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DRAFT

Chapter 4

Paso Robles Subbasin Groundwater Sustainability Plan

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Close of 45-day public comment period: **pending recommendation by the Cooperative Committee at the October 17, 2018 Regular Meeting*	***December 10, 2018**

Revisions have been proposed to Section 4.7 of the Draft GSP Chapter 4 that was originally received by the Cooperative Committee at the September 12, 2018 Special Meeting. This revised Draft GSP Chapter 4 (attached) is available for public review and comment and will be brought back to the Committee at the October 17, 2018 Regular Meeting. Comments from the public are being collected using a comment form available at www.pasogcp.com. If you require a paper form to submit by postal mail, please contact your local Groundwater Sustainability Agency (GSA).

- County of San Luis Obispo
- Shandon-San Juan Water District
- Heritage Ranch CSD
- San Miguel CSD
- City of Paso Robles

Pending the Cooperative Committee's recommendation on October 17, 2018, the attached revised Draft GSP Chapter 4 will be distributed to the five Paso Robles Subbasin GSAs to receive and file.

Draft
Paso Robles Subbasin
Groundwater Sustainability Plan
Chapter 4

Prepared for the Paso Robles Subbasin
Cooperative Committee and the
Groundwater Sustainability Agencies

October 10, 2018

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CHAPTER 4. HYDROGEOLOGIC CONCEPTUAL MODEL

This chapter describes the hydrogeologic conceptual model of the Paso Robles Subbasin, including the Subbasin boundaries, geologic formations and structures, and principal aquifer units. The chapter also summarizes general Subbasin water quality, the conceptual interaction between groundwater and surface water, and generalized groundwater recharge and discharge areas. This chapter draws upon previously published studies, primarily hydrogeologic and geologic investigations by Fugro Consultants Inc. completed for San Luis Obispo County in 2002 and 2005. Fugro Consultants' 2002 and 2005 reports are the definitive geologic reports of the Subbasin. All subsequent investigations, such as the 2016 groundwater model update, adopted the geologic interpretations of the 2002 and 2005 Fugro Consultant reports. The Hydrogeologic Conceptual Model presented in this chapter is not intended to be exhaustive, but is a summary of the relevant and important aspects of the Subbasin hydrogeology that influence groundwater sustainability. More detailed information can be found in the original reports (Fugro, 2002 and 2005). This chapter, along with Chapter 3 – Basin Setting, sets the framework for subsequent chapters on groundwater conditions and water budgets.

4.1 Subbasin Topography and Boundaries

The Subbasin is a structural northwest-trending trough filled with sediments that have been folded and faulted by regional tectonics. The top of the Subbasin is the ground surface. The elevation of the Subbasin ranges from approximately 2,000 feet above mean sea level (msl) at the southeastern corner to approximately 600 feet above msl in the northwest where the Salinas River exits the Subbasin. The central part of the Subbasin forms a broad plain with relatively minor relief.

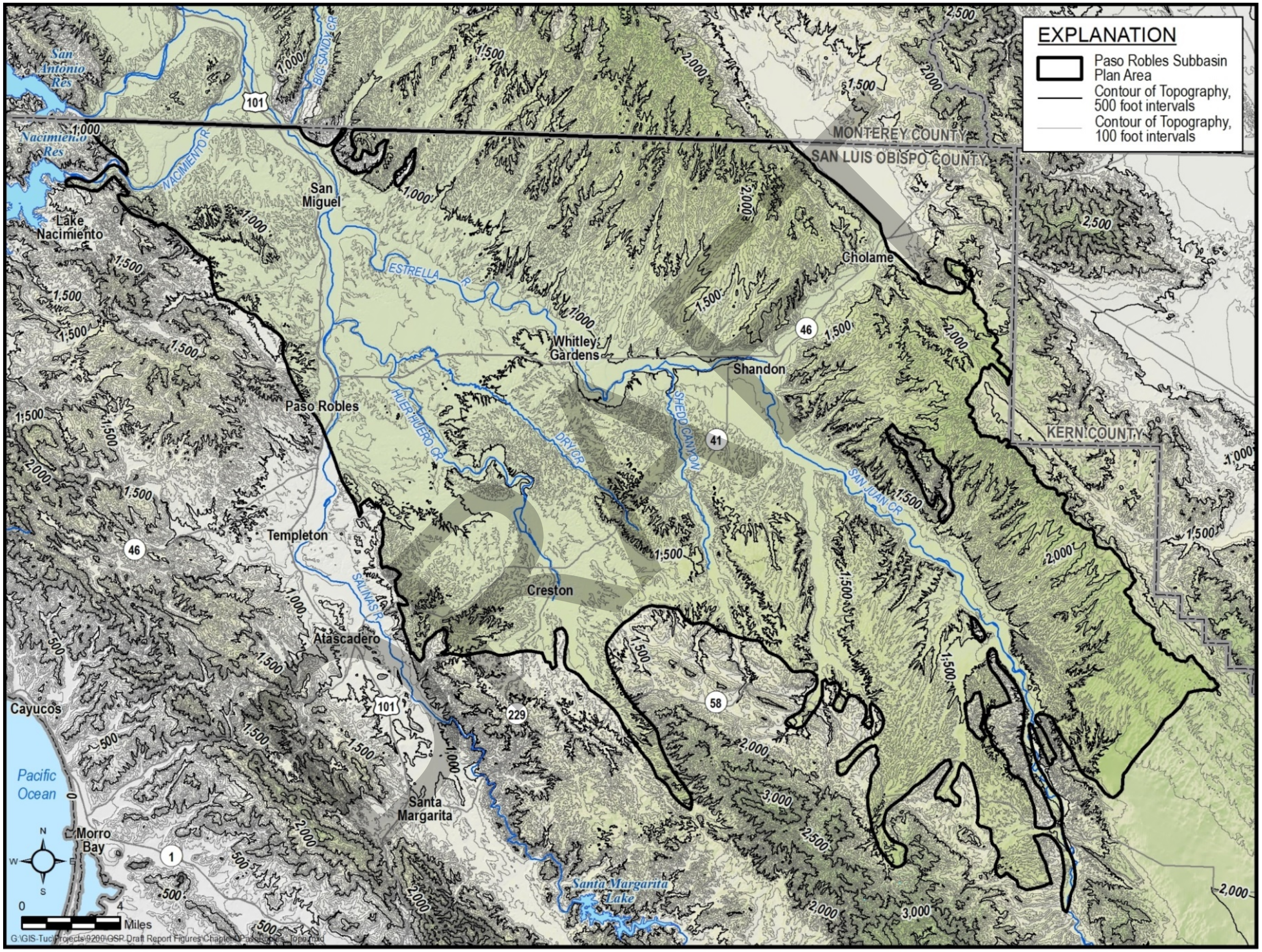


Figure 4-1. Paso Robles Subbasin Topography

Figure 4-1 shows the topography of the Subbasin using 100-foot contour intervals. The Subbasin is bounded by sediments with low permeability, sediments with poor groundwater quality, rock, and structural faults. In some areas the sediments of the Subbasin are continuous with adjacent subbasins. Specific Subbasin lateral boundaries include the following:

- The western boundary of the Subbasin is defined by the contact between the sediments in the Subbasin and the sediments of the Santa Lucia Range. An additional section of the western boundary is defined by the San Marcos-Rinconada fault system which separates the Paso Robles Subbasin from the Atascadero Subbasin.
- The northern boundary of the Subbasin is defined by the county line between San Luis Obispo County and Monterey County. This boundary is not defined by a physical barrier to groundwater flow; water-bearing sediments are continuous with the Salinas Valley Upper Valley Subbasin in Monterey County.
- The eastern boundary of the Subbasin is defined by the contact between the sediments in the Subbasin and the sediments of the Temblor Range. The San Andreas Fault forms the northeastern Subbasin boundary and is approximately parallel to the boundary further south.
- The southern boundary of the Subbasin is defined by the contact between the sediments in the Subbasin and the sediments of the La Panza Range. To the southeast, a watershed divide separates the Subbasin from the adjacent Carrizo Plain Basin; sedimentary layers are likely continuous across this divide.

The bottom of the Subbasin is generally defined as the base of the Paso Robles Formation, which is an irregular surface formed as the result of folding, faulting, and erosion (Fugro, 2002). The Subbasin boundary and bottom are not considered absolute barriers to flow because some of the geologic units underlying the Paso Robles Formation produce sufficient quantities of water, but the water is generally of poor quality and it is therefore not considered part of the Subbasin.

Figure 4-2 shows the lateral boundaries of the Subbasin and the approximate depth to the bottom of Paso Robles Formation in areas where it is saturated. The Paso Robles Formation is either not present or not saturated east of the San Juan fault system and there is very little well data in this portion of the subbasin.

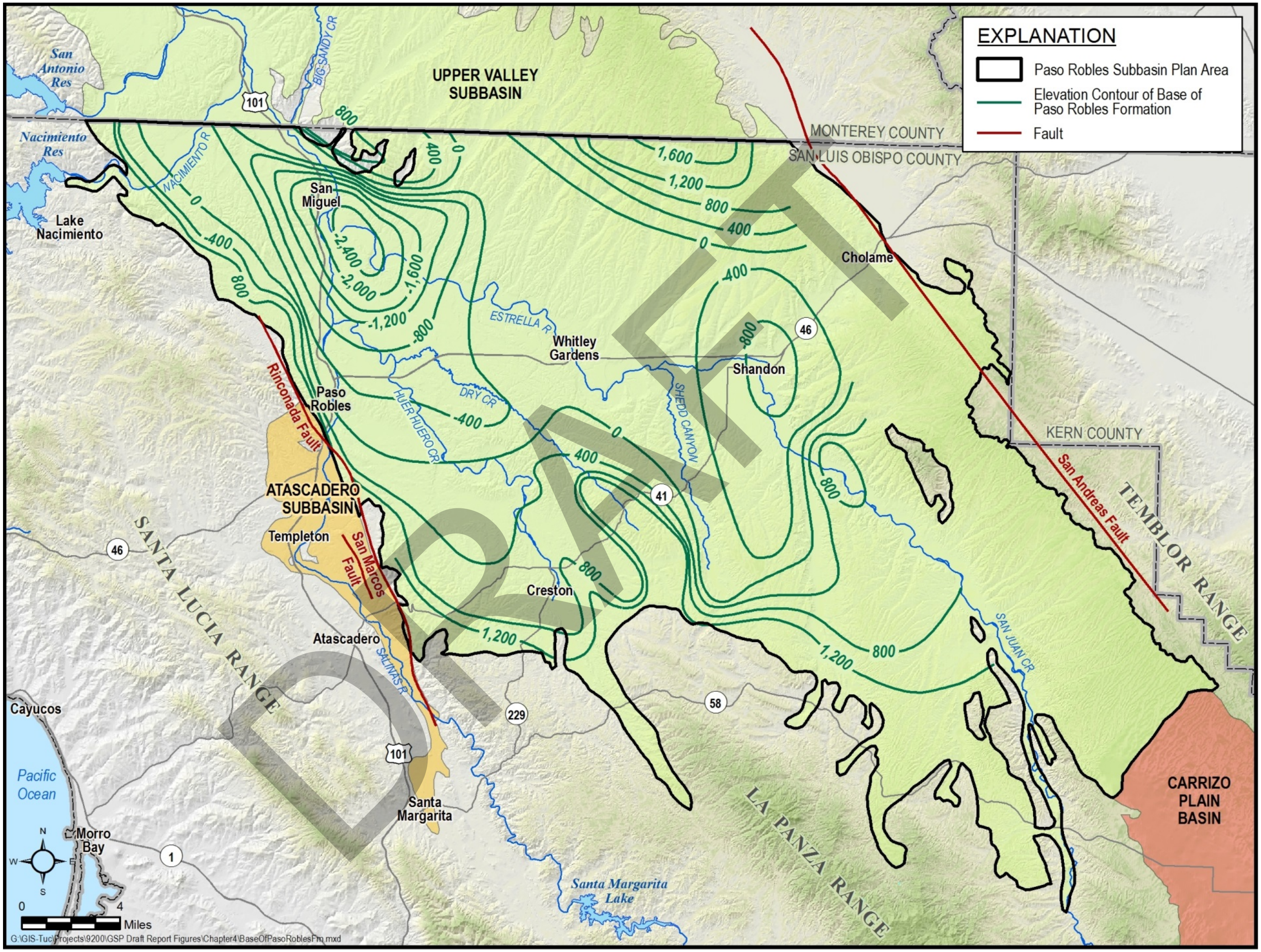


Figure 4-2. Base of Subbasin as Defined by the Base of the Paso Robles Formation

4.2 SOILS INFILTRATION POTENTIAL

Saturated hydraulic conductivity of surficial soils is a good indicator of the soil's infiltration potential. Soil data from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) (USDA NRCS, 2007) is shown by the four hydrologic groups on Figure 4-3. The soil hydrologic group is an assessment of soil infiltration rates that is determined by the water transmitting properties of the soil, which includes hydraulic conductivity and percentage of clays in the soil, relative to sands and gravels. The groups are defined as:

- Group A – High Infiltration Rate: water is transmitted freely through the soil; soils typically less than 10 percent clay and more than 90 percent sand or gravel.
- Group B – Moderate Infiltration Rate: water transmission through the soil is unimpeded; soils typically have between 10 and 20 percent clay and 50 to 90 percent sand
- Group C – Slow Infiltration Rate: water transmission through the soil is somewhat restricted; soils typically have between 20 and 40 percent clay and less than 50 percent sand
- Group D – Very Slow Infiltration Rate: water movement through the soil is restricted or very restricted; soil stypically have greater than 40 percent clay, less than 50 percent sand

The hydrologic group of the soil generally correlates with the hydraulic conductivity of underlying geologic units, with lower soil hydraulic conductivity zones correlating to areas underlain by clayey portions of the Paso Robles Formation. The higher soil hydraulic conductivity zones correspond to areas underlain by alluvium or areas of coarser sediments within the Paso Robles Formation.

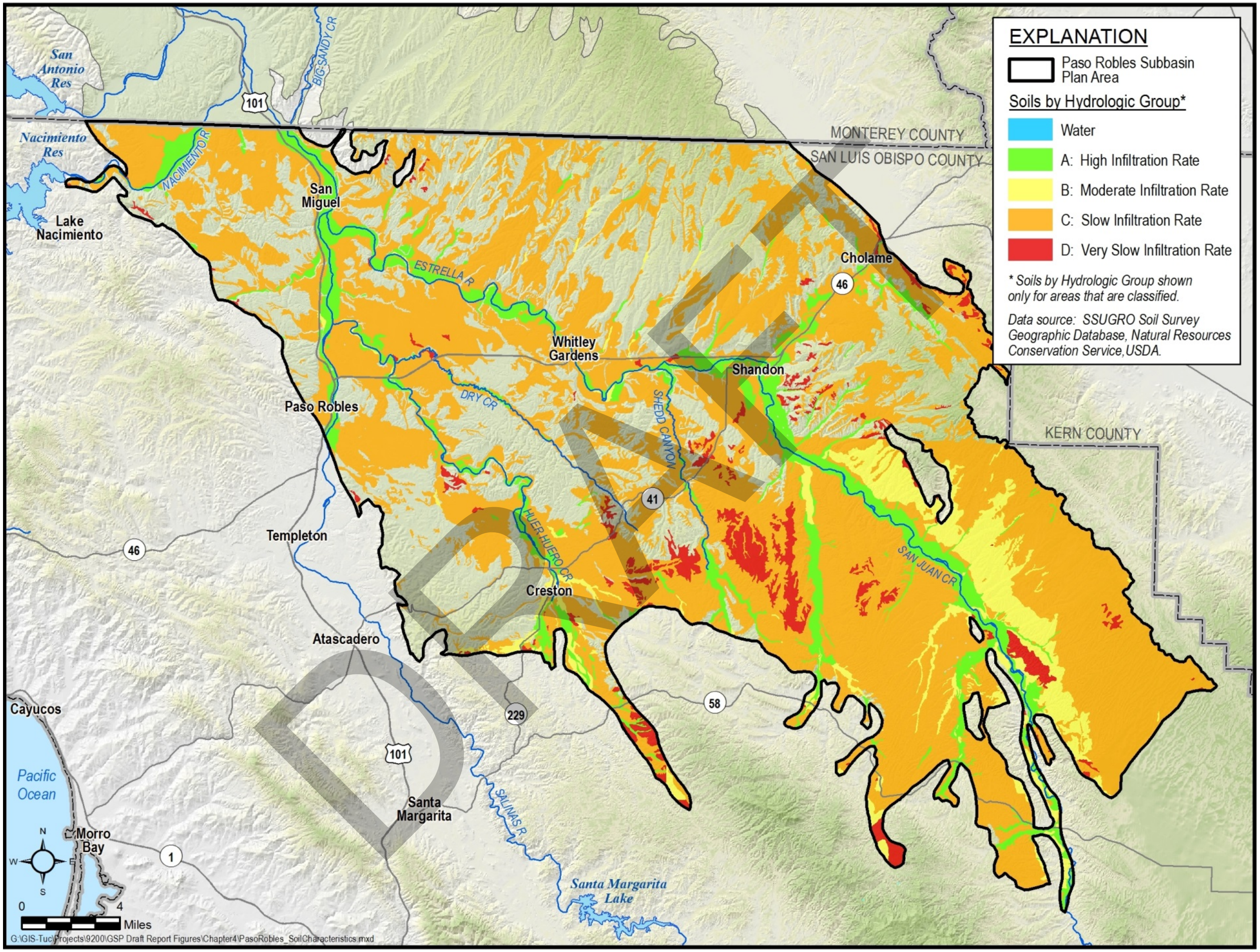


Figure 4-3. Paso Robles Subbasin Soil Characteristics

4.3 REGIONAL GEOLOGY

This section provides a description of the geologic formations in the Subbasin. These descriptions are summarized from previously published reports by Fugro (2002 and 2005). Figure 4-4 shows the surficial geology and geologic structures of the Subbasin (County of SLO, 2007). Figure 4-5 provides the location of the geologic cross-sections shown on Figure 4-6 through Figure 4-10. The selected geologic cross-sections illustrate the relationship of the geologic formations that constitute the Subbasin and the geologic formations that underlie and surround the subbasin. The cross-sections are from different reports so the format differs but the units are consistent. Figure 4-6 through Figure 4-8 are from the *Paso Robles Groundwater Basin Study* (Fugro, 2002); Figure 4-9 and Figure 4-10 are from the *Paso Robles Groundwater Basin Study, Phase II: Numerical Model Development, Calibration, and Application* (Fugro, 2005).

4.3.1 REGIONAL GEOLOGIC STRUCTURES

The base of the Subbasin is locally divided by two semi-parallel bedrock ridges: the San Miguel Dome and the Creston Anticlinorium (Figure 4-4). These two bedrock ridges are often not exposed at the ground surface, but are apparent in the subsurface cross-sections. The subsurface expression of the bedrock is illustrated on the cross-sections shown on Figure 4-6, which shows the Creston Anticlinorium, and Figure 4-8 which shows the San Miguel Dome. Between the San Miguel Dome and Creston Anticlinorium, there is no clear bedrock ridge as shown on Figure 4-7. This gap allows for sediments on the east side of the ridges near Shandon to continue and be connected with sediments on the west side of the ridges.

The deepest portion of the Subbasin is west of the San Miguel Dome and north of Paso Robles, with over 3,000 feet of sediments (Fugro, 2005). This deep trough extends through the Paso Robles area and shallows progressively to the south. As shown on Figure 4-6, the sediments are generally relatively thin on the order of a few hundred feet in the Creston area. East of the San Miguel Dome and near the community of Shandon the Paso Robles Formation is over 2,000 feet thick.

The faults within and along the borders of the Subbasin boundaries are shown on Figure 4-6. The predominant fault near the eastern side of the Subbasin is the San Andreas Fault. The predominant fault near the western side of the Subbasin is the San Marcos-Rinconada fault system. Within the Subbasin and sub-parallel to the San Andreas Fault are the Red Hill, San Juan, and White Canyon faults. It is unknown to what degree these faults are barriers to groundwater flow. In the center of the Subbasin are the King City fault and various unnamed faults. It is unknown to what degree these internal faults are barriers to groundwater flow. These faults could create compartments in the sediments and limit the ability of groundwater to move within the Subbasin.

