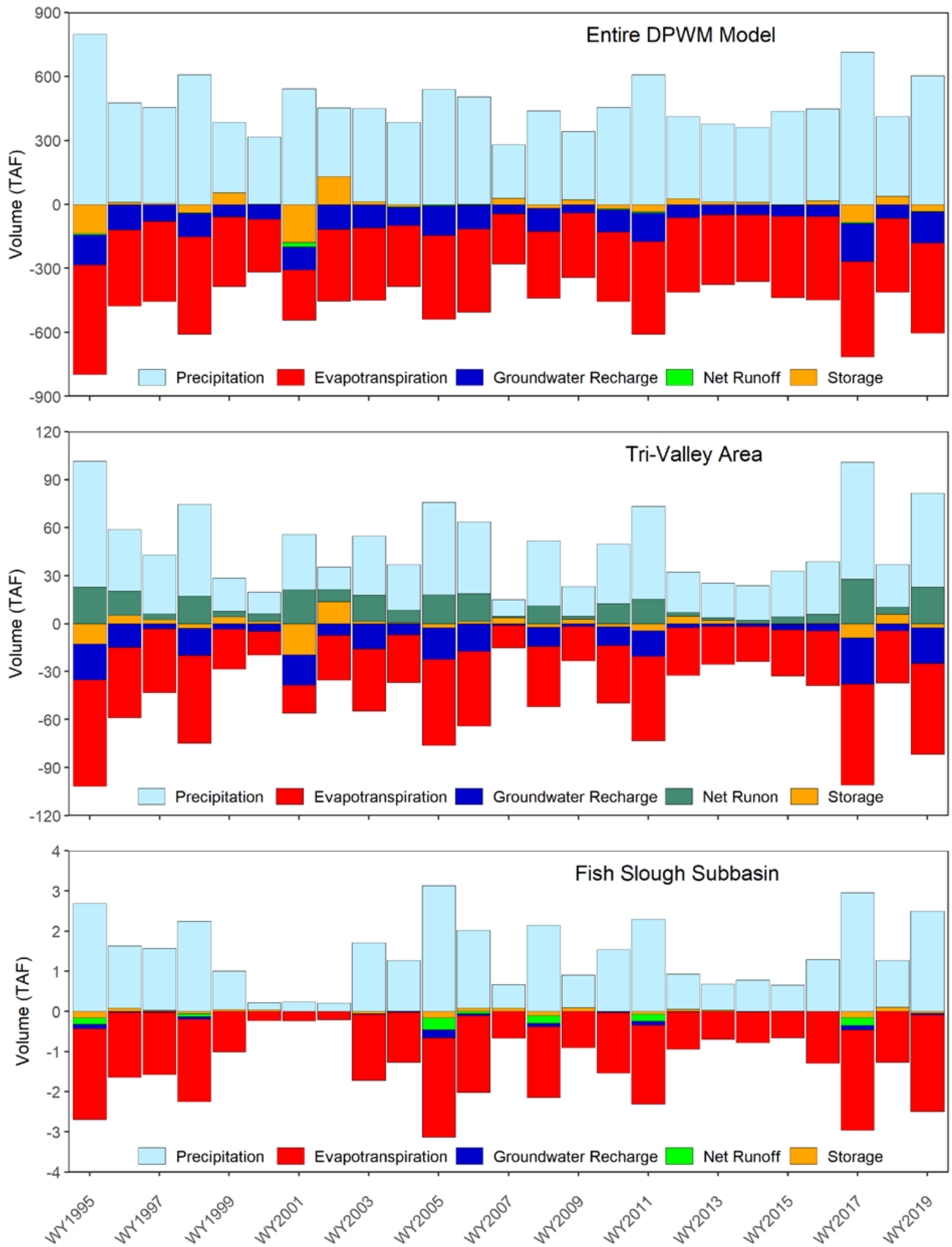

Figure 10 DPWM Annual Water Budget

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