TODD GROUNDWATER

January 31, 2022

MEMORANDUM

To: Blaine Reely, San Luis Obispo County and
Christopher Alakel, City of Paso Robles

From: Gus Yates, PG, CHG and Iris Priestaf, PhD

Re: Interconnected Surface Water Assessment, Paso Robles Basin GSP

The Sustainable Groundwater Management Act (SGMA) regulations define interconnected surface water as “surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted” (§351 (o)). SGMA requires that GSPs evaluate “impacts on groundwater dependent ecosystems.” (Water Code §10727.4(l)). Groundwater dependent ecosystems (GDEs) are defined in the GSP regulations as “ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface” (CCR § 351 (mm)). GDEs can be divided into two groups: plants and animals that depend on surface flow in streams (for example, fish, invertebrates, amphibians) and plants and animals that depend on a shallow water table accessible by plant roots (phreatophytic riparian vegetation and bird or other animal species that inhabit riparian vegetation). In this GSP, GDEs are discussed in the general category of interconnected surface water even though organisms in the second group strictly speaking rely only on a shallow water table, not surface flow in a stream.

This GSP addresses both types of interconnection between groundwater and surface water: interconnection with open surface water (streams, springs or lakes) and interconnection with the root zone of riparian vegetation. These two categories involve different groundwater elevation thresholds and often have different frequencies and durations of occurrence. Along seasonally intermitted streams—which includes all stream reaches crossing the Subbasin—large surface inflow events can quickly raise the alluvial water table up to near the level of the water in the stream. At that point, surface water and groundwater are hydraulically interconnected, and there may be short gaining and losing segments along the overall stream reach. When surface inflow dries up, regional groundwater discharge may continue to sustain flow for a longer period. The maximum water table depth at which the roots of phreatophytic riparian vegetation can access groundwater is perhaps 30 feet below the ground surface based on the observed locations of dense riparian vegetation. After the water table falls below the stream bed elevation during the dry season, it will remain within the 0 to 30 foot depth range for an extended period, in some locations perennially. Thus, the duration of interconnection of groundwater with the riparian root zone is much greater than the duration of interconnection with surface flow in the stream.

Locations of interconnection between groundwater and surface water are shown in Figure 1. The identification of interconnected stream reaches was based on a joint evaluation of stream flows, groundwater levels and riparian vegetation. For GSP purposes, it is further necessary to separate the effect of groundwater levels from the effects of other hydrologic variables that are typically correlated over time, such as precipitation and surface runoff. The following data sets were analyzed to quantify the relationships among variables:

- Annual precipitation and cumulative departure of annual precipitation at Paso Robles
- Gaged stream flows in the Salinas and Estrella Rivers
- Historical aerial photographs from 1989-2021
- Groundwater levels in shallow alluvial wells and deeper (Paso Robles Formation) wells
- Changes in the extent and density of riparian and wetland vegetation
- The water status of vegetation based on spectral analysis of satellite images during 1987-2020

Each of these data sets is described below. Taken together, the data sets were remarkably consistent with a hydrogeologic conceptual model of the Subbasin described in a SWRCB decision in 1982. That conceptual model and its extension to interconnected surface water is presented first to provide a framework for considering the individual data sets.

Many of the data used in the analysis pre-date 2015, which was the start of the SGMA management period. SGMA does not require that GDEs be restored to any condition that occurred prior to 2015. However, long-term data sets provide greater opportunity for differentiating the separate effects of variables that are often correlated. For example, precipitation, stream flow and groundwater levels are all potential sources of water for riparian vegetation, and all three are low during droughts. The extensive use of pre-2015 data in the analysis does not mean that this GSP intends to restore any conditions to a pre-2015 level.

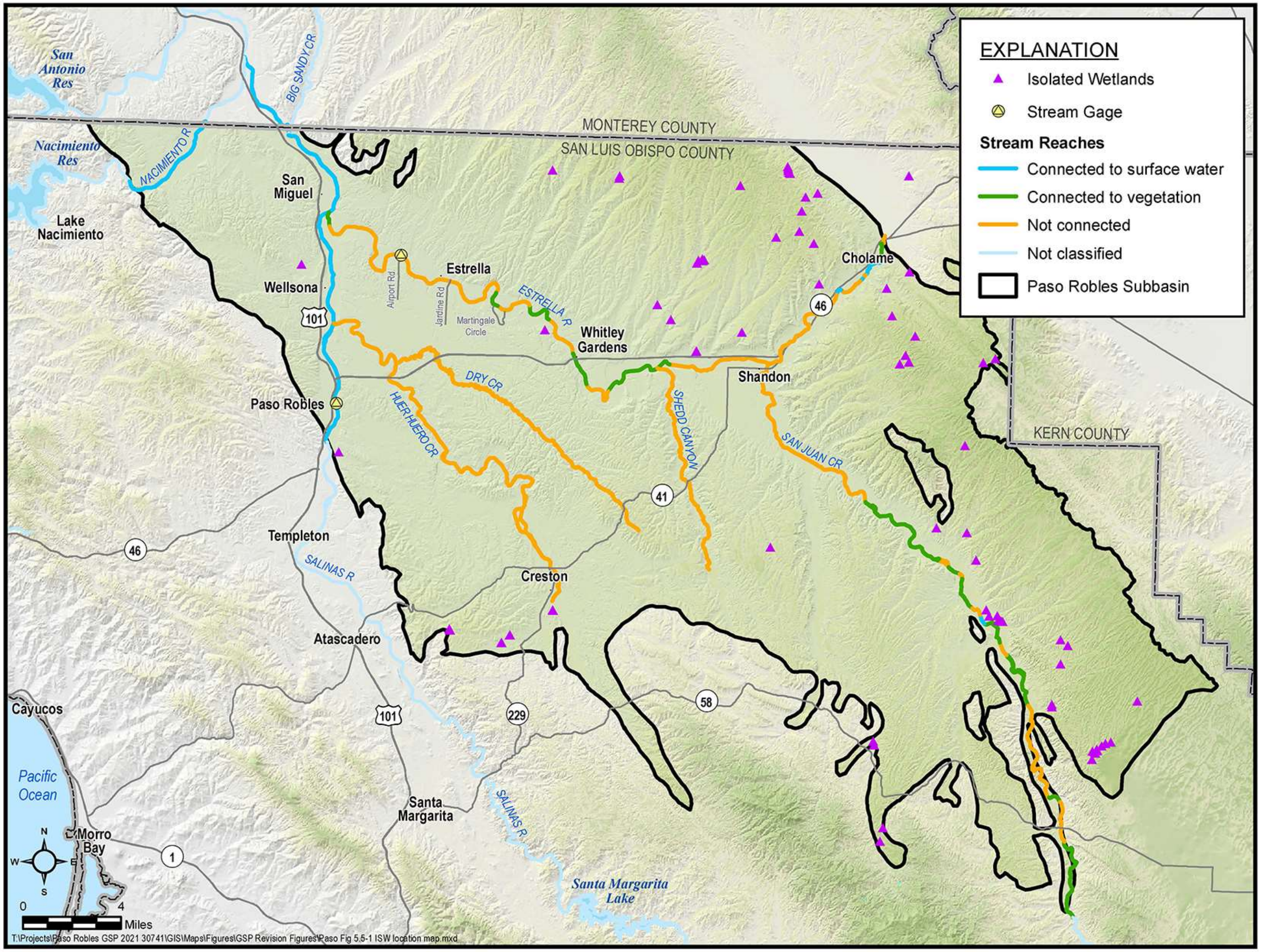


Figure 1. Locations of Interconnection Between Groundwater and Surface Water

1. CONCEPTUAL MODEL OF INTERCONNECTED SURFACE WATER

In 1982, the SWRCB issued Decision 1585 regarding a group of applications for surface diversions from tributaries to the Salinas River between Salinas Dam and the Nacimiento River (SWRCB, 1982). By that date, the SWRCB had already determined that groundwater in alluvial deposits along the Salinas River was classified as underflow subject to the rules of surface water appropriation. The Decision described hydrogeologic conditions and recharge processes in the Paso Robles Groundwater Basin, stating that there are "silty clays of low permeability existing within the upper portion of the Paso Robles Formation beneath and adjacent to the Salinas River alluvium… [that] appear to be sufficiently thick and extensive to act as a barrier separating underflow in the river alluvium from groundwater that occurs in the underlying older water-bearing formations." The clays were said to extend eastward to about the community of Estrella along the Estrella River and the community of Creston along Huerhuero Creek. Upstream of the clays, percolation from the Estrella River and Huerhuero Creek directly recharges the Paso Robles Formation.

This hydrogeological conceptual model suggests that groundwater pumping—the preponderance of which is from the Paso Robles Formation—would tend to deplete stream flows upstream of the clay layers but have only a small effect on stream flows overlying the clay layers. An additional geographic variation in regional hydrology is that the western part of the watershed surrounding the Subbasin is much wetter than the eastern part. Average annual precipitation over the Coast Ranges along the western side of the watershed is about four times greater than precipitation along the eastern edge of the watershed. As a result, surface runoff into the Salinas River is substantially greater than surface runoff into the Estrella River. The combined effect of greater surface inflow and confining layers beneath the alluvium is to enable the Salinas River to maintain high, steady groundwater levels that support the establishment and growth of riparian vegetation. Except during major droughts, river recharge has been able to outpace leakage across the confining layers, even after water levels in deep wells declined by many tens of feet. In contrast, many stream reaches in the eastern half of the Subbasin do not appear to be buffered from the effects of pumping. Over several decades, pumping has lowered groundwater levels in the Paso Robles Formation, depleted stream flow and may have caused the observed decrease in the extent and health of riparian vegetation.

2. PRECIPITATION

The history of annual precipitation at Paso Robles is useful for interpreting other data sets. It identifies individual dry and wet years as well as droughts and sequences of wet years and allows changes in groundwater levels and vegetation to be related to general hydrologic conditions. For example, comparing vegetation at the end of one drought with vegetation at the end of a later drought controls for drought effects and allows the effects of long-term water-level declines to be assessed.

Figure 2 shows annual precipitation at Paso Robles during water years 1910-2021. The blue bars show annual precipitation, and the orange line shows the cumulative departure of annual precipitation. The cumulative departure line goes down in years that are drier than average and up in years that are wetter than average. Thus, droughts appear as long, large declining segments of the cumulative departure line. Two droughts used in the present analysis were 1987-1990 and 2012-2016. They were similar in intensity (63-64 percent of long-term average precipitation), but the more recent drought was one year longer.

3. STREAM FLOW

Stream flow gages with useful historical records are “Salinas River at Paso Robles” (USGS station 11147500), with a period of record of water years 1940-2021, and “Estrella River near Estrella” (USGS station 11148500), with a period of record of water years 195696 and 2016-2018. The Salinas River gage is near the upstream end of the reach crossing the Subbasin. Flows at that location do not reflect pumping depletion within the basin, but they can be used to evaluate flow duration and the amount of flow required to create continuous throughflow to the Nacimiento River confluence. Aerial photographs from nineteen dates between 1989 and 2021 were examined to determine whether throughflow was present, which was on five dates. However, the amount of flow at the gage associated with throughflow is inconsistent and might have been affected by flows over the weeks and months preceding the respective photograph. Live flow was present with gaged flows as small as 5-8 cubic feet per second (cfs), when flow had been continuous but slowly receding for weeks beforehand. Conversely, discontinuous flow was present with gaged flows as high as 73 cfs. The location where flow first becomes discontinuous was not obvious from the aerial photographs. Commonly, the entire reach from about Wellsona to the Nacimiento River was dry, damp or flowing.

Along the Estrella River, open water or at least ribbons of very damp soil along the channel were commonly present at various locations from about 4 miles upstream of Whitley Gardens to about 0.5 mile downstream of Whitley Gardens and along about a 1-mile reach near Martingale Circle (about 5 channel miles downstream of Whitley Gardens) prior to 2012. Since then, those possible gaining reaches have not been visible in dry season air photos.

Figure 3 shows annual discharge and cumulative departure of annual discharge in the Salinas River at the Paso Robles gage. The patterns of annual discharge and cumulative departure are similar to those for precipitation, which confirms that river flows derive primarily from rainfall runoff.

Flows in the Estrella River are much smaller than those in the Salinas River due primarily to the smaller amount of annual rainfall. For example, average annual discharge in the Salinas River during water years 1972-1994 (74,925 acre-feet per year) was close to the long-term average and was 4.6 times greater than annual discharge in the Estrella River for the same time period.