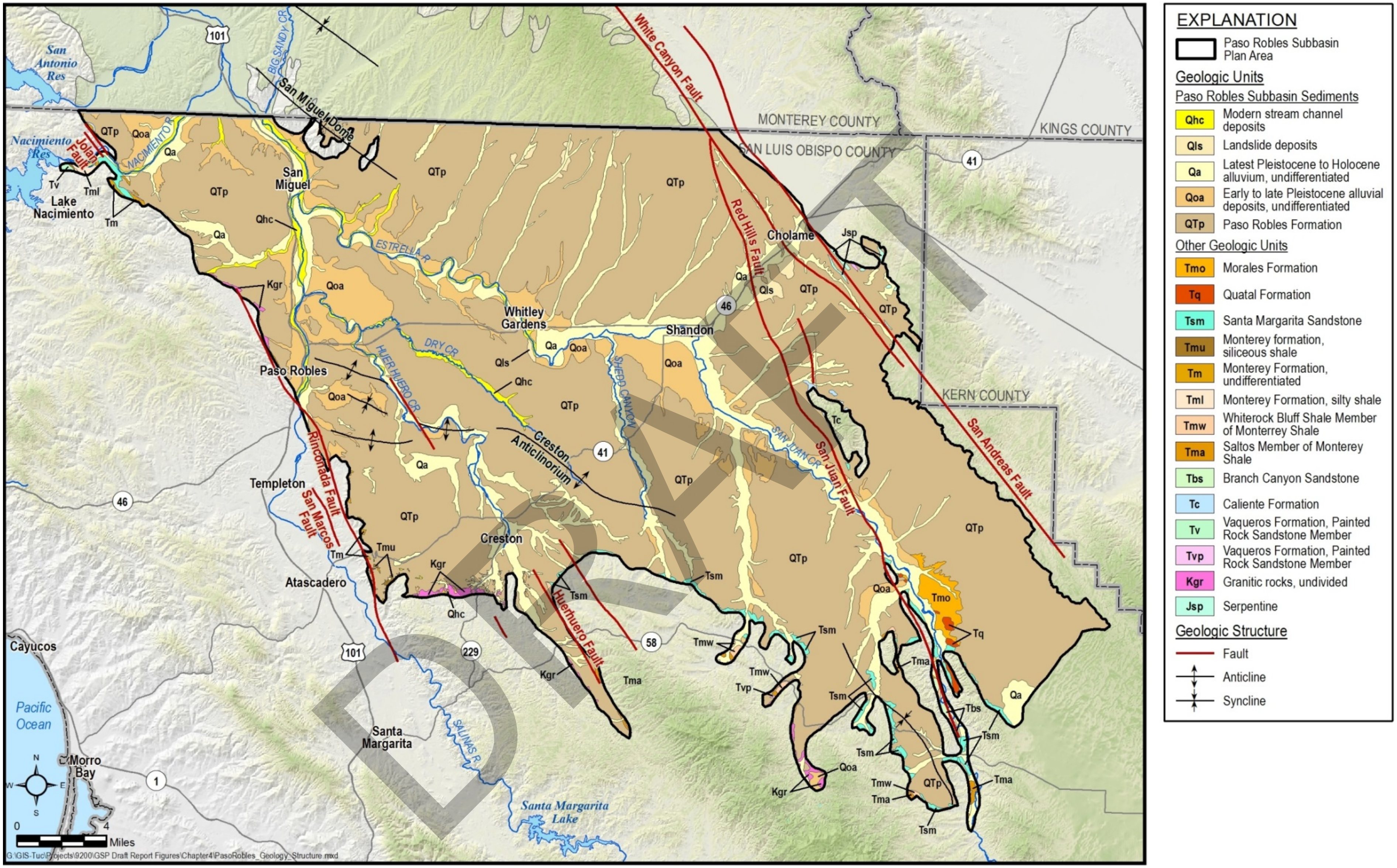


Figure 4-4. Surficial Geology and Geologic Structures

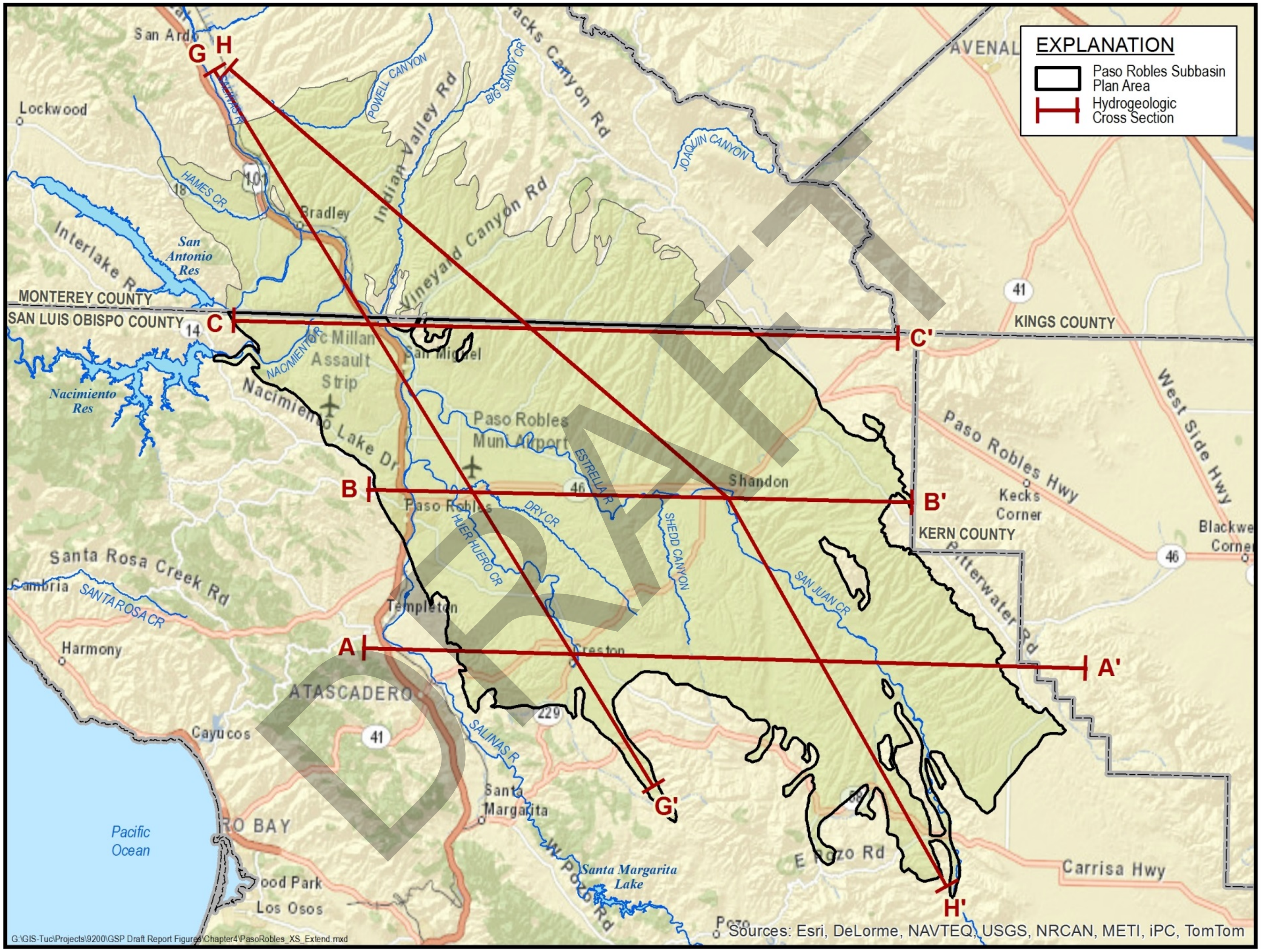


Figure 4-5. Cross Sections Locations

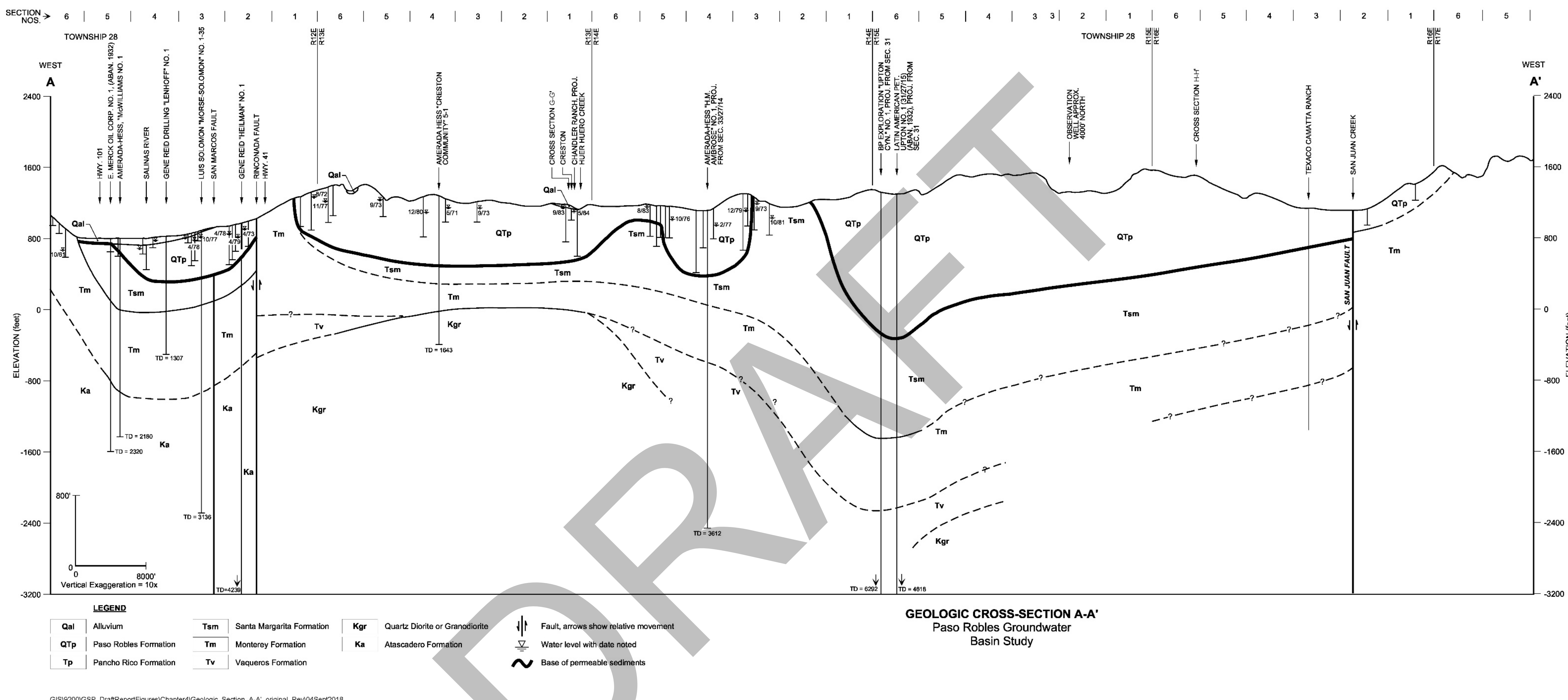
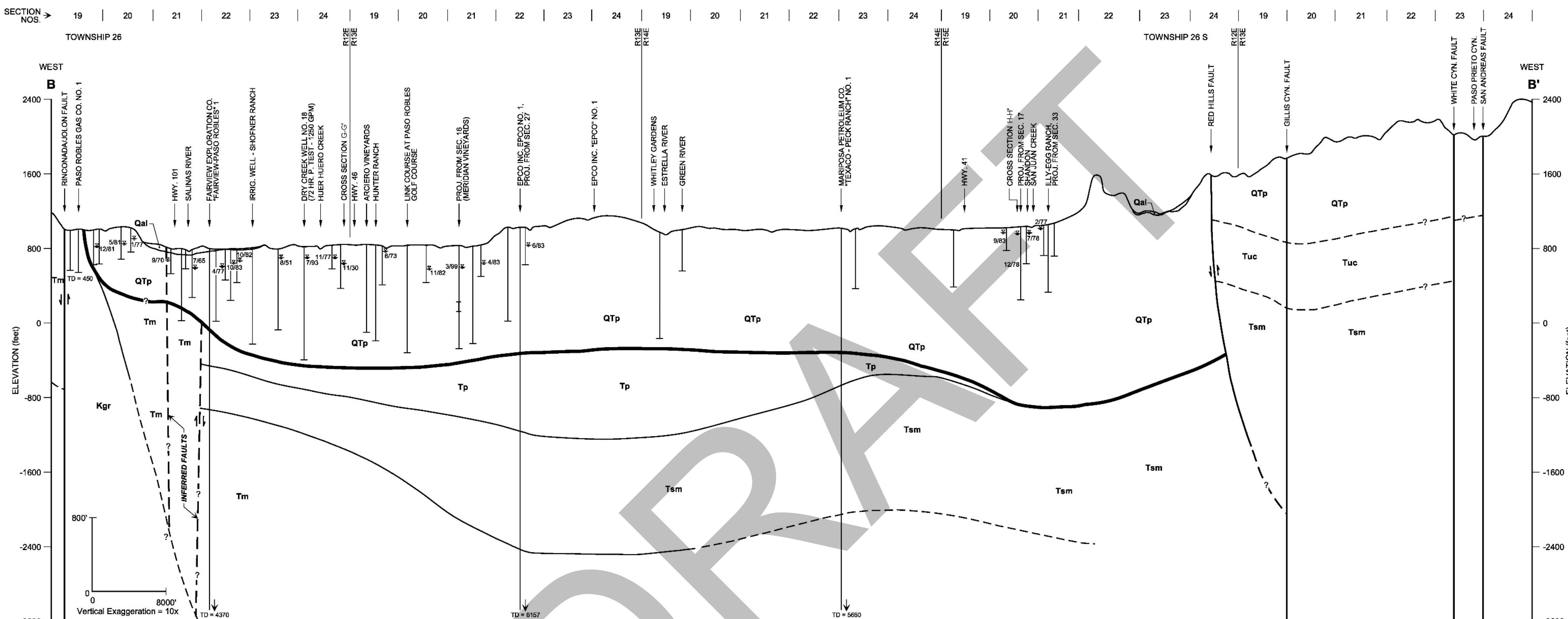


Figure 4-6. Geologic Section A-A′

Source: Modified from Fugro (2002)



GIS\9200\GSP_DraftReportFigures\Chapter4\Geologic_Section_B-B'_original_Rev\04Sept2018

Figure 4-7. Geologic Section B-B′

Source: Modified from Fugro (2002)

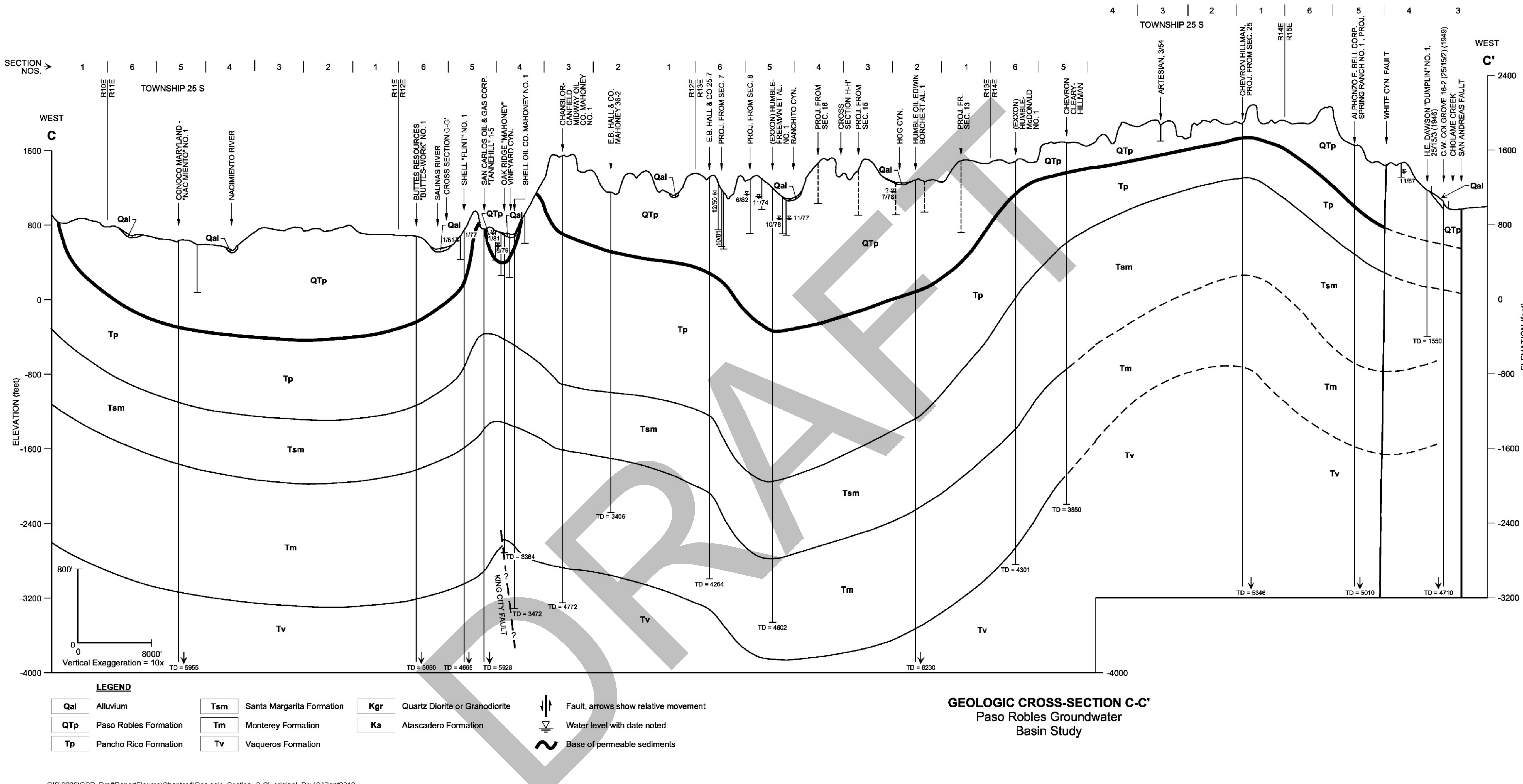


Figure 4-8. Geologic Section C-C′

Source: Modified from Fugro (2002)

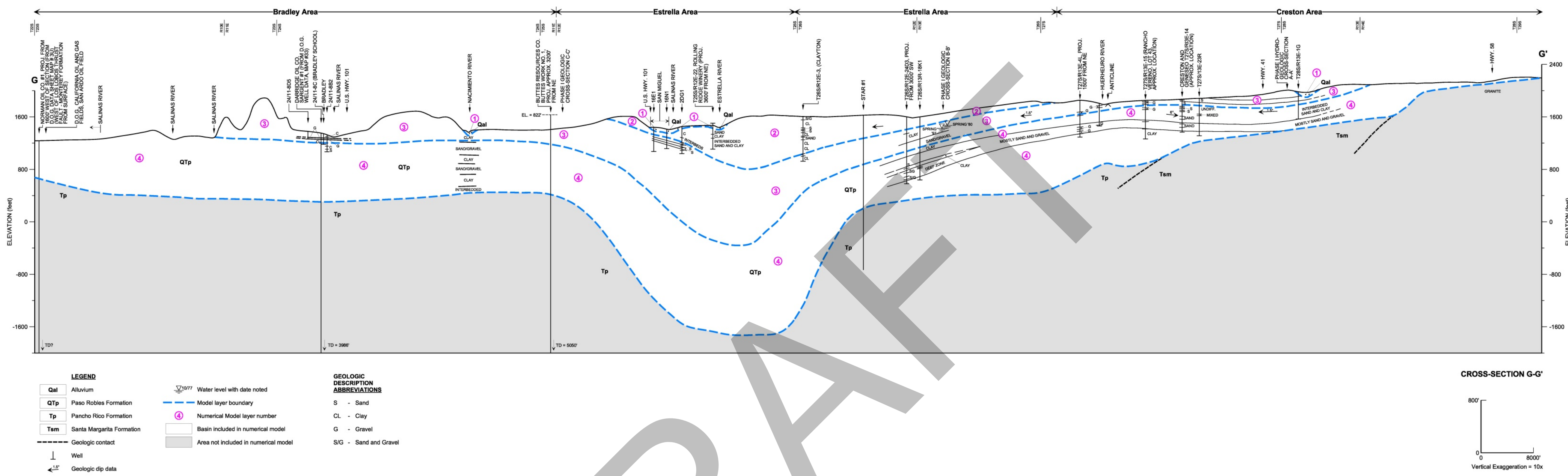


Figure 4-9. Geologic Section G-G'

Source: Modified from Fugro (2005)

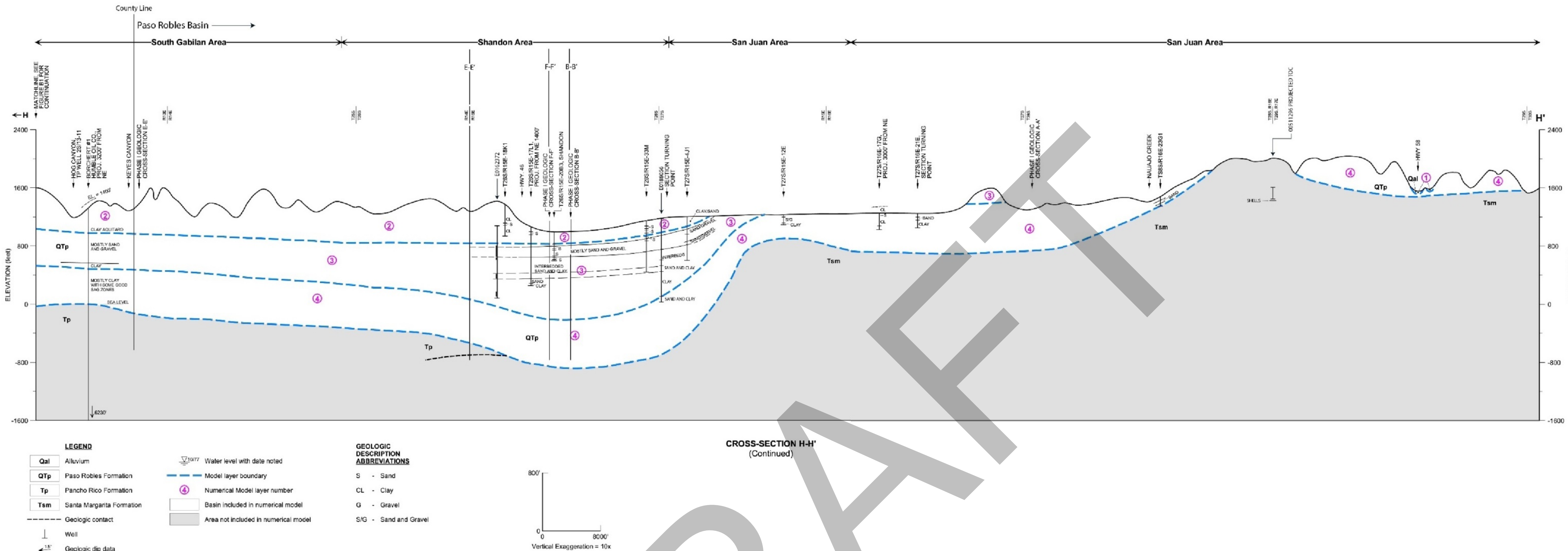


Figure 4-10. Geologic Section H-H'

Source: Modified from Fugro (2005)

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4.3.2 Geologic Formations Within the Subbasin

The main criteria used by previous authors for defining which geologic formations constitute the groundwater basin are:

1. The formation must have sufficient permeability and storage potential for the movement and storage of groundwater such that wells can reliably produce more than 50 gallons per minute (gpm) on a long-term basis, and
2. The groundwater produced from the geologic formation must be of generally acceptable quality (Fugro, 2002). DWR (1979) classifies groundwater with a conductivity of 3,000 micromhos/centimeter or less as fresh, and therefore of acceptable quality.

The only two geologic formations that reliably meet these two criteria are the Quaternary-age alluvial deposits and the Tertiary-age Paso Robles Formation. Therefore, these are the only two formations that constitute the Subbasin. A general discussion of these two formations is presented below.

Alluvium

Alluvium occurs beneath the flood plains of the rivers and streams within the Subbasin. Figure 4-4 shows the location of the alluvial deposits, labeled as Quaternary alluvium, identified as Qa. These deposits are typically no more than 100 feet thick and comprise coarse sand and gravel with some fine-grained deposits. The alluvium is generally coarser than the Paso Robles Formation, with higher permeability that results in well production capability that often exceeds 1,000 gpm.

Paso Robles Formation

The largest volume of sediments in the Subbasin are in the Paso Robles Formation. This formation has sedimentary layers up to 3,000 feet thick in the northern part of the Estrella area and up to 2,000 feet near Shandon. Figure 4-4 shows the location of the Paso Robles Formation deposits, identified as QTp. Throughout most of the Subbasin the Paso Robles Formation sediments have a thickness of 700 to 1,200 feet.

The Paso Robles Formation is derived from erosion of nearby mountain ranges. Sediment size decreases from the east and the west, becoming finer towards the center of the Subbasin, indicating sediment source areas are both to the east and west. The Paso Robles Formation is a Plio-Pleistocene, predominantly non-marine geologic unit comprising relatively thin, often discontinuous sand and gravel layers interbedded with thicker layers of silt and clay. The formation was deposited in alluvial fan, flood plain, and lake depositional environments. The formation is typically unconsolidated and generally poorly sorted. The sand and gravel beds in the Paso Robles Formation have a high percentage of eroded Monterey shale and have lower permeability compared to the overlying alluvial unit. The formation also contains minor amounts of gypsum and woody coal.

Poor quality groundwater with elevated concentrations of iron, manganese, and in some cases hydrogen sulfide odor have been observed within deeper portions of the Paso Robles Formation in some areas.

4.3.3 Geologic Formations Surrounding the Subbasin

Underlying and surrounding the Subbasin are older geologic formations that either typically have low well yields or have poor quality water. In general, the geologic units underlying the Subbasin include:

1. Tertiary-age or older consolidated sedimentary beds;
2. Cretaceous-age metamorphic rocks; and
3. Granitic rock.

Figure 4-11 shows the location of oil and gas exploration wells drilled in the Subbasin. These oil and gas wells help identify the depth and extent of the geologic formations that surround and underlie the Subbasin.

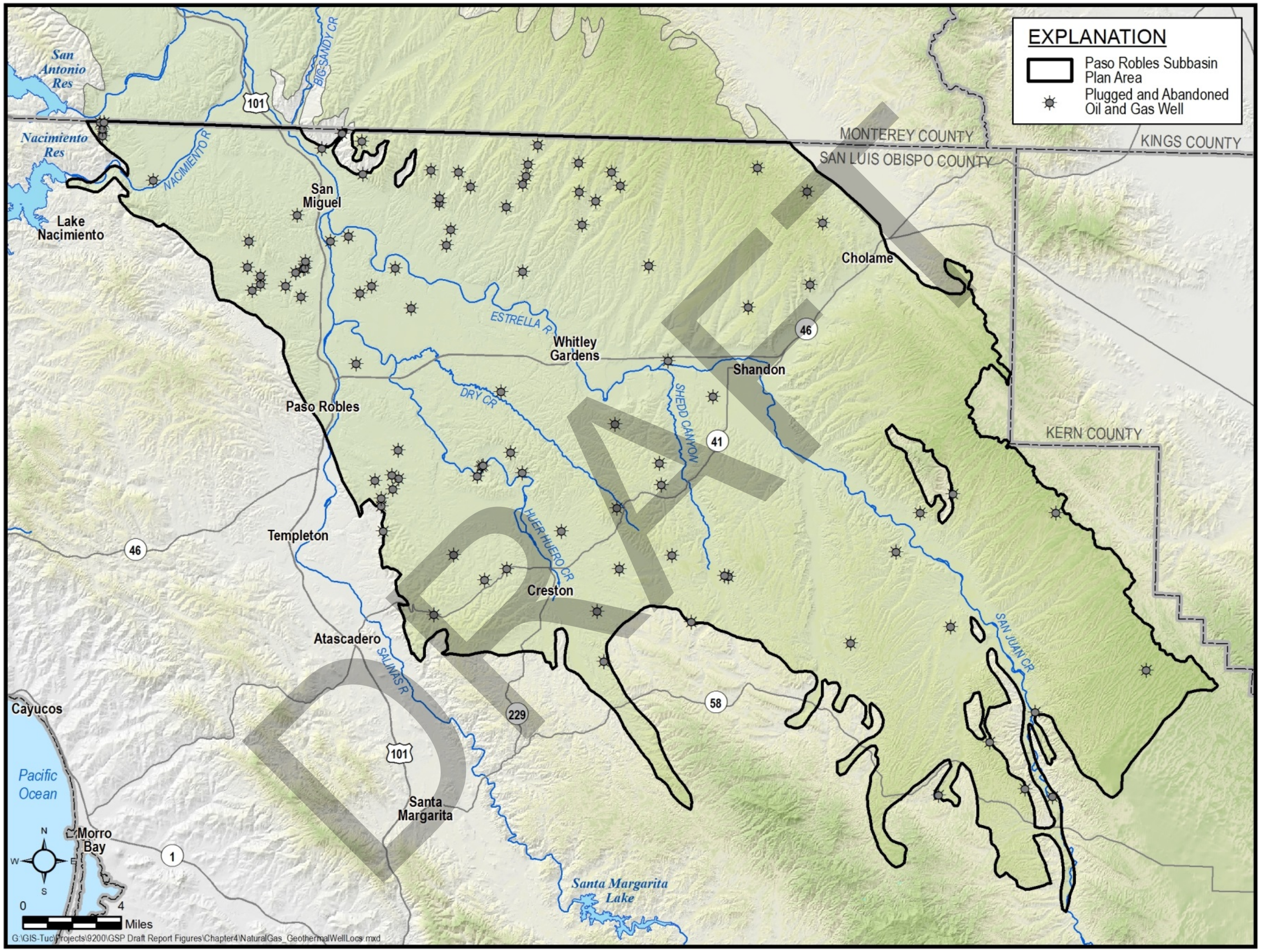

Figure 4-11. Natural Gas Exploration Well Locations and Geothermal Wells

PANCHO RICO FORMATION

The Pancho Rico Formation (Tp) is a Pliocene-age marine deposit found mostly in the northern portion of the study area. In places it appears to be time-correlative to the Paso Robles Formation, and may be in lateral contact as a facies change. The unit predominantly consists of fine-grained sediments up to 1,400 feet thick that yield low quantities of water. The Pancho Rico Formation additionally has poor water quality associated with tar sands that are present at the bottom of this formation (State Division of Mines, 1974).

SANTA MARGARITA FORMATION

The Santa Margarita Formation (Tsm) is an upper Miocene-age marine deposit, consisting of a white, fine-grained sandstone and siltstone with a thickness of up to 1,400 feet. The unit is found beneath most of the Subbasin. The Santa Margarita Formation is relatively permeable, but is not considered part of the Subbasin because the water quality is usually very poor. The geothermal waters contained in the Santa Margarita Formation in this area are often highly mineralized and characterized by elevated boron concentrations that restrict agricultural uses.

MONTEREY FORMATION

The Miocene-age Monterey Formation (Tm) consists of interbedded argillaceous and siliceous shale, sandstone, siltstone, and diatomite. The unit is as great as 2,000 feet thick in the study area, and is often highly deformed. Wells in the Monterey Formation are generally of too low yield to consider the Monterey Formation part of the Subbasin; although isolated areas in the Monterey Formation can yield more than 50 gpm. Additionally, groundwater produced from the Monterey Formation often has high concentrations of hydrogen sulfide, total organic carbon, manganese, and iron.

VAQUEROS FORMATION

The marine Oligocene-age Vaqueros Formation (Tv) is a highly cemented fossiliferous sandstone that reaches a thickness up to 200 feet. Springs in the Vaqueros Formation with flows up to 25 gpm are common in canyons on the western and southern sides of the study area. Most water wells tapping this formation produce less than 20 gpm. Generally, the quality of water in this unit is good, though hard due to the calcareous cement within the rock.

METAMORPHIC AND GRANITIC ROCKS

The southern and western edges of the Subbasin are bordered by Cretaceous-age metamorphic and granitic rock. The metamorphic rock units include the Franciscan, Toro, and Atascadero Formations. The Franciscan consists of discontinuous outcrops of shale, chert, metavolcanics, graywacke, and blue schist, with or without serpentinite. The Toro Formation (Kt) is a highly consolidated claystone and shale that does not typically yield significant water to wells. The Atascadero Formation (Ka) is highly consolidated, but does have some sandstone beds that yield limited amounts of water to wells.

The granitic rock unit (Kgr) lies east of the Rinconada fault system, south of Creston, east of Atascadero, and in the area northwest of the City of Paso Robles. The granitic rocks are often capped by a layer of granular decomposed granite that may be weathered to clay. This decomposed granite may be up to 80 feet in thick and may contain limited amounts of groundwater.

