SUMMARY OF PAST GROUNDWATER MODELS AND WATER BUDGETS FOR THE PIRU, FILLMORE, AND SANTA PAULA GROUNDWATER BASINS

United Water Conservation District
Open-File Report 2020-02
November 2020

United Water
CONSERVATION DISTRICT

WATER RESOURCES DEPARTMENT
UNITED WATER CONSERVATION DISTRICT

THIS REPORT IS PRELIMINARY AND SUBJECT TO MODIFICATION BASED UPON FUTURE ANALYSIS AND EVALUATIONS

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EXECUTIVE SUMMARY

This report summarizes the water budgets of the Piru, Fillmore, and Santa Paula groundwater basins based on major hydrologic investigations that have taken place over the past century. Reviewing these previous investigations related to numerical groundwater modeling and water budgets of the groundwater basins supports United's efforts in the expansion of United's active numerical groundwater flow model domain to include the remaining groundwater sub-basins of the Santa Clara River Valley within Ventura County, California.

Table E-1 summarizes the hydrologic investigations which contributed water budget components related to the Piru, Fillmore, and Santa Paula groundwater basins. Table E-2 summarizes the range of reported water budget component values for each of the groundwater basins which were presented in the previous hydrologic studies that are listed in Table E-1. The majority of the values presented in Table E-2 were extracted from a California Department of Water Resources (DWR, 1956) or Mann (1959), with other primary sources being CH2M HILL (2004, 2005), CH2M HILL and HydroGeoLogic (CH2M HILL/HGL, 2008), LWA and others (2015) and DBS&A and RCS (2017). Values of lower and upper ranges were sourced from all the investigations reported. Each of the reports used for this review are representative of varying, sometimes overlapping, climatic periods and conditions (Table E-1). Since the values reported from DWR (1956) and Mann (1959) provided the most complete summaries of water budgets, most of the lower and upper bounds of the reported range for many of the components, presenting the results in this way is considered appropriate, and helpful, for comparison purposes.

Reviewing previous water budget component estimates helps during numerical model development and calibration by confirming that values of various water budget components from the new model are reasonable, and that differences may be explained due to physical changes or processes considered. The numerical groundwater model expansion efforts further support United's ability of regional water management planning, with the most immediate need in supporting local Groundwater Sustainable Agencies (GSAs) in developing Groundwater Sustainability Plans (GSPs).

Based on this review, United offers the following conclusions related to the previous studies and reported water budgets for the Piru, Fillmore, and Santa Paula groundwater basins:

- There are extensive previous studies available for these basins that were based on field, analytical, and numerical studies, dating back to the 1920s (Table E-1).
- The most significant inflows to each basin consist of recharge from streamflow (Santa Clara River) percolation, areal recharge from precipitation and applied water from groundwater and surface water sources, and incoming subsurface underflow from upstream groundwater basins.
- The most significant outflows to each basin consist of groundwater extractions for beneficial use and outgoing subsurface underflow to downstream groundwater basins.

- With the Santa Clara River (SCR) being the largest source of recharge (especially for Piru and Fillmore Basins), these basins are highly variable due to the dependence on local rainfall within the SCR watershed. This variability and dependence on surface water inflows leads to the large range observed in the previously reported water budget components (Table E-2). This dependence to surface water flows is expected to continue in the future, resulting in variable water budgets of similar ranges.
- Basin boundary modifications have recently been adopted that expanded the extent of the Piru, Fillmore, and Santa Paula groundwater basins. The majority of the studies reviewed for this document utilized boundaries that captured most of the water-bearing and productive alluvial deposits and underlying aquifers along the valley floor, and the overall effect on the ranges for many of the water budget components is not expected to be significant. Changes to the upstream extent of the Piru basin will however result in an increase in the subsurface underflow into Piru basin from the east. This value is expected to increase using the Department of Water Resources (DWR, 2019) boundary moving forward due to the substantial increase in saturated aquifer thickness near the Los Angeles County line compared to the downstream locations used in previous studies. The increased area will also result in increased recharge to the underlying aquifers due to precipitation.

Table E-1: Chronology of hydrologic investigations which contributed water budget components related to Santa Clara River Valley groundwater basins (Piru, Fillmore, and Santa Paula).