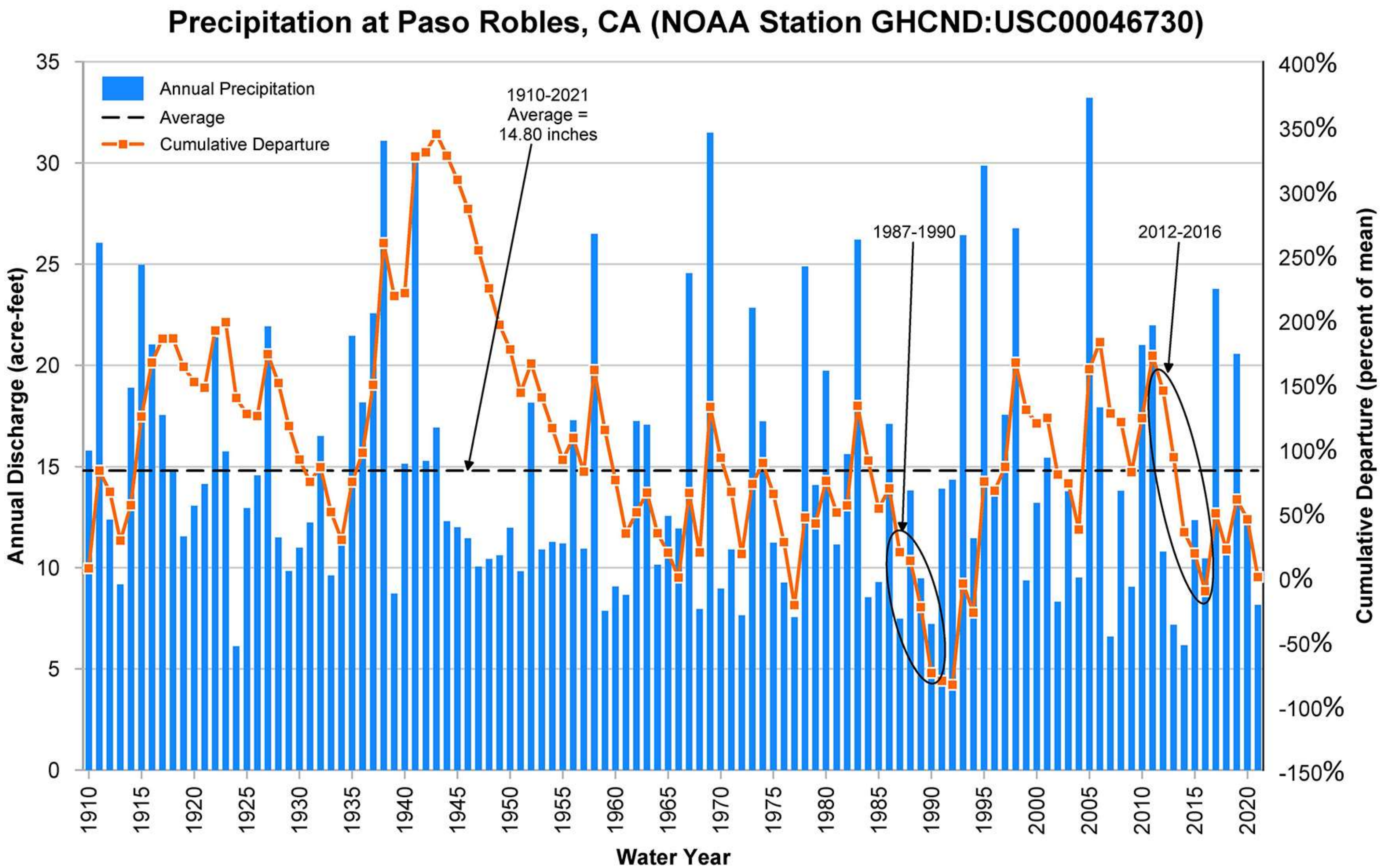


Figure 2. Annual Precipitation at Paso Robles, Water Years 1910 to 2021

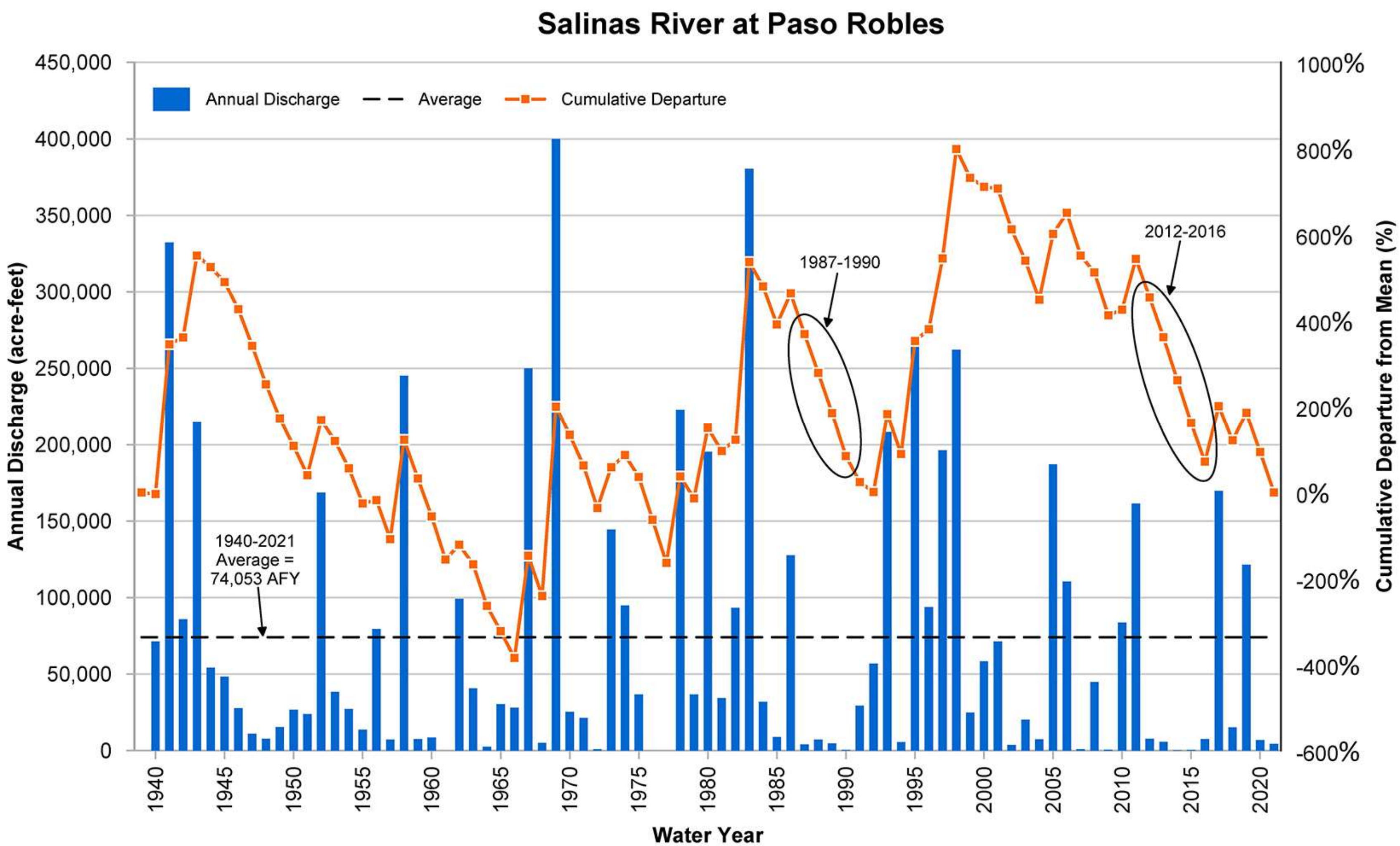


Figure 3. **Annual Discharge and Cumulative Departure of Annual Discharge, Salinas River at Paso Robles Gage**

Estrella River flows at the "near Estrella" gage (see Figure 1) have also been depleted by groundwater pumping and declining groundwater levels, whereas the Salinas River flows have not. Figure 4 shows flow-duration curves for both rivers for four three-year time intervals, roughly a decade apart from the 1960s to 2010s. Each curve displays all daily flows during a three-year period sorted from largest to smallest. The horizontal X axis shows the percentage of time each flow magnitude is exceeded. For perennial streams, the curves would extend across the entire width of the graph because flow exceeds zero 100 percent of the time. For seasonally intermittent streams, the curve bends down and crosses the X axis indicating the percentage of time flow is greater than zero. By plotting the vertical Y axis on a logarithmic scale, changes in low flows are visually expanded. If groundwater pumping is depleting stream flow, the effect is to curtail the duration of low flows (bend the curve downward) and shift the X axis intercept to the left.

As documented in Figure 4, in the Estrella River, low flows have become increasingly depleted by groundwater pumping over the past five decades, causing the curves to shift progressively to the left. In contrast, the curves for the Salinas River have remained in a cluster, with no trend to the right or left. The Estrella River gage is near the eastern edge of the shallow clay layers in the Paso Robles Formation. These curves confirm that flows upstream of the gage were historically interconnected with groundwater and subject to depletion by groundwater pumping and lowered groundwater levels.

Prior to 2012, there were several locations along the Estrella River where subsurface hydrogeologic conditions appeared to push the water table closer to the land surface, resulting in flow or visible dampness along the low-flow channel when nearby reaches were dry. This most commonly occurred 3-4.5 miles above Highway 46, 0-1 miles above Highway 46 (at Whitley Gardens), and 3.8-5 miles downstream of Highway 46 near Martingale Circle. Neither flow nor dampness has been visible during the dry season at these locations since 2012.

4. GROUNDWATER LEVELS

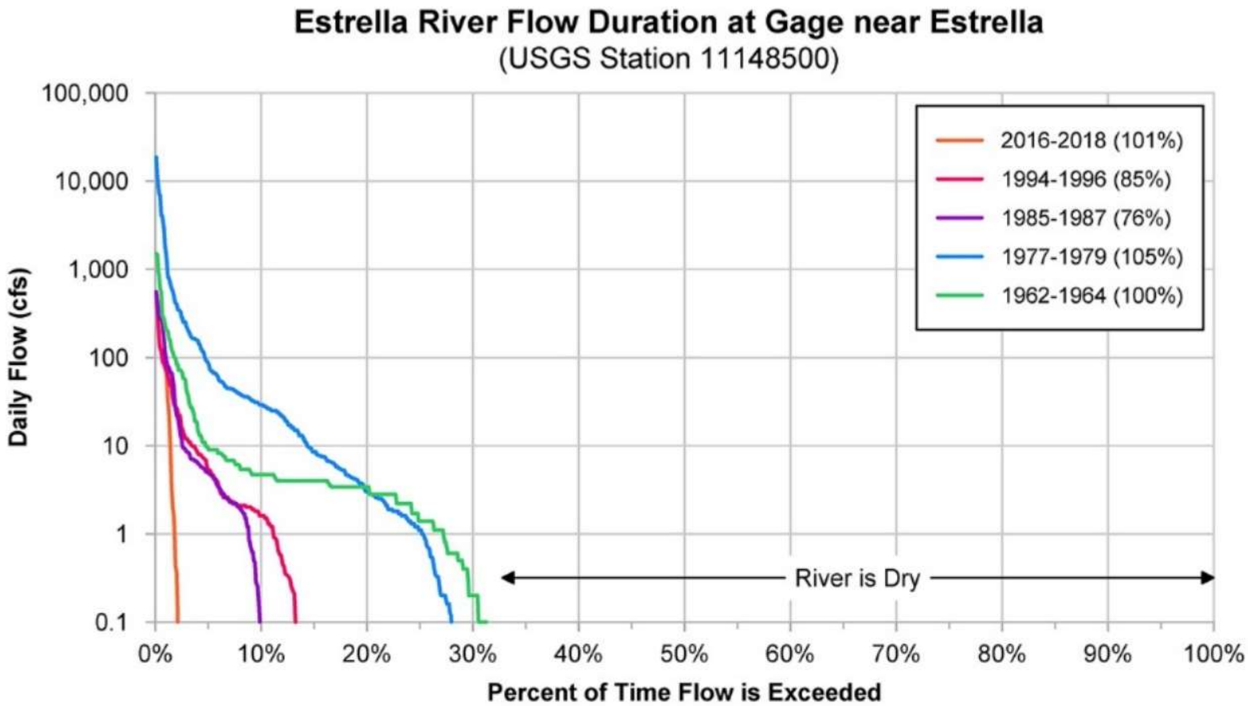
Relating groundwater levels to interconnected surface water requires that the depth of the well screen be known because wells screened at different depths can have different water levels. Only the true water table at the uppermost zone of saturation is relevant to interconnection with surface water or tree roots. In alluvial basins like the Paso Robles Subbasin the true water table is typically higher than the water level in deeper aquifer units tapped by water supply wells because confining layers within the basin fill materials slow the rates at which pumping from deep aquifers affect water levels in shallow ones. For example, a very large difference between shallow and deep water levels was found near the Airport Road bridge over the Estrella River (see Figure 1), where two monitoring wells were installed in 2021. The shallower well was screened down to 40 feet below the ground surface and had a depth to water of 29.5 feet (Cleath-Harris Geologists, 2021). The top of the screen in the second well was 160 feet deeper and its water level was 158 feet lower.

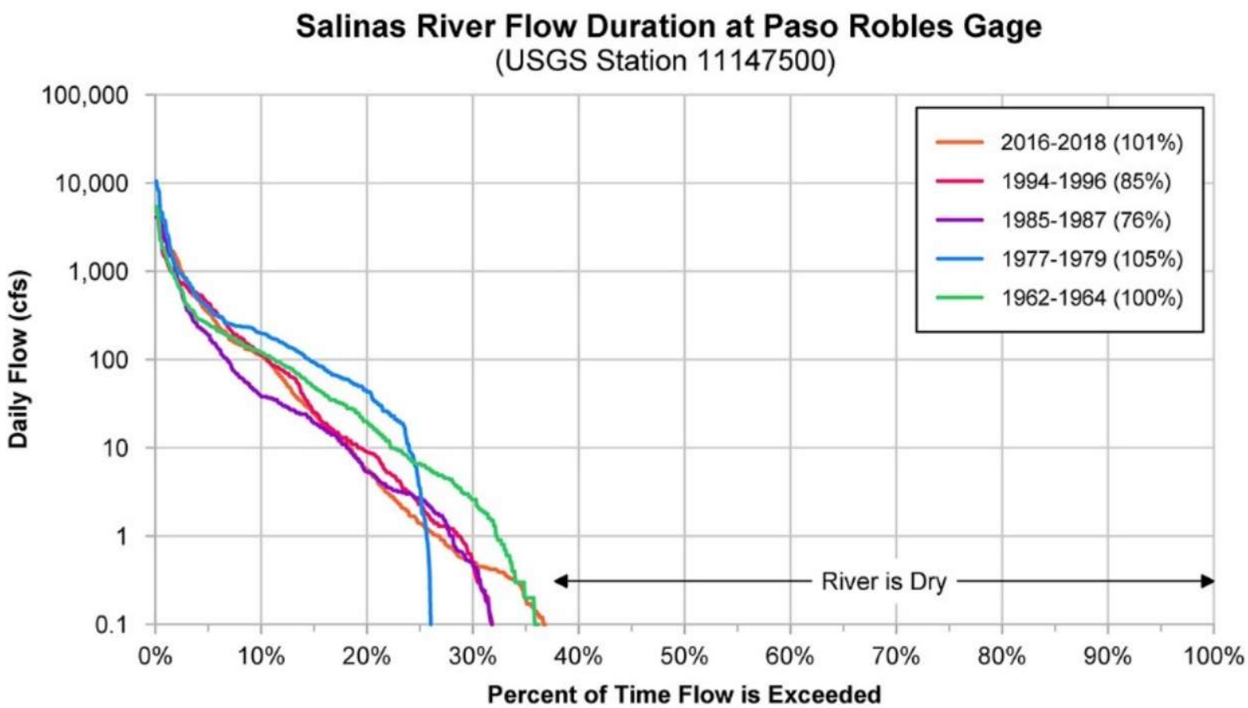
This represents a vertical water-level gradient close to unity, which means the shallow aquifer is perched and there is an unsaturated zone between the shallow and deep aquifers.