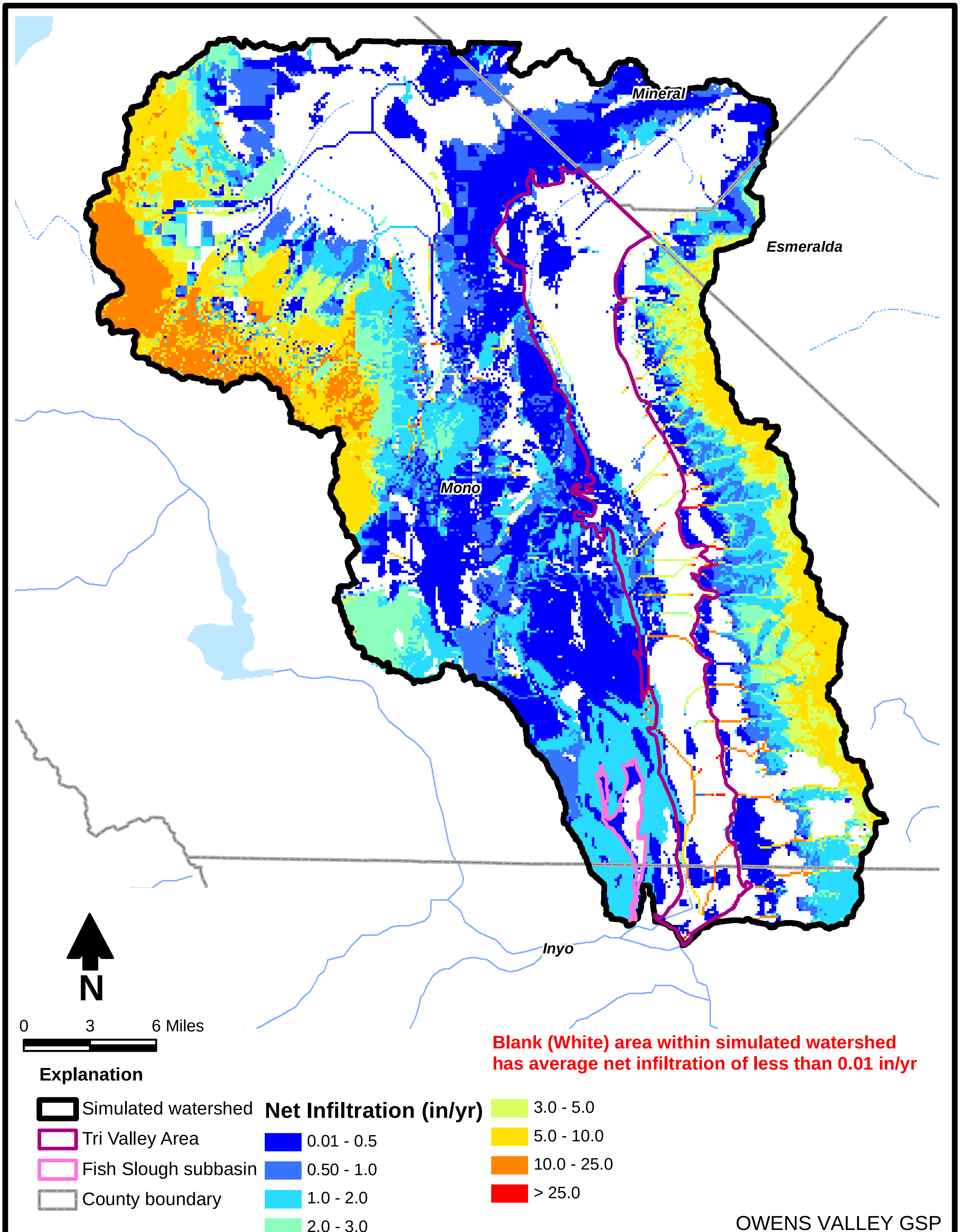

OWENS VALLEY GSP

Simulated Average Net Infiltration within Tri-Valley Model

Daniel B. Stephens & Associates, Inc.

