

Distributed Parameter Watershed Model Tri-Valley Area Watershed

Submitted to
Owens Valley Groundwater Authority

Prepared by



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Certification

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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 ($^{\circ}\text{F}$) 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 ($\text{mm/d}/^{\circ}\text{C}$) on December 21 to 5.2 $\text{mm/d}/^{\circ}\text{C}$ 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

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 Freshwater 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



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 Genuchten 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-



Table 2. Simulated bedrock hydraulic conductivity

Geology Code	Rock Type 1	Rock Type 2	Hydraulic Conductivity (cm/sec)	Hydraulic Conductivity (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



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 runoff/runoff patterns. The Tri-Valley area budget showed more water entering than leaving as surface flow, resulting in net runoff 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.



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Appendix A DPWM Manual