Entity	Year Published	Reference	Budget Components Provided?	Representative Years
California Department of Public Works, Division of Water Resource[1]	1933	DWR, 1933	All, various	1927 - 1932
California State Water Resources Board[1]	1956	DWR, 1956	All, various	1936 - 1951
John F. Mann and Associates	1959	Mann, 1959	All, various	1936 - 1957
California Department of Water Resources	1974	DWR, 1974a	Piru, subsurface inflow	1956 - 1967
Law/Crandall Inc.	1993	Law/Crandall, 1993	Fillmore, subsurface outflow	1956 - 1990
United States Geological Survey	2003	Reichard and others, 2003	Fillmore, subsurface outflow	1984 – 1993
CH2M HILL	2004	CH2M HILL, 2004	Piru, subsurface inflow	1980 - 1999
CH2M HILL	2005	CH2M HILL, 2005	Piru, subsurface inflow	1980 - 2005
CH2M HILL/ HydroGeoLogic Inc; HydroMetrics (United-sponsored analysis)	2008	CH2M HILL/ HGL, 2008	Piru and Fillmore, subsurface inflow	1975 - 2005
HydroMetrics (United-sponsored updates)	2015	LWA and others, 2015	All, various	1996 - 2012
Steve Bachman	2015	Bachman, 2015	Fillmore, subsurface outflow	1947 - 2014
Daniel B. Stephens and Associates, Inc/ Richard C. Slade and Associates LLC	2017	DBS&A and RCS, 2017	Fillmore and Santa Paula, various	1999 - 2012

[1]One of the predecessor agencies to California's current Department of Water Resources (DWR). DWR was formed in 1956 with legislation that simultaneously dissolved the Water Project Authority and Division of Water Resources within the Department of Public Works as well as took over duties of a reconstituted State Water Resources Board (DWR, 2020).

Table E-2: Range of water budget components for the study area's groundwater basins that were presented in previous studies listed in Table E-1. Majority of values extracted from DWR (1956) or Mann (1959), with other references being CH2M HILL (2004, 2005), CH2M HILL/HGL (2008), LWA and others (2015) and DBS&A and RCS (2017). Values rounded to nearest 10 AF.

	Piru		***Fillmore***		***Santa Paula***	
Budget Components (AFY)	*Lower*	*Upper*	*Lower*	*Upper*	*Lower*	*Upper*
Inflows						
Subsurface underflow	240	18,800	12,570	111,210	3,900	30,910
Stream Percolation	6,400	61,850	1,790	49,130	4,210	24,440
Precipitation Recharge	190	20,200	470	54,200	40	25,590
Mountain Front Recharge	2,620	2,620	3,530	3,530	3,600	3,600
Managed Recharge	0	11,800	--	--	--	--
Local Wastewater Treatment Percolation Ponds	210	210	1,040	1,040	2,230	2,230
Imported	0	5,840	4,900	11,770	4,220	8,570
Outflows						
Subsurface underflow	12,570	111,210	3,900	30,910	1,800	7,350
Rising groundwater	0	37,800	6,030	48,200	2,040	17,340
Consumptive use*	6,450	15,000	20,590	36,200	15,420	33,730
Exported	2,200	6,450	0	5,160	310	2,100
Change in Groundwater Storage*	***-19,600***	***44,600***	***-20,170***	***49,300***	***-10,900***	***21,680***

*Of applied water and precipitation on basin (including phreatophytes)

**Reported changes in annual storage (not calculated from inflows and outflows presented here)

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1 INTRODUCTION

United Water Conservation District (United) is a California special district (i.e., a public agency) with a service area of approximately 335 square miles (214,000 acres) of southern Ventura County. United's service area includes the Ventura County portion of the Santa Clara River Valley and much of the Oxnard coastal plain, including the lower part of the Calleguas Creek watershed, as shown on Figure 1-1. United serves as a steward for managing the surface water and groundwater resources within all or part of eight groundwater basins. It is governed by a seven-person board of directors elected by region, and receives revenue from property taxes, pump charges, recreation fees, and water delivery charges. United is authorized under the California Water Code to conduct water resource investigations, acquire water rights, build facilities to store and recharge water, construct wells and pipelines for water deliveries, commence actions involving water rights and water use, prevent interference with or diminution of stream/river flows and their associated natural subterranean supply of water, and to acquire and operate recreational facilities (California Water Code, section 74500 et al).

1.1 PURPOSE

This report summarizes the water budgets and hydrologic investigations of the Piru, Fillmore, and Santa Paula groundwater basins based on investigations that have taken place over the past century. The investigations described herein often included the Piru, Fillmore, and Santa Paula groundwater basins as parts of regional efforts to better understand the quantity of water resources available for current use and future planning. Other studies were motivated by water quality issues. The field investigations that took place in the earlier portion of the 20th century ultimately lead into numerical modeling development and additional field investigations that have estimated hydrologic components of the groundwater basins' water budgets over various periods of analysis.