1/31/2020

JN DB18.1418

Figure 10a

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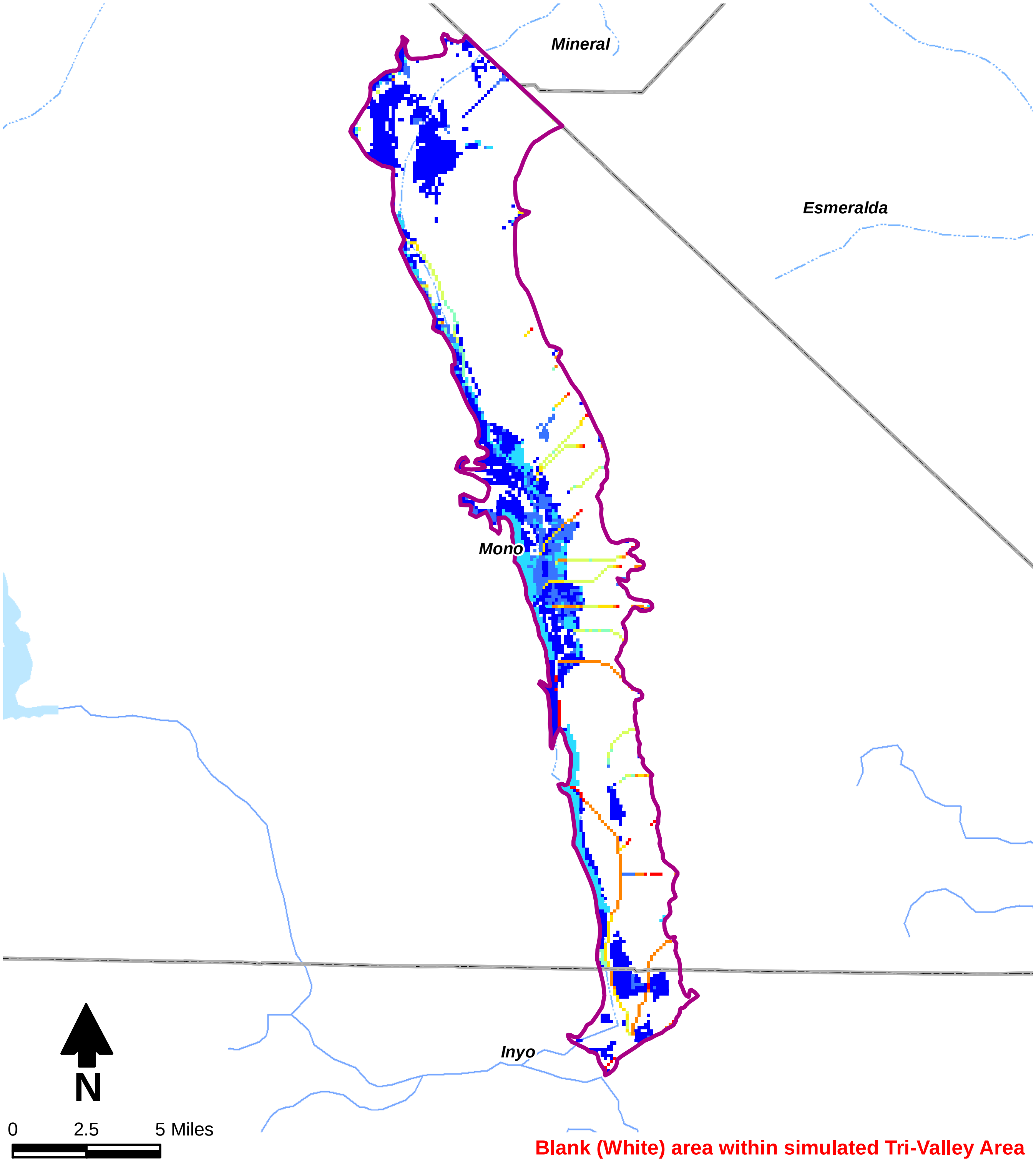

Blank (White) area within simulated Tri-Valley Area has average net infiltration of less than 0.01 in/yr

Explanation

Tri Valley Area

County boundary

Net Infiltration (in/yr)