Most attempts to group water level data by well depth have been hampered by lack of depth or screened interval information for the wells (see for example GSP Sections 4.4 and 4.4.4). Groundwater levels have been monitored in about 3,600 wells in the Subbasin by SLOFCWCD, but construction information is available for only 244 of them. Only one well was usable as an RMS for alluvial aquifer groundwater levels.

A different approach was used for this analysis of interconnected surface water. Monitored wells with relatively long periods of record and located within about 2,000 feet of a surface waterway were selected from the water level database. Of these 31 wells, most were along the Salinas and Estrella Rivers, with a few along San Juan Creek, Huerhuero Creek and Shedd Canyon. The hydrographs for these wells were classified as alluvial or Paso Robles based on the water level patterns. In alluvial wells, water levels were close to the adjacent stream bed elevation, had small seasonal fluctuations and were stable from year to year except during droughts, when larger water-level declines occurred. Figure 5 shows examples of alluvial well hydrographs. The figure also shows examples of hydrographs characteristic of Paso Robles Formation wells. In those hydrographs, seasonal fluctuations are larger, water levels in winter are more irregular and not necessarily close to the elevation of the nearby stream, and steady long-term water-level declines commenced sometime between the 1970s and 2000s. Almost all of the hydrographs fit clearly into one or the other of these two patterns.

All of the wells along the Salinas River fit the alluvial well hydrograph pattern except for two multi-depth monitoring well clusters in San Miguel that appeared to be completed in the Paso Robles Formation. The only well along the Estrella River with the alluvial well signature is the one farthest downstream, within the region characterized by shallow clay layers that separate alluvial groundwater levels from deeper Paso Robles groundwater levels. All of the wells farther upstream along the Estrella River exhibit the Paso Robles well pattern. One well next to San Juan Creek has a hydrograph closer to an alluvial pattern than a Paso Robles pattern. This well is upstream of most agricultural pumping. It might be completed in the Paso Robles Formation but has not yet experienced long-term water-level declines due to pumping. The geographic distribution of all of the hydrographs fits the conceptual model for interconnected surface water: where extensive shallow clay layers are present in the Paso Robles Formation, alluvial groundwater levels have remained relatively stable and at an elevation close to that of the adjacent stream bed. The aforementioned new multi-depth monitoring well site on the Estrella River at Airport Road likewise fits the pattern.





Note: Percentages in legend indicate precipitation at Paso Robles as percent of 1910-2021 average

Figure 4. Flow-Duration Curves for Estrella and Salinas Rivers

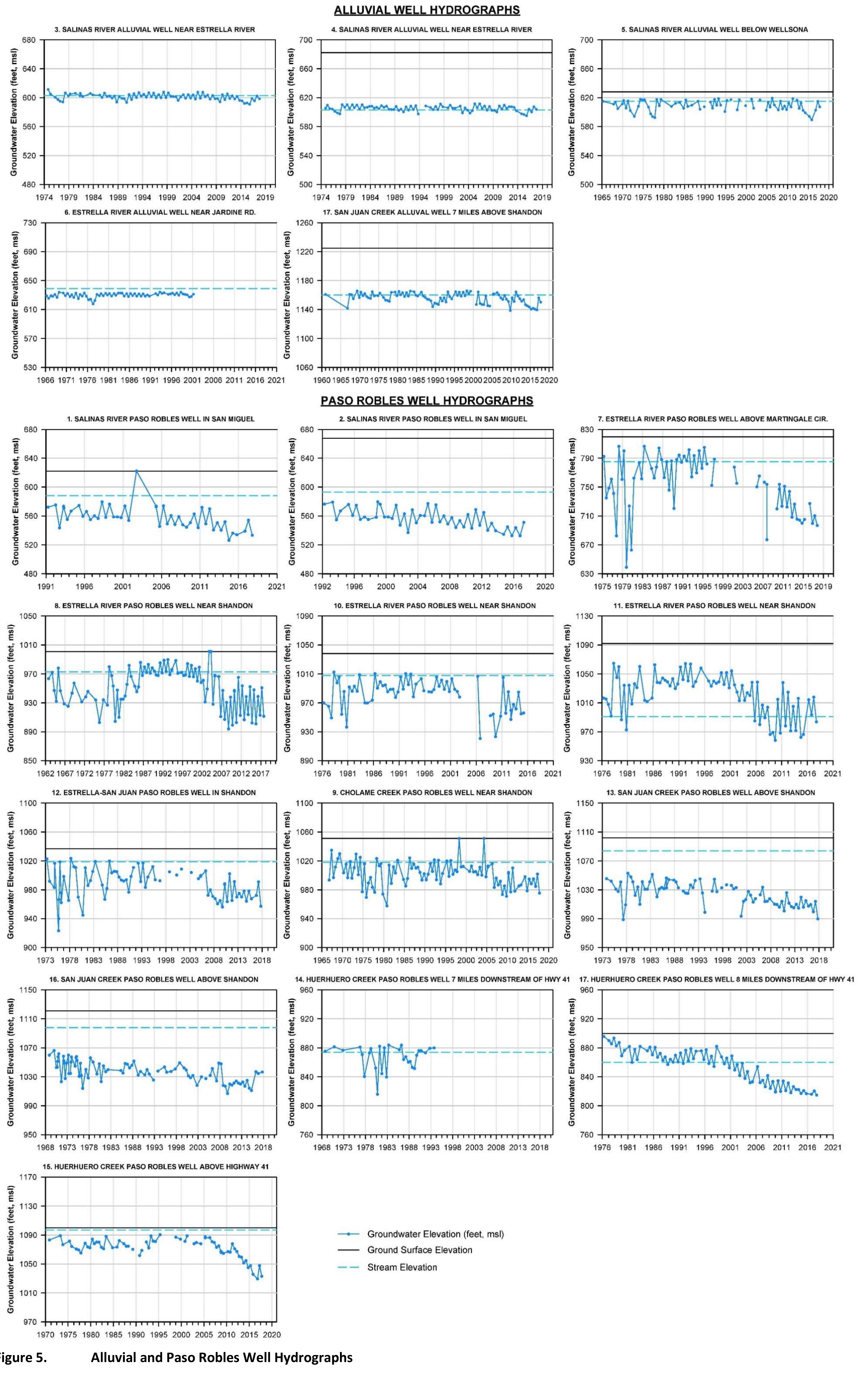


Figure 5. Alluvial and Paso Robles Well Hydrographs

5. RIPARIAN VEGETATION

Vegetation patterns along streams can also be used to map potential interconnection of surface water and groundwater because growth is more vigorous where plant roots can reach the water table. There are limitations to this approach, however. First, some plant species are facultative phreatophytes, which means they will establish and grow with or without access to the water table. A second limitation is that riparian vegetation in shallow water table areas is subject to mechanical removal by flood scour or by clearing for agricultural land use. A third limitation is that a narrow band of vegetation can survive along a stream channel even where the water table is deep if surface flows periodically replenish soil moisture in the stream bank. In spite of these limitations, broad patches of dense riparian vegetation stand out in aerial photographs and provide an indication of where the water table is shallow and interconnected with the root zone and possibly also the stream channel.

Two sources of vegetation mapping were used in the analysis: maps of Natural Communities Commonly Associated with Groundwater (NCCAG) and historical aerial photographs. The NCCAG maps of potential riparian and wetland vegetation are statewide compilations of numerous local vegetation mapping studies, mostly from the early 2000s. The NCCAG maps are provided in georeferenced digital formats on DWR's SGMA Data Portal. Historical aerial photographs taken on nineteen dates between 1989 and 2021 can be viewed on Google Earth©. Some of the older photography was low-resolution, so the Google Earth data were supplemented with high-resolution photography for 1994 obtained from Netronline (www.historicaerials.com).

A comparison of the NCCAG maps with aerial photographs revealed that the accuracy of the NCCAG vegetation delineations is poor in the Subbasin. This is illustrated in Figure 6, which shows NCCAG vegetation polygons overlain on aerial photographs at four locations along the Salinas and Estrella Rivers. The riparian vegetation polygons clearly miss many areas of vegetation that is denser and more likely phreatophytic than the vegetation in the polygons or simply cover areas with little vegetation at all. The wetland polygons along the river channels were mapped in greater detail but do not consistently correspond to a particular type of vegetation visible in the photograph. In particular, wetlands within the river channels are commonly present as long, narrow ribbons along the low-flow channel. Slight shifting in the low-flow channel location or small errors in georeferencing the data can place the mapped polygon over the incorrect type of vegetation.

The NCCAG wetland map also includes numerous off-channel vegetation patches mapped as springs or seeps. Mapping accuracy for these features was also uneven, as shown in Figure 7.

For the purposes of the interconnected surface water analysis for this GSP, a new map of riparian and wetland vegetation was created by digitally outlining areas of visibly dense riparian trees or shrubs more than about 50 feet wide along river and creek channels based on May 2017 aerial photography. The photography represents dry-season conditions in a year close to the start of the SGMA management era (January 2015). In-channel wetlands are indicated where bright green herbaceous vegetation was visible, generally in narrow strips along low-flow channels. This type of wetland vegetation comes and goes between seasons and years. The mapping is intended to show areas where it can often be found.

For isolated wetlands, all of the mapped features in the NCCAG data set were reviewed and classified as groundwater dependent wetlands if they exhibited open water or bright green herbaceous vegetation in the dry season. Many of the features in the data set do not appear to be wetlands at all, are artificial water features such as stock ponds or are seasonal wetlands. Seasonal wetlands—including vernal pools—are transient features that derive water from ponding of rainfall runoff in localized depressions. In some instances, near-surface groundwater perched on the same shallow clay layer that holds the surface runoff might contribute subsurface flow to the seasonal wetland for a few weeks or months (Williamson and others, 2005). That shallow groundwater is perched above an unsaturated zone and not connected to regional groundwater. Where regional groundwater intersects the land surface, it generally does so perennially or nearly so. Hence, it supports wetland vegetation that is green year-round.

The resulting map of groundwater-dependent vegetation is shown in Figure 8. In-channel riparian and wetland vegetation is mapped as polygons accurately delineating the perimeter of the vegetation patch. Isolated wetlands are shown using symbols because many of them would otherwise be too small to see on a basin-scale map. The vegetation distribution is generally consistent with the conceptual model for interconnected surface water. Dense riparian vegetation is most abundant along the Salinas River, which has relatively large and persistent surface flows as well as consistently shallow depth to groundwater. These conditions also result in a relatively high abundance of in-channel wetlands. Riparian vegetation along the Estrella River is sparser and has become more so in recent decades, as described below. Patches of sparse and dense riparian vegetation and even wetlands are present along San Juan Creek at locations more than about 10 miles upstream of Shandon.

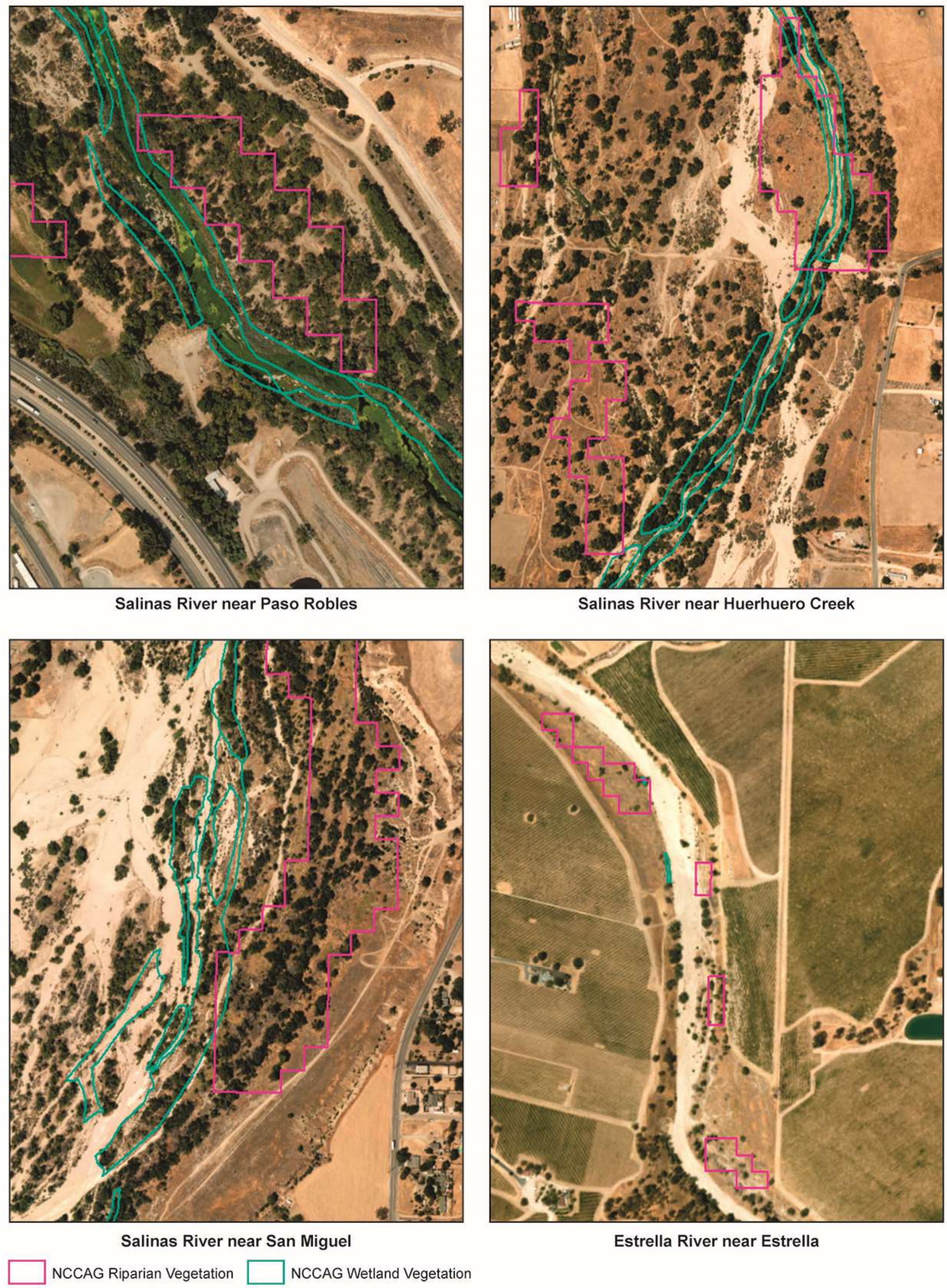


Figure 6. NCCAG Vegetation Polygon Accuracy Along the Salinas and Estrella Rivers