Additionally, this report supports United's efforts in the expansion of United's active numerical groundwater flow model domain to include the remaining groundwater sub-basins of the Santa Clara River Valley within Ventura County, California. The basins are connected sub-basins in the larger groundwater system of the Santa Clara River Valley (DWR basin number 4-004), but the common vernacular is to refer to them as basins. United's groundwater flow model extension study area will include the remaining groundwater basins of the Santa Clara River Valley within Ventura County: Piru (DWR 4-004.06), Fillmore (DWR 4-004.05), and Santa Paula (DWR 4-004.04; Figure 1-2). The current effort of extending the numerical groundwater modeling builds from United's initial groundwater flow model development (UWCD, 2018) which included the coastal basins of the Santa Clara River Valley (Oxnard (DWR 4-004.02) and Mound (DWR 4-004.03)) as well as the Pleasant Valley groundwater basin (DWR 4-006) and a western portion of the Las Posas Valley groundwater basin (DWR 4-008). Following the completion of this model expansion, United's numerical groundwater flow model will include all of its direct service area as well as portions of the adjacent region.

1.2 PHYSICAL SETTING

The Santa Clara River is located in Southern California, with a total watershed area of approximately 1,625 square miles (Figure 1-3). The main channel is oriented east to west and runs approximately 83 miles from its headwaters along the northern slopes of the San Gabriel Mountains in Los Angeles County and through Ventura County until it meets the Pacific Ocean (Figures 1-2 and 1-3). The Santa Clara River is the largest river in the Southern California region that remains in a relatively natural state (Los Angeles Regional Water Quality Control Board [Regional Board], 2006). After flowing through the Santa Clarita Valley within Los Angeles County, the Santa Clara River then flows through a narrow and thin geologic constriction near the Ventura County line, where the river and minor groundwater underflow enters the Santa Clara River Valley within Ventura County. The Santa Clara River then flows down the valley through the alluvial Piru, Fillmore, and Santa Paula groundwater basins of Ventura County before entering the Oxnard and Mound basins near the Pacific Ocean.

The Santa Clara River watershed encompasses three significant tributary watersheds within Ventura County -- those of Piru, Sespe, and Santa Paula Creeks (Figure 1-3), which enter the Piru, Fillmore, and Santa Paula groundwater basins, respectively. Land surface elevations in the watershed range from sea level at the coast to nearly 8,850 feet at the headwaters of Piru Creek near the border between Ventura and Kern Counties. Much of the discharge in the Santa Clara River is derived from streamflow originating in the mountain regions drained by these tributaries. The flows within the Santa Clara River watershed is highly variable with nearly all of the flows coming during the winter and spring months.

Along the Santa Clara River Valley, the river is the primary source of recharge to the underlying groundwater basins. Beneficial users, such as agricultural, domestic, and municipal are wholly dependent upon the groundwater resources stored in the groundwater basins for their water supply, which are extracted with groundwater pumping wells. The alluvial groundwater basins of interest for this report contain about 29 miles of the main channel of the Santa Clara River and represent a total of 55,600 acres (86.8 mi^2) within Piru (10,900 acres, 17.0 mi^2); Fillmore (22,580 acres, 35.3 mi^2); and Santa Paula (22,110 acres, 34.5 mi^2).

2 PREVIOUS INVESTIGATIONS RELATED TO HYDROLOGIC DATA AND CONDITIONS

The Santa Clara River Valley has been the subject of geologic and hydrologic investigations for nearly a century now. Many of these studies included the Piru, Fillmore, and Santa Paula groundwater basins as part of regional efforts for hydrologic understanding and planning of water resources by various agencies (e.g. United Water Conservation District, Ventura County, the cities of Fillmore, Santa Paula, Ventura, and Oxnard, as well as agricultural pumpers associations). This section summarizes these previous reports relating to the Santa Clara River Valley and describes their relevance to the Piru, Fillmore, and Santa Paula groundwater basins.

2.1 VENTURA COUNTY INVESTIGATIONS

Western practices of stock-raising and small-scale agriculture were introduced to the Ventura County region following the founding of the San Buenaventura Mission in 1782 (SFEI, 2011). Prior to the 1880s, the Ventura County region predominantly supported large cattle (up to about 1864) and sheep ranchos. An extremely dry year in 1877 lead to significant losses to the sheep populations, and landowners within the region quickly transitioned to commercial agricultural land uses, which developed during the period dating from the 1880s to the 1920s (SFEI, 2011). With increased interest from landowners to turn to agriculture production for their livelihoods, increased use of groundwater brought reductions to water table elevations which caused some shallow wells to go dry. As a result of increased demand and reduced supply in the region, numerous applications for water rights were submitted to the State of California (State) in the early 1920s. Competing applications sought to appropriate water from Sespe Creek (Fillmore basin) and Piru Creek (Piru basin) and convey water out of the Santa Clara River watershed into other portions of the County. Little was known about Ventura County water resources at that time and the State reasoned that a study was required before significant water rights could be granted.