0.01 - 0.5

0.50 - 1.0

1.0 - 2.0

2.0 - 3.0

3.0 - 5.0

5.0 - 10.0

10.0 - 25.0

> 25.0

OWENS VALLEY GSP

Simulated Average Net Infiltration in the Tri-Valley Area

Figure 10b

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1/30/2020

JN DB18.1418

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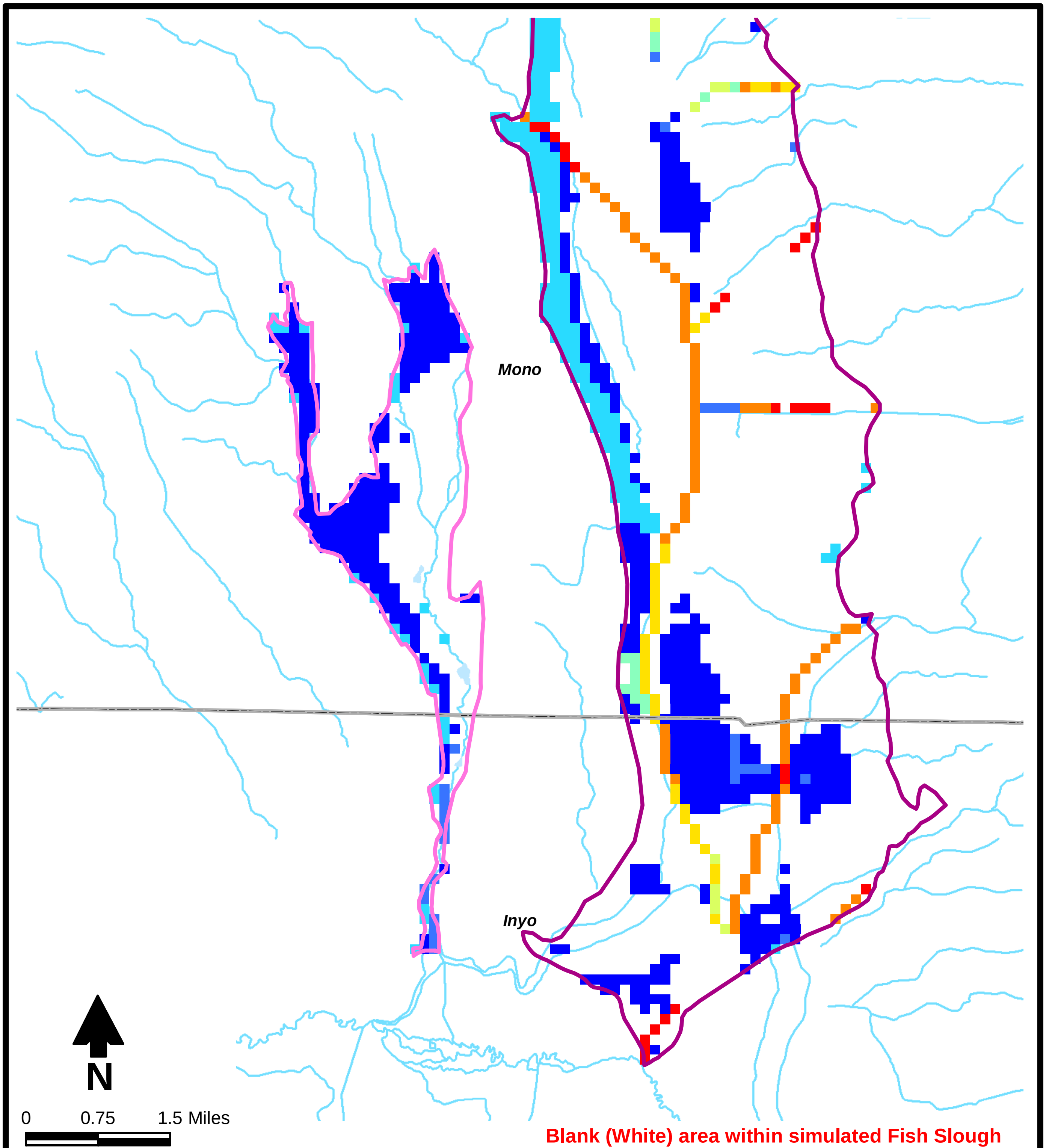

Blank (White) area within simulated Fish Slough subbasinand Tri-Valley Areas has average net infiltration of less than 0.01 in/yr

Explanation

- Tri Valley Area
- Fish Slough subbasin
- County boundary

Net Infiltration (in/yr)