Figure 7. NCCAG Wetland Map Accuracy within Paso Robles Subbasin

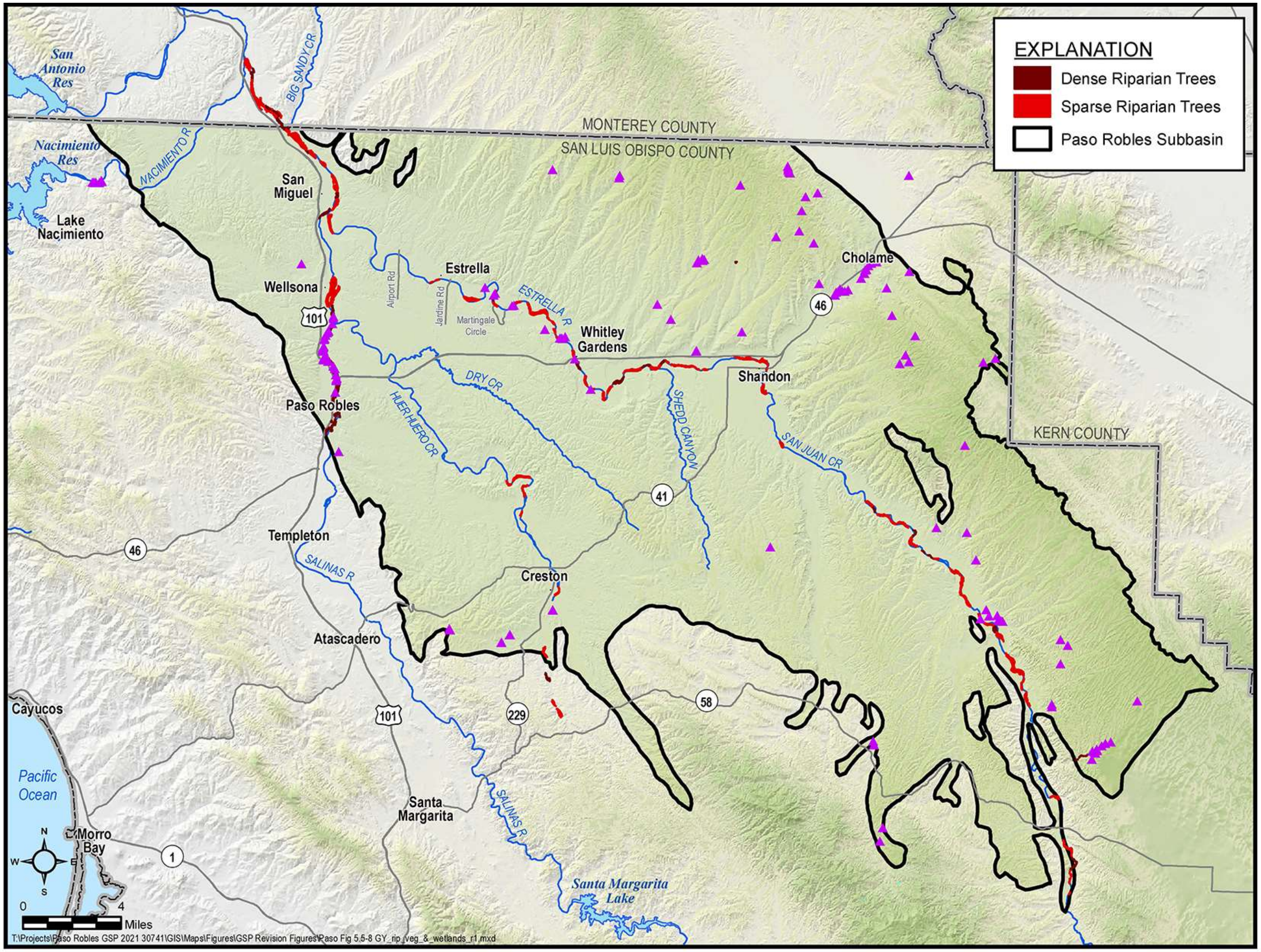


Figure 8. Groundwater-Dependent Vegetation in Paso Robles Subbasin

6. CHANGES IN RIPARIAN VEGETATION OVER TIME

Changes in the location, extent and density of riparian tree and shrub canopy over time provide important clues regarding the variables affecting vegetation GDEs. For example, unusually low stream flow and water levels occurred along the Salinas River only during the 2012-2016 drought, whereas stream flow and groundwater levels along the upper half of the Estrella River and lower reach of San Juan Creek have been gradually declining for decades. Thus, if vegetation impacts can be observed in aerial photographs or satellite imagery, then the timing of the impacts is informative. Three types of temporal vegetation analysis were completed: comparisons of vegetation in 1949, 1978, 1994, 2003 and 2018, mapping of riparian tree mortality during the 2012-2016 drought, and mapping of changes in satellite-based measurements of vegetation moisture status over time.

6.1 Comparison of Riparian Vegetation in 1949-2018

In 2004, the Upper Salinas-Las Tablas Resource Conservation District measured changes in the extent and density of riparian vegetation at several locations along Subbasin streams by comparing aerial photographs from 1949, 1978 and 2003 (US-LTRCD, 2004). Along two Salinas River sample reaches near Atascadero and Paso Robles, the percent cover of in-channel riparian vegetation decreased from 84-95 percent in 1949 to 10-23 percent in 2003. Similar tabulations at thirteen additional locations along the Salinas and Estrella Rivers and Huerhuero Creek found that overall about two-thirds of the riparian vegetation that existed along those waterways in 1949 had disappeared by 2003. The report listed nine possible causes of the decrease in riparian vegetation but did not include any analysis to quantify which were the most significant.

Looking back at those data, some conclusions regarding causality can be inferred. The reductions in riparian vegetation along the Estrella River and Huerhuero Creek could not have been the result of upstream dam operation, which was a potential cause of reductions along the Salinas River (Salinas Dam was completed in 1942). It is possible that riparian vegetation was exceptionally abundant in 1949 because it was a few years after 1936-1943, which was the largest sequence of wet years in the 1910-2021 period of record for precipitation (see Figure 2). Long-term declines in groundwater levels could not have explained the decrease in vegetation along the Salinas River, where alluvial water levels have remained stable and shallow since at least the early 1970s. Elsewhere in the Subbasin, chronic declines in groundwater levels mostly started in the 1980s or 1990s, although they started earlier in a few cases. Water-level declines since 1980 could not have caused vegetation declines during 1949-1978.

A similar analysis was completed for this GSP, comparing riparian vegetation conditions in 2018 with conditions in 1994 along the entire lengths of the Salinas River, Estrella River, Huerhuero Creek and San Juan Creek using aerial photographs. Each of those dates were soon after the end of a major drought. As discussed in section 5.5.2, the 1987-1990 drought and the 2012-2016 drought were similar in intensity (low precipitation), but the more recent drought lasted a year longer. In other words, precipitation and stream flow conditions during the years immediately preceding the two photographs were similar, but groundwater levels were different. Between those two periods, there were cumulative water-level declines in the Paso Formation wells of 25-70 feet in the eastern part of the Subbasin. Water levels along the Salinas River remained stable until 2011, declined 12-18 feet during 2012-2016 and then recovered (see Figure 5). The density and extent of patches of riparian vegetation along the waterways in 2018 was visually classified as “more”, “the same” or “less” than in 1994.

The results of the vegetation comparison are shown in Figure 9. Where there were differences along the Salinas River, they were all decreases in vegetation coverage. This suggests that the relatively small and temporary water level declines during 2012-2016 were large enough to adversely impact vegetation. Along the Estrella River, vegetation coverage mostly declined near Shandon and along the downstream end toward the Salinas River. Along the middle reach, however, vegetation coverage unexpectedly increased in a number of locations. This is the same river segment where gaining flow could be seen in aerial photographs up until 2012, indicating a near-surface water table. Although that river segment is thought to be east of the extensive near-surface clay layers in the Paso Robles Formation, some aspect of hydrogeology and recharge appears to be sustaining a high water table in spite of large water-level declines in deeper wells in that region.

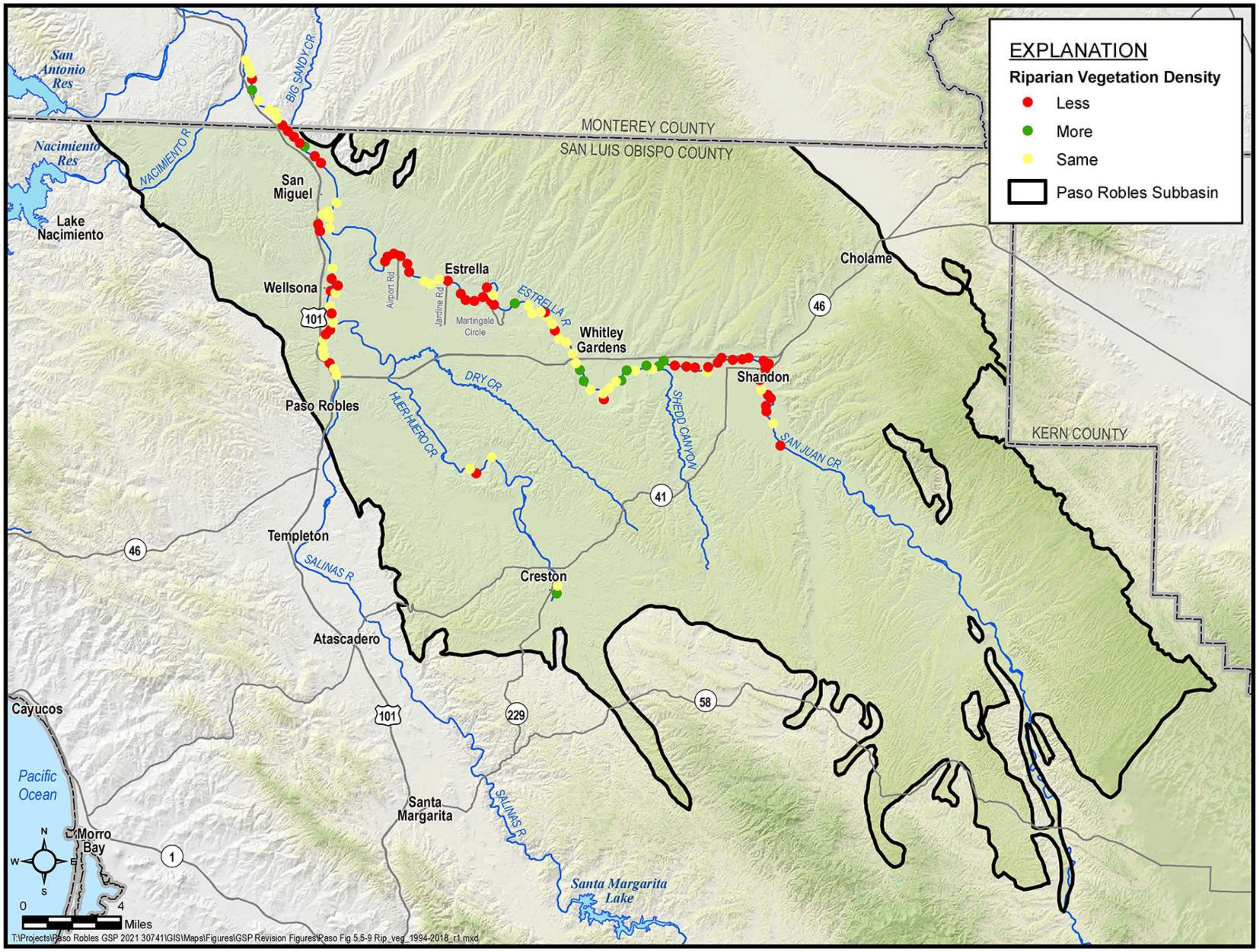


Figure 9. **Density of Riparian Vegetation, Paso Robles Subbasin**

6.2 Riparian Tree Mortality during 2013-2017

The resolution of recent historical aerial photographs on Google Earth© is sufficiently high that the death of individual trees or groups of trees can be readily detected by comparing photographs before and after the mortality event. The 2012-2016 drought caused noticeable riparian tree mortality in a number of locations. Aerial photographs bracketing the drought (2013 and 2017) were systematically compared to map locations of significant tree mortality. Pairs of photographs illustrating tree mortality are shown in Figure 10, and a map showing the locations and percent canopy reduction where mortality was observed is shown in Figure 11.

Mortality occurred along the Salinas and Estrella Rivers. The number of locations and extent of mortality was less for the Salinas River. Along the Salinas River, groundwater levels declined 12-18 feet during the drought as a result of insufficient surface flow to maintain the normal high water table. This indicates that for trees accustomed to shallow depths to water (less than 20 feet), water-level declines of 12-18 feet can be fatal. The situation along the Estrella River is more complex. Tree mortality was concentrated during the 2012-2016 period even though Paso Robles Formation groundwater levels had been declining for years before the drought. Like the presence of emergent flow and relatively dense riparian vegetation along the middle segment of the Estrella River prior to 2012, the delayed mortality of trees along the river might indicate the presence of a water table normally shallower than the water levels in nearby Paso Robles Formation wells.

6.3 Trends in Moisture Status using NDVI and NDMI

The health and vigor of riparian vegetation cannot be reliably detected in aerial photographs. However, spectral analysis of light reflected from the vegetation does provide that information and can be obtained from Landsat satellite imagery. Two commonly used metrics of vegetation health and vigor are the normalized difference vegetation index (NDVI) and normalized difference moisture index (NDMI), both of which involve ratios of selected visible and infrared wavelengths. NDVI relates to the greenness of vegetation and NDMI relates to transpiration. The Nature Conservancy compiled these two metrics from historical satellite imagery for riparian vegetation throughout California and incorporated it into the GDE Pulse on-line mapping tool (The Nature Conservancy, 2019b). Values are only calculated for NCCAG mapped wetland and riparian vegetation polygons. For each polygon, the tool displays time series plots of annual summertime NDVI and NDMI during 198719. Figure 12 shows examples of NDVI and NDMI time series for two vegetation polygons and illustrates the GDE Pulse tool that calculates trends for user-selected periods. In general, NDVI and NDMI tend to rise and fall together, as they both represent measures of water-related vegetation health.