4.4 PRINCIPAL AQUIFERS AND AQUITARDS

Water-bearing sand and gravel beds that may be laterally and vertically discontinuous are generally grouped together into zones that are referred to as aquifers. The aquifers can be vertically separated by fine-grained zones that can impede movement of groundwater between aquifers. Two aquifers exist in the Subbasin:

- A relatively continuous aquifer comprising alluvial sediments that underlie streams;
- An interbedded and discontinuous aquifer comprising sand and gravel lenses in the Paso Robles Formation.

Figure 4-4 shows the location of geologic sections that were used to depict the aquifers in the subsurface. Figure 4-12 through Figure 4-15 show the aquifers and model layers in profile, which are interpreted from the geologic logs, geophysical logs, groundwater levels, and water quality (Fugro, 2002 and 2005). For the GSP several additional well logs were added to the sections to refine the extent of the aquifers. These logs have been labeled with the state well inventory number (e.g. E0188061). Appendix 4A contains the well logs used to update the sections.

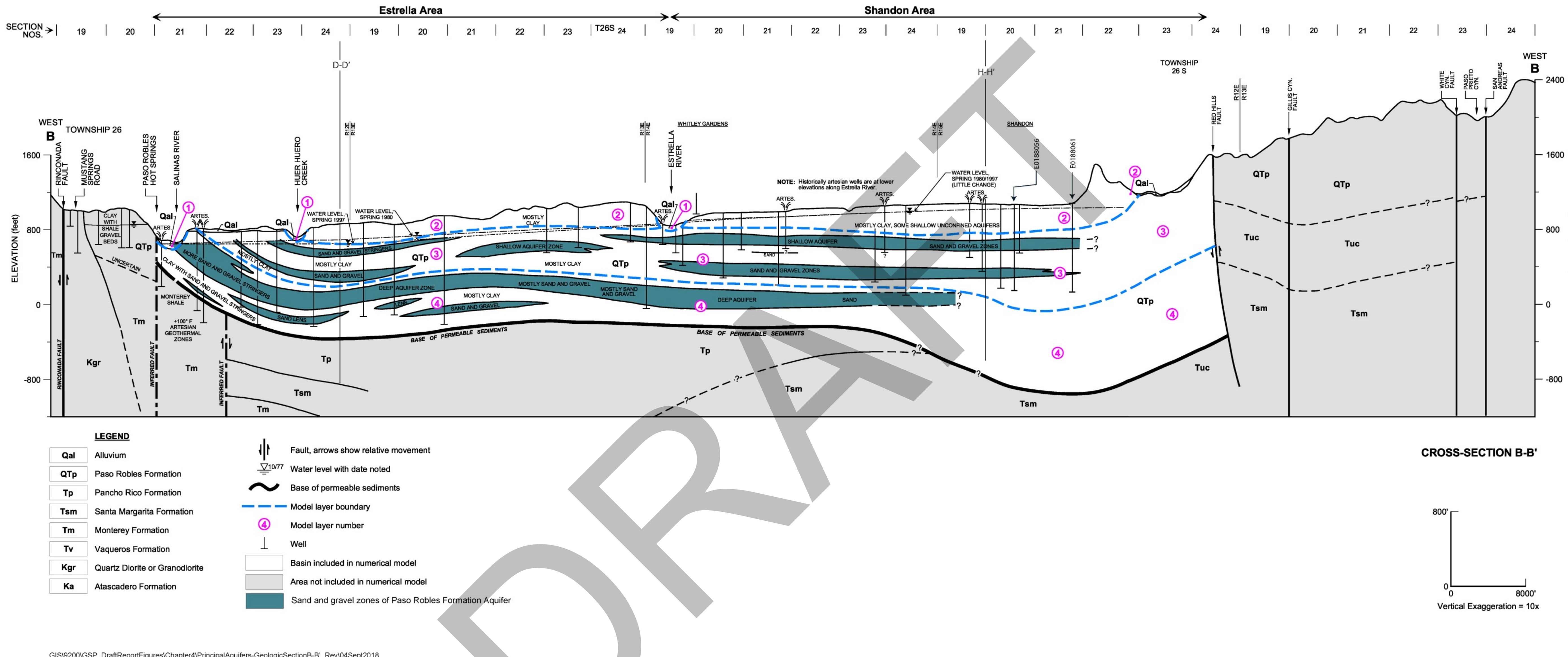

Figure 4-12. Aquifers - Geologic Section B-B'

Source: Modified from Fugro (2005)

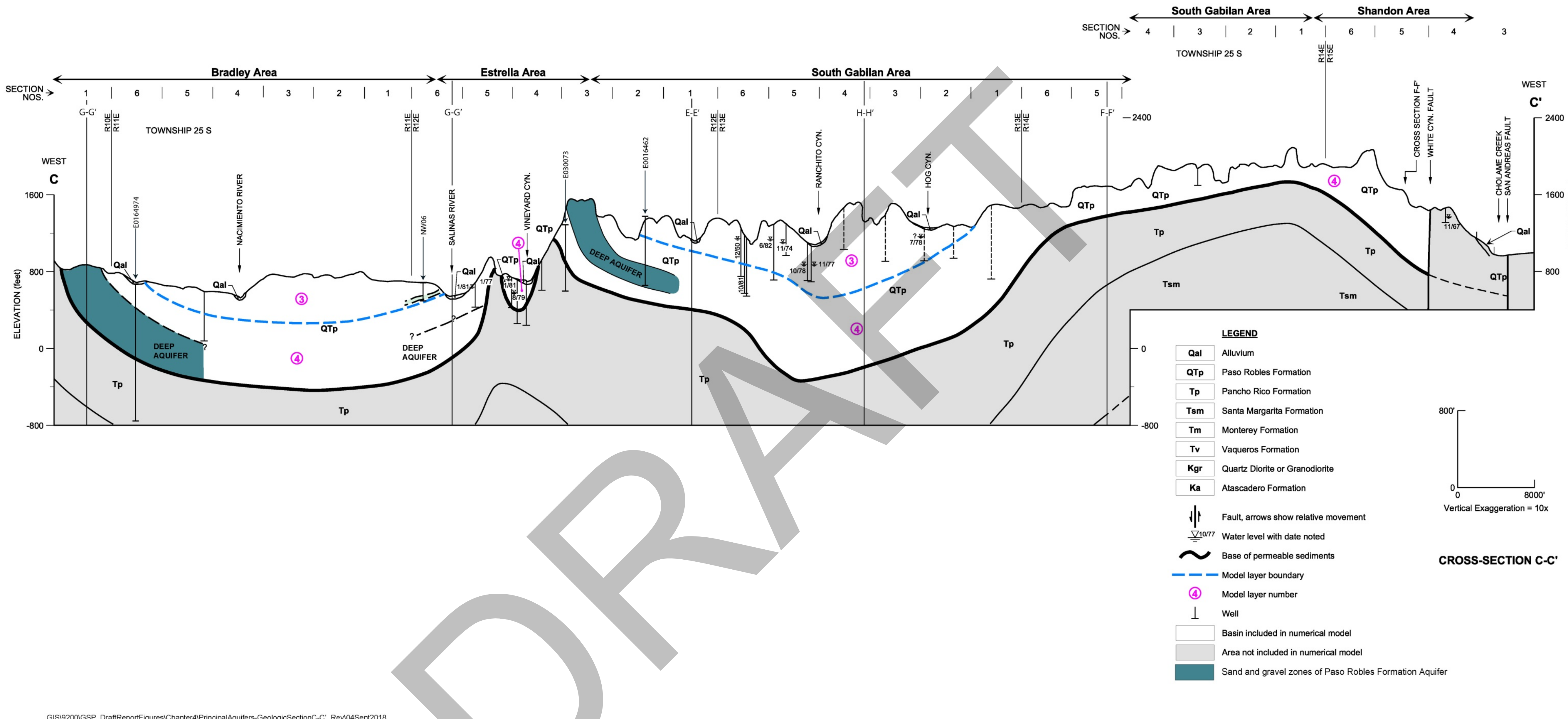

Figure 4-13. Aquifers - Geologic Section C-C′

Source: Modified from Fugro (2005)

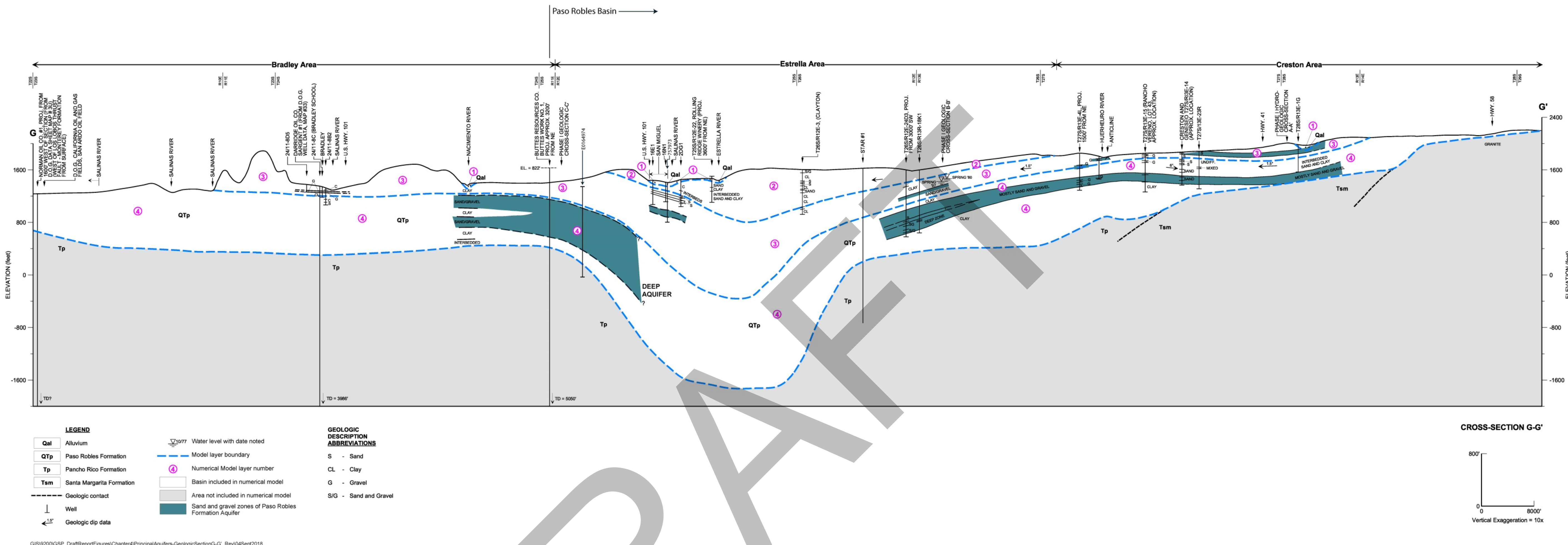

Figure 4-14. Aquifers - Geologic Section G-G'

Source: Modified from Fugro (2005)

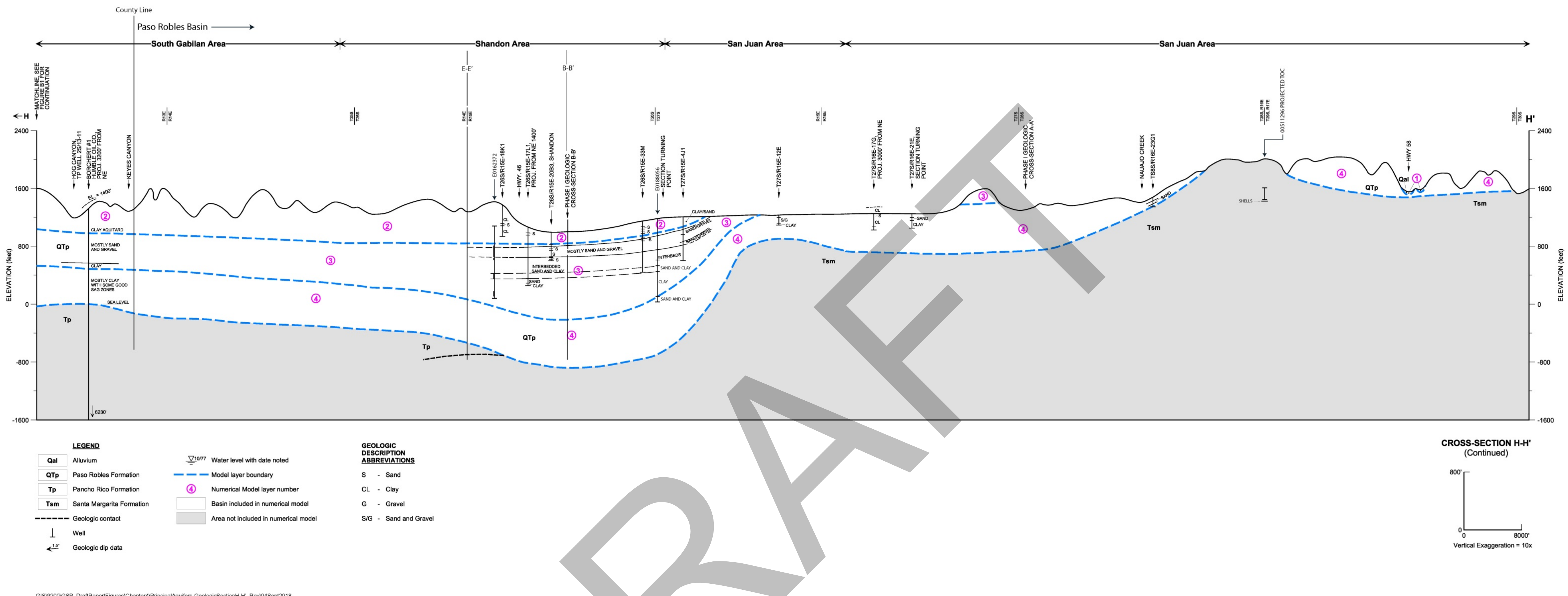

Figure 4-15. Aquifers - Geologic Section H-H'

Source: Modified from Fugro (2005)

4.4.1 ALLUVIAL AQUIFER

The unconfined Alluvial Aquifer is generally composed of saturated coarse-grained sediments and occurs along Huer Huero Creek, the Salinas River, and the Estrella River; the extent of this aquifer is shown on Figure 4-4. The alluvial aquifer varies in thickness, but is generally about 100 feet thick. The Alluvial Aquifer is highly permeable. Wells screened in the alluvial aquifer can yield up to a 1,000 gpm (Fugro, 2005).

4.4.2 PASO ROBLES FORMATION AQUIFER

Geologic information reported in Fugro (2002) suggests that the sand and gravel zones that constitute the Paso Robles Formation Aquifer are generally thin, discontinuous, and are usually separated vertically by relatively thick zones of silts and clays. Figure 4-4 shows the extent of the Paso Robles Formation in the Subbasin. In general, the sand and gravel zones occur throughout the Paso Robles Formation, although they may be locally discontinuous or absent in some areas. As shown on Figure 4-14, near Creston the shallow sand and gravel zones appear to be disconnected from other parts of the Paso Robles aquifer by faults and structural folds. The shallow aquifer zone near Creston may be an isolated aquifer area.

4.4.3 AQUIFER PROPERTIES

Data reported in Fugro (2002) were reviewed to estimate representative aquifer hydraulic properties. Most aquifer tests have been conducted in the Estrella and Creston areas. Estimated aquifer properties are summarized in Table 4-1.

Table 4-1. Paso Robles Subbasin Aquifer Hydrogeologic Properties

Well Location	Test Duration (hours)	Flow (gpm)	Well Depth (feet)	Perforated Interval	Transmissivity (gpd/ft)	Q/s (gpm/ft)	Hydraulic Conductivity (ft/day)
Alluvial Aquifer							
28S/13E-36	24	367	70	40	186,300	68	620
Paso Robles Formation Aquifer							
27S/12E-09	72	300	450	170	8,800	4.9	6.9
26S/12E-22	12	220	430	100	900	1.2	1.2
25S/11E-24	12	150	350	90	800	0.62	1.2
27S/12E-18	8	140	225	35	4,100	3	15.7
26S/12E-20	48	115	400	50	7,600	10	20
26S/12E-36	24	400	660	280	8,800	5.1	4.2
26S/12E-35	18	690	830	370	7,900	4.9	2.9
27S/14E-18	24	600	740	220	6,100	5.5	3.7
26S/13E-16	24	200	820	350	3,100	2.63	1.2
26S/12E-25	24	500	730	340	5,700	3.6	2.2
25S/13E-30	24	600	720	260	6,900	79	3.5
26S/13E-7	24	600	825	380	3,200	3	1.1
26S/13E-7	24	600	990	610	5,000	4.2	1.1
24S/11E-34	24	850	612	100	2,805	4.5	3.8

Source: Fugro, 2002

Based on limited aquifer property data available for the Alluvial Aquifer, the transmissivity may be in the range of 150,000 to 200,000 gallons per day per foot (gpd/ft); or between 20,000 and 27,000 square feet per day (ft^2/day). Hydraulic conductivity of the Alluvial Aquifer may be over 500 feet per day (ft/d).

The estimated transmissivity of the Paso Robles Formation Aquifer ranges between 800 gpd/ft and about 9,000 gpd/ft; or between 100 and 1,200 ft^2/day. The geometric mean of the tabulated transmissivity values for the shallow aquifer zone is about 3,500 gpd/ft, or 470 ft^2/day.

The estimated hydraulic conductivity of the Paso Robles Formation Aquifer ranges from about 1 ft/d to about 20 ft/d. The geometric mean of the tabulated hydraulic conductivity values for the Paso Robles Formation Aquifer is 5 ft/d.

Limited data exist to assess the confined storage properties, such as storativity, of the Paso Robles Formation aquifer (Fugro, 2002). Table 4-2 summarizes reported estimates of specific yield for unconfined portions of the aquifers. Average specific yield was estimated by analyzing 10 to 20 of the deepest well completion logs for each area. Each lithologic interval was assigned a specific yield by comparison of the formation description with published estimates based on extensive field and laboratory investigations conducted in southern coastal basins by the DWR and modified for the Paso Robles Formation (DWR, 1958). The assigned specific yield was then weighted according to the thickness of each bed and averaged over the entire depth of the well (Fugro, 2002). Results of this analysis suggested that a representative average value for specific yield for the Paso Robles Formation in the Subbasin was 0.09. This specific yield may be low. Average specific yields for unconsolidated sand and gravel sedimentary aquifers are commonly between 0.1 and 0.3 (Driscoll, 1986).

Table 4-2. Paso Robles Subbasin Specific Yield Estimates

Area	Number of Wells Used to Calculate	Average Estimated Specific Yield
Creston Area	47	0.09
Estrella	20	Not provided
San Juan	5	0.10
Shandon	20	0.08
North and South Gabilan	20	0.09
Basin Wide Average		**0.09**

Estimates of vertical hydraulic conductivity for each of the aquifers were not in reports from previous studies for the Subbasin. Estimates of vertical hydraulic conductivity incorporated into the basin-wide groundwater model are discussed in an appendix to Chapter 6.

4.4.4 Confining Beds and Geologic Structures

There is limited information regarding the continuity of stratigraphic features in the Subbasin that restrict groundwater flow within the Subbasin. Conceptually, the presence of laterally continuous zones of fine-grained strata within the Paso Robles Formation can restrict vertical movement of groundwater. These fine-grained zones are generally shown on the sections on Figure 4-12 through Figure 4-15. These figures show that the fine-grained strata are likely more continuous than the sand and gravel layers. These fine-grained zones act as confining beds, and are the cause of the artesian wells that were historically reported in the Subbasin. Fine-grained layers that limit vertical movement of groundwater appear to be more prevalent in the Estrella and Creston areas than in the eastern portion of the Shandon area. This may indicate that infiltration and recharge is more limited to the west.

There is some anecdotal evidence that subsurface geologic structures such as folds and faults may affect groundwater flow in the Subbasin. Additional investigations would be needed to characterize the effect of structures on groundwater flow.

4.5 Primary Users of Groundwater

The primary groundwater users in the Subbasin include municipal, agricultural, rural residential, small community water systems, and small commercial entities. Municipal, domestic, and agricultural demands in the Subbasin currently rely almost entirely on groundwater. The municipal sector pumps primarily from the Paso Robles Aquifer. The agriculture sector uses groundwater from the Alluvial Aquifer and the Paso Robles Aquifer.

4.6 General Water Quality

This section presents a general discussion of the natural groundwater quality in the Subbasin, focusing on general minerals. The general water quality of the Subbasin described in this section is a summary of results in the Fugro 2002 report. A more complete discussion of the distribution and concentrations of specific constituents is presented in Chapter 5: Current Conditions.

Groundwater in the Subbasin is generally suitable for drinking and agricultural uses. The two main water types found in the Subbasin are calcium bicarbonate and sodium bicarbonate. Calcium-bicarbonate type is the most prominent and is found in the Creston and San Juan areas. Sodium-bicarbonate is the second most dominant water type and is found in the Estrella and Shandon areas. Minor areas of sodium-chloride type water can be found in the eastern portion of the Subbasin and near Cholame Valley. In the northwest portion of the Subbasin, magnesium bicarbonate waters are found in the San Miguel area and a mixed water type is seen in the Bradley area. A summary of general water quality as indicated by average total dissolved solids (TDS), chloride (Cl), and nitrate (NO3) concentrations in groundwater is provided in Table 4-4 (Fugro 2002).

Table 4-3. Summary of General Water Quality by Area

Area	TDS (ppm)			Cl (ppm)			NO3 (ppm)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Creston	490	190	1620	112	25	508	16	2	41
San Juan	753	160	2170	162	13	699	18	ND[1]	56
Shandon	606	270	1610	110	31	451	13	5.6	35
Estrella	624	350	1270	126	32	572	9	ND	30
Bradley	897	400	1280	131	40	400	14	ND	55
Gabilan	745	370	1320	87	38	209	39	11	71

[1]ND = Non-detect. For the purpose of computing an average, half the detection limit was used.

4.7 Groundwater Recharge and Discharge Areas

Areas of significant, natural, areal recharge and discharge within the Paso Robles Subbasin are discussed below. Quantitative information about all natural and anthropogenic recharge and discharge is provided in Chapter 6: Water Budgets.

4.7.1 Groundwater Recharge Areas Inside The Subbasin

In general, natural areal recharge occurs via the following processes:

1. Distributed areal infiltration of precipitation, and
2. Infiltration of surface water from streams and creeks.

Figure 4-16 is a map that ranks soil suitability to accommodate groundwater recharge based on five major factors that affect recharge potential, including: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. The map[1] was developed by the California Soil Resource Lab at UC Davis and the University of California Agricultural and Natural Resources Department.

Areas with excellent recharge properties are shown in green. Areas with poor recharge properties are shown in red. Not all land is classified, but this map provides good guidance on where natural recharge likely occurs.

[1] Figure 4-16 shows the Soil Agricultural Groundwater Banking Index (SAGBI) map for the Paso Robles Subbasin. While the UC Davis database title SAGBI includes the term "banking", its use in this section is strictly as a dataset for evaluating recharge potential in the basin.

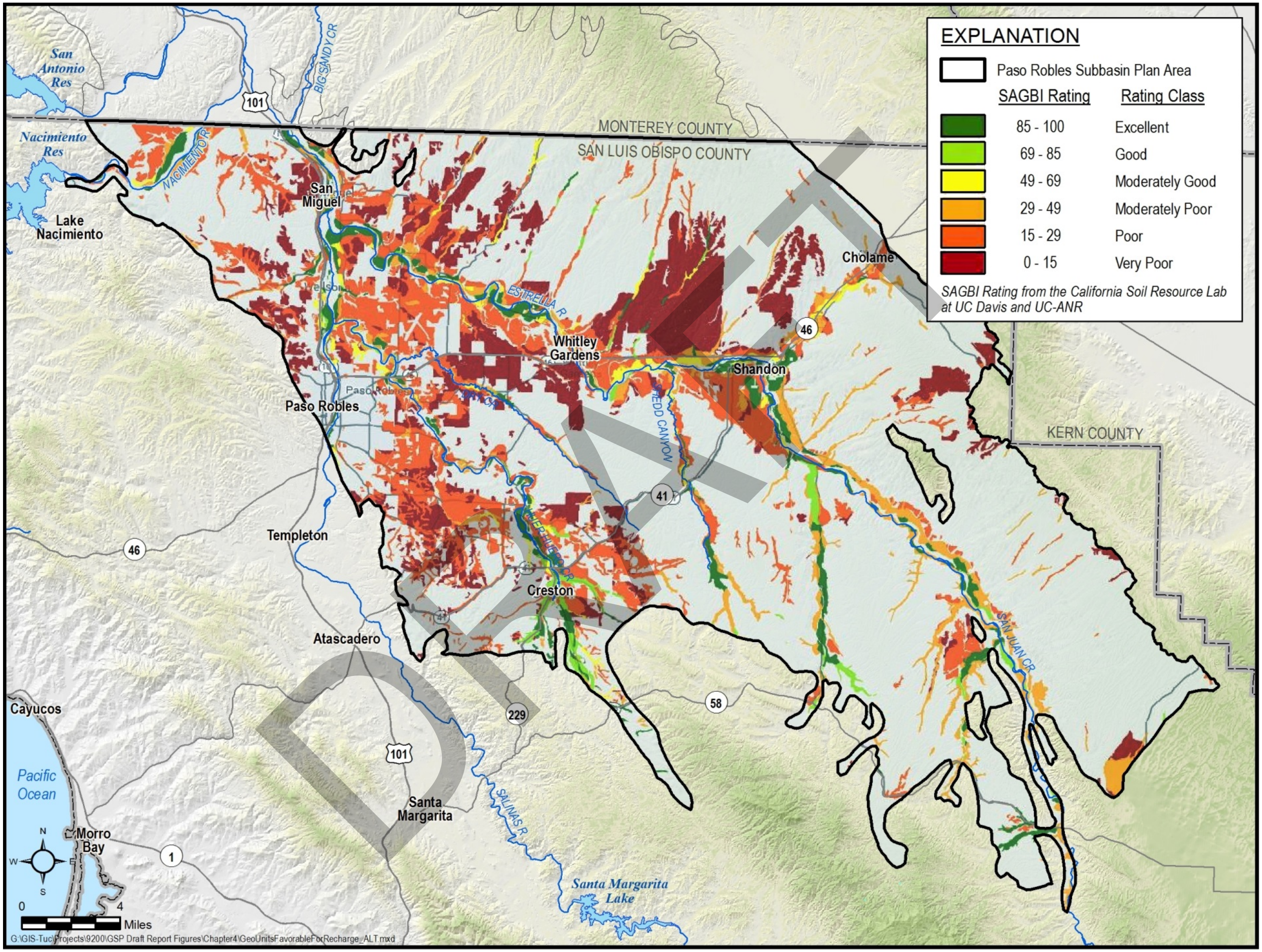

Figure 4-16. Potential Recharge Areas

4.7.2 Groundwater Discharge Areas Inside the Subbasin

Natural groundwater discharge areas within the Plan area include springs and seeps, groundwater discharge to surface water bodies, and evapotranspiration (ET) by phreatophytes. Springs and seeps identified in the National Hydrology Dataset (NHD), and shown on Figure 4-17, tend to be located in the foothills of the Santa Lucia and Temblor mountain ranges. Based on the elevation of mapped springs and seeps, it is likely that these discharge groundwater from shallow, and possibly perched aquifer units. Groundwater discharge to streams – primarily, the Salinas River and Estrella River – has not been mapped to date. Instead, areas of potential groundwater discharge to streams are identified using the groundwater flow model. Orange areas on Figure 4-17 represent streams in the model where simulated average groundwater discharge to the stream reach is at least 10 acre-feet per year. In contrast to mapped springs and seeps, which are derived from groundwater in the Paso Robles Formation, groundwater discharge to streams is derived from the Alluvium.