- 0.01 - 0.5
- 0.50 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 5.0
- 5.0 - 10.0
- 10.0 - 25.0
- > 25.0

OWENS VALLEY GSP

Simulated Average Net Infiltration in the Fish Slough Subbasin

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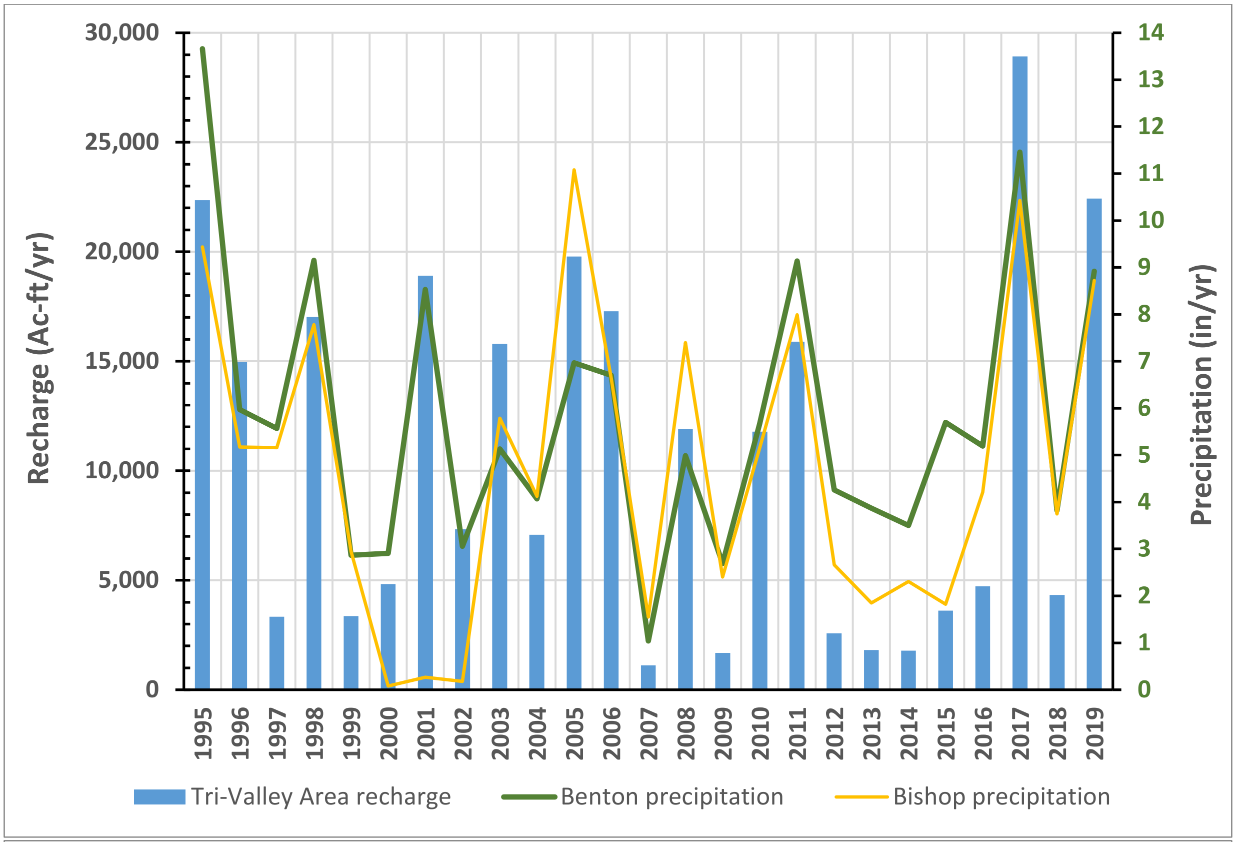
JN DB18.1418

Figure 10c

S:\Projects\DB18.1418_Owens_Valley\GIS\MXDs\Figures\Figure10c_Average_Infiltration_FishSlough.mxd