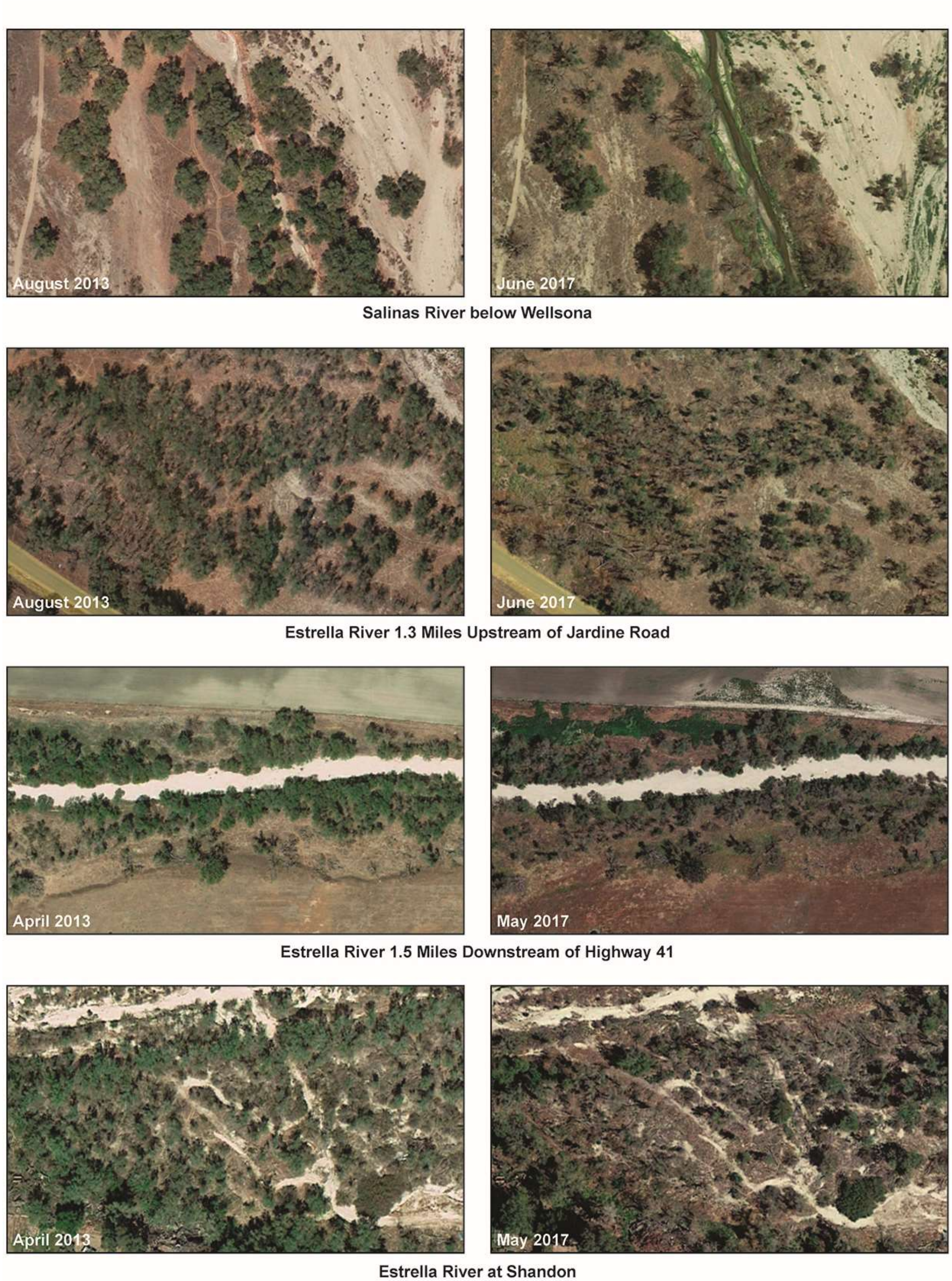


Figure 10. Riparian Vegetation Mortality between 2013 and 2017

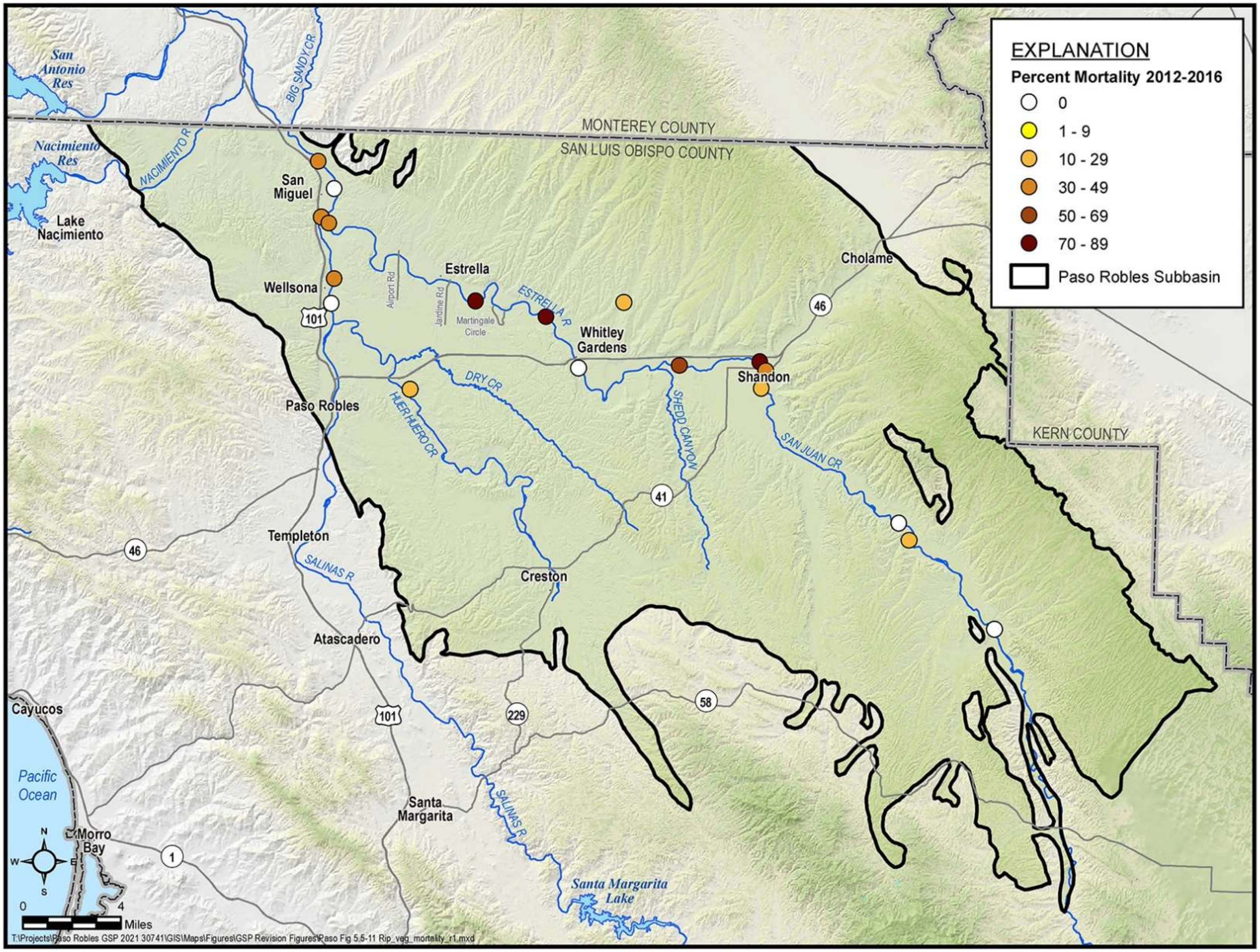
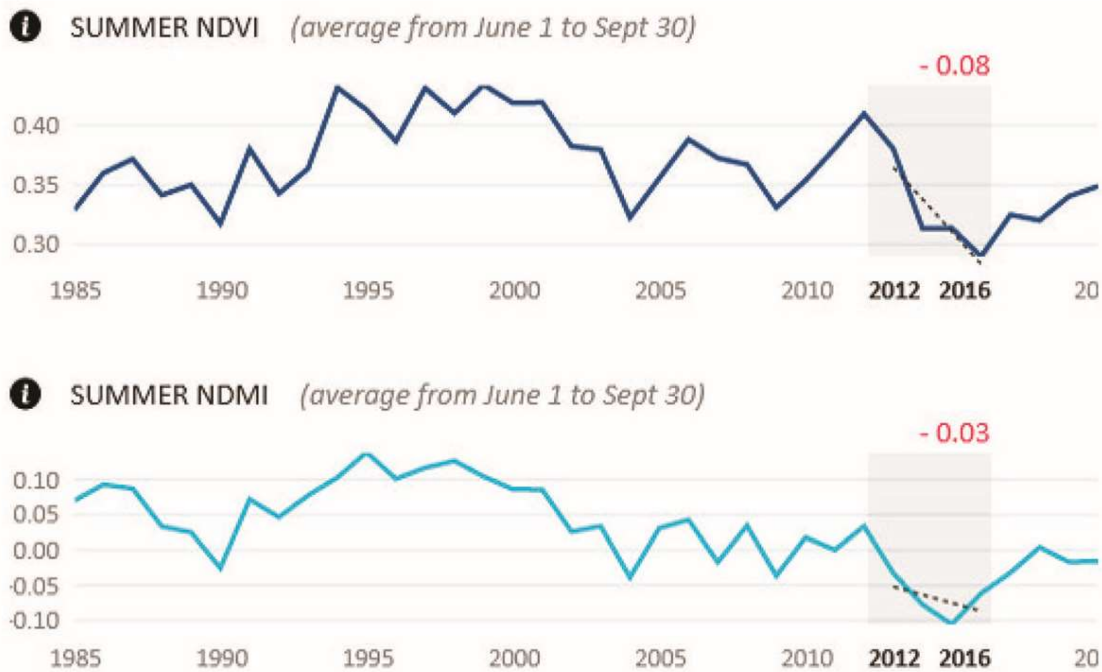
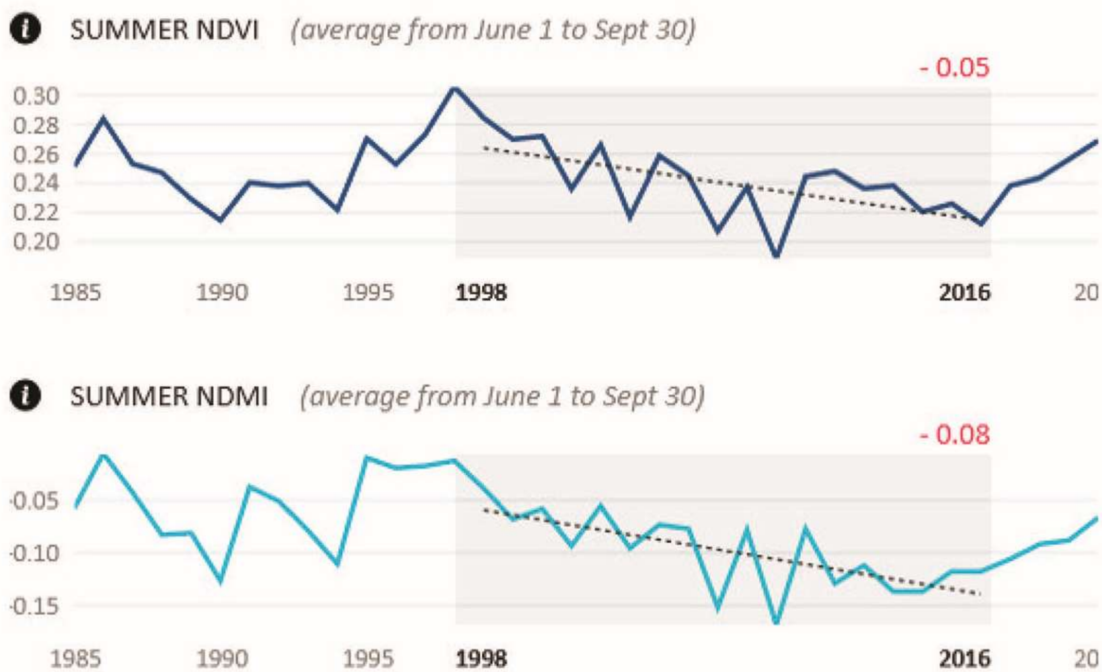