Figure 4-18 shows the distribution of potential groundwater-dependent ecosystems (GDEs) and Natural Communities Commonly Associated with Groundwater (NCCAG) within the Plan area. In areas where the water table is sufficiently high, groundwater discharge may occur as ET from phreatophyte vegetation within these GDEs. Appendix 4B describes methods used to determine the extent and type of potential GDEs. Figure 4-18 shows only potential GDEs. There has been no verification that the locations shown on this map constitute groundwater dependent ecosystems. Additional field reconnaissance is necessary to verify the existence of these potential GDEs.

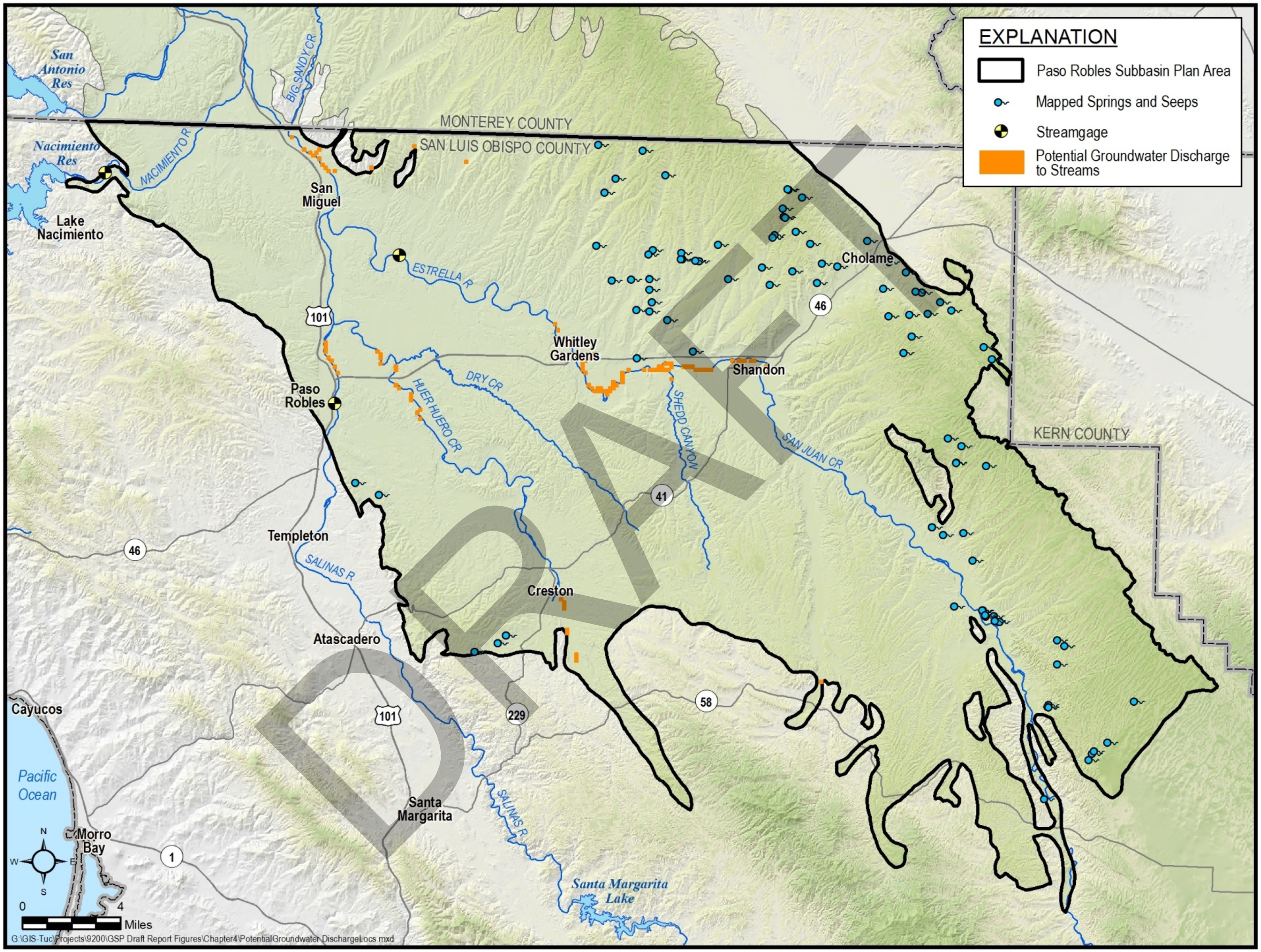

Figure 4-17. Potential Groundwater Discharge Areas

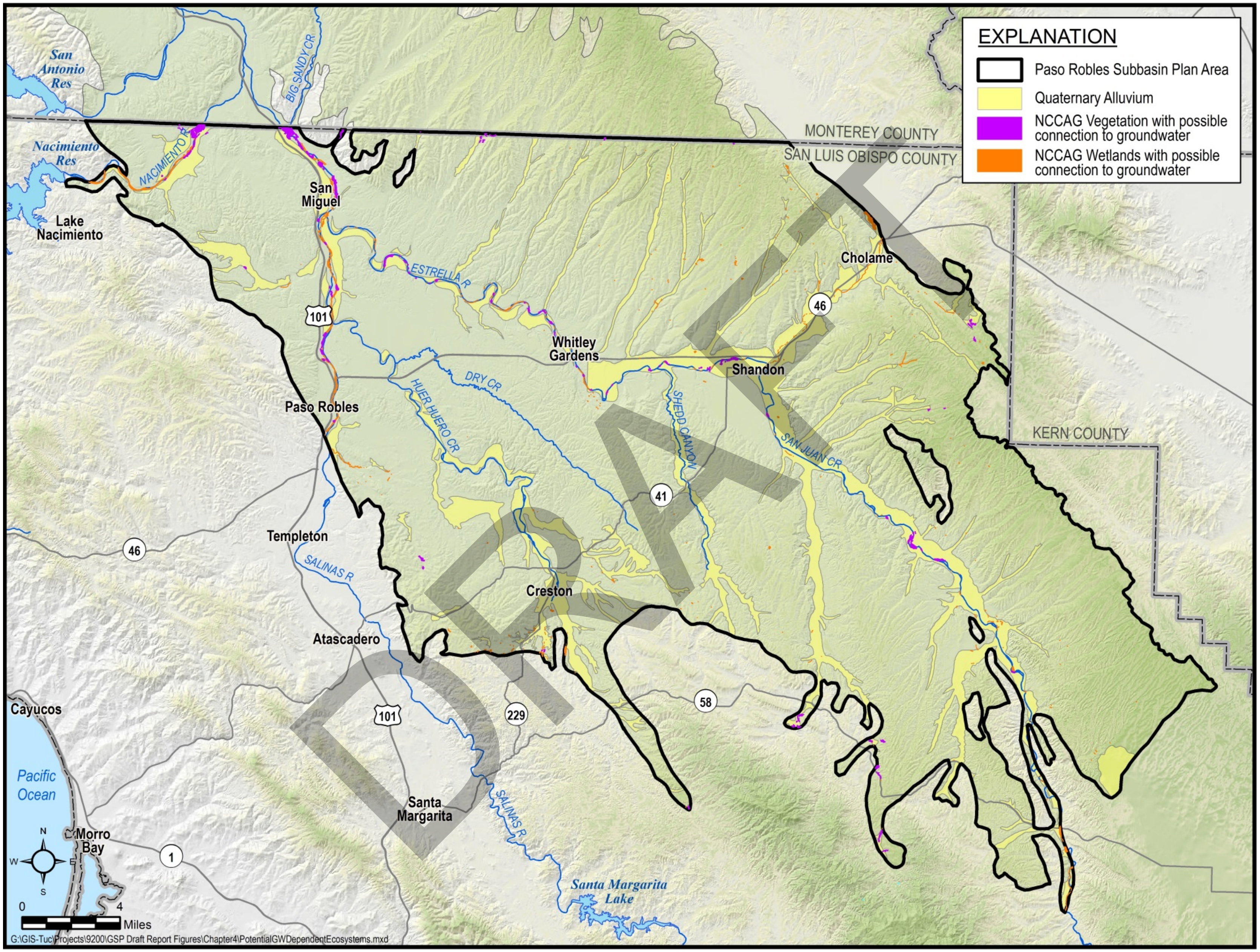

Figure 4-18. Potential Groundwater- Dependent Ecosystems

4.8 SURFACE WATER BODIES

Figure 4-19 shows the rivers in the Subbasin that are considered significant to the management of groundwater in the Subbasin. Significant streams in the Subbasin include the Salinas River, the Estrella River, Huer Huero Creek, San Juan Creek, Dry Creek, and Shedd Canyon. These rivers and creeks are ephemeral, and during most of the year the streams lose water to the shallow aquifers. A complete description and quantification of the stream/aquifer interaction is included in Chapters 5 and 6. There are no natural lakes in the Subbasin.

There are no reservoirs within the Subbasin; however, there are two reservoirs in the watershed. The Salinas Dam south of the Subbasin on the Salinas River forms Santa Margarita Lake. The Salinas Dam was constructed in the early 1940s as an emergency measure to provide adequate water supplies for Camp San Luis Obispo. The United States Army Corps of Engineers (USACE) now has jurisdiction over the dam and reservoir facilities. The City of San Luis Obispo has an agreement with USACE to divert the entire yield of Santa Margarita Reservoir for water supply. Nacimiento Reservoir lies just outside of the Subbasin to the northwest. The reservoir discharges to the Nacimiento River, which crosses the northwest corner of the Subbasin.

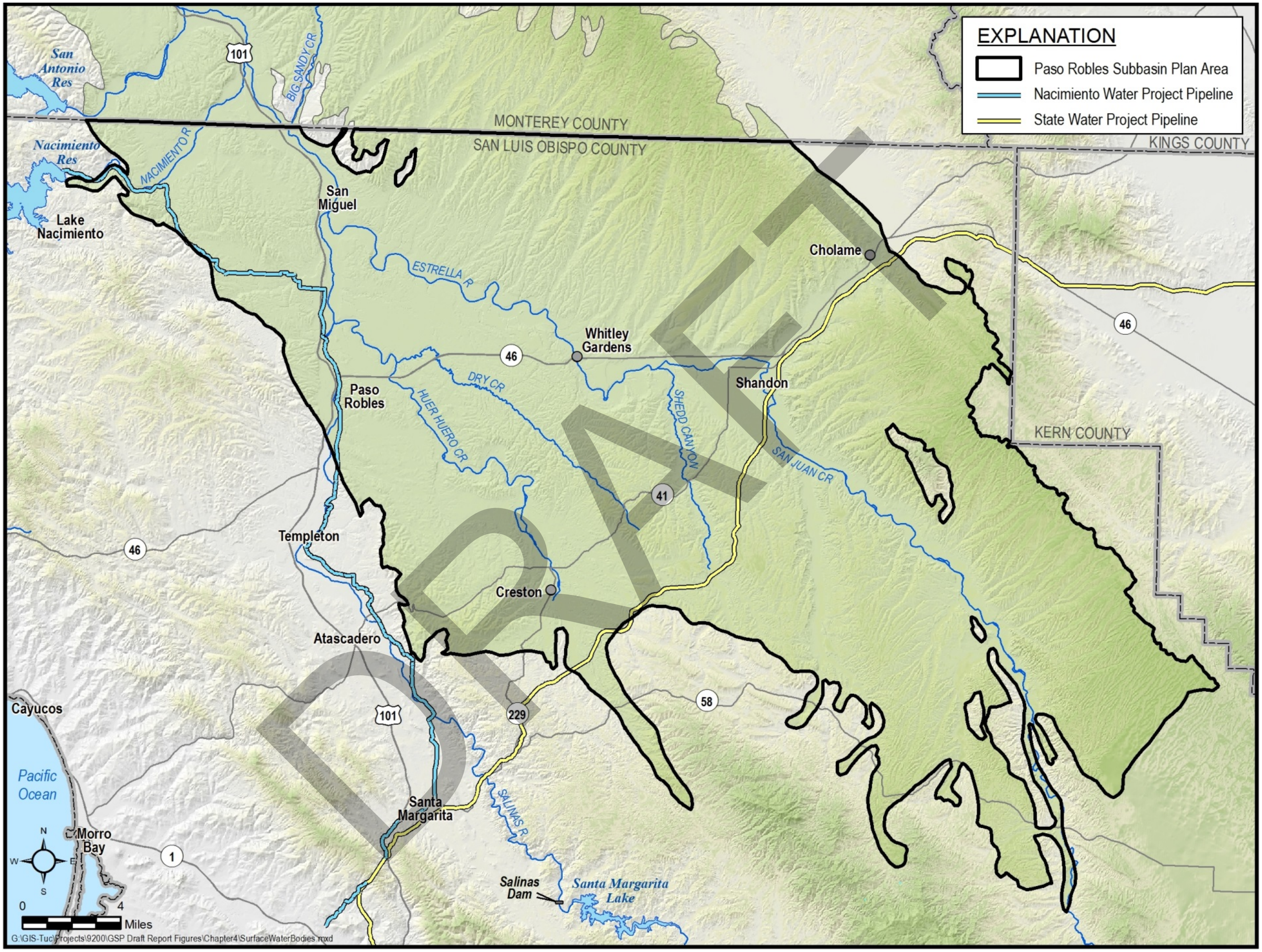

Figure 4-19. Surface Water Bodies

4.9 DATA GAPS IN THE HYDROGEOLOGIC CONCEPTUAL MODEL

All hydrologic conceptual models contain a certain amount of uncertainty, and can be improved with additional data and analysis. The hydrogeologic conceptual model of the Paso Robles Subbasin could be improved with certain additional data and analyses. Several data gaps are identified below.

AQUIFER CONTINUITY

Aquifer continuity has a significant impact on how projects and management actions in one part of the Subbasin may influence sustainability in other parts of the Subbasin. As noted earlier, the Paso Robles aquifer comprises many discontinuous sand and gravel beds. However, Figure 4-12 shows a previous interpretation of a deep sand and gravel zone that is relatively continuous across the Subbasin. The continuity of this zone may prove to be important in how effective various projects and programs may promote sustainability. The extent and continuity of the Paso Robles Aquifer should be confirmed through existing or new well logs or other methods such as aerial geophysics. This is particularly important in the areas around Shandon and San Juan.

FAULT INFLUENCE ON GROUNDWATER FLOW

Southeast of the City of Paso Robles is an interbasin fault. It is unknown whether this fault and others are barriers to groundwater flow. If these interbasin faults are barriers to groundwater flow, they could compartmentalize the Subbasin and have a significant impact on where projects must be located in order to achieve sustainability. It may be possible to get a better understanding of the influence of these faults by performing aquifer tests and geophysical surveys in the vicinity of these faults.

VERTICAL GROUNDWATER GRADIENTS

There are no nested wells to demonstrate vertical hydraulic gradients. Demonstrating vertical gradients could be important to assess vertical flows between the Alluvium and the Paso Robles Aquifer as well as vertical flows within the Paso Robles Aquifer.

DRAFT

Chapter 5

Paso Robles Subbasin Groundwater Sustainability Plan

Published on:	**October 11, 2018**
Received by the Paso Basin Cooperative Committee:	**October 17, 2018**
Posted on PasoGCP.com:	**October 24, 2018**
Close of 45-day public comment period: **pending recommendation by the Cooperative Committee at the October 17, 2018 Regular Meeting*	***December 10, 2018**

This Draft document is posted on pasogcp.com and is being distributed to the five Paso Robles Subbasin Groundwater Sustainability Agencies (GSAs) to receive and file. Comments from the public are being collected using a comment form available at www.pasogcp.com. If you require a paper form to submit by postal mail, please contact your local Groundwater Sustainability Agency (GSA).

- County of San Luis Obispo
- Shandon-San Juan Water District
- Heritage Ranch CSD
- San Miguel CSD
- City of Paso Robles

Pending the Cooperative Committee's recommendation on October 17, 2018, the Draft GSP Chapter 5 will be distributed to the five Paso Robles Subbasin GSAs to receive and file.

Draft
Paso Robles Subbasin
Groundwater Sustainability Plan
Chapter 5

Prepared for the Paso Robles Subbasin
Cooperative Committee and the
Groundwater Sustainability Agencies

October 10, 2018

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CHAPTER 5. GROUNDWATER CONDITIONS

This chapter describes the current and historical groundwater conditions in the Alluvial Aquifer and the Paso Robles Formation Aquifer in the Paso Robles Subbasin. In accordance with the SGMA emergency regulations §354.16, current conditions are any conditions occurring after January 1, 2015. By implication, historical conditions are any conditions occurring prior to January 1, 2015. The chapter focuses on information required by the GSP regulations and information that is important for developing an effective plan to achieve sustainability. The organization of Chapter 5 aligns with the five sustainability indicators applicable to the Subbasin including:

1. Chronic lowering of groundwater elevations,
2. Changes in groundwater storage,
3. Seawater intrusion,
4. Subsidence,
5. Depletion of interconnected surface waters, and
6. Groundwater quality.

5.1 GROUNDWATER ELEVATIONS

The following assessment of groundwater elevation conditions is largely based on data from the San Luis Obispo County Flood Control and Water Conservation District's (SLOFCWCD) groundwater monitoring program. Groundwater levels are measured by the SLOFCWCD through a network of public and private wells in the Subbasin. Additional groundwater elevation data for wells were obtained from other available data sources, including the California Statewide Groundwater Elevation Monitoring (CASGEM) database, USGS, and other regulatory compliance programs. Locations of the wells (about 50 to 55 depending on year) used for the groundwater elevation assessment are shown on Figure 5-1. Data from some of the wells on this figure were collected under confidentiality agreements. To remain consistent with these confidentiality agreements, the well owner information and specific locations for these wells are not provided in this GSP.

The set of wells shown on Figure 5-1 were selected from a larger set of monitor wells in the SLOCFCWCD database based on the following criteria:

- The wells have groundwater elevation data for 1997 and/or 2017;
- Sufficient information exists to assign the well to either the Alluvial Aquifer or Paso Robles Formation Aquifer; and
- Groundwater elevation data were deemed representative of static conditions based on a check of consistency with nearby wells.

Additional information on the monitoring network is provided in Chapter 8 – Monitoring Networks.

Based on available data, the following information is presented in subsequent subsections for both aquifers in the Subbasin.

- Groundwater elevation contour maps for the seasonal high and low periods for 1997 and 2017
- A map depicting the change in groundwater elevation between 1997 and 2017
- Hydrographs for wells with publicly available data
- Assessments of horizontal and vertical groundwater gradients

5.1.1 ALLUVIAL AQUIFER

Groundwater elevation data for the Alluvial Aquifer are limited. The locations of the Alluvial Aquifer monitor wells with available groundwater elevation data are shown on Figure 5-1.

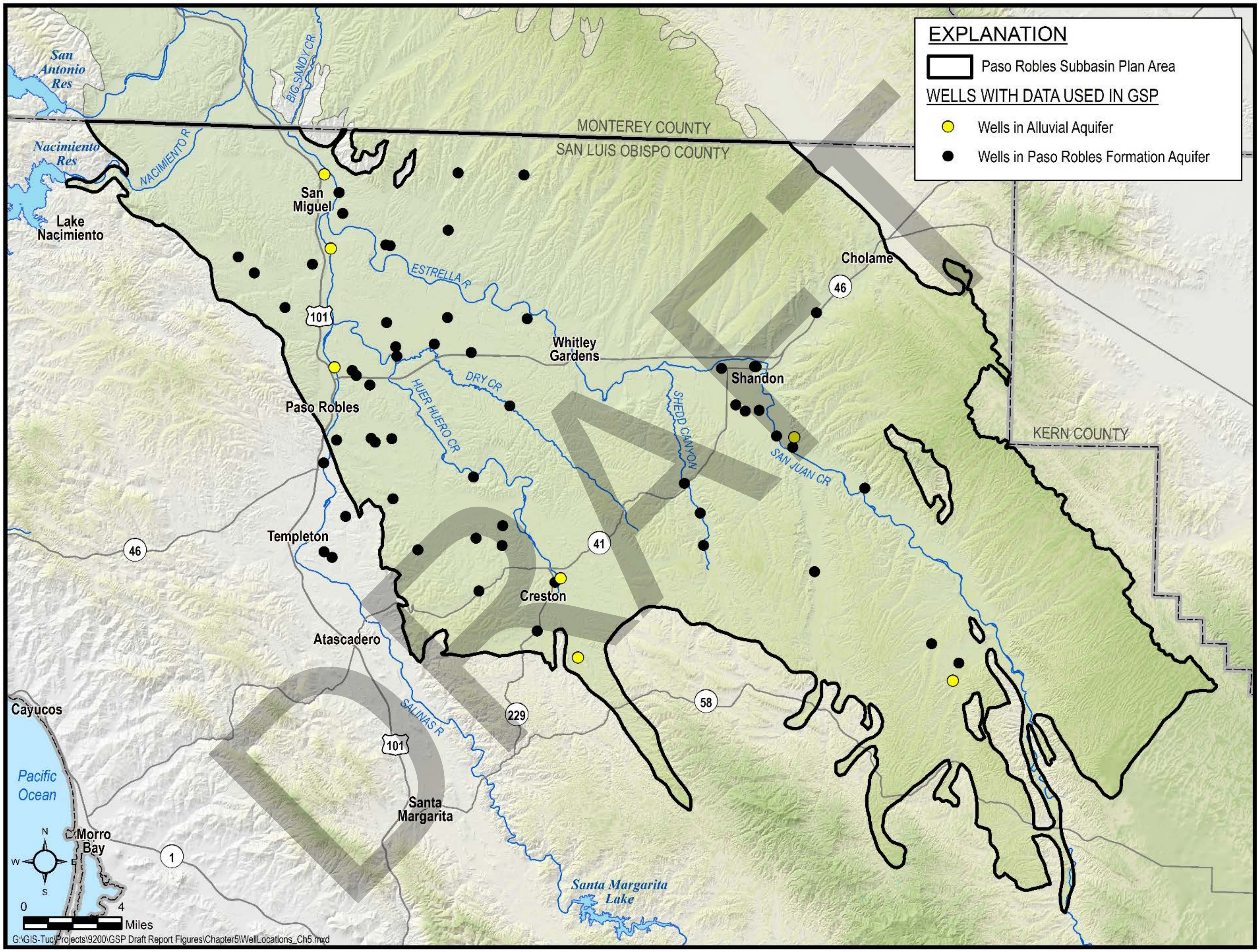

Figure 5-1. Location of Wells used for the Groundwater Elevation Assessments

5.1.1.1 Alluvial Aquifer Groundwater Elevation Contours and horizontal groundwater gradients

Groundwater elevation data for the Alluvial Aquifer are too limited to prepare representative contour maps for the seasonal high and seasonal low groundwater elevations, or to prepare maps for historical groundwater elevations. Figure 5-2 shows current groundwater elevation contours for the Alluvial Aquifer. The contours were developed using 2017 data when available and the most recent data prior to 2017. Contours are only depicted on the map in areas near the wells that are shown on Figure 5-1.

Groundwater elevations range from approximately 1,400 feet above mean sea level (ft msl) in the southeastern portion of the Subbasin to approximately 600 ft msl near San Miguel. Groundwater flow in the Alluvial Aquifer generally follows the alignment of the creeks and rivers. Overall, groundwater in the Alluvial Aquifer flows from southeast to northwest across the Subbasin. Groundwater elevation data in the Alluvial Aquifer are too sparse to develop meaningful estimates of local horizontal groundwater gradients. On a basin-wide scale, the average horizontal hydraulic gradient in the alluvium is about 0.004 from the southeastern portion of the Subbasin to San Miguel.

5.1.1.1 Alluvial Aquifer Hydrographs

Groundwater level data for all of the Alluvial Aquifer wells shown on Figure 5-1 were collected under confidentiality agreements. Therefore, hydrographs for the Alluvial Aquifer are not included in this GSP. The lack of publicly available groundwater level data for the Alluvial Aquifer is a significant data gap.