Field work for the Ventura County Investigation was initiated in August 1927 and was completed in September 1932. Findings were presented in Bulletin 46 in order to provide additional data to aid in determining the available water supply and inform decision makers at the State (California Department of Public Works, Division of Water Rights; DWR, 1933). Bulletin 46 characterized five years of records from the groundwater basins of Ventura County, including Piru, Fillmore, and Santa Paula basins, and included measurements of rainfall, streamflow, and percolation rates from various stream channels (including Santa Clara River, Piru Creek, Sespe Creek, and Santa Paula Creek) to the underlying groundwater basins (Figure 2-1). Of these five years of records, the region received unusually little rainfall in the first four years, and average to above-average rainfall in the final year.

From the surface water data that had been gathered, Bulletin 46 provided estimates of costs and yields related to potential water supply projects (storage reservoirs, spreading activities, and conveyance). The study also included a crop survey and provided statistics on irrigated area and estimated draft on storage from the groundwater basins at that time. Relating to developing a plan for the area's water supply, the report concluded that due to the extremely expensive nature of surface reservoirs, "consideration should be given to spreading work and other methods of utilizing the natural underground reservoirs prior to construction of reservoirs" (DWR, 1933; page 26). Bulletin 46 concluded that spreading works in the Montalvo (Oxnard) Forebay would be enough at that time for conservation of Santa Clara River water because spreading alone could put sufficient volumes of water into storage and was also the cheapest option (DWR, 1933; page 27). Relating to groundwater basin hydrologic budgets for Piru, Fillmore, and Santa Paula basins, Bulletin 46 presented changes in storage from fall 1927 through fall 1932 (pages 77 – 79 in DWR, 1933) and estimated consumptive use representative of the crops and land use at that time (Table 20 in DWR, 1933).

2.2 VENTURA COUNTY INVESTIGATIONS UPDATE

In 1950, the Ventura County Board of Supervisors and the Ventura County Flood Control District requested that the State Water Resources Board perform a comprehensive investigation related to the water resources of the County. In 1956, the final version of Bulletin 12 was published and provided an update to the earlier Ventura County Investigations in order to reevaluate the "water problems in the County of Ventura and the formulation of plans for their solution" (DWR, 1956). The scope of this expanded Ventura County Investigation included analysis of water quality, the replenishment and utilization of the underground water supplies, and preliminary plans and cost estimates for the development of several surface water reservoirs.

Bulletin 12 utilized previous reports and data dating back to Bulletin 46 (DWR, 1933), primarily analyzing available data from 1936 to 1951, and the newly acquired data from field investigations performed from 1951 to 1953. Additionally, Bulletin 12 identified seven groundwater basins of the Santa Clara River Hydrologic Unit as the most important in Ventura County, from an economic standpoint (Figure 2-2; Piru, Fillmore, Santa Paula, Mound, Oxnard Forebay, Oxnard Plain, and Pleasant Valley). Whereas Bulletin 46 described the area downstream of Santa Paula Basin as the Montalvo Basin (Figure 2-1), Bulletin 12 now identified that area in more detail as the Mound Basin and the Oxnard Forebay.

Consistent with earlier investigations, groundwater occurring in the Piru, Fillmore, and Santa Paula groundwater basins was classified as unconfined, with westerly and northwesterly portions of alluvium in the Santa Paula basin showing localized pressure conditions. Relating to recharge mechanisms for the unconfined aquifers, DWR (1956) identified that "the unconfined ground water basins are replenished by percolation of flow in the Santa Clara River and its tributaries, percolation of direct precipitation, artificial spreading and percolation of surface waters [Piru Creek and Santa Clara River], and by percolation of the unconsumed residuum of water applied for irrigation and other uses." DWR (1956) also identified the major mechanisms for groundwater losses from the basins as "effluent discharge to lower basins [groundwater rising to the surface and flowing as surface water downstream], by pumped extractions to meet beneficial consumptive uses, by consumptive use of phreatophytes in areas of high ground water, and by subsurface flow to lower basins."

Relevant to the water budgets for Piru, Fillmore, and Satna Paula basins, Bulletin 12 estimated detailed annual budgets for each of the groundwater basins. A summary of these results for Piru and Fillmore are presented in Tables 2-1 to 2-3, below. The time periods analyzed were the studies' base period (1936 - 1951) as well as sub-periods within the base periods that represented both wet conditions (1936 - 1944) and dry conditions (1945 - 1951). The period under consideration began and ended with the same available storage value for the Piru, Fillmore, and Santa Paula groundwater basins, resulting in zero change in storage over the analyzed period. Subsurface inflow into the Piru basin was not estimated or described in Bulletin 12.