Figure 11. Riparian Canopy Reduction between 2013 and 2017



A. Valley Foothill Riparian Polygon on Salinas River near Huerhuero Creek



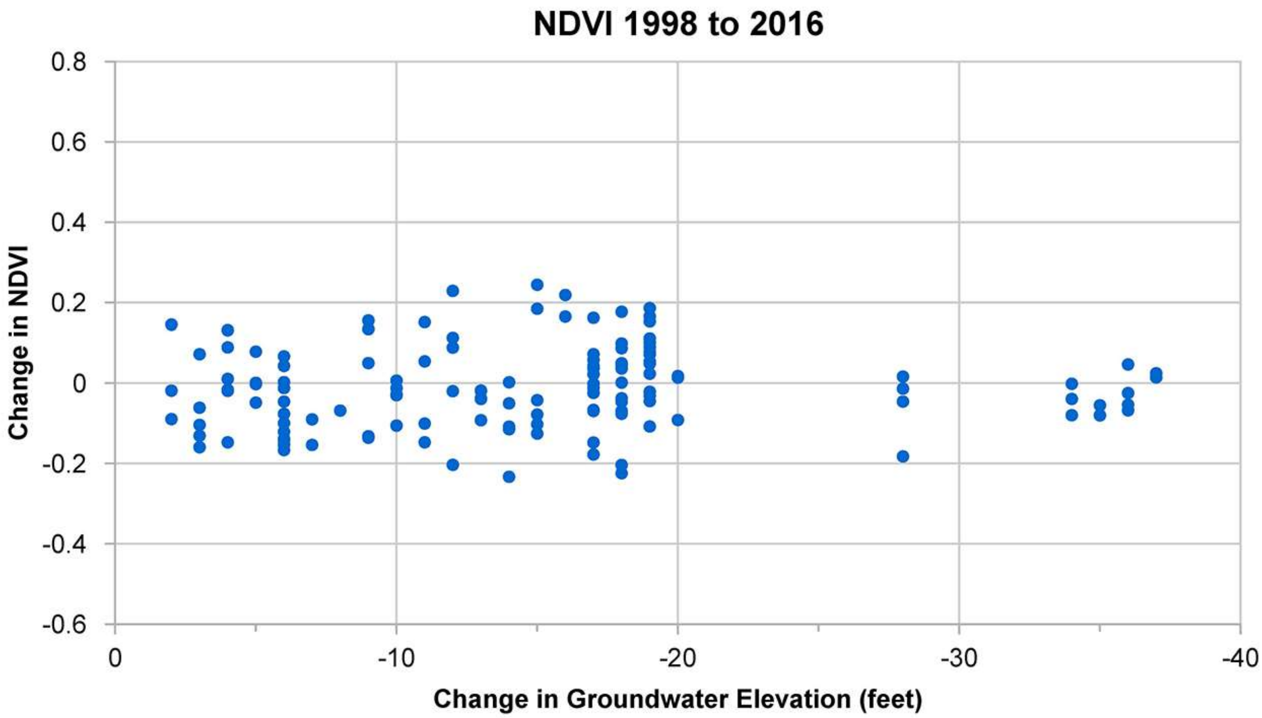
B. Valley Foothill Riparian Polygon on Estrella River near Shandon

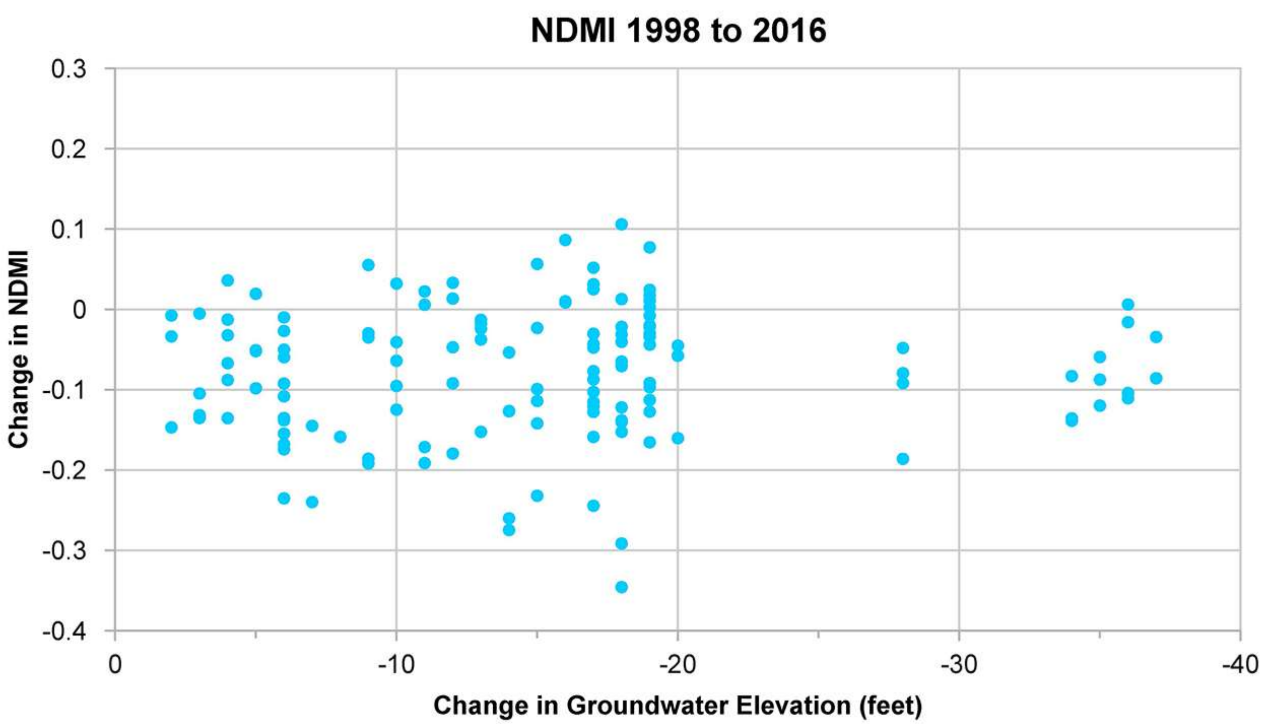
Figure 12. NDVI and NDMI Time Series, Two Vegetated Areas

The NDVI and NDMI data were tested for consistency with changes in precipitation, water levels, vegetation extent and vegetation mortality. The first test consisted of tabulating the NDVI and NDMI trends during 2012-2016 and 2016-2020 for all riparian vegetation polygons along the Salinas and Estrella Rivers. The expectation was that trends would be declining during 2012-2016 due to drought conditions and rising during 2016-2020 due to the return to more normal hydrologic conditions. Along the Salinas River between Paso Robles and Camp Roberts, 95 percent of the polygons had declining NDVI trends during 2012-2016 (72 percent for NDMI). During 2016-2020, 86 percent of the polygons had increasing trends (82 percent for NDMI). So that reach of the Salinas River exhibited the expected pattern. Below Camp Roberts, NDVI and NDMI results were inconsistent during 2012-2016 (75 percent decreased in NDVI; 82 percent increased in NDMI). Results in this reach were also mixed during 2016-2020 (only about half of the polygons experienced an increasing trend in NDVI or NDMI).

Results for the Estrella River were generally counterintuitive. Downstream of Martingale Circle, NDVI and NDMI both increased in 92 percent of polygons during 2012-2016, and 69-75 percent continued increasing during 2016-2020. From Martingale Circle up nearly to Shedd Canyon Road, 62-92 percent of polygons decreased in NDVI or NDMI during 2012-2016, and 71-77 percent increased during 2016-2020 (the expected pattern). From Shedd Canyon Road up to Shandon, NDVI and NDMI conflicted during 2012-2016 (92 percent decreased in NDVI while 85 percent increased in NDMI). However, both metrics tended to increase during 2016-2020.

A second analysis compared changes in NDVI and NDMI with changes in groundwater levels. A common pattern in NDVI and NDMI plots for riparian vegetation polygons was a declining trend from around 1998 to around 2016. The net change in each of those metrics for each riparian polygon was compared with the net change in groundwater elevation at that location. Historical groundwater elevations for those two dates at each polygon were obtained from simulated groundwater levels in layer 1 of the regional groundwater flow model. Layer 1 represents the alluvial deposits along rivers and creeks in the Subbasin. If vegetation is groundwater-dependent, one would expect a decline in groundwater levels to be correlated with a decline in NDVI and NDMI. However, the scatterplots of change in NDVI and NDMI versus change in groundwater level exhibited no correlation. The plots are shown in Figure 13. A possible explanation for the lack of correlation is inaccuracies in the vegetation mapping, which were described in Section 5.5.5. Riparian and wetland vegetation patches along river channels tend to be long and narrow. A small lateral offset in registering the satellite data with the vegetation mapping could result in selecting satellite image pixels for land cover adjacent to the intended vegetation type. Alternatively, the distribution of vegetation patches in the year that polygons were mapped might not have been the same as the distribution in 1998 or 2016. Finally, simulated groundwater levels might not be highly accurate, but errors would tend to appear as a bias affecting a broad region equally or affecting 1998 or 2016 uniformly. That type of bias would still allow NDVI and NDMI patterns to appear, rather than the random results seen in the data plots.





Source: each data point represents one NCCAG riparian vegetation polygon from GDE Pulse map: https://gde.codefornature.org/#/map

Figure 13. NDVI and NDMI Versus Change in Groundwater Level

In any case, the apparent lack of correlation between groundwater levels and NDVI or NDMI is not interpreted here as proving that vegetation is not dependent on groundwater. Rather, it just demonstrates that this particular data set is not particularly helpful for quantifying that relationship.

7. SIMULATED GROUNDWATER-SURFACE WATER INTERCONNECTION

The regional groundwater flow model used to develop water budgets for this GSP is another source of information regarding interconnected surface water. The simulated basin-wide groundwater budgets for 1981-2011 (Tables 6-3 and 6-4) included stream percolation averaging 26,900 AFY (38 percent of total inflows), and groundwater discharge to streams averaging 7,300 AFY (9 percent of total outflows). Stream reaches that lose water to percolation are not necessarily interconnected with groundwater. They can be perched high above the water table. In contrast, reaches where groundwater discharges into streams are by definition interconnected. Thus, simulated discharge to streams amounting to 9 percent of total basin outflow indicates that substantial reaches of one or more streams in the Subbasin are interconnected with groundwater.

Simulated gains and losses in stream flow for every stream reach and stress period in the model were extracted from the results for the historical calibration simulation. The gaining and losing stream reaches in September 1998 (high groundwater levels) and September 2016 (low groundwater levels) were then plotted on the maps shown in Figures 14 and 15. Along the Salinas River in 1998, most of the reaches from Paso Robles to Wellsona and from San Miguel to the Nacimiento River were gaining. In 2016, there were gaining reaches in both of those general locations, but considerably shortened at both the upstream and downstream ends.

Along lower San Juan Creek and the Estrella River, flow was absent or losing to a point downstream of Shandon in 1998 and 2016. In 1998, predominantly gaining conditions were present from above Shedd Canyon almost to Estrella, with one lengthy losing reach upstream of Martingale Circle. The gaining reaches retracted substantially but did not disappear entirely in 2016. They were still present upstream of Highway 46 at Whitley Gardens and near the Shedd Canyon confluence.

The accuracy of these particular model results is uncertain because few stream flow and alluvial water level measurements are available for model calibration. It is noteworthy, however, that the reaches simulated as gaining by the model correspond closely to reaches where riparian vegetation is relatively dense and/or gaining flow or damp soils could be seen in aerial photographs. Also, the difference in length of the gaining reaches between 1998 and 2016 is reasonably consistent with differences that would be expected based on the stream flow, water level and vegetation data.

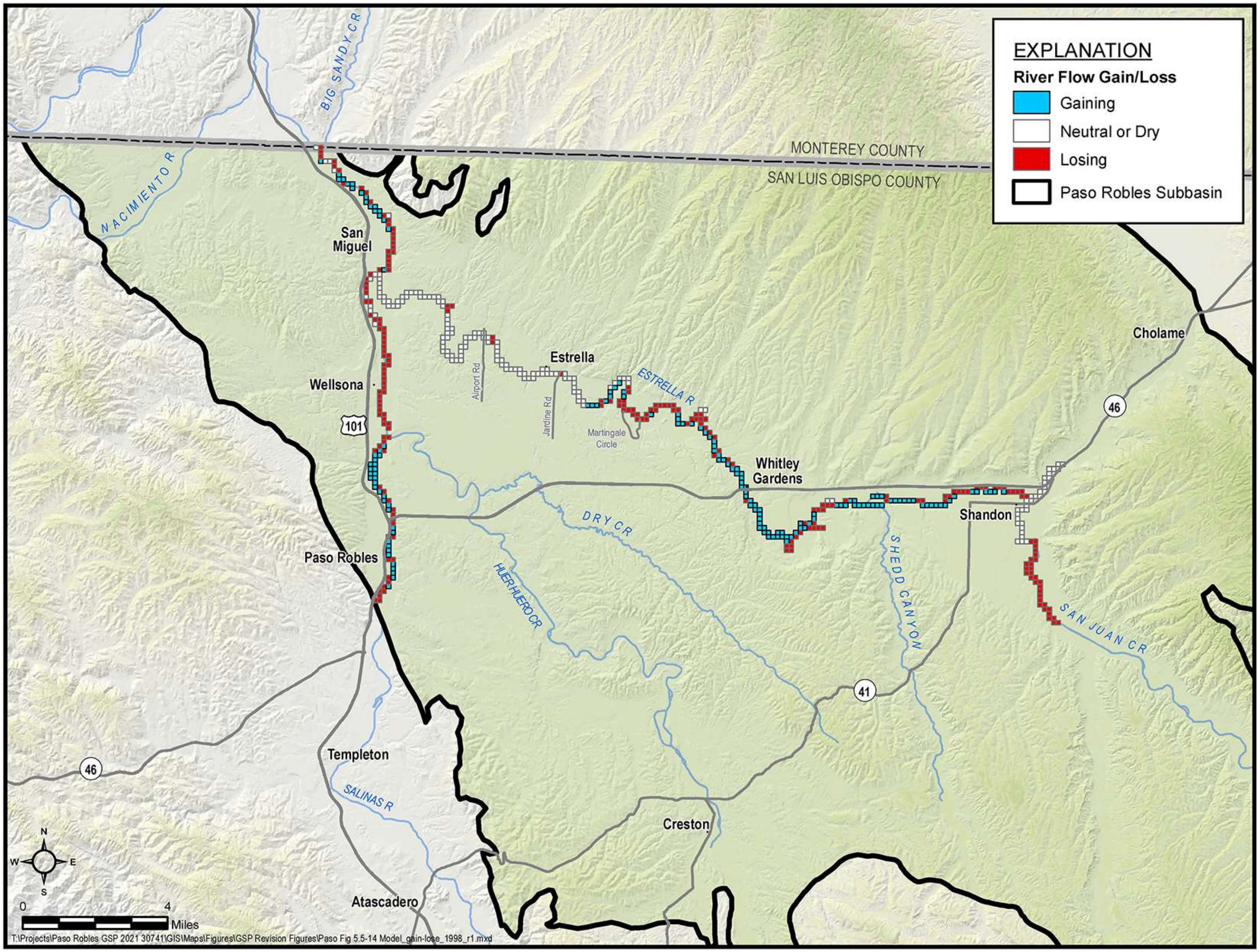


Figure 14. Gaining and Losing Stream Reaches, September 1998 (high groundwater levels)