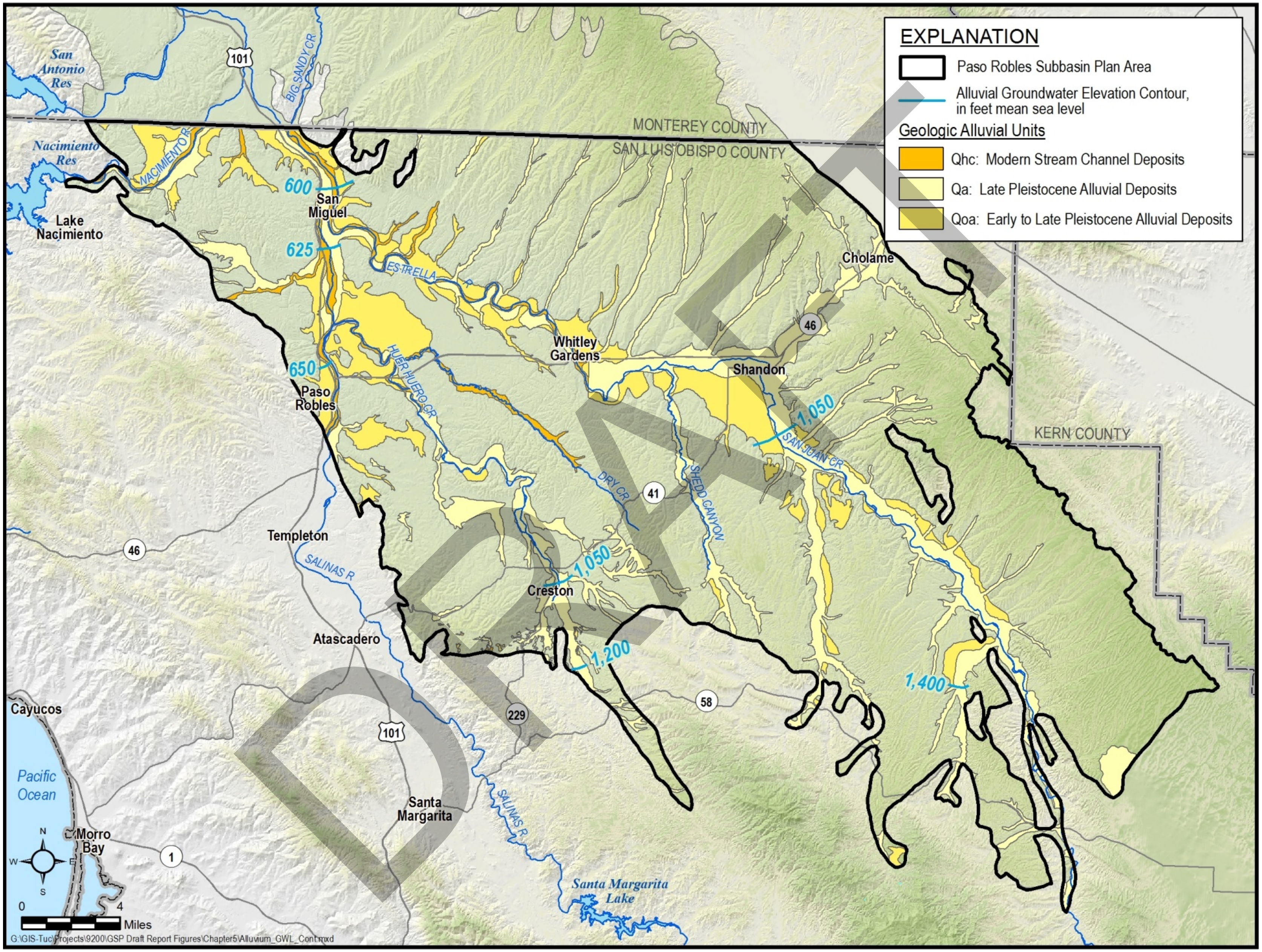

Figure 5-2. Groundwater Elevation Contours for the Alluvial Aquifer

5.1.2 PASO ROBLES FORMATION AQUIFER

The locations of the Paso Robles Formation Aquifer monitor wells used to assess the hydrogeologic conditions of the Paso Robles Formation Aquifer are shown on Figure 5-1. Groundwater occurs in the Paso Robles Formation Aquifer under unconfined, semi-confined, and confined conditions.

5.1.2.1 PASO ROBLES AQUIFER GROUNDWATER ELEVATION CONTOURS AND HORIZONTAL GROUNDWATER GRADIENTS

Groundwater elevation data for 1997 and 2017 for the Paso Robles Formation Aquifer were contoured to assess current spatial variations, groundwater flow directions, and horizontal groundwater gradients. Contour maps were prepared for the seasonal high groundwater levels, which is typically in the spring, and the seasonal low groundwater levels, which is typically in the fall. In general, the spring groundwater data are for April and the fall groundwater data are for October. Data from public and private wells were used for contouring; information identifying the owner or detailed location of private wells is not shown on the maps. The contours are based on groundwater elevations measured at the well locations shown on Figure 5-1. Contour maps were generated using a computer-based contouring program and checked for representativeness by a qualified hydrogeologist. Groundwater elevation data deemed unrepresentative of static conditions or obviously erroneous were not used for contouring. Similar to groundwater elevation contour maps prepared for previous studies, close inspection of the maps indicates localized areas where interpolated groundwater elevations are above land surface. This typically occurs near streams and incised drainages where land surface tends to be locally lower than surrounding areas. While it is hydrologically possible that groundwater elevations in the Paso Robles Formation Aquifer are above land surface in some local areas, our assessment is that this is more likely an artifact of the computer contouring of sparse groundwater elevation data.

Figure 5-3 and Figure 5-4 show contours of historical groundwater elevations in the Paso Robles Formation Aquifer for spring 1997 and fall 1997, respectively. Overall, groundwater conditions in the Subbasin in the spring and fall of 1997 are similar. Close inspection of the contour maps indicates that groundwater elevations are generally lower in the fall than spring. Groundwater elevations ranged from about 1,300 ft msl in the southeast portion of the Subbasin to about 550 ft msl near the City of Paso Robles and the town of San Miguel (Figure 5-3 and Figure 5-4). Groundwater flow is generally to the northwest and west over most of the Subbasin, except in the area north of the City of Paso Robles where groundwater flow is to the northeast. In general, groundwater flow in the western portion of the Subbasin tends to converge toward areas of low groundwater elevations. These areas of low groundwater elevation are caused by pumping in the area between the City of Paso Robles, and the communities of San Miguel and Whitley Gardens.

Horizontal groundwater gradients range from approximately 0.003 foot/foot in the southeast portion of the Subbasin to approximately 0.01 foot/foot in the areas both southeast of the City of Paso Robles and northwest of Whitley Gardens. The steepest horizontal groundwater gradients in the Subbasin are on the margins of the pumping depression in the vicinity of the city of Paso Robles and community of San Miguel.

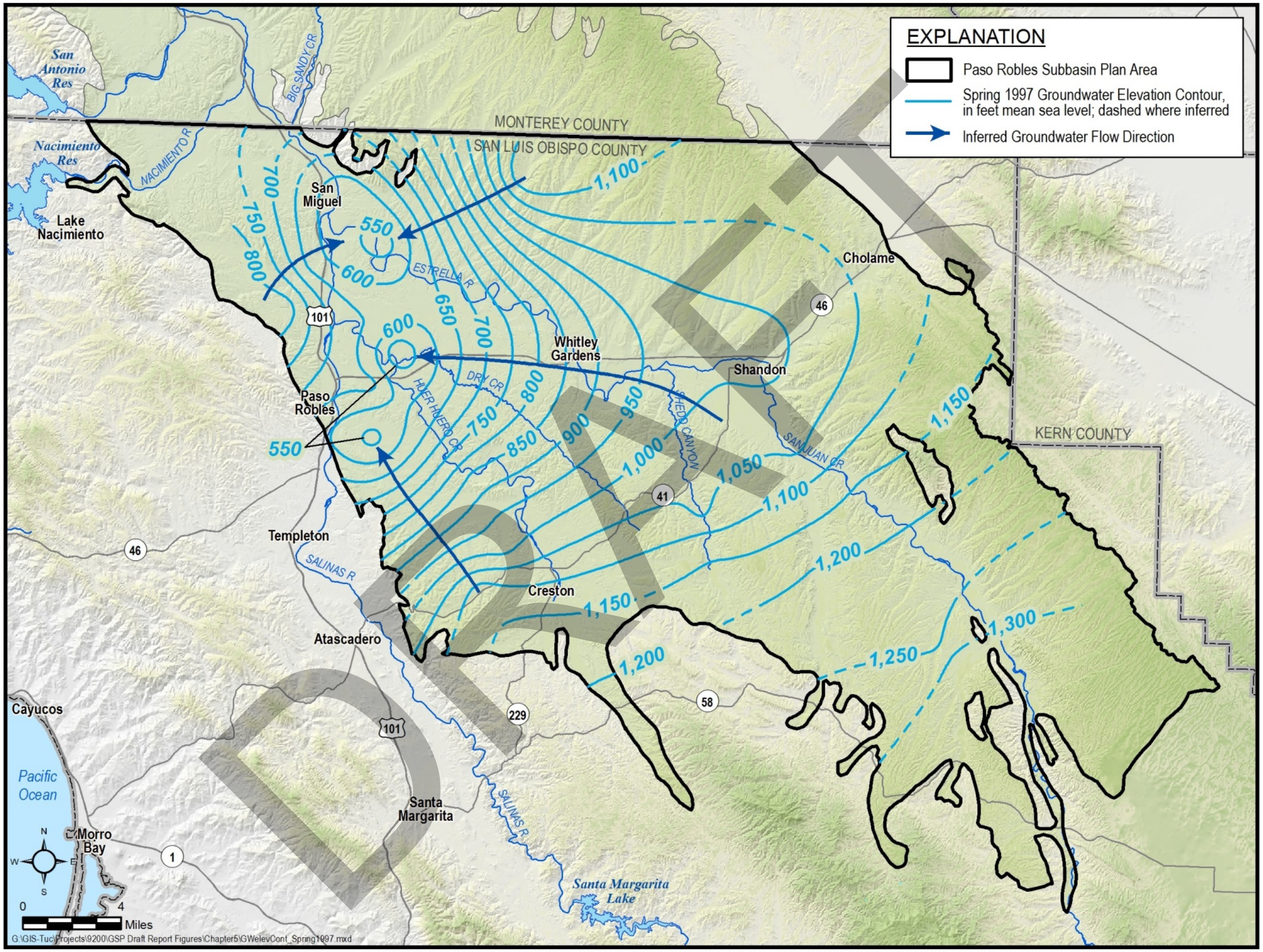

Figure 5-3. Spring 1997 Paso Robles Formation Aquifer Groundwater Elevation Contours

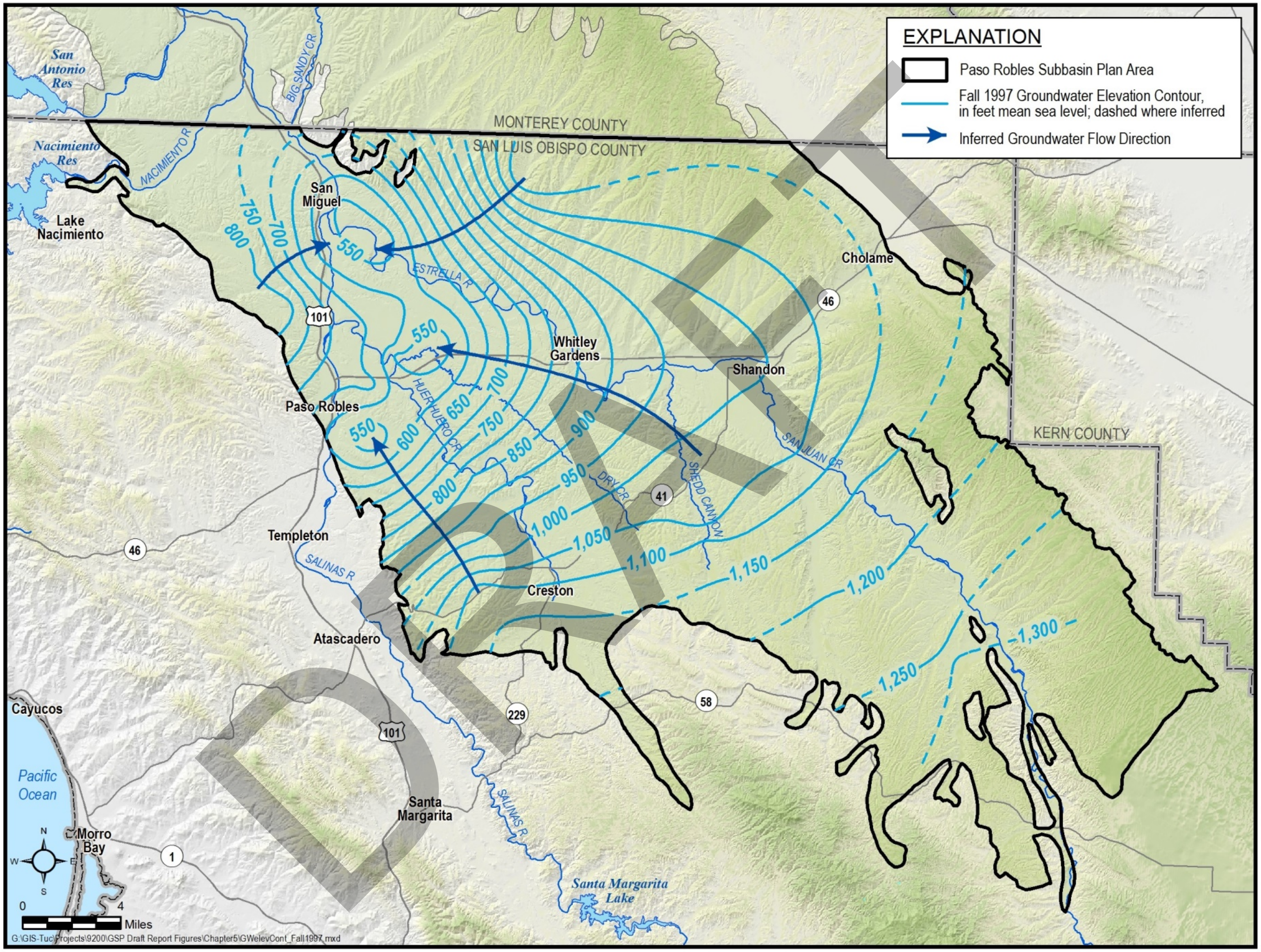

Figure 5-4. Fall 1997 Paso Robles Formation Aquifer Groundwater Elevation Contours

Figure 5-5 and Figure 5-6 show contours of current groundwater elevations in the Paso Robles Formation Aquifer for spring 2017 and fall 2017, respectively. Overall, groundwater conditions in the Subbasin in the spring and fall of 2017 were similar. Close inspection of the contour maps indicates that groundwater elevations are generally lower in the fall than spring. Groundwater elevations in 2017 are also lower than groundwater elevations in 1997. Groundwater elevations in 2017 ranged from about 1,250 ft msl in the southeast portion of the Subbasin to about 500 ft msl east of the City of Paso Robles (Figure 5-5 and Figure 5-6). Groundwater flow is generally to the northwest and west over most of the Subbasin, except in the area north of the City of Paso Robles where groundwater flow is to the northeast. In general, groundwater flow in the western portion of the Subbasin tends to converge toward areas of low groundwater elevations. These areas of low groundwater elevation are caused by pumping in the area between the City of Paso Robles and the communities of San Miguel and Whitley Gardens. Horizontal groundwater gradients range from approximately 0.002 foot/foot in the southeast portion of the Subbasin to approximately 0.02 foot/foot in the area southeast of the City of Paso Robles. The steepest horizontal groundwater gradients in the Subbasin in 2017 are on the margins of the pumping depression east of the city of Paso Robles and southeast of the community of San Miguel.

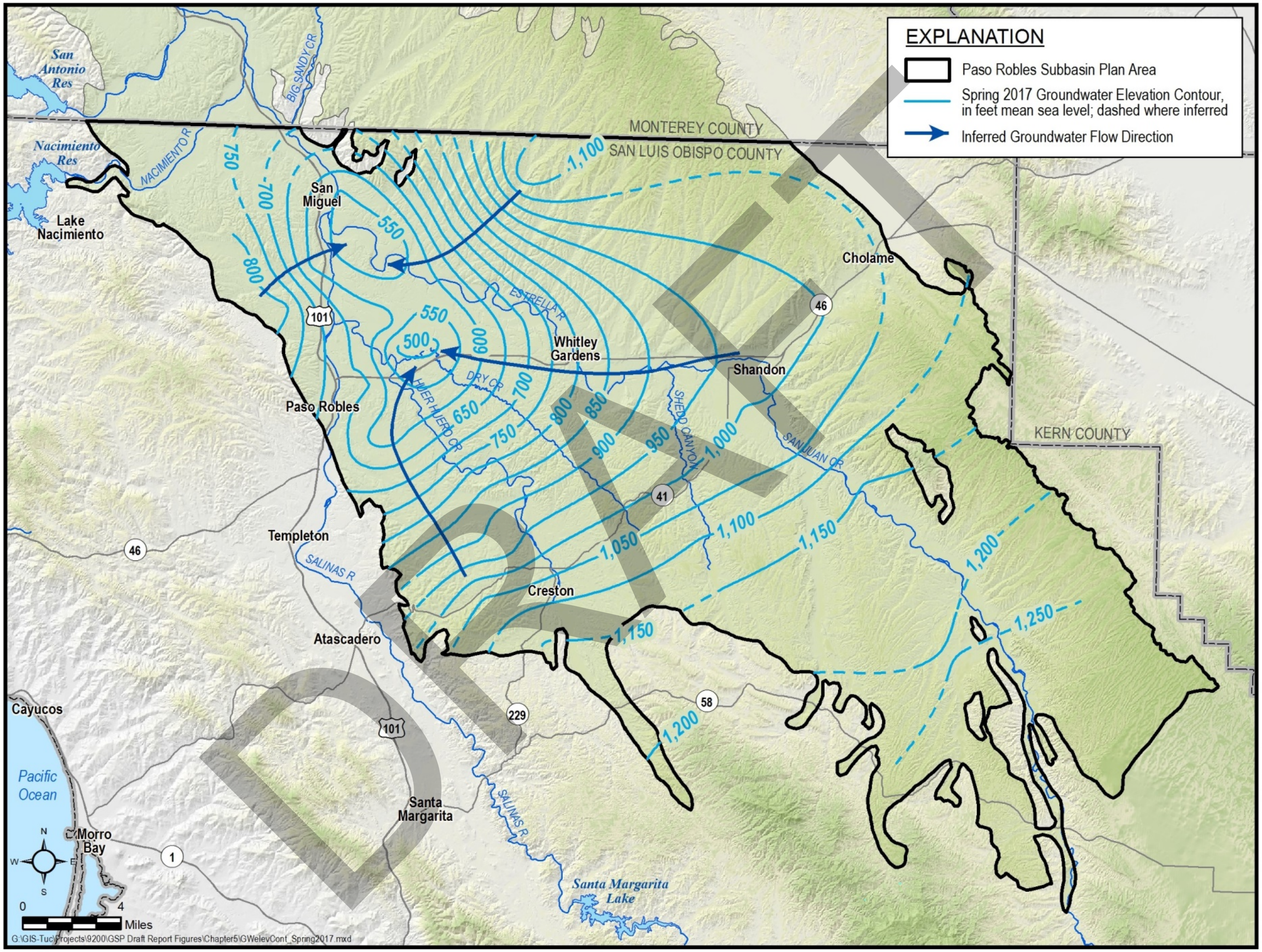

Figure 5-5. Paso Robles Formation Aquifer Spring 2017 Groundwater Elevation Contours

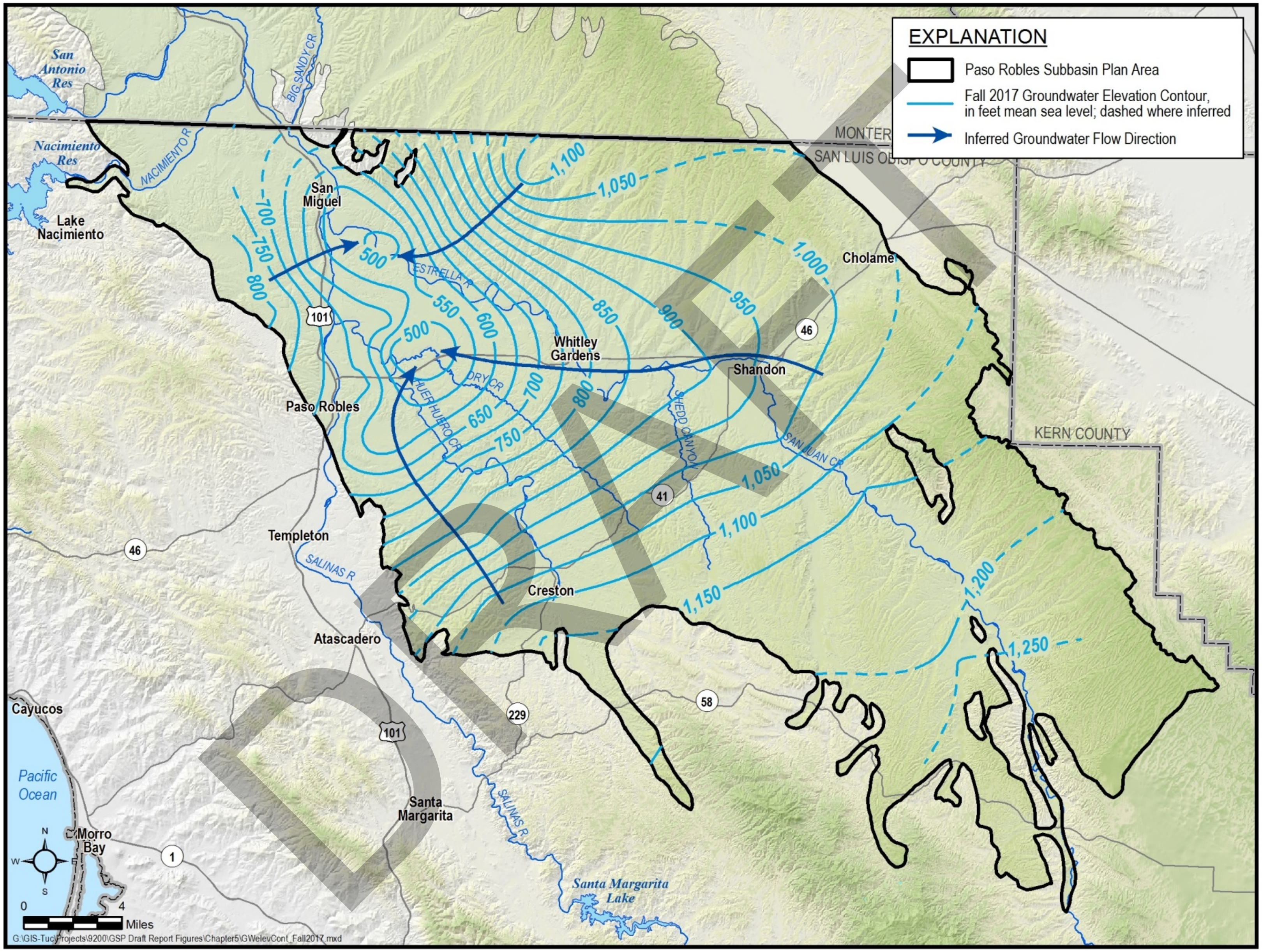

Figure 5-6. Paso Robles Formation Aquifer Fall 2017 Groundwater Elevation Contours

Figure 5-7 depicts the change in spring groundwater elevations in the Paso Robles Formation Aquifer between 1997 and 2017. Figure 5-8 depicts the change in fall groundwater elevations in the Paso Robles Formation Aquifer between and 1997 and 2017. Groundwater elevations are lower in 2017 than 1997 throughout most of the Subbasin. In general, the pattern of groundwater level decline in the spring and fall are similar, with a more pronounced area of decline extending toward Shandon in the fall. More than 80 feet of decline is observed in places during this period. Areas of largest decline are east of the city of Paso Robles, near Creston, and in the southeastern portion of the basin. Limited data suggest an area of higher groundwater elevations exists in the vicinity of the city of Paso Robles in 2017 compared to 1997. The increase may be related to reductions in groundwater pumping in the area.

The groundwater level contours and groundwater level change maps in this GSP are based on a reasonable and thorough analysis of the currently available data. As discussed in Chapter 8, the monitoring network should be expanded to more completely assess Subbasin conditions and demonstrate compliance with the sustainability goal for the Subbasin. Expanding the monitoring network and acquiring more groundwater elevation data will allow the GSAs to refine and modify this GSP in the future based on a more complete understanding of Subbasin conditions.