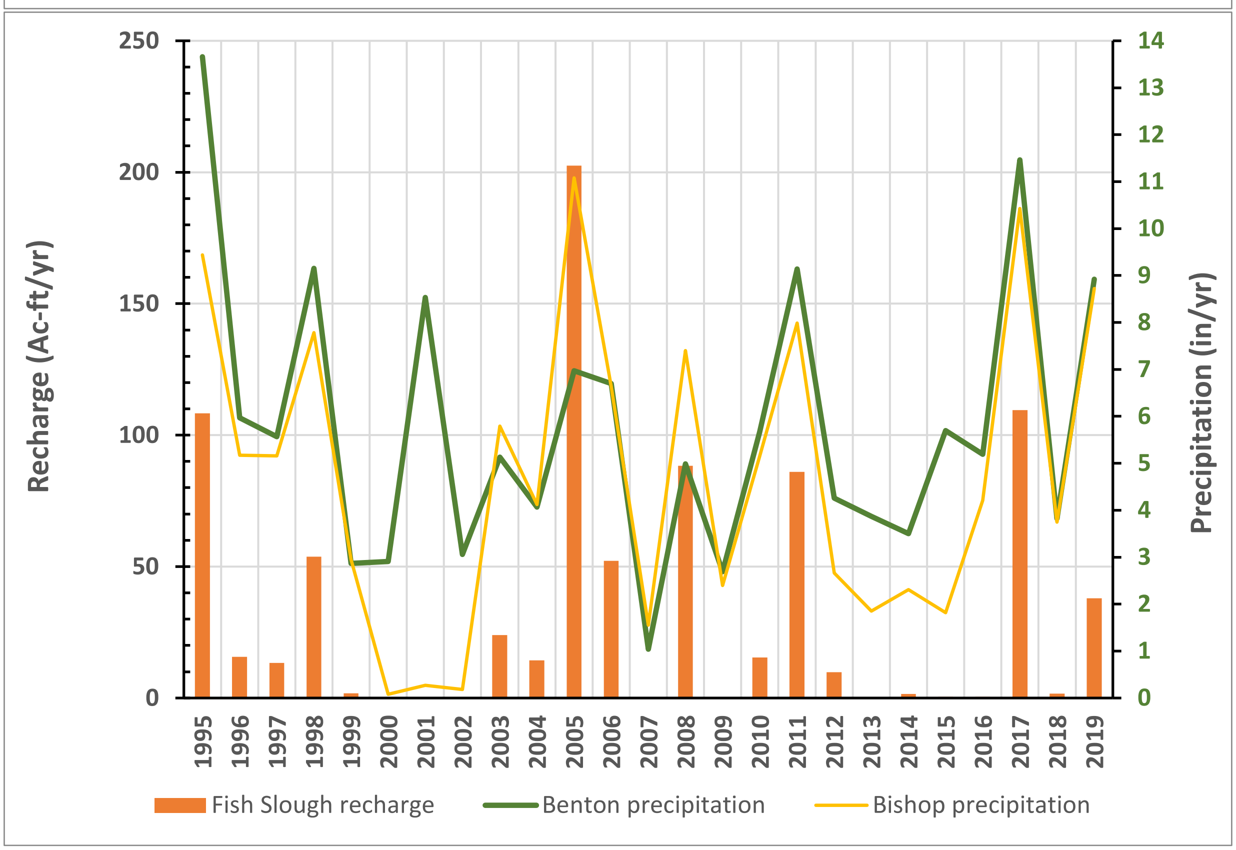


Figure 11. Simulated Infiltration (Recharge) in the Tri-Valley Area (top) and Fish Slough Subbasin (bottom)