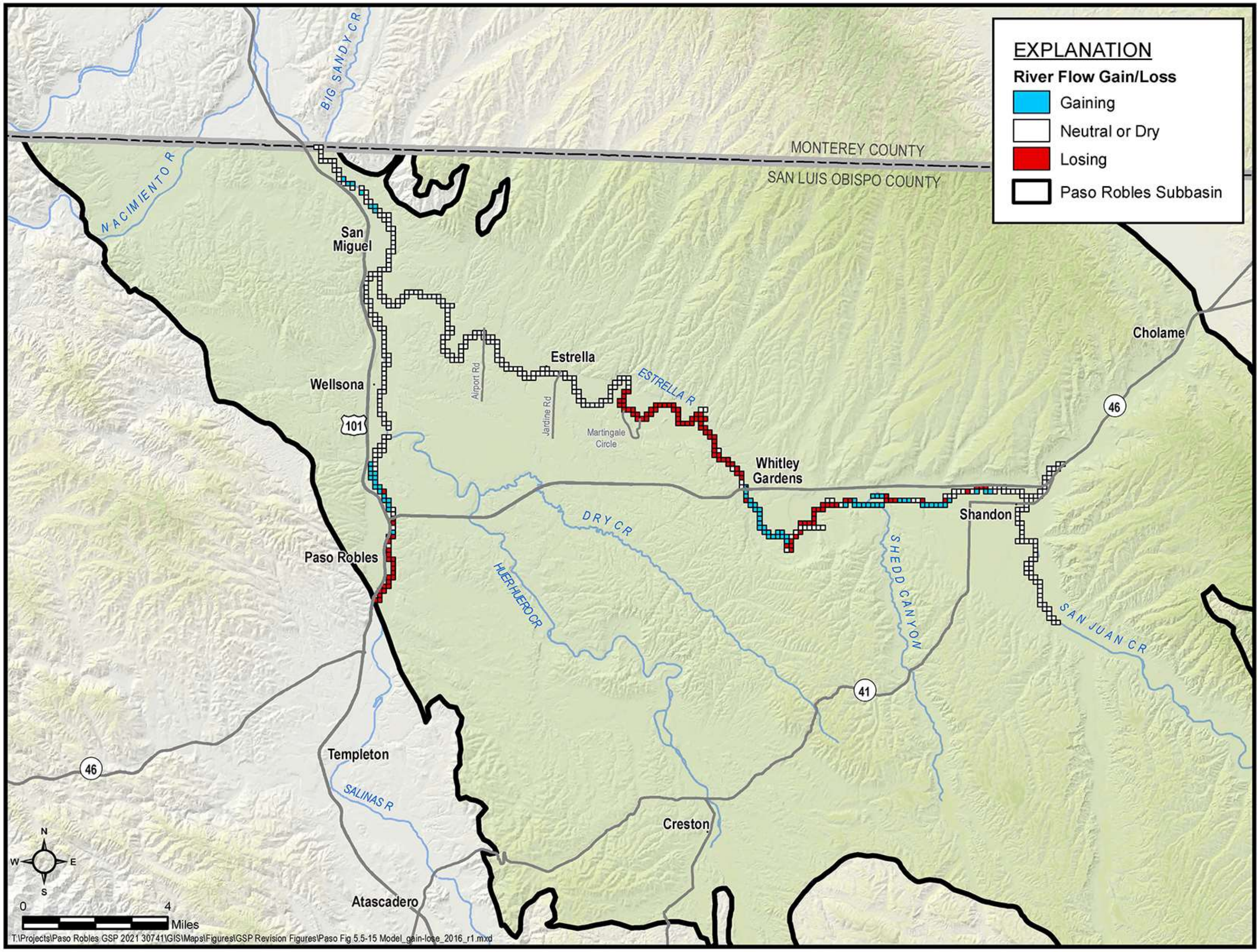


Figure 15. Gaining and Losing Stream Reaches, September 2016 (low groundwater levels)

8. NON-CONFORMING DATA

Some of the data reviewed for this section do not appear to fit the conceptual model for interconnected surface water and are worth mentioning. They include the following:

- The lower part of the Estrella River, from Estrella to the confluence with the Salinas River reportedly overlies shallow clay layers in the Paso Robles Formation and should have shallow alluvial water levels similar to those along nearby reaches of the Salinas River. The new shallow monitoring well at Airport Road confirmed the presence of a water table only 30 feet below the ground surface. On the basis of groundwater conditions, one would expect dense riparian vegetation to be present along this reach of the Estrella River, but vegetation has been absent or sparse continuously since at least the early 1990s. One possible explanation is that surface flows are too infrequent and brief to support recruitment of new phreatophytic vegetation. That is, a depth to water of 30 feet might be shallow enough to sustain mature vegetation with deep roots, but sustained surface flows and a shallower water table—at least in wet years—is probably necessary for new seedlings to become established. The magnitude and duration of surface flows have steadily decreased over the past four decades, so the probability of successful recruitment has become increasingly slim.
- Dense riparian vegetation and even emergence of groundwater at various points along the middle segment of the Estrella River (roughly from Shedd Canyon Road to Martingale Circle) appears inconsistent with regionally declining groundwater levels. That reach is reportedly upstream of the shallow clay layers in the western part of the Subbasin. Thus, pumping from wells in the Paso Robles Formation would be expected to lower the water table and deplete surface flows. It appears that some aspect of subsurface hydrogeology sustains a relatively high and steady alluvial water table along this reach. One possible mechanism is that shallow clay layers extend farther up the Estrella River than previously thought. Another possible explanation is that recharge and groundwater flowing south from the uplands on the north side of the river provide inflow to shallow aquifer horizons that helps buffer their water levels against drawdown caused by deeper pumping. An example of high Paso Robles water levels on the north side of the river is shown in hydrograph 11 of Figure 5. Water levels in that well were historically 40-50 feet above the riverbed elevation before starting to decline around 2000. A third possible explanation could be the presence of a fault or a northward extension of the Creston Anticlinorium creating a barrier to westward groundwater flow. In any case, there appears to be some combination of subsurface hydrogeology and recharge processes that has helped sustain riparian vegetation to at least a limited extent along the middle reach of the Estrella River.
- There was considerable local variability in the observed changes in riparian vegetation extent and density from 1994 to 2018, especially along the Estrella River. Changes in groundwater levels would likely be more uniform over broader areas. One possible explanation for the local variability in vegetation is the limitations of air photo interpretation for that purpose. Tree and shrub species cannot be accurately identified in the photographs. Some species are facultative phreatophytes, meaning they can become established and grow with or without access to the water table. Coast live oak is an example. Changes in non-phreatophytic vegetation could obscure changes in phreatophytic vegetation.

9. DELINEATION OF INTERCONNECTED SURFACE WATER

The delineation of interconnected surface water (Figure 1) reflects a preponderance of evidence based on the data and analyses described in the preceding sections. This involved some subjective assessments such as differentiating “dense” from “sparse” riparian vegetation or estimating how frequent and persistent interconnection must be to be designated “interconnected”. Along stream channels, two categories of interconnection were assigned: interconnection with surface water and interconnection with riparian vegetation. The former requires higher water levels and typically occurs less frequently or for shorter periods of time. The latter includes areas where the water table is less than about 25 feet below the stream bed most of the time. Empirically, this is the root zone depth associated with the present of dense riparian vegetation. These considerations are discussed by stream reach below.

The entire length of the Salinas River from Paso Robles to the confluence with the Nacimiento River was classified as interconnected with surface water. The presence of very stable water levels close to the river bed elevation in all alluvial wells along that reach supports this designation, as does the presence of sparse to dense riparian vegetation along most of the reach. Even small inflows to the upper end of the reach commonly extend along the entire length of the reach, which also indicates that the water table is at or near the riverbed elevation along the entire length of the reach.

The Estrella River below Estrella (near Jardine Road) was classified as not interconnected. This classification reflects the very small amount of riparian vegetation along the entire reach throughout the analysis period (1989-2021). Although shallow clay layers are thought to be present in this area and the new shallow monitoring well at Airport Road confirms the presence of a water table 30 feet below the ground surface, this depth to water appears to be too great for vegetation to readily establish given the low frequency and duration of surface flow in the river.

The middle reach of the Estrella River, from Jardine Road up to Shedd Canyon contains alternating segments that are not connected or are connected to the vegetation root zone. These segments were classified primarily on the density of riparian vegetation. The only confirmation of groundwater levels is at a single well near the downstream end of the middle reach, where the depth to water was consistently about 10 feet below the riverbed. Emergent flow was present in some dry-season aerial photographs along a segment below Shedd Canyon, about 2.5 to 4 miles upstream of Highway 46. Open water or wet channel sediments can still be seen in some air photos in winter or spring but not during the dry season since about 2012. Thus, that segment was not classified as interconnected with surface water as of the start of the SGMA management period (2015).

The Estrella River from Shedd Canyon up to Shandon and lowermost 10 miles of San Juan Creek were classified as not interconnected. Although sparse riparian vegetation is present in places, the depth to groundwater in wells has been declining for decades and now exceeds the rooting depth of riparian vegetation. The vegetation that remains probably consists of facultative phreatophytes or is vestigial mature vegetation that has managed to survive declining water levels. In any case, recruitment of new phreatophytic riparian vegetation is very unlikely under current conditions.

Much of San Juan Creek more than 10 miles upstream of Shandon appears to be interconnected to riparian vegetation based on the presence of sparse or dense vegetation along most of the reach. One short reach was classified as interconnected to surface water because it usually has emerging groundwater along a low-flow channel bordered by wetland vegetation. The one well with water-level data along this reach has water levels that are usually within 10 feet of the creek bed elevation.

The lowermost 5 miles of Cholame Creek were delineated as not connected based on the absence of significant riparian vegetation and water levels in the sole monitoring well that average about 30 feet below the ground surface. Farther up the creek, however, is a reach several miles long that has open water or wetland vegetation in most historical aerial photographs. Shallow groundwater along that reach could be caused by faults that pass through the area (see Figure 4-4) or by fine-grained geologic layers intersecting the land surface and impeding lateral groundwater flow. For unknown reasons, the shallow water table and surface flow conditions have not caused the establishment of dense woody riparian vegetation.

Riparian vegetation is rare along Huerhuero Creek, Dry Creek and Shedd Canyon and is typically sparse where it is present. The depth to water in wells in that part of the Subbasin is uniformly too large to support riparian vegetation. Accordingly, those waterways were all classified as not connected to groundwater.

The reach of the Nacimiento River that traverses the northwest corner of the Subbasin was classified as interconnected to surface water because reservoir releases during the dry season are more than sufficient to sustain a high water table adjacent to the river. That reach is far from major pumping centers in the Paso Robles Subbasin and hence unlikely to be significantly depleted by pumping.

Isolated, off-channel wetlands shown on the interconnected surface water map (Figure 1) are the subset of the NCCAG wetlands where distinctly green vegetation was visible in dry season aerial photographs and the feature appeared to be a natural depression, not a constructed stockpond.

10. GROUNDWATER DEPENDENT ANIMALS

Many fish and wildlife species use aquatic and riparian habitats that are supported by groundwater. For the purpose of this GSP, beneficial use for habitat is limited to native species present in the Subbasin as of 2015, when SGMA took effect. The focus was on species that are state or federally listed as threatened, endangered or of special concern. This implicitly assumes that non-listed species will probably also be sustained if hydrologic conditions are suitable for sustaining the rarer species. The life history needs of listed bird, mammal, reptile, amphibian, and insect species were reviewed to estimate whether they have groundwater requirements beyond those needed to sustain the riparian habitat in which they live. A separate analysis was made for fish, which have flow requirements considerably different from the requirements to sustain vegetation.

References that were used to inventory and evaluate groundwater dependent animal species included the Upper Salinas River Watershed Plan (US-LTRCD, 2004), the California Department of Fish and Wildlife's (CDFW) BIOS on-line habitat map tool (https://apps.wildlife.ca.gov/bios/), critical habitat area maps for listed species prepared by the U.S. Fish and Wildlife Service (USFWS) also available on-line (https://fws.maps.arcgis.com/home/webmap/viewer.html?webmap=9d8de5e265ad4fe09893cf75b8dbfb77), several reports on steelhead trout (NMFS, 2007; Woodard, 2012; Stillwater Sciences, 2020), and interviews with Upper Salinas-Las Tablas Resource Conservation District (US-LTRCD) and National Marine Fisheries Service (NMFS) staff (Bell, 2021; Stevens and Rogers, 2021).

10.1 Invertebrates, Amphibians, Reptiles, Mammals and Birds

USFWS delineates critical habitat areas for federally listed species, and the three critical habitat areas overlapping the Subbasin are for vernal pool fairy shrimp, California red-legged frog (CRLF) and California tiger salamander. Their critical habitat areas are shown in Figure 16. A large area in the central part of the Subbasin is mapped as critical habitat for vernal pool fairy shrimp. Vernal pools are not considered GDEs in this GSP. They form for a few weeks to a few months in spring where rainfall runoff collects in depressions underlain by clay soils that allow ponding to persist. In some cases, vernal pools can receive inflow from shallow, perched aquifers covering a limited upslope area (Williamson and others, 2005). However, that supply is also seasonal and is perched over an unsaturated zone separating it from the regional groundwater system that is the focus of the GSP. Groundwater pumping from the regional aquifer does not impact vernal pools or adjacent perched aquifers. The critical habitat area for California tiger salamander overlaps a tiny part of the far eastern edge of the subbasin. Tiger salamanders are a primarily upland species, but they lay eggs in vernal pools. Thus, they are not considered a groundwater dependent species.

The mapped critical habitat area for CRLF also overlies a small part of the eastern edge of the Subbasin. That area is a hilly region far from significant amounts of groundwater pumping, which mostly occurs in agricultural areas. Thus, the handful of springs that might be used by frogs in that region are very unlikely to be depleted by groundwater pumping. The potential for suitable CRLF habitat in the Subbasin exceeds the mapped critical habitat area. The Upper Salinas River Watershed Plan (Plan) noted that the frogs are present along the Salinas River near Paso Robles and in Atascadero Creek. The surface flow requirements for CRLF are shallow, slow-moving water with emergent vegetation, with flow persisting at least to mid-summer to provide enough time for the tadpoles to metamorphose. These flow conditions could plausibly be met along the Salinas River—especially close to Paso Robles—and possibly some locations along San Juan Creek. Thus, groundwater pumping that depletes base flow and in-channel wetland habitat probably decreases CRLF habitat.