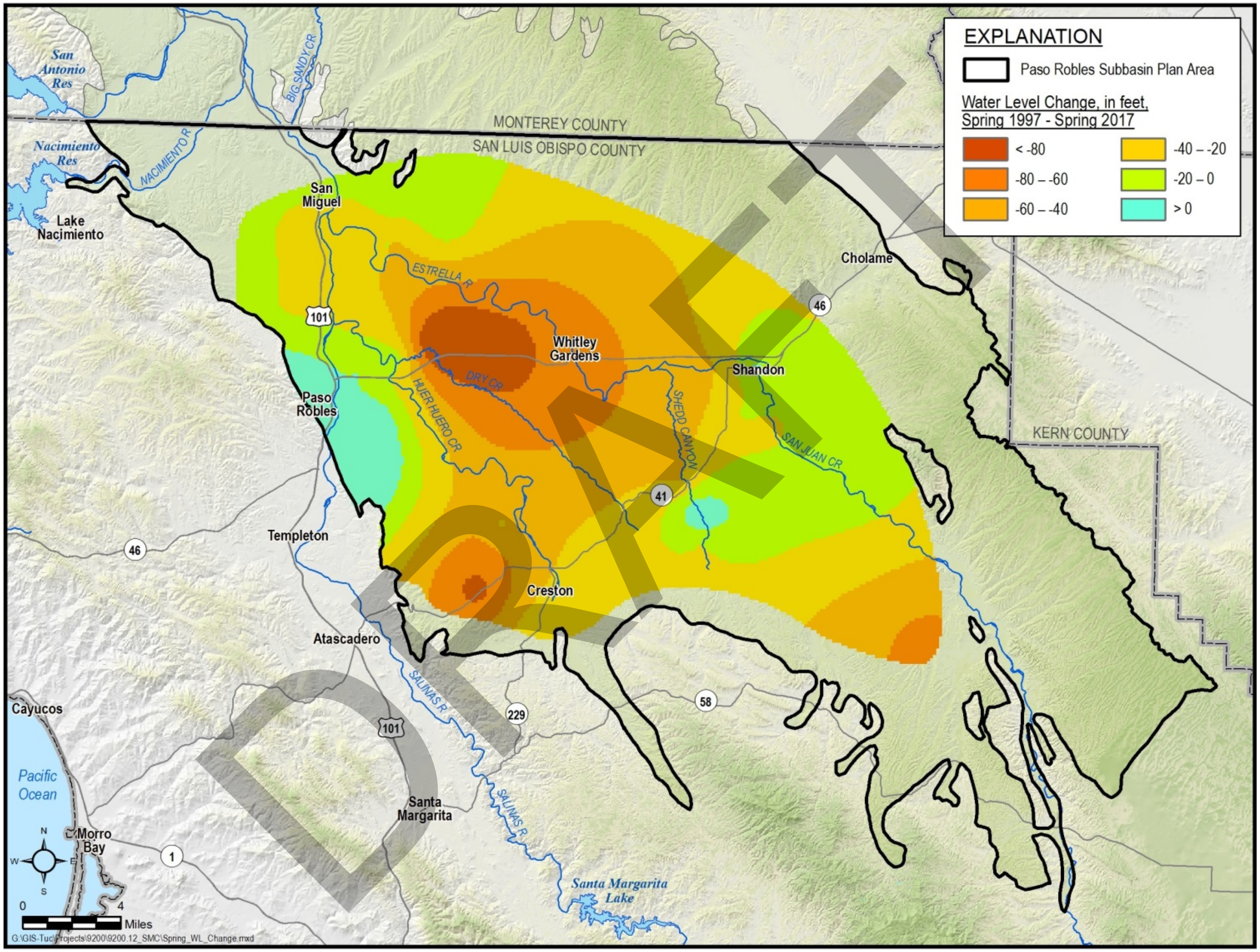

Figure 5-7. Paso Robles Formation Aquifer Change in Groundwater Elevation – Spring 1997 to Spring 2017

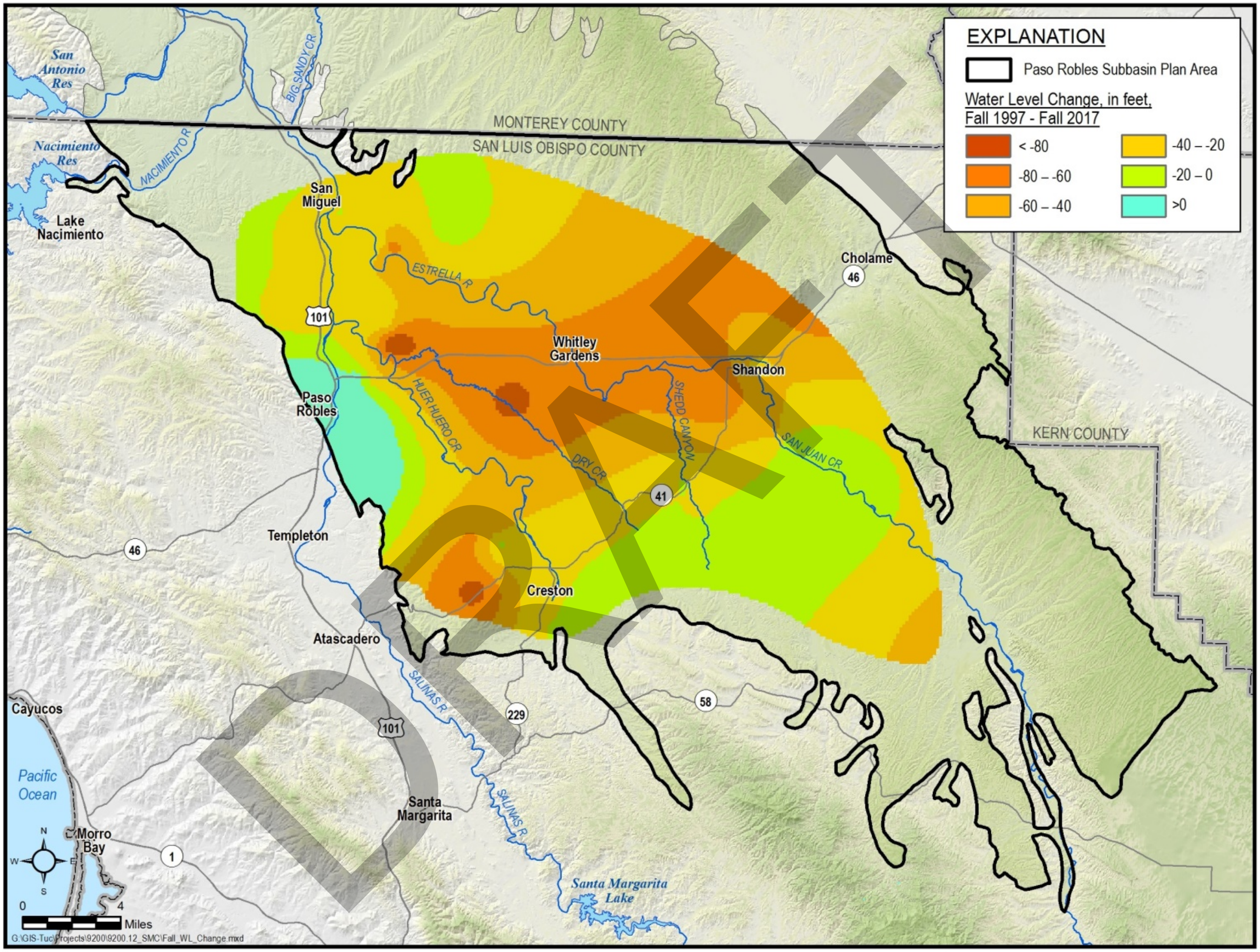

Figure 5-8. Paso Robles Formation Aquifer Change in Groundwater Elevation – Fall 1997 to Fall 2017

5.1.2.2 PASO ROBLES FORMATION AQUIFER HYDROGRAPHS

Appendix 5A includes hydrographs for wells in the Paso Robles Formation Aquifer that have publicly available data. Only 18 of the monitor wells have groundwater elevation data that were not collected under confidentiality agreements. The lack of publicly available groundwater level data for the Paso Robles Formation Aquifer is a significant data gap.

Figure 5-9 through Figure 5-11 show example hydrographs for wells located in the Estrella, Shandon, and Creston subareas of the Paso Robles Subbasin. Wells with publicly available data do not exist in the San Juan subarea. Long-term groundwater elevation declines are evident on all three hydrographs. The magnitude of measured declines over the period of record is generally more than 50 feet at well 25S/12E-06L01, 26S/15E-20B02, and 27S/13E-28F01.

The hydrographs show periods of climatic variations grouped by the following designations: wet, dry, or average/alternating wet and dry. Precipitation data were reviewed and analyzed to determine the occurrence and duration of wet and dry periods for the Paso Robles Subbasin. Precipitation from the Paso Robles weather station (NOAA station 46730) was used for this analysis because it is representative of conditions in the Subbasin and has the longest period of record of any station in the Subbasin. Figure 5-12 shows total annual precipitation by water year recorded at the Paso Robles station. Mean annual precipitation over the period 1925 to 2017 was 14.6 inches.

Wet and dry periods were determined based on a calculation and review of the Standardized Precipitation Index (SPI), which quantifies deviations from normal precipitation. The SPI was calculated at 1-, 2-, and 5-year time scales using the SPI Generator Tool developed by the National Drought Mitigation Center (NDMC, 2018). The 5-year, or 60-month SPI was selected as representative of multi-year meteorological fluctuations in the basin based on review of the data and computed SPI time series. For a given water year, the 60-month SPI quantifies the wetness or dryness of the preceding 60 months relative to the overall period of record. The annual time-series of the 60-month SPI was reviewed and generalized to determine wet and dry periods from 1930 to 2017 (Figure 5-12). A third category, "Average/ alternating", is included for years during which the preceding 60-month period does not show a strong and persistent deviation from normal precipitation.

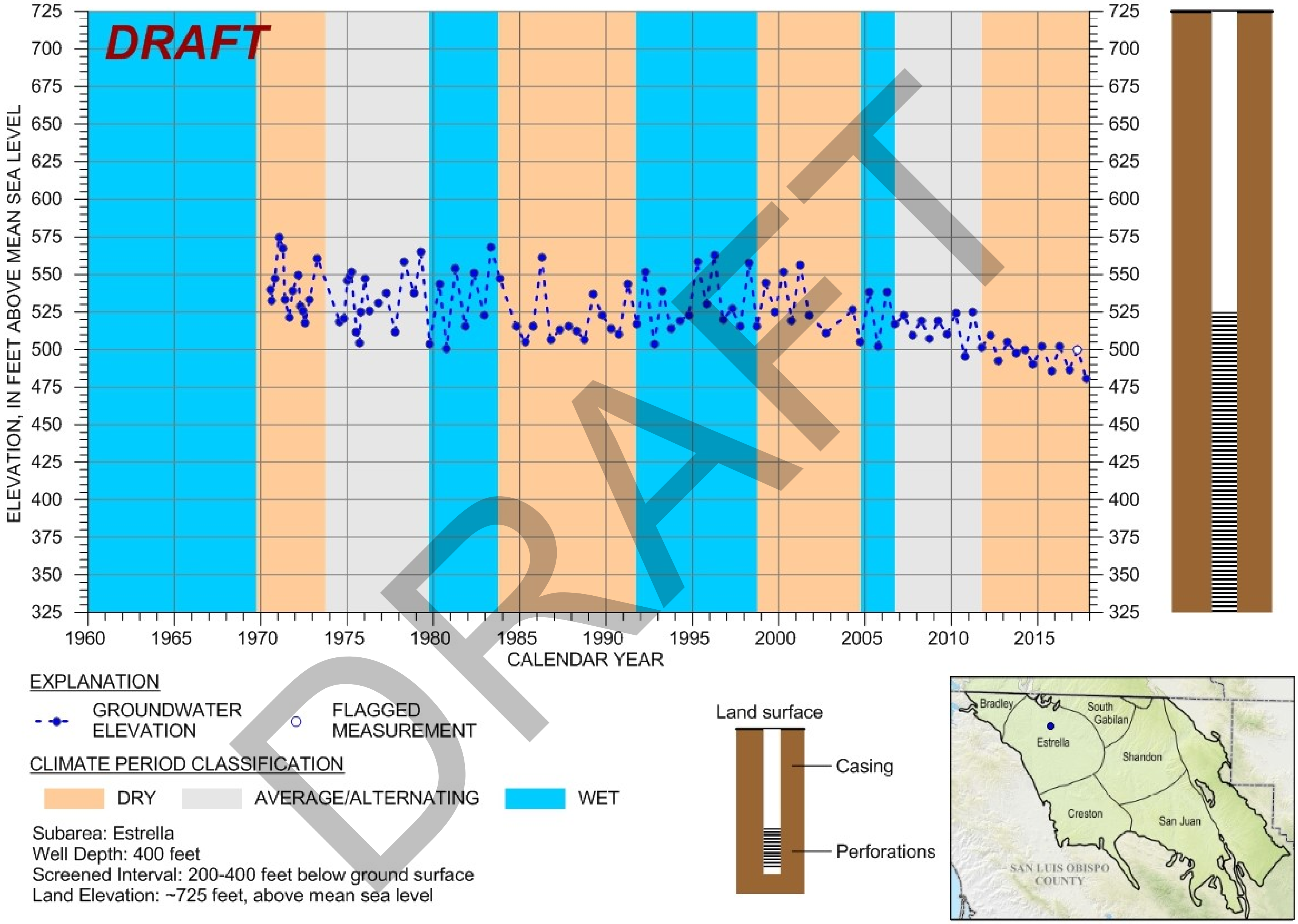

Figure 5-9. Groundwater Elevation at Paso Robles Formation Aquifer Well 25S/12E-26L01

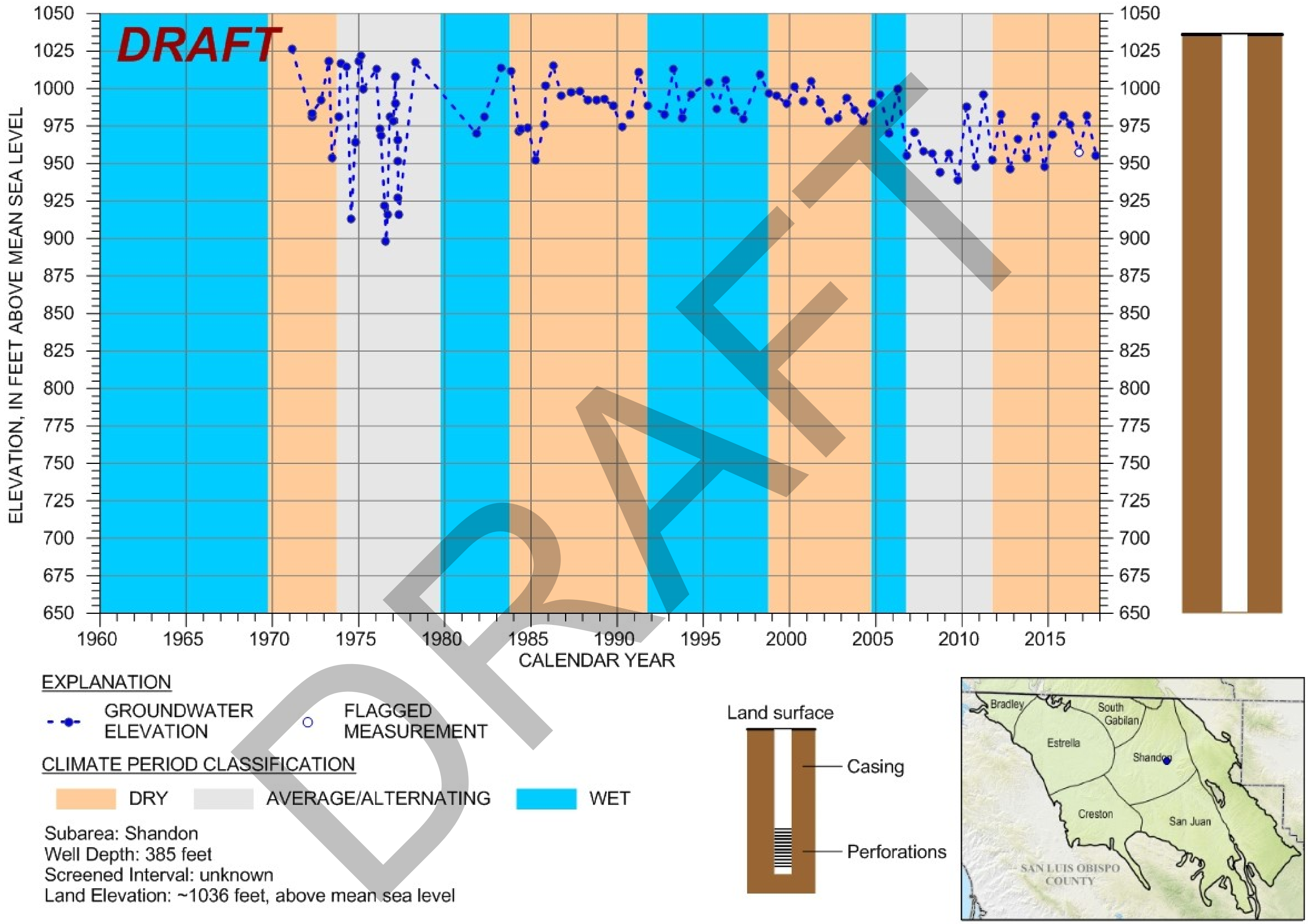

Figure 5-10. Groundwater Elevation at Paso Robles Formation Aquifer Well 26S/15E-20B02

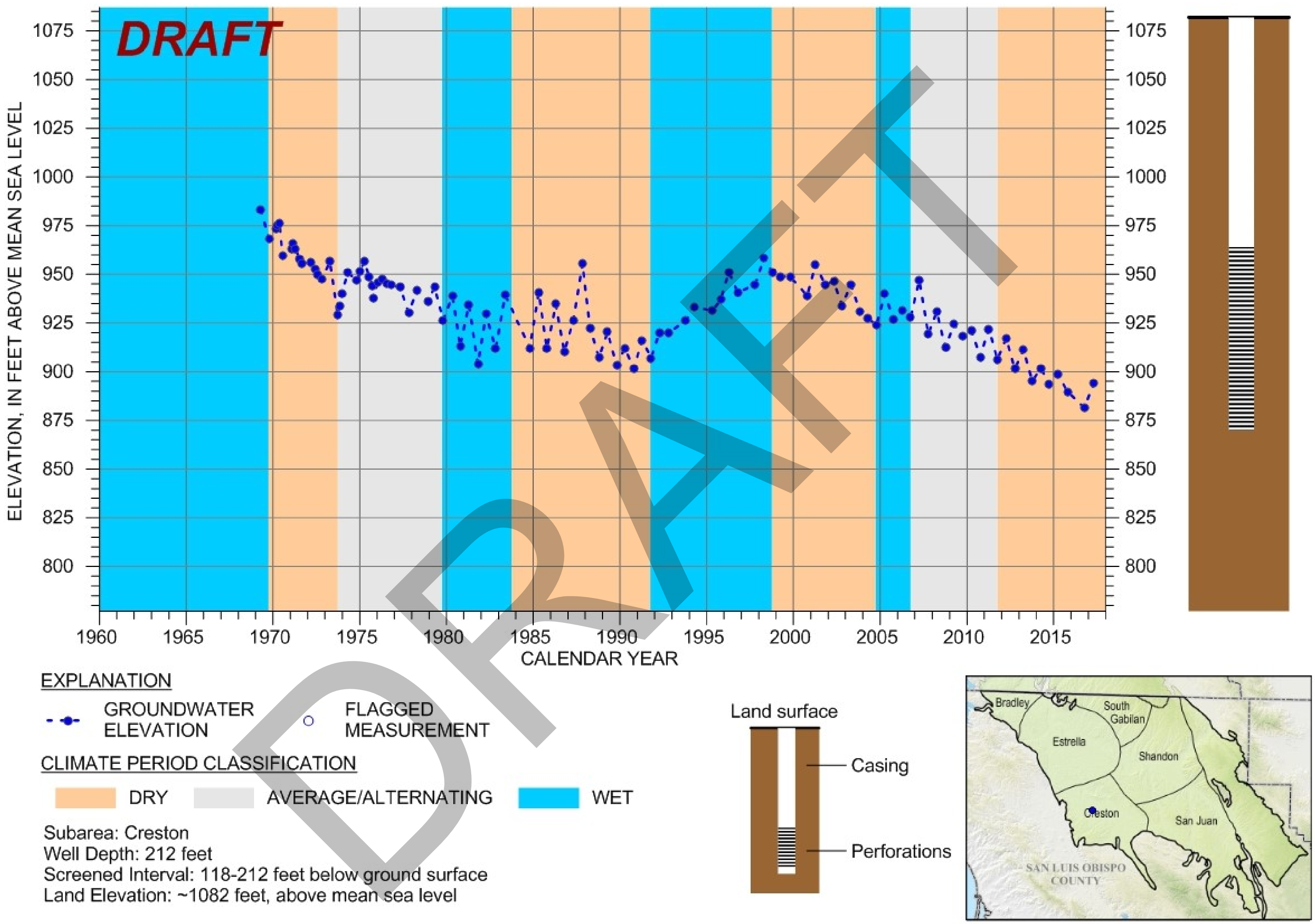

Figure 5-11. Groundwater Elevation at Paso Robles Formation Aquifer Well 27S/13E-28F01

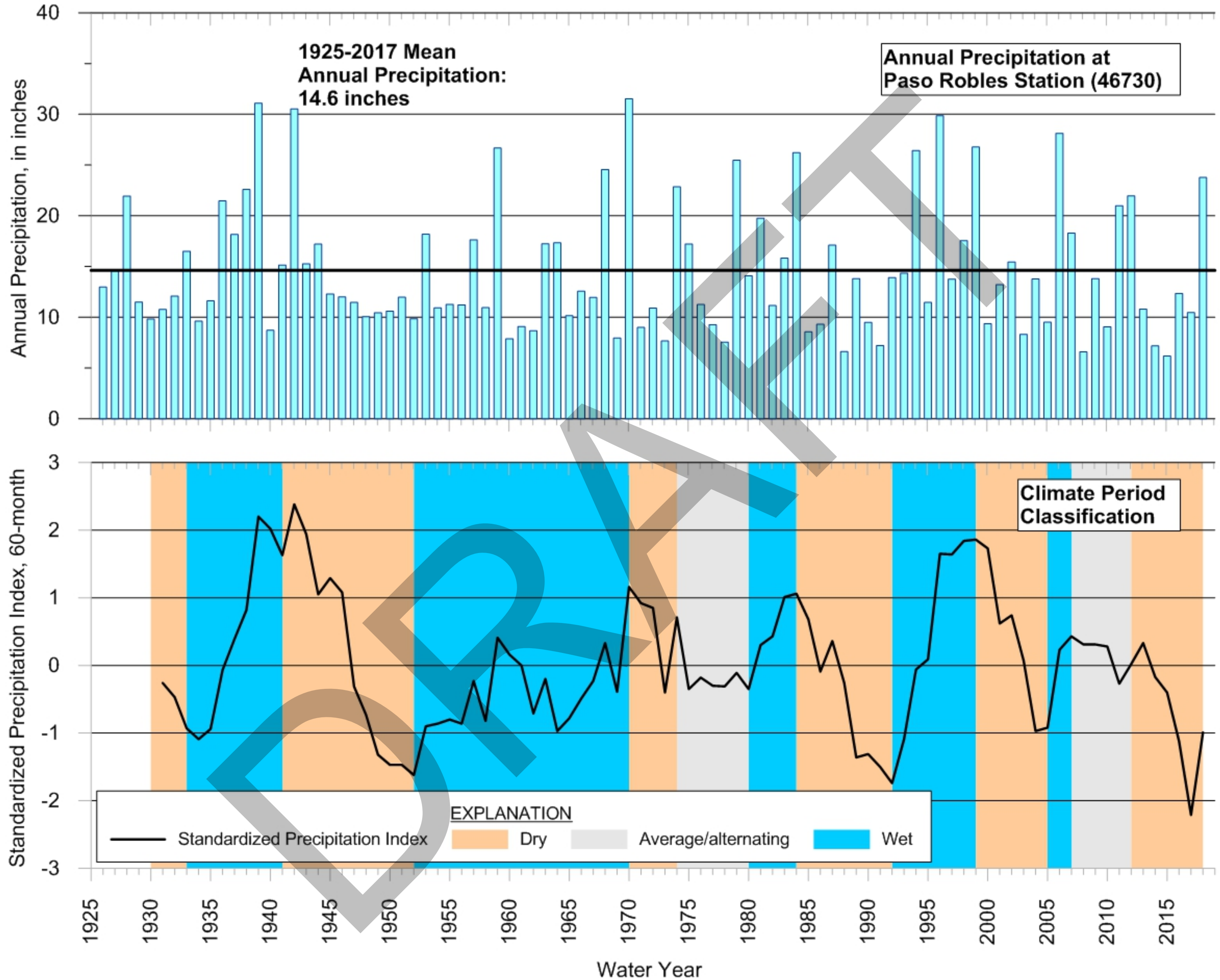

Figure 5-12. Climatic Periods in the Paso Robles Subbasin

5.1.3 VERTICAL GROUNDWATER GRADIENTS

Limited data exist to assess vertical groundwater gradients. Previous hydrologic studies of the Subbasin indicate that groundwater elevations are generally higher in the Alluvial Aquifer than the underlying Paso Robles Formation Aquifer, resulting in groundwater flow from the Alluvial Aquifer to the underlying Paso Robles Formation aquifer (Fugro, 2005). The *Paso Robles Groundwater Basin Study, Phase II* (Fugro, 2005) stated that there is an assumed upward vertical groundwater gradient near the northern portion of the Subbasin, although data were not provided to verify this assumption.

Vertical groundwater gradients can be estimated from nested or clustered wells. Wells 25S/12E-16K04, K05, and K06 are nested and provide groundwater elevation data from different depths in the Paso Robles Formation Aquifer near San Miguel. These wells are adjacent to a water supply well and therefore the vertical groundwater gradients may reflect local pumping conditions rather than broad, regional conditions. Hydrographs for these wells are shown on Figure 5-13. On this figure, groundwater levels in the shallowest well are shown with a green line, groundwater levels in the middle depth well are shown with a yellow line, and groundwater levels in the deepest well are shown with a red line. Prior to 2002, groundwater levels in the deepest well (red line) were generally higher than the groundwater levels in the middle and shallow wells, indicating an upward vertical groundwater gradient. A consistent vertical groundwater gradient is not apparent between the shallow and middle wells prior to 2002; groundwater elevations in the shallow and middle depth wells fluctuate around each other. After 2012, groundwater elevations in the deepest well were usually similar to or below the groundwater elevations in the shallow and middle depth wells; indicating a downward vertical groundwater gradient.

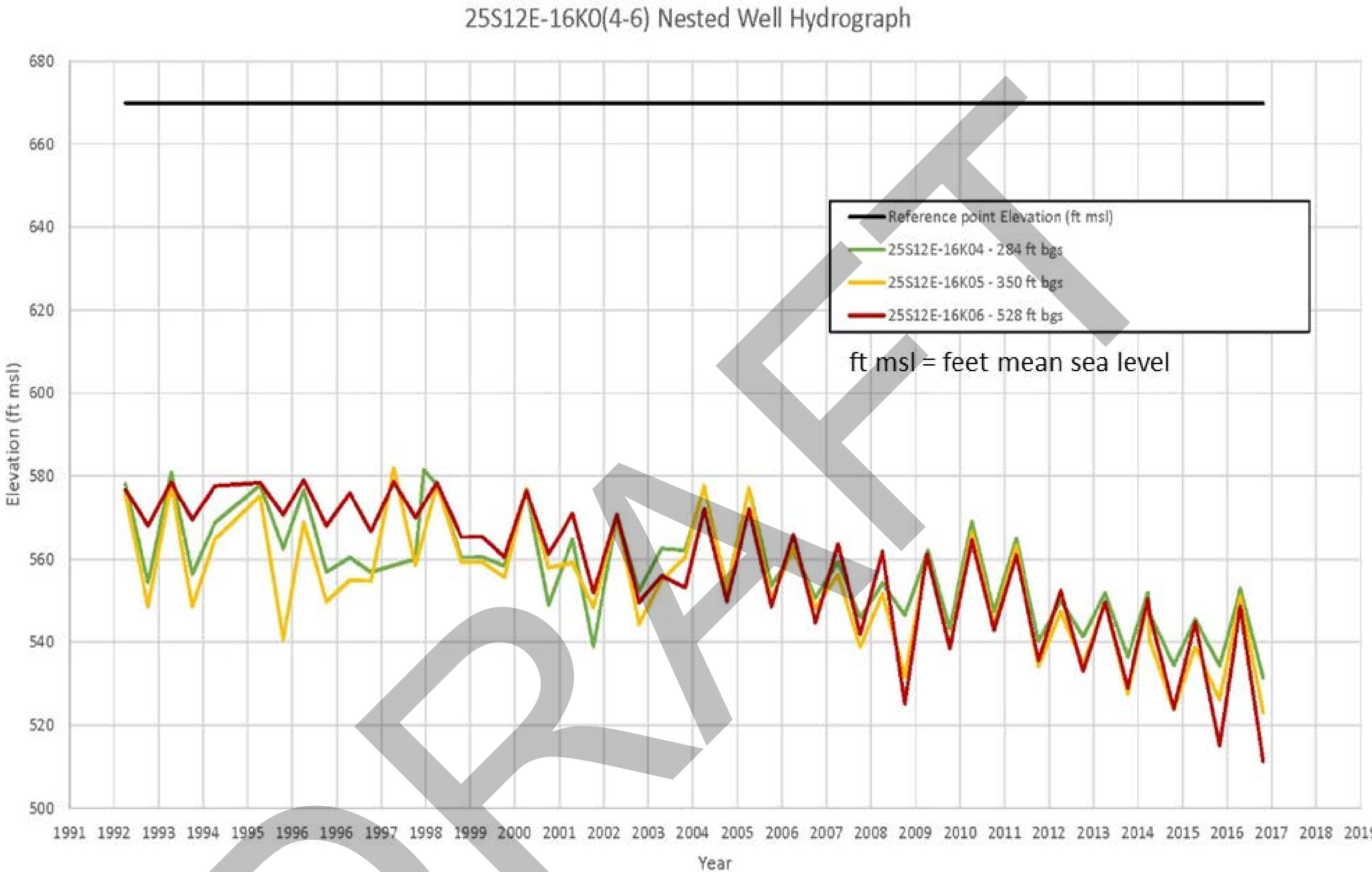

Figure 5-13. Vertical Groundwater Gradients near San Miguel

5.2 Change in Groundwater Storage

This section summarizes changes in groundwater storage in the Subbasin within the GSP area. Change in groundwater storage was estimated for water years 1981 through 2016 using the updated Paso Robles Subbasin groundwater model.