Table 2-1. Estimated average water budget components for the Piru basin; representative average base period (1936 - 1951), wet conditions (1936 - 1944) and dry conditions (1945 - 1951) from DWR's Bulletin 12 (1956; Table 12).

Budget Components (AFY)	Average for base period (1936 - 1951)	Average for wet period (1936 - 1944)	Average for dry period (1945 - 1951)
Surface inflow	102,000	161,500	34,000
Import	1,800	1,000	2,800
Precipitation	9,600	124,00	6,200
Total inflow	**113,400**	**174,900**	**43,000**
Surface outflow	72,900	123,100	15,500
Subsurface outflow	20,600	21,100	19,900
Export	5,700	5,600	5,700
*Total consumptive use**	14,200	14,500	14,000
Total outflow	**113,400**	**164,300**	**55,100**
Change of storage over period	0	--	--
Minimum	-19,600	--	--
Maximum	44,600	--	--
Average annual storage depletion	38,410	--	--
Minimum	8,000	--	--
maximum	94,300	--	--

*Of applied water and precipitation on basin (including phreatophytes)

Table 2-2. Estimated average water budget components for the Fillmore basin; representative average base period (1936 - 1951), wet conditions (1936 - 1944) and dry conditions (1945 - 1951) from DWR's Bulletin 12 (1956; Table 13).

Budget Components (AFY)	Average for base period (1936 - 1951)	Average for wet period (1936 - 1944)	Average for dry period (1945 - 1951)
Surface inflow	176,900	290,900	46,600
Subsurface inflow	20,600	21,100	19,900
Import	5,700	5,600	5,700
Precipitation	25,800	33,500	17,000
Total inflow	**229,000**	**351,100**	**89,200**
Surface outflow	181,300	296,800	49,200
Subsurface outflow	11,500	11,500	11,500
Export	1,400	400	2,400
*Total consumptive use**	34,800	35,300	34,200
Total outflow	**229,000**	**344,000**	**97,300**
Change of storage over period	0	--	--
Minimum	-16,200	--	--
Maximum	49,300	--	--
Average annual storage depletion	17,570	--	--
Minimum	1,400	--	--
Maximum	61,000	--	--

*Of applied water and precipitation on basin (including phreatophytes)

Table 2-3. Estimated average water budget components for the Santa Paula basin; representative average base period (1936 - 1951), wet conditions (1936 - 1944) and dry conditions (1945 - 1951) from DWR's Bulletin 12 (1956; Table 14).

Budget Components (AFY)	Average for base period (1936 - 1951)	Average for wet period (1936 - 1944)	Average for dry period (1945 - 1951)
Surface inflow	209,700	342,800	57,600
Subsurface inflow	11,500	11,500	11,500
Import	1,400	400	2,400
Precipitation	18,500	24,500	11,700
Total inflow	**241,100**	**379,200**	**83,200**
Surface outflow	203,200	338,700	48,300
Subsurface outflow	7,200	7,200	7,200
Export	1,300	1,400	1,100
*Total consumptive use**	29,400	29,600	29,100
Total outflow	**241,100**	**376,900**	**85,700**
Change of storage over period	0	--	--
Minimum	-10,800	--	--
Maximum	15,600	--	--
Average annual storage depletion	9,210	--	--
Minimum	2,200	--	--
Maximum	22,600	--	--

*Of applied water and precipitation on basin (including phreatophytes)

2.3 UNITED GROUNDWATER MANAGEMENT PLAN

In the 1950s, John F. Mann, Jr. and Associates was contracted by United to conduct several investigations and provide reports (e.g. Mann, 1952; Mann, 1953; Mann, 1958). Mann (1959) synthesized available information from previous investigations and data collected by United staff and other agencies, with the following objectives:

1. "A refinement of the ground water geology of the District (United), in order to analyze the influence of the geologic complexities on ground water management;

2. A recalculation of the District's ground water inventories on the basis of the refined geologic framework;

3. A detailed study of ground water quality to spell out the influence of poor-quality waters on continued ground water development;

4. A description of the current status of sea-water intrusion, and the development of a general plan for combating it."

Mann's (1959) final report estimated potential groundwater yields from the various basins, delineated hydrostratigraphic units (HSUs), and reported on water quality problems specific to certain aquifers and locations (Figure 2-3). Concerning estimated water budgets, Mann performed similar analysis that was presented in Bulletin 12 (DWR, 1956) and previous United investigations (Wilde and Long, 1953; Kawano and Parson, 1956). These "Ground Water Inventories" were a major component of Mann's report and were based largely on the previous United investigations (Wilde and Long, 1953; Kawano and Parson, 1956), extending them over the representative time period of 1936 – 1957. The water budgets for each of the individual groundwater basins included estimates of inflows, outflows, change in storage as well as estimated available storage for each year considered. Like Bulletin 12, the period of investigation contained wet and dry variability throughout. Water budget inventories were made on a monthly basis, but annual summaries were provided for the water year for each of the water budget components that Mann (1959) included (Table 2-4).