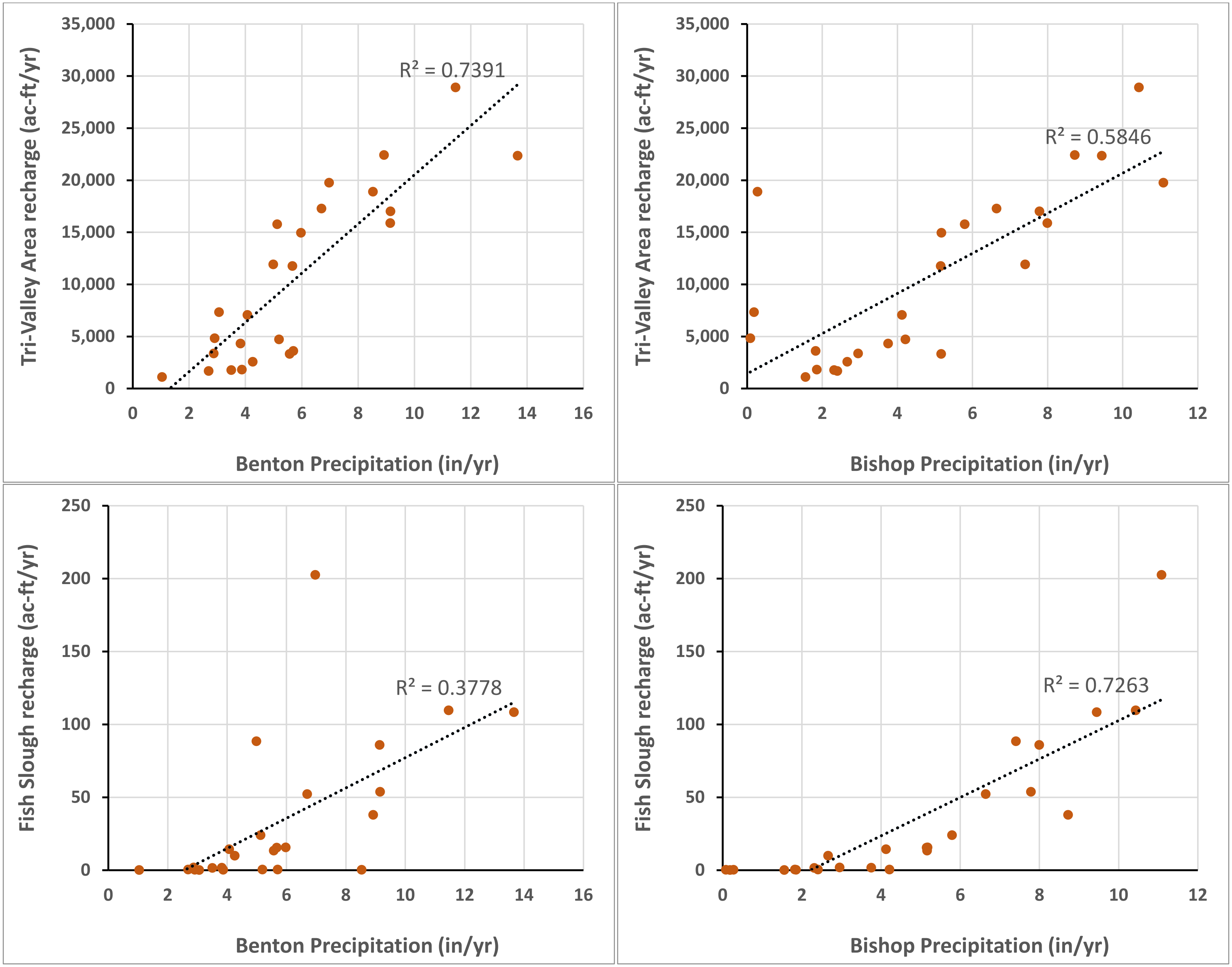


Figure 12. Correlation between Annual Precipitation at Different Stations and Annual Recharge in the Study Area

Table 1 - Simulated Plant Height and Root Depth for the Different Vegetation Classes in the Tri-Valley Model