5.2.1 Alluvial Aquifer

Figure 5-14 shows the cumulative change in groundwater storage for water years 1981 through 2016 for the Alluvial Aquifer. The period from 1981 through 2011 is considered representative on long-term hydrologic conditions prior to the drought period of 2012 through 2016. The graph also shows the estimated annual groundwater pumping derived from the updated groundwater model and wet, dry, and average/alternating climatic periods based on the analysis presented in Section 5.1.2.2.

Over the period 1981 through 2011, the model indicates no net change in storage occurred in the Alluvial Aquifer. This projection is consistent with the observed stable groundwater elevations in hydrographs for wells screened in the Alluvial Aquifer. During the drought period 2012 through 2016, the model suggests a loss of groundwater in storage in the Alluvial Aquifer of about 50,000 acre-feet (AF).

As indicated on, a decrease in groundwater storage generally occurs during dry periods and an increase in groundwater storage generally occurs during wet periods. During the period 1981 through 2011, estimated groundwater pumping from the Alluvial Aquifer decreased from about 6,000 acre-feet per year (AFY) to about 2,000 AFY as indicated by the black bars on Figure 5-14. This suggests that the loss in groundwater storage is not due to increased pumping, but is more likely a result of lack of recharge during low precipitation years. A secondary cause for the storage loss might be increased downward flow from the Alluvial Aquifer into the Paso Robles Aquifer during this period, although this is difficult to definitively assess from the data.

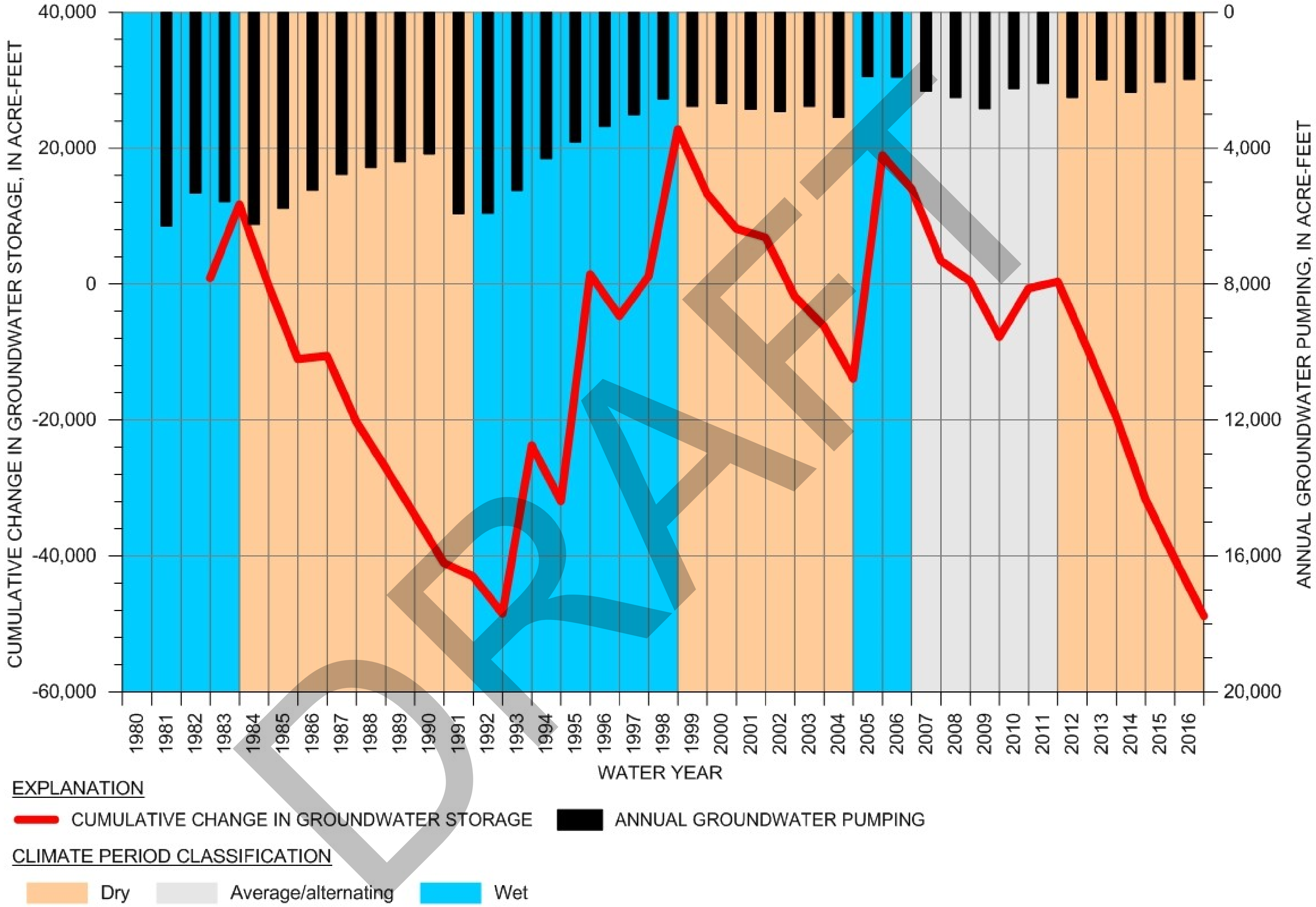

Figure 5-14. Estimated Cumulative Change in Groundwater Storage in Alluvial Aquifer

5.2.2 PASO ROBLES FORMATION AQUIFER

Figure 5-15 shows precipitation data and the cumulative change in groundwater storage for water years 1981 through 2016 for the Paso Robles Formation Aquifer. The graph also shows the annual groundwater pumping and water year type. The climatic variation shown on Figure 5-15 is the same climatic variation developed on Figure 5-12. Over the period 1981 through 2011, approximately 170,000 AF were removed from storage in the Paso Robles Formation Aquifer. Over the period 1981 through 2016, approximately 440,000 AF were removed from storage in the Paso Robles Formation Aquifer. Depletion of groundwater storage generally occurs during dry periods and increases in groundwater storage generally occur during wet periods, as indicated on Figure 5-15. Groundwater pumping decreased during the period from 1981 to 1999 and generally increased from 1999 to 2016. The loss in groundwater storage appears to be from a combination of increased pumping since 1999 and a number of dry years with limited recharge.

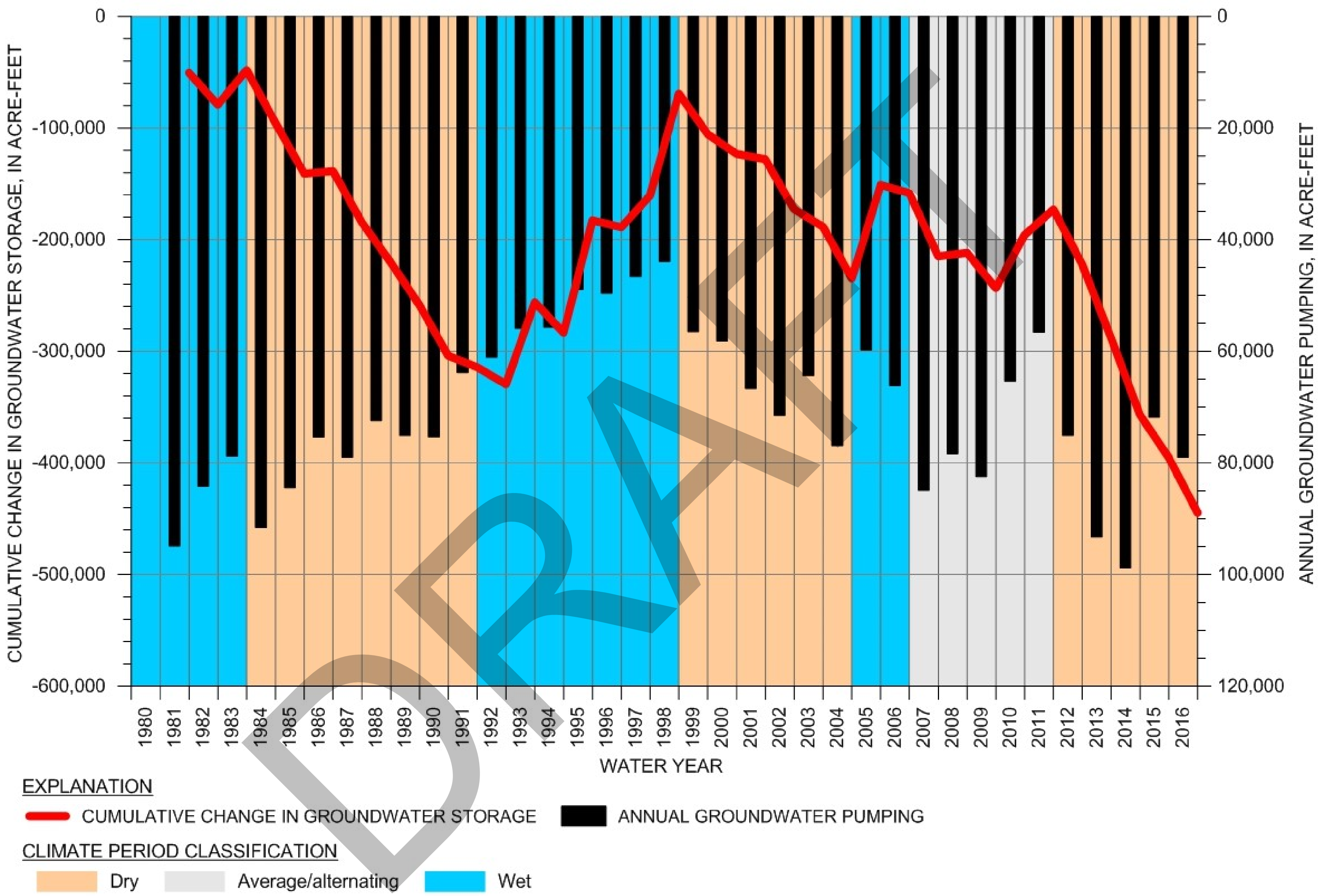

Figure 5-15. Estimated Cumulative Change in Groundwater Storage in Paso Robles Formation Aquifer

5.3 SEAWATER INTRUSION

Seawater intrusion is not an applicable sustainability indicator for the Subbasin. The Subbasin is not adjacent to the Pacific Ocean, a bay, or inlet.

5.4 SUBSIDENCE

Land subsidence is the lowering of the land surface. While several human-induced and natural causes of subsidence exist, the only process applicable to the GSP is subsidence due to lowered groundwater elevations caused by groundwater pumping.

Direct measurements of subsidence have not been made in the Subbasin using extensometers or repeat benchmark calibration; however, interferometric synthetic aperture radar (InSAR) has been used in the area to remotely map subsidence. This technology uses radar images taken from satellites that are used to create maps of changes in land surface elevation. The studies done in the area show that a localized area three miles northeast of the City of Paso Robles had a downward displacement of 0.6 to 2.1 inches between Spring 1997 and Fall 1997 (Valentine, D. W. et al., 2001).

5.5 INTERCONNECTED SURFACE WATER

Limited and ephemeral surface water flows in the Subbasin over the last 40 years make it difficult to study the interconnectivity of surface water and groundwater and to quantify the degree to which surface water depletion has occurred. The spatial extent of interconnected surface water was evaluated based on results from the basin-wide groundwater flow model of the Paso Robles Subbasin. In accordance with the SGMA emergency regulations §351 (o), "Interconnected surface water refers to 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". We estimated which surface water bodies are inter-connected by comparing simulated groundwater elevations in the Alluvial Aquifer and Paso Robles Formation Aquifer with the elevation of the stream or river bottom. If model-simulated groundwater elevations in any aquifer were above the bottom of the stream or river for at least half of the time between 2010 and 2016, then the surface water was considered interconnected with the groundwater. This concept is illustrated in Figure 5-16. In this figure, both diagrams A and B represent interconnected surface waters. Diagram C shows non-interconnected surface water.

Figure 5-17 shows the extent of interconnected surface water for Water Years 2010 through 2016 based on this model evaluation.

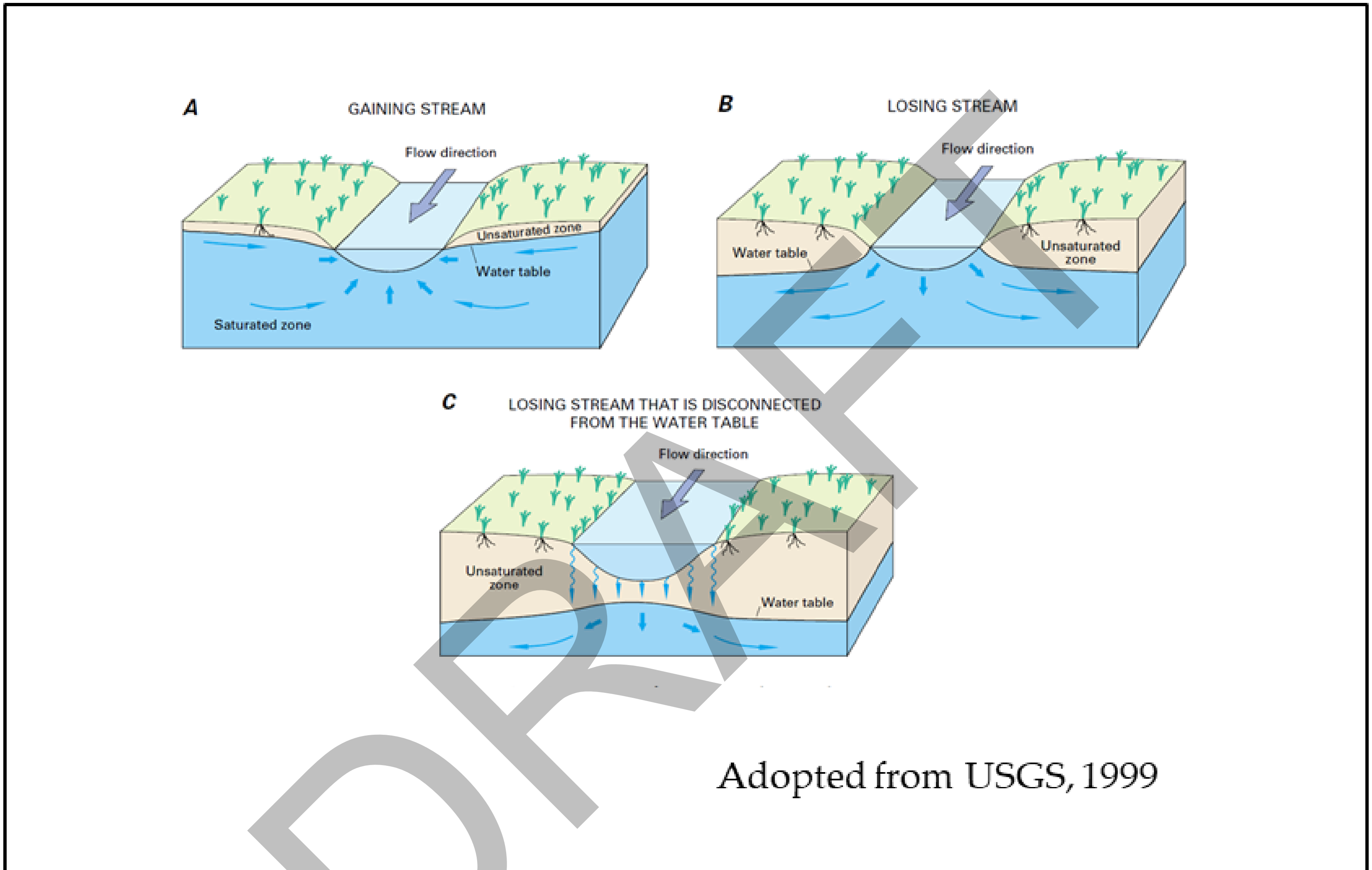

Figure 5-16. Interconnected and Non-Interconnected Surface Waters

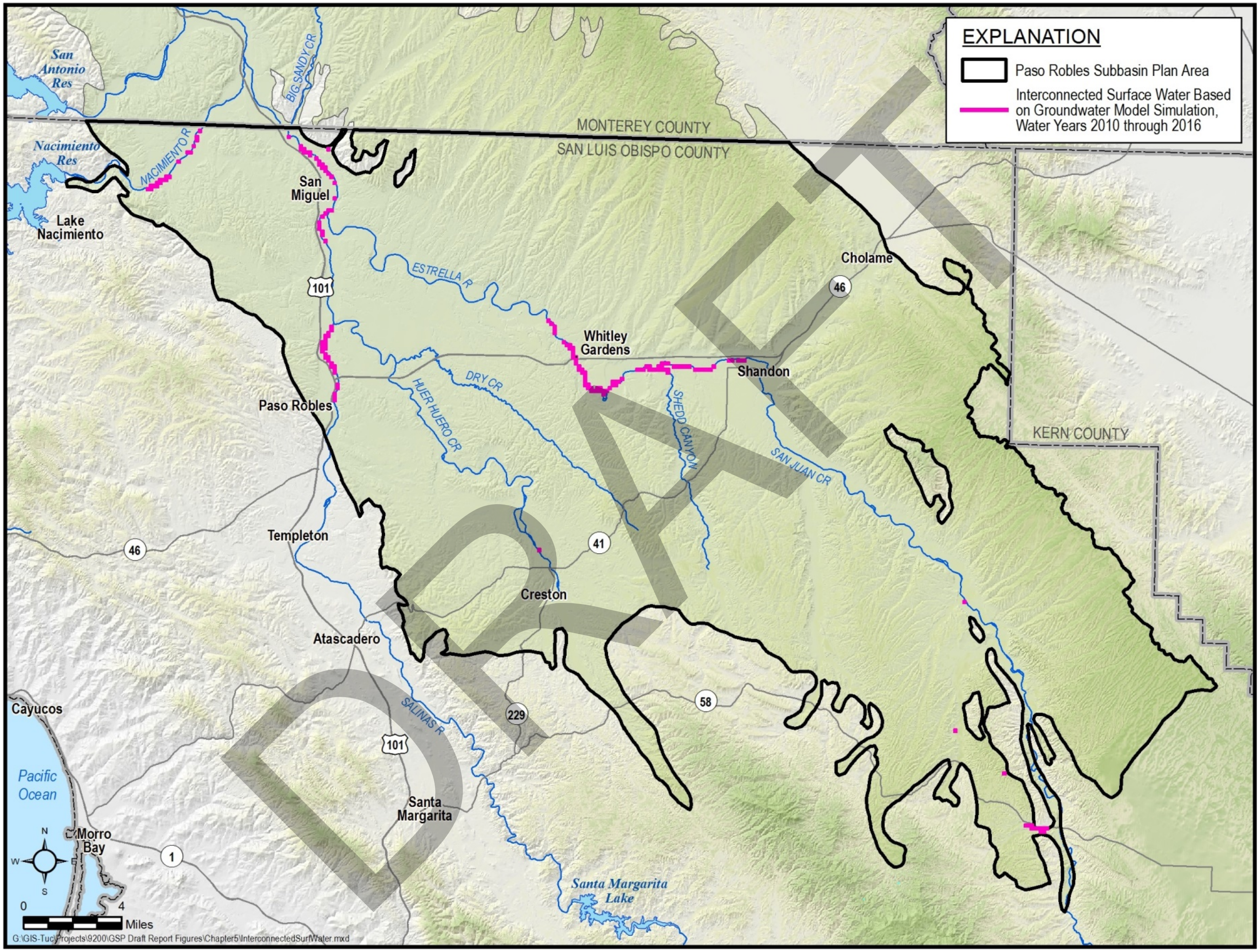

Figure 5-17. Locations of Interconnected Surface Waters

5.5.1 DEPLETION OF INTERCONNECTED SURFACE WATER

Groundwater withdrawals are balanced by a combination of reductions in groundwater storage and changes in the rate of exchange across hydrologic boundaries. In the case of surface water depletion, this rate change could be due to reductions in rates of groundwater discharge to surface water, and increased rates of surface water percolation to groundwater. These two changes together comprise the amount of surface water depletion.

Depletion of interconnected surface water was estimated by evaluating the change in the modeled stream leakage with and without pumping. A model simulation was run without groundwater pumping and was compared to the existing model with groundwater pumping. The difference in stream depletion between the two models is the depletion caused by the groundwater pumping. The stream depletion differences are only estimated for the interconnected segments identified in Figure 5-17. The methodology for quantifying stream depletion is described in detail by Barlow and Leake (2012).

Figure 5-18 shows the estimated annual depletion of the interconnected surface water along the stream segments shown in Figure 5-17 due to groundwater pumping. During the period Water Years 1991 to 2011, mean annual surface water depletion was about 7,600 AFY. During the period of time representative of current conditions (Water Year 2012 through 2016), mean annual surface water depletion was about 8,500 AFY.

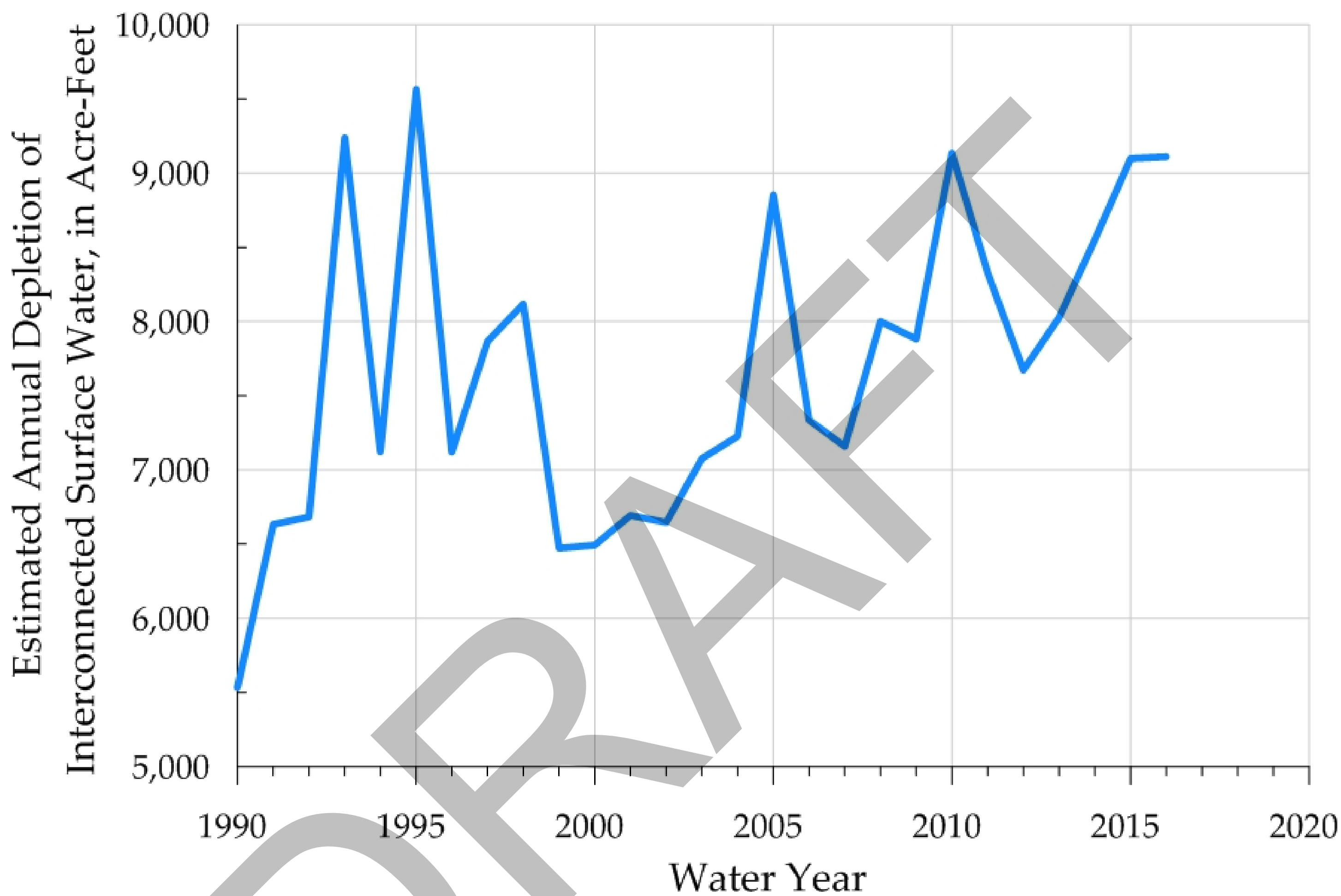

Figure 5-18. Estimated Annual Depletion of Interconnected Surface Water

5.6 Groundwater Quality Distribution and Trends

Groundwater quality samples have been collected and analyzed throughout the Subbasin for various studies and programs. Water quality samples have been collected on a regular basis for compliance with regulatory programs. Additionally, a broad survey of groundwater quality sampling was conducted for the *Paso Robles Groundwater Basin Study, Phase I* (Fugro, 2002), and most recently by the USGS in 2018. Historical groundwater quality data were compiled for use in the Salt and Nutrient Management Plan (SNMP) (RMC, 2015).

5.6.1 Groundwater Quality Suitability for Drinking Water

Groundwater in the basin is generally suitable for drinking water purposes. The *Paso Robles Groundwater Basin Study, Phase I* (Fugro 2002) reviewed water quality data from public supply wells to identify exceedances of drinking water standards. The drinking water standards Maximum Contaminant Levels (MCLs) and Secondary MCLs (SMCLs) are established by Federal and State agencies. MCLs are legally enforceable standards, while SMCLs are guidelines established for nonhazardous aesthetic considerations such as taste, odor, and color. The most common water quality standard exceedance in the Subbasin was exceedance of the SMCL for total dissolved solids, which exceeded the standard in 14 samples from the 74 samples. Nitrate also exceeded the MCL in four samples. One exceedance of mercury was found in the San Miguel area in a 1990 sample.

5.6.2 Groundwater Quality Suitability for Agricultural Irrigation

Groundwater in the basin is generally suitable for agricultural purposes. Fugro (2002) evaluated the agricultural suitability of groundwater using three metrics:

1. Salinity as indicated by electrical conductivity;
2. Soil structure as indicated by sodium absorption ratio and electrical conductivity; and
3. Presence of toxic salts as indicated by concentrations of sodium, chloride, and boron.