Notably, this report described and included in their reported water budgets the occurrence of groundwater underflow between the various groundwater basins within the District, including subsurface underflow into Piru basin (DWR, 1956 did not estimate this value) as well as the occurrences of rising groundwater within the Piru, Fillmore, and Santa Paula basins. Subsurface underflow was based on available observed water level fluctuations near the basin boundaries. Related to pumping demand and water demand by natural vegetation from the groundwater basin, Mann determined the pumping demand within a basin "by applying unit consumptive use values to acreages devoted to the various crops or other uses" and also considered consumptive use by phreatophytes as part of the pumping demand. Water used in excess of this calculated demand was returned to the groundwater system.

Additionally, more detailed importation and exportation of water for each basin were included in comparison with Bulletin 12. For the Piru, Fillmore, and Santa Paula groundwater basins these considered pumping of groundwater by various entities (e.g. Newhall Land and Farming Company, California Department of Fish and Wildlife at the Fillmore Fish Hatchery, La Cienega Water Company, Southside Improvement Company, and Farmers Irrigation Company) which extracted groundwater outside of a given basin and applied within another, typically downstream, basin. In some cases, these groundwater extraction operations were previously surface water diversion operations in areas of rising groundwater near basin boundaries (e.g. Farmers Irrigation Company).

Lastly, Mann's "Plan for Ground Water Management" (1959) provided safe yield estimates, which defines "the maximum perennial rate of extraction which will not produce certain undesirable conditions," such as:

- "Lower water levels so far as to make pumping uneconomical;
- Causing a serious deterioration of water quality;
- interfering unreasonably with existing water rights."

Mann (1959) stated that to date of the report, the Piru, Fillmore, and Santa Paula groundwater basins had not yet exceeded safe yield during the historical period from 1936 – 1957 considered. Within these basins Mann considered safe yield equal to:

- "The amount of water supplied to satisfy consumptive use requirements for urban and irrigation purposes, and the draft on ground water by phreatophytes;
- Plus the total pumpage exported or surface diversions delivered to the next basin downstream;
- Minus the total imported water"

The safe yield values for Piru, Fillmore, and Santa Paula groundwater basins are provided within Table 2-4, below.

Table 2-4. Piru, Fillmore, and Santa Paula Basin's Average Annual Summary of Groundwater Inventory (AFY) representative of 1936 – 1957 (Mann, 1959).

Average Budget Components (AFY)	**Piru**	**Fillmore**	**Santa Paula**
Flood inflow	75,180	127,880	135,610
Imports	2,580	8,170	6,250
Rising water inflow	--	14,170	27,600
Underflow inflow	240	17,200	5,400
Total inflow to basin[1]	**78,000**	**167,420**	**174,860**
Rainfall penetration	4,070	10,010	5,630
Stream percolation	30,410	24,680	15,420
Artificial spreading	5,140	--	--
Total to groundwater basin[1]	**39,860**	**51,890**	**26,450**
Net consumptive use requirement	8,750	25,140	19,340
Net extraction from groundwater basin	5,520	17,890	13,580
Underflow out	17,200	5,400	1,800
Rising water outflow	14,170	29,040	11,340
Export	3,860	980	580
Total from groundwater basin[2]	**40,750**	**53,310**	**26,720**
Flood outflow	44,770	117,370	147,390
Total outflow from basin[1]	**85,520**	**170,680**	**174,110**
Annual change of storage	**-900**	**-1,420**	**-270**
Minimum[3]	-17,770	-20,170	-10,900
Maximum[3]	44,530	42,970	21,680
Annual available storage	**55,050**	**38,250**	**12,330**
Minimum[3]	12,320	5,380	4,420
Maximum[3]	103,220	91,700	27,330
Safe Yield	**12,600**	**23,100**	**18,500**

[1]Total inflow and outflow to and from each basin/groundwater basin were calculated as the sum of the components inflowing or outflowing

[2]Total from gw basin = Net extraction from gw basin + Underflow out + Rising water outflow + Export

[3]All values are average annual values except for minimum and maximum components related to storage