The Plan asserts that a number of other species dependent on riparian habitat are present in the upper Salinas River watershed, but in some cases the BIOS database does not show the Subbasin as being within the range of that species or possessing suitable habitat. These include Arroyo toad and Swainson's hawk. Western pond turtle is a listed species that has been found in the canyon reach of the Salinas River below Salinas Dam. However, it requires channel and flow conditions not present in stream reaches overlying the Subbasin. The turtle needs deep, slow-moving perennial pools with boulders or large woody debris. The wide, gravelly channels with intermittent flow in the Subbasin area would not be suitable for Western pond turtle. The Plan also mentions Least Bell's vireo, but the Subbasin does not contain critical habitat for that species, and expanses of dense willows preferred by the bird are generally not present in the Subbasin.

10.2 Fish

The Plan states that four native fish species are present in the upper Salinas River watershed: Sacramento sucker, hitch, three spine stickleback and southern steelhead. All of these require clear, cold, perennial flow for spawning and rearing, and those conditions are present only in the upper reaches of the Salinas River and its tributaries. Those locations are far from groundwater pumping intense enough to materially affect flow. Unlike the other three species, southern steelhead is anadromous and does migrate seasonally up and down stream reaches that cross the Subbasin.

Steelhead require a minimum amount of flow to swim along a stream channel. This minimum passage flow is defined by the minimum required width and depth of flow at the shallowest point along the channel reach, which is called the "critical riffle". At the critical riffle, the water must be at least 0.7 foot deep for adult steelhead up-migration and cover at least 25 percent of the channel width. For out-migrating smolts, the minimum depth is 0.3 foot (Woodard, 2012). The only stream channel in the Subbasin used for migration by steelhead is the Salinas River, which the fish traverse to reach spawning areas in tributaries farther upstream: Graves, Santa Rita, Atascadero and Santa Margarita Creeks, which enter the river in the Atascadero Subbasin (Stillwater Sciences, 2020). No study has been done to identify the critical riffle along the Subbasin reach of the Salinas River or to estimate the passage flow associated with it (Stevens and Rogers, 2021; Bell, 2021). A reasonable estimate would be the minimum passage flow at Bradley (9 miles downstream of the Subbasin), which the National Marine Fisheries Service estimated at 300-380 cfs in the biological opinion prepared for the Salinas River Water Project (NMFS 2007). Sections of the Salinas River channel between Paso Robles and the Nacimiento River confluence are at least as wide and gravelly as the channel at Bradley.

The lowest flows along the Subbasin reach of the Salinas River are largely protected by the "live stream" requirement in the water rights permit for Salinas Dam. That requirement was first imposed in 1952 and allows Salinas River flow to be diverted to storage behind Salinas Dam (in Santa Margarita Lake) only when there is continuous flow in the Salinas River from the dam to the confluence with the Nacimiento River (SWRCB, 1982). The purpose of this condition on the water right permit was to ensure that the needs of downstream users with prior rights were being met, including groundwater users pumping from the underflow of the river. It was assumed that as long as continuous flow was present, the river was replenishing the underflow at a rate sufficient to meet those needs. The live stream requirement is implemented by visually inspecting Salinas River flow at nine bridge crossings between Salinas Dam and the Nacimiento River. When one or more locations has zero flow, live stream conditions are not met and diversions to storage must cease. At that point, all inflows to Santa Margarita Lake are passed through Salinas Dam to the downstream reach of the river. San Luis Obispo County staff conduct the "live stream" observations, and records since 2011 show that flow at the Paso Robles gage on the day live stream conditions ended was on average 5.5 cfs. This means a very small flow at Paso Robles was able to maintain continuous flow all the way across the Subbasin. This confirms the ISW conceptual model assertion that Salinas River inflows are generally able to sustain high water table elevations in the alluvium along the river, such that percolation losses are small at the time flow recession in spring eventually becomes discontinuous.

The live stream requirement is reasonably protective of groundwater users and riparian vegetation, but not necessarily of fish passage. If there were 300 cfs of inflow to Santa Margarita Lake during the steelhead migration season, only a few cfs would need to be released to sustain live flow to the Nacimiento River. Thus, the diversion to storage would eliminate the passage opportunity unless tributary inflows below the dam were sufficient to provide it.

Groundwater pumping would not plausibly decrease the duration of steelhead passage flows along the Subbasin reach of the Salinas River. This is because the shallow clay layers beneath the river alluvium greatly diminish the ability of deeper wells (in the Paso Robles Formation) from lowering alluvial groundwater levels and depleting river flow. This is borne out by the alluvial well hydrographs, which show steady water table elevations near the river bed elevation in all years and seasons except when large droughts substantially diminish Salinas River inflows to the Subbasin reach.

Even without the clay layers, groundwater pumping would not likely diminish passage opportunity to a significant degree because the high flows required for passage tend to recede quickly anyway. Suppose, for example, that 10,000 AFY of the 26,900 AFY of stream recharge simulated in the groundwater model were from the Salinas River and all of the percolation resulted from pumping-induced percolation, it would be equivalent to 13.8 cfs of flow depletion. That depletion would only affect passage opportunity when flow is between the minimum passage flow and 13.8 cfs greater than that flow. If flows were higher than that range, passage would still be possible even with the depletion. If flows were lower, passage would not have been possible anyway. Assuming a minimum passage flow of 300 cfs, which is the low end of the estimated range at Bradley, the depletion would only affect passage opportunity when flow is 300-313.8 cfs. Thirty-six flow event recession rates during 1970-2019 were evaluated, and the average time during which flow was in that range averaged 8 hours (minimum = 1 hour; maximum = 34 hours). These results are illustrated in Figure 17. A flow event duration of two days would probably be needed for steelhead to traverse the reach from the Nacimiento River to Paso Robles, based on the 5-day estimate for swimming upstream from Monterey Bay to Bradley (NMFS, 2007). Almost all flow events with flows greater than 300 cfs were above 300 cfs for at least two days. This simplified passage analysis did not account for downstream flow conditions such as releases from Nacimiento and San Antonio Reservoirs to meet the NMFS flow prescription for steelhead, or concurrent Arroyo Seco flows or whether the beach barrier between the Salinas River lagoon and Monterey Bay is open or closed. Those factors would likely decrease the height of the blue bars somewhat. Nevertheless, even under this unrealistically worst-case scenario, the impact of flow depletion on steelhead passage opportunity would usually be a few hours. Although this would be detrimental, it would not likely result in a significant decrease in long-term reproductive success.

To summarize the analysis of GDE animals, it appears that sustainability criteria that would be protective of riparian vegetation and wetlands would be protective of the animal species that use those habitats. Any impact of groundwater pumping on steelhead passage opportunity appears to be negligibly small.

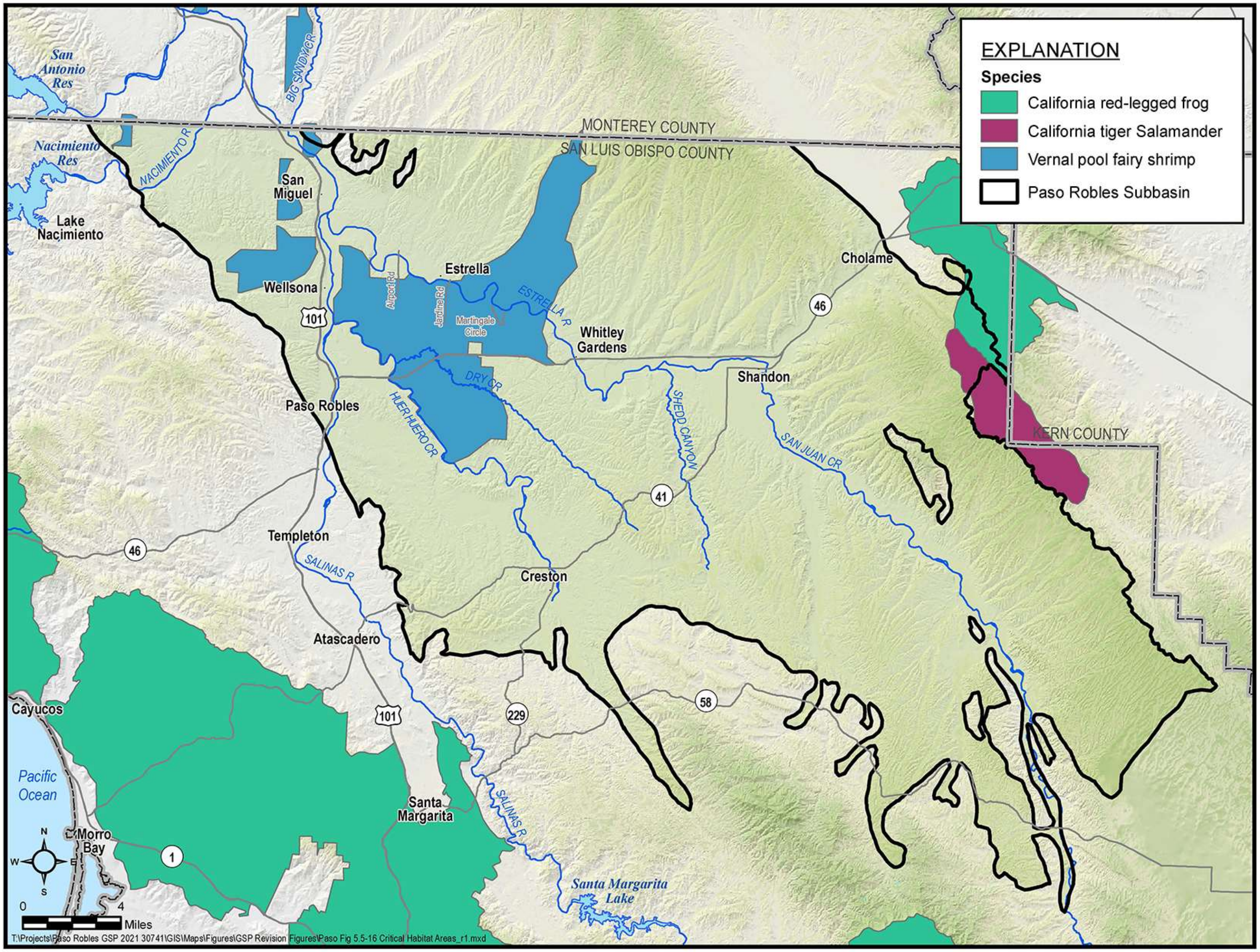


Figure 16. Critical Habitat Areas

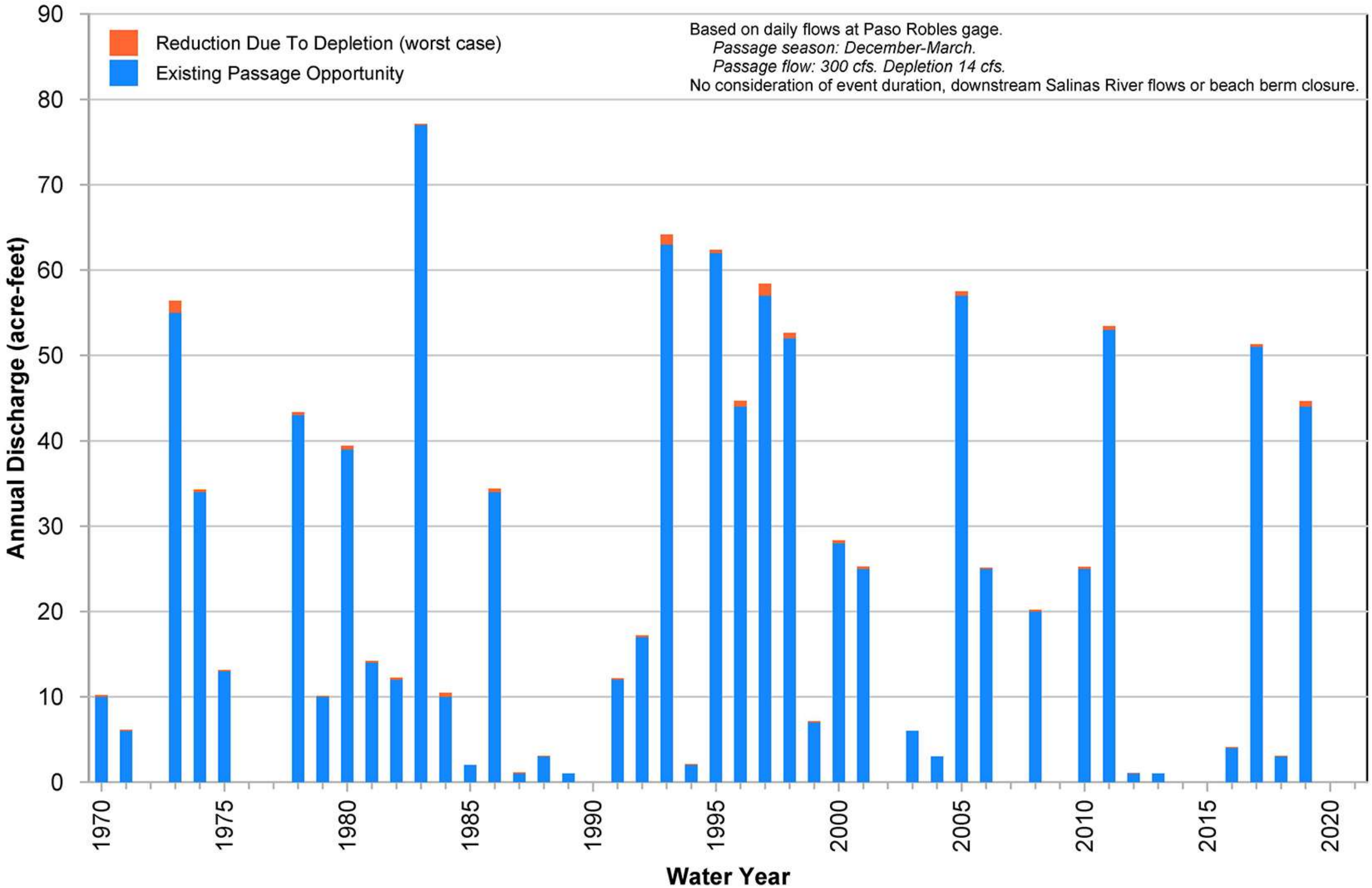


Figure 17. Simplified Steelhead Passage Opportunity, Salinas River

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