Of the 74 samples evaluated, 37 had no restrictions on irrigation use (Fugro, 2002). This does not imply that half of the groundwater in the basin is unsuitable for irrigation; only that half of the samples had some constituent that may restrict unlimited irrigation use. Most cases of slight to moderate restriction on irrigation use were due to sodium or chloride toxicity. Severe restrictions for 13 samples were generally the result of high sodium, chloride, or boron toxicity.

5.6.3 Distribution and Concentrations of Point Sources of Groundwater Constituents

Potential point sources of groundwater quality degradation were identified using the State Water Resources Control Board (SWRCB) Geotracker website. Waste Discharge permits were also reviewed from on-line regional SWRCB websites. Table 5-1 summarizes information from these websites. Figure 5-19 shows the location of potential groundwater contaminant point sources. Based on available information there are no mapped groundwater contamination plumes at these sites, although investigations are ongoing.

Table 5-1. Potential Point Sources of Groundwater Contamination

SITE NAME	SITE TYPE	CONSTITUENTS OF CONCERN (COCs)	STATUS
Former Chevron 9-0750	LUST Cleanup Site	petroleum hydrocarbons	Remedial action plan submitted Q2 2018
Kirkpatrick Property (Unocal Portion)	Cleanup Program Site	crude oil	Impacted soil; health risk assessment prepared in 2016
Lucy Brown Road Pipeline Site (Former ConocoPhillips Site #3469)	Cleanup Program Site	crude oil, diesel, gasoline	Initial groundwater monitoring data no significant impacts to groundwater.
Estrella Airfield (Paso Robles Municipal Airport)	Military Cleanup Site	Unknown	Unknown
Camp Roberts Solid Waste Site	Land Disposal Site	metals, cyanide, sulfide, herbicides, volatile organic compounds (VOCs), pesticides, PCBs, phthalate esters, phenols, semi-VOCs	Total dissolved solids (TDS), nitrate and manganese detected in wells at concentrations above regulatory standards.
Camp Roberts South and Closed Landfill	Land Disposal Site	VOCs, chloride, sulfate, nitrate, sodium, manganese, TDS, total organic carbon	Carbon tetrachloride detected at concentrations exceeding MCL.
Paso Robles Solid Waste Site	Land Disposal Site	chloride, total alkalinity, manganese, nitrate, sodium, sulfate, temperature, TDS, VOCs, Pesticides, PCBs, organophosphorus compounds, herbicides, semi-VOCs	COCs not detected in groundwater; sulfate and barium locally elevated; no remedial activities.

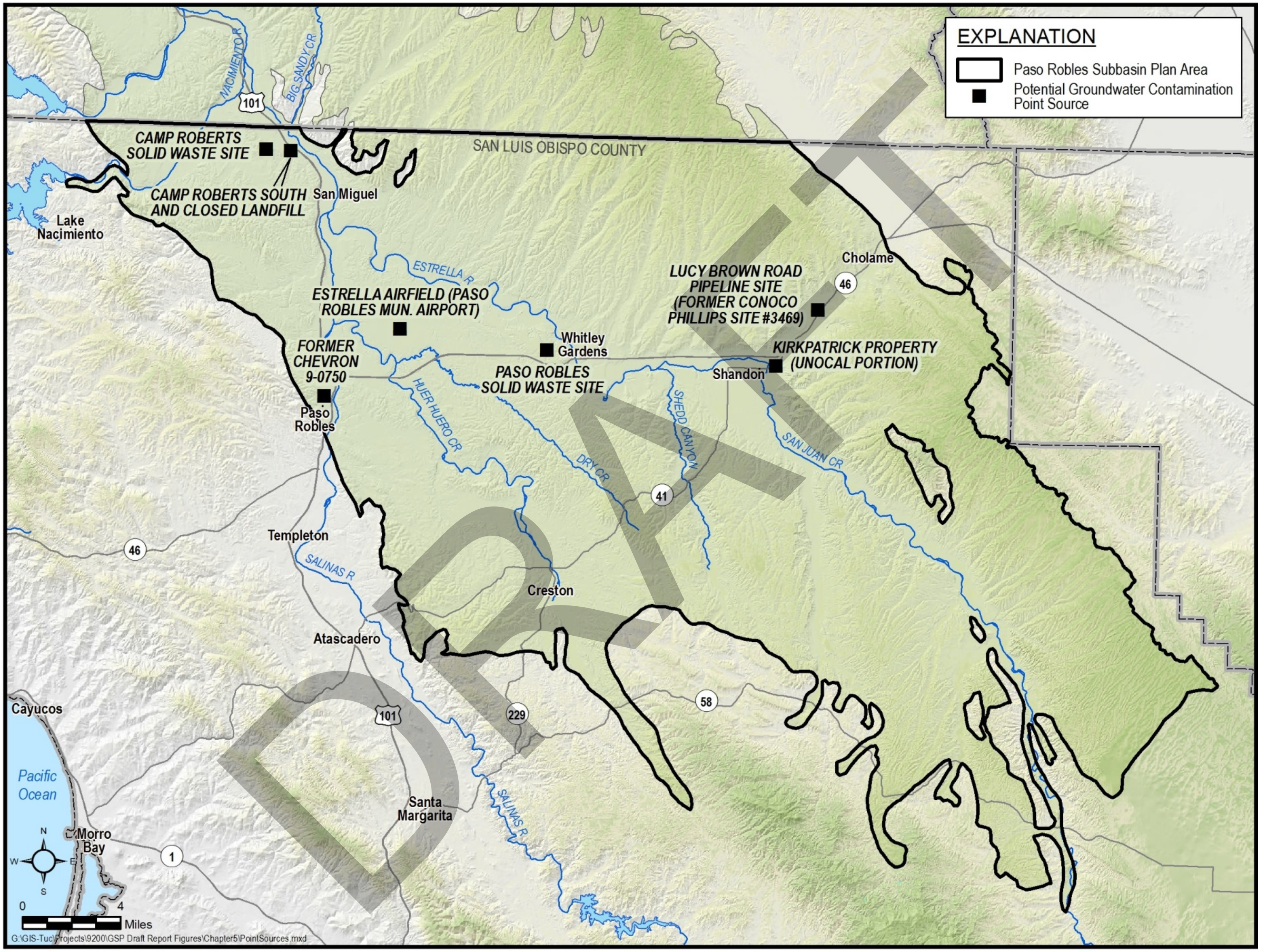

Figure 5-19. Location of Potential Point Sources of Groundwater Contaminants

5.6.4 Distribution and Concentrations of Diffuse or Natural Groundwater Constituents

Fugro (2002) identified a number of constituents of concern that are broadly distributed throughout the Subbasin. The SNMP (RMC, 2015) provides additional data on the distribution of certain constituents. This GSP focuses only on constituents that might be impacted by groundwater management activities. The constituents discussed below are chosen because:

1. The constituent has either a drinking water standard or a known effect on crops.
2. Concentrations have been observed above either the drinking water standard or the level that affects crops.

5.6.4.1 Total Dissolved Solids

Total Dissolved Solids (TDS) is a constituent of concern in groundwater because it has been detected at concentrations greater than its SMCL of 500 milligrams per liter (mg/L). Table 5-2 shows the range and average TDS concentrations by subarea as reported in the SNMP (RMC, 2015). This table shows the average TDS concentrations are greater than the SMCL of 500 mg/L in parts of the Subbasin. This table includes data for portions of the Bradley, North Gabilan, and South Gabilan subareas that are outside the GSP area.

Table 5-2. TDS Concentration Ranges and Averages

Hydrogeologic Subarea	TDS Concentration Range (mg/L)	Average TDS Concentration (mg/L)
Estrella	350 – 1,560	552
Shandon	270 – 3,160	563
Creston	190 – 1,620	388
San Juan	160 – 2,170	425
Bradley	400 – 1,280	751
North Gabilan	370 – 1,320	856
South Gabilan	370 – 1,320	451

Source: RMC, 2015

The distribution and trends of TDS in the Subbasin are shown on Figure 5-20. This figure is from the SNMP (RMC, 2015) and includes portions of the Subbasin north of the Monterey County line which are outside the GSP area. The study area for the SNMP also did not extend as far southeast as the GSP area. TDS distribution shown on this figure is not differentiated by aquifer or well depth. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause TDS concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

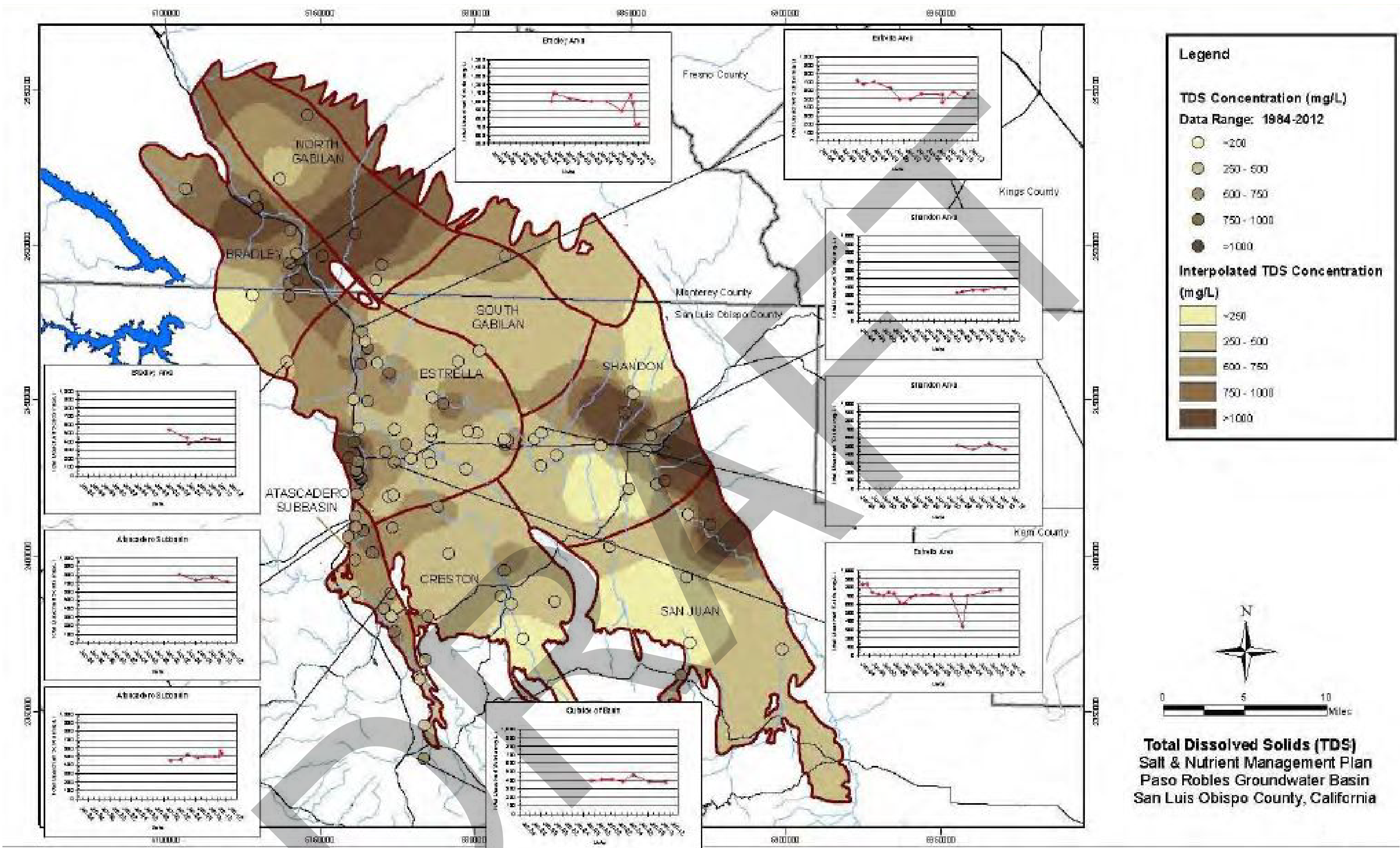

Figure 5-20. TDS Regional Distribution and Trends

Source: RMC, 2015

5.6.4.1 CHLORIDE

Chloride is a constituent of concern in groundwater because it has been detected at concentrations greater than its SMCL of 250 mg/L. Elevated chloride concentrations in groundwater can damage crops and affect plant growth. The *Paso Robles Groundwater Basin Study, Phase I* (Fugro 2002) reported that slight to moderate restrictions on irrigating trees and vines may occur when chloride concentrations exceed 100 mg/L. Severe restrictions on irrigating trees and vines may occur when chloride concentrations exceed 350 mg/L.

Table 5-3**,** which was compiled based on various tables and related information in the SNMP (RMC, 2015), shows the range and average chloride concentrations by subarea. This table indicates that average chloride concentrations are less than the SMCL of 250 mg/L throughout Subbasin. This table includes data for areas of the Bradley, North Gabilan, and South Gabilan subareas that are outside the GSP area.

Table 5-3. Chloride Concentration Ranges and Averages

Hydrogeologic Subarea	Chloride Concentration Range (mg/L)	Average Chloride Concentration (mg/L)
Estrella	32 - 572	94
Shandon	31 - 550	80
Creston	25 - 508	69
San Juan	13 - 699	64
Bradley	40 - 400	84
North Gabilan	35 - 209	113
South Gabilan	35 - 209	37

Source: RMC, 2015

The distribution and trends of chloride in the Subbasin are shown on Figure 5-21. This figure is from the SNMP (RMC, 2015) and includes portions of the Subbasin north of the Monterey County line which are outside the GSP area. Chloride distribution shown on this figure is not differentiated by aquifer or well depth. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause chloride concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

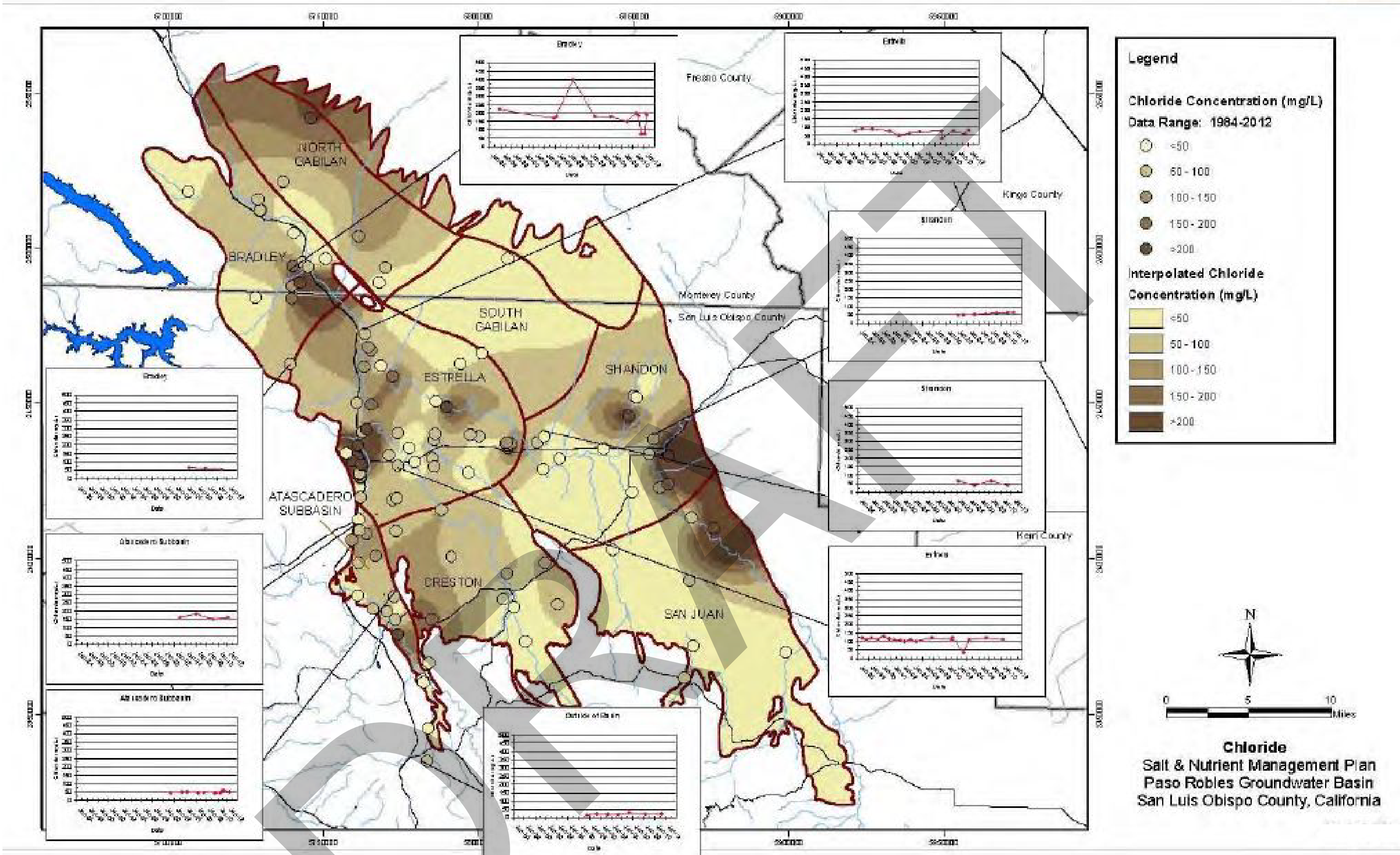

Figure 5-21. Chloride Regional Distribution and Trends

Source: RMC, 2015

5.6.4.2 SULFATE

Sulfate is a constituent of concern in groundwater because it has been observed at concentrations above its SMCL of 250 mg/L. Table 5-4 shows the range and average sulfate concentrations by subarea as reported in the SNMP (RMC, 2015). This table shows the average sulfate concentrations are greater than the SMCL of 250 mg/L in many areas of the Subbasin. This table includes data for areas of the Bradley, North Gabilan, and South Gabilan subareas that are outside the GSP area.

Table 5-4. Sulfate Concentration Ranges and Averages

Hydrogeologic Subarea	Sulfate Concentration Range (mg/L)	Average Sulfate Concentration (mg/L)
Estrella	11 - 375	129
Shandon	14 – 2,010	360
Creston	7 - 353	67
San Juan	24 - 722	248
Bradley	30 - 704	296
North Gabilan	9 - 648	194
South Gabilan	9 - 648	194

Source: RMC, 2015

Maps of sulfate distribution in the Subbasin were not found in previous studies. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause sulfate concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

5.6.4.3 NITRATE

Nitrate is a constituent of concern in groundwater because concentrations have been detected greater than its MCL of 10 mg/L (measured as nitrogen). Nitrate concentrations in excess of the MCLs can result in health impacts.

Table 5-5 shows the range and average nitrate concentrations by subarea as reported in the SNMP (RMC, 2015). This table shows the average nitrate concentrations are less than the MCL of 10 mg/L throughout Subbasin. The range of measured nitrate concentrations however exceeds the MCL of 10 mg/L in every subarea. This table includes data for areas of the Bradley, North Gabilan, and South Gabilan subareas that are outside the GSP area.

Table 5-5. Nitrate Concentration Ranges and Averages

Hydrogeologic Subarea	Nitrate Concentration Range (mg/L)	Average Nitrate Concentration (mg/L)
Estrella	0 – 16.2	2.5
Shandon	1.2 – 12.1	4.6
Creston	0.8 – 9.2	3.2
San Juan	0.1 – 5.8	2.8
Bradley	0.0 – 5.8	2.7
North Gabilan	5.0 – 9.8	8.4
South Gabilan	15.8	6.3

Source: RMC, 2015; data are from Table 3-12; the range of nitrate concentration in the South Gabilan subarea is uncertain

The distribution and trends of nitrate in the Subbasin are shown on Figure 5-22. This figure is from the SNMP (RMC, 2015) and includes portions of the Subbasin north of the Monterey County line which are outside the GSP area. This nitrate distribution shown on this figure is not differentiated by aquifer or well depth. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause nitrate concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

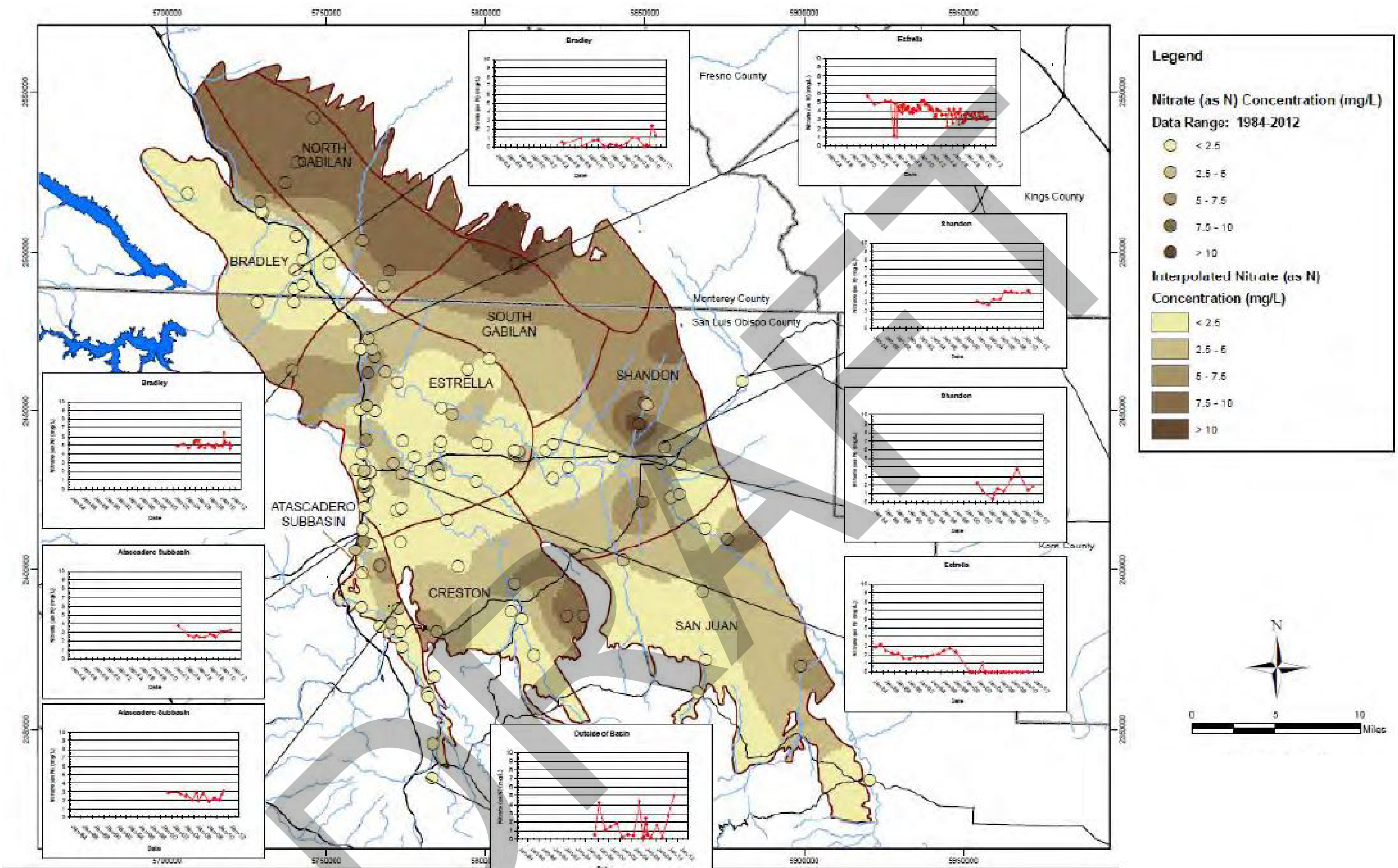

Figure 5-22. Nitrate Regional Distribution and Trends

Source: RMC, 2015. Figure 3-10

5.6.4.4 Boron

Boron is an unregulated constituent and therefore does not have a regulatory standard. However, boron is a constituent of concern because elevated boron concentrations in water can damage crops and affect plant growth. The *Paso Robles Groundwater Basin Study, Phase I* (Fugro 2002) reported that severe restrictions on irrigating trees and vines may occur when boron concentrations exceed 0.5 mg/L.

Table 5-6 shows the range and average boron concentrations by subarea as reported in the SNMP (RMC, 2015). Average boron concentration exceeds the severe irrigation restriction level of 0.5 mg/L in the Estrella, Shandon, and San Juan subareas. The table includes data for areas of the Bradley, North Gabilan, and South Gabilan subareas that are outside the GSP area.

Table 5-6. Boron Concentration Ranges and Averages

Hydrogeologic Subarea	Boron Concentration Range (mg/L)	Average Boron Concentration (mg/L)
Estrella	0.13 – 5.66	1.8
Shandon	0.08 – 2.97	0.81
Creston	0.06 – 0.31	0.14
San Juan	0.08 – 2.29	0.74
Bradley	0.12 – 0.18	0.15
North Gabilan	0.11 – 0.44	0.24
South Gabilan	0.11 – 0.44	0.24

Source: RMC, 2015

Maps of boron distribution in the Subbasin were not found in previous studies. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause boron concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

5.6.4.5 Gross Alpha Radiation

Gross alpha radiation is a constituent of concern because it has been detected at concentrations greater than its MCL of 15 picocuries per liter (pCi/L). Fugro (2002) reports that gross alpha radioactivity is present in most areas of the basin. Gross alpha particle count activity in groundwater exceeded the MCL for drinking water in the Estrella and Bradley areas. Gross alpha data included in Fugro's 2002 report are summarized in Table 5-7.

Table 5-7. Gross Alpha Concentration Ranges and Averages

Hydrogeologic Subarea	Gross Alpha Maximum Concentration (pCi/L)	Gross Alpha Average Concentration (pCi/L)
Estrella	31	20
Shandon	3	3
Bradley	23	2

Source: Fugro, 2002

No maps exist of the gross alpha distribution in the Subbasin. Sustainability projects and management actions implemented as part of this GSP are not anticipated to directly cause gross alpha radiation concentrations in groundwater in a well that would otherwise remain below the SMCL to increase above the SMCL.

5.6.5 Groundwater Quality Surrounding the Paso Robles Subbasin

Poor quality groundwater has been documented in wells that screen sediments and rocks below the Paso Formation as well as sediments and rocks surrounding the Subbasin. Based on limited observations, there is a concern that this poor quality groundwater may be drawn into wells in the Subbasin and degrade the groundwater quality if groundwater levels are allowed to fall too low. Groundwater levels must be maintained at elevations that prevent migration of poor quality groundwater from beneath or around the Subbasin.