2.4 VENTURA COUNTY COOPERATIVE INVESTIGATION

As awareness of saltwater intrusion increased, other water quality issues and concerns about long-term water reliability grew within the Oxnard plain. DWR and the Ventura County Flood Control District entered into a cooperative agreement to conduct additional investigations to provide comprehensive studies of geology, hydrology, water quality, and operation-economics of the major groundwater basins within the county (DWR, 1976). These studies would: 1) provide an update to the data compiled in DWR's Bulletin 12 (DWR, 1956) and 2) support development of numerical modeling for regional water resources management planning purposes. The study area included the Piru, Fillmore, Santa Paula, Mound, Oxnard Plain and Forebay basins associated with the Santa Clara River, as well as Las Posas, Pleasant Valley, and Arroyo Santa Rosa Valley (Santa Rosa) basins within the Calleguas Creek watershed. This update was released in two volumes that contained a compilation of various Technical Information Records prepared by Ventura County Department of Public Works' Flood Control and Drainage Department staff (Mukae and Turner, 1975) and DWR staff (DWR, 1975). Mukae and Turner (1975) performed and presented geologic studies that reviewed previous reports, water-well logs, and oil- and gas-well logs to update geologic maps and cross-sections. DWR (1975) presented hydrologic, operational, and economic studies, some of which included new and reinterpreted evaluations of groundwater and surface-water parameters for much of the study area (Figure 2-4). DWR used the data compiled by these investigations (Mukae and Turner, 1975; DWR, 1975) to develop numerical modeling that would be used for future water resources management planning (DWR, 1974a,b), described in Section 3.1, below. The results of these investigations were then summarized in DWR Bulletin 104-8 (DWR, 1976).

2.5 USGS SANTA CLARA RIVER VALLEY INVESTIGATIONS

Beginning in the late 1980s and extending through the 1990s, the United States Geological Survey (USGS) performed investigations within the Santa Clara River and Calleguas Creek watersheds in cooperation with UWCD, The Fox Canyon Groundwater Management Agency and Calleguas Municipal Water District. This cooperative effort also helped to support the USGS' Southern California investigation as part of their Regional Aquifer-System Analysis program (RASA; Sun and Johnston, 1994). Several studies were conducted that focused on data collection and analysis of regional groundwater conditions (Izbicki and others., 1995; data collected from 1989 - 1993), seawater intrusion in the coastal plains (Densmore, 1996; data collected 1989 – 1995), and interactions between groundwater and surface water along the Santa Clara River Valley (Densmore and others, 1992; Reichard and others, 1999; data collected in 1991 and between 1993 – 1995, respectively). Reichard and others (1999) measured discharge and water quality during several time periods that included both base flows as well as conservation releases from Lake Piru (Figure 2-5). In addition to surface water measurement, a monitoring site was installed (RP1) in the Piru basin, about 8,000 ft downstream of the confluence of Piru Creek and the Santa Clara River. The RP1 site consists of five wells which were screened at various intervals below the land surface in order to understand the vertical gradients at that location within the region. Co-located with this well site was a drive point piezometer within the stream bed of the Santa Clara River that provided an estimate of the changes in the stream stage. Continuous monitoring of water levels within the drive point piezometer and the shallow aquifer well at RP1 (RP1-5; perforations at the interval of 50 – 70 feet below land surface) allowed for analysis of the gradients and interaction between the surface water and the groundwater. The USGS report summarized "…the groundwater system and stream-aquifer interactions along the Santa Clara River," and included additional technical discussion of the observed hydrologic conditions (e.g., rising groundwater at subbasin boundaries, correlations of water quality with surface water flow magnitudes, interaction between various aquifers) in the Santa Clara River Valley (Reichard and others, 1998).

2.6 UWCD BASIN CONDITIONS REPORTS

With the USGS well installations and RASA program data collection ending by the mid-1990's, United expanded their own monitoring programs. These efforts continue and have increased over time, and include measuring groundwater elevations in wells, collecting water quality samples from a lessor number of wells, measuring surface water discharge, and collecting surface water samples for water quality analysis (e.g. UWCD, 2017). As water wells have come in and out of operation across the basins, United has revised their program to expand and enhance the monitoring network for increased spatial and temporal resolution. These data collection efforts have supported numerous studies performed by United to better understand the movement of water and change of conditions within the eight groundwater basins within the District's boundaries (Piru, Fillmore, Santa Paula, Mound, Oxnard Forebay, Oxnard Plain, Pleasant Valley, and West Las Posas).

Related to Piru and Fillmore groundwater basins, United helped to prepare a Groundwater Management Plan for the Piru and Fillmore Basin Groundwater Management Planning Council, which represented United, the City of Fillmore, and the Pumpers of the Piru and Fillmore basins (Piru and Fillmore Groundwater Planning Council, 1996). Following this, United produced an Annual Groundwater Conditions Reports from 1997 to 2009 (e.g. UWCD, 1997 and 2010) and Biennial Groundwater Conditions Reports from 2010 to 2015 (e.g. UWCD, 2013, 2015, and 2016). These Fillmore and Piru reports were produced to support water resource initiatives and activities, and summarized recent data related to basin location and dimensions, hydrogeology, precipitation, groundwater recharge and surface flows, reservoir releases, groundwater pumping, groundwater elevations, surface water quality, groundwater quality. Specific topic of interest included Santa Clara River Chloride Total Maximum Daily Load (TMDL) requirements, wastewater reclamation plant discharges, landfills, conditions near the basin boundaries and changes in agricultural land uses over time.

Related to Santa Paula basin, United has produced a *Santa Paula Basin Annual Report* each year since 1997 (e.g. UWCD, 1998, 2019a, and 2020) as a requirement of a 1996 stipulated judgement by the Superior Court of the State of California for the County of Ventura. The judgement established pumping allocations for the Santa Paula basin (United Water Conservation District vs. City of San Buenaventura, original March 7, 1996, amended August 24, 2010). The judgment requires annual reports summarizing results of the monitoring program, and further specifically provides that "United Water Conservation District shall have the primary responsibility for collecting, collating, and verifying the data required under the monitoring program, and shall present the results thereof in annual reports to the Technical Advisory Committee" (UWCD, 2018).

3 PREVIOUS INVESTIGATIONS RELATED TO NUMERICAL MODELING DEVELOPMENT

Several numerical modeling efforts have taken place within Ventura County that focused on the groundwater basins associated with the Santa Clara River and the Calleguas Creek watersheds. The efforts began in the late 1960s and early 1970s, with the initial focus primarily being the coastal plain basins and concerns related to seawater intrusion. However, once modeling tools were developed along the coast, efforts pushed up the Santa Clara River Valley groundwater basins. The following sections briefly detail each of the numerical modeling efforts as well as detail and discuss water budget components that were estimated for the Piru, Fillmore, and Santa Paula groundwater basins.

3.1 CALIFORNIA DEPARTMENT OF WATER RESOURCES

The earliest numerical groundwater flow model of the aquifers underlying the Santa Clara River Valley and Oxnard coastal plain was completed in the early 1970s by DWR. The groundwater flow model developed (DWR, 1974a) used a digital Thiessan-Weber Polygon superposition methodology (adaptation of DWR software, reference not available) that was combined with a newly developed solute-transport model (DWR, 1974b). This work was summarized in Bulletin 104 (DWR, 1976). A total of 158 grid nodes were used for the study area (Figure 3-1) and each represented areal extents ranging from hundreds of acres to several thousand acres. The Piru, Fillmore, Santa Paula, Mound, Las Posas, Pleasant Valley, and Arroyo Santa Rosa Valley basins were simulated using a single layer, and the Oxnard Plain and Forebay basins were simulated using two layers.

The numerical modeling simulated historical transient hydraulic and water-quality conditions for the verification period from the spring of 1957 to the spring of 1967 using 201 time-steps. The model was calibrated using measured groundwater elevations over the entire time period. As part of the calibration process, recharge, transmissivity, and storage coefficients were adjusted to obtain better matches between measured and simulated groundwater levels. Using the calibrated model, DWR selected five management alternatives for analysis over a time period representing the years 1970 – 2020, for the purpose of long-term regional water resources planning (DWR, 1976).

The detailed documentation of the numerical modeling developed by DWR for this investigation (DWR, 1974 a,b) provided some water budget information, but was often presented as net inflows into the modeling sub-domains. The one relevant piece of information related to water budgets of groundwater basins was the estimation of approximately 245 AFY of subsurface underflow into Piru basin representative from 1957 – 1967 (DWR, 1974a; Table 14).

3.2 UNITED STATES GEOLOGICAL SURVEY

In parallel with their data collection efforts of the late 1980s (Section 2.5 above), the USGS also initiated a major numerical modeling effort of the regional alluvial-aquifer systems of the Santa Clara River and Calleguas Creek watersheds. This study of the hydrogeology of the Santa Clara-Calleguas watersheds was completed as part of the Southern California Regional Aquifer-System Analysis (RASA) program (Sun and Johnston, 1994). The regional groundwater system in southern Ventura County was selected as a representative southern California basin for study, with cultural practices and hydrogeologic processes common to other basins or groups of basins.

3.2.1 GROUNDWATER SURFACE WATER OPTIMIZATION STUDY

The first local modeling effort by the USGS (Reichard, 1995) focused on the current study area groundwater basins