Vegetation Class	Plant Height (m)	Root Depth (m)	Number of Cells in the Model
Rocky Mountain Subalpine-High Montane Conifer Forest	12.19	3.50	1,353
Southern Rocky Mountain Lower Montane Forest	12.19	3.50	2
Southern Vancouverian Montane-Foothill Forest	12.19	3.50	283
Vancouverian Subalpine Forest	12.19	3.50	452
Intermountain Singleleaf Pinyon - Utah Juniper - Western Juniper Woodland	7.62	4.57	23,469
Southern Rocky Mountain & Colorado Plateau Two-needle Pinyon - One-seed Juniper Woodland	7.62	4.57	3
Western North American Montane-Subalpine Marsh, Wet Meadow & Shrubland	7.62	4.57	238
Rocky Mountain-Great Basin Montane Riparian Forest	7.62	4.57	1
Rocky Mountain-Vancouverian Subalpine-High Montane Mesic Meadow	7.62	4.57	26
Cool Interior Chaparral	7.62	4.57	17
Arid West Interior Freswater Marsh	0.50	2.00	79
Warm & Cool Desert Alkali-Saline marsh, Playa & Shrubland	0.50	2.00	953
Great Basin-Intermountain Dry Shrubland & Grassland	0.50	2.00	3,047
Mojave-Sonoran Semi-Desert Scrub	0.50	2.00	1,858
Great Basin Saltbush Scrub	0.50	2.00	12,158
Great Basin-Intermountain Tall Sagebrush Steppe & Shrubland	10.67	4.00	28,668
Western North American Temperate Cliff, Scree & Rock Vegetation	0.10	0.15	1,062
Intermountain Basins Cliff, Scree & Badlands Sparse Vegetation	0.10	0.15	149
Vancouverian Alpine Tundra	0.10	0.15	3,060
Herbaceous Agricultural Vegetation	3.00	0.50	310
Pasture & Hay Field Crop	1.00	1.00	500
Introduced & Semi Natural Vegetation	0.30	1.00	14
Recently Disturbed or Modified	0.30	1.00	30
Open Water	0.00	0.15	210
Developed & Urban	0.30	1.00	523

Table 2 - Simulated Bedrock Hydraulic Conductivity for the Different Rock Types in the Tri-Valley Model

Geology Code	Rock Type 1	Rock Type 2	Hydraulic Conductibity (cm/sec)	Hydraulic Conductibity (ft/day)	Number of Cells in the Model
Ca	sandstone	dolostone (dolomite)	1.00E-06	2.83E-03	5,128
CZs	siltstone	limestone	3.53E-07	1.00E-03	300
gr-m	plutonic rock (phaneritic)	gneiss	1.00E-06	2.83E-03	1,084
grMz	granodiorite	quartz monzonite	1.00E-06	2.83E-03	14,347
Jgr	quartz monzonite	granodiorite	1.00E-06	2.83E-03	322
Kgr	granodiorite	quartz monzonite	1.00E-06	2.83E-03	564
KJd	diorite	quartz diorite	1.00E-06	2.83E-03	223
m	schist	gneiss	1.00E-06	2.83E-03	995
Mzv	felsic volcanic rock	intermediate volcanic rock	3.53E-06	1.00E-02	2,260
Os	chert	shale	3.53E-08	1.00E-04	59
pC	sandstone	mudstone	3.53E-07	1.00E-03	3
PZ	hornfels	quartzite	1.00E-06	2.83E-03	1,592
Q	alluvium	terrace	5.00E-04	1.42E+00	16,310
Qa	alluvium	mass wasting	5.00E-04	1.42E+00	1,393
Qg	glacial drift		5.00E-04	1.42E+00	2
Qls	landslide	colluvium	5.00E-04	1.42E+00	224
QPc	sandstone	conglomerate	3.53E-05	1.00E-01	1,145
Qrv	rhyolite		3.53E-05	1.00E-01	729
QTb	basalt	andesite	1.00E-06	2.83E-03	1,608
QToa	alluvium	lake or marine deposit (non-glacial)	5.00E-04	1.42E+00	239
Qv	rhyolite	andesite	3.53E-05	1.00E-01	2,978
Qvp	rhyolite	ash-flow tuff	3.53E-05	1.00E-01	16,876
sch	schist	hornfels	1.00E-06	2.83E-03	48
Ta3	andesite	latite	3.53E-06	1.00E-02	1,384
Tr3	rhyolite	dacite	3.53E-05	1.00E-01	191
Tt2	rhyolite	dacite	3.53E-05	1.00E-01	124
Tt3	rhyolite	No data	3.53E-05	1.00E-01	236
Tv	tephrite (basanite)	trachybasalt	1.00E-06	2.83E-03	7,594
Tvp	rhyolite	dacite	3.53E-05	1.00E-01	297
water	water		3.53E-10	1.00E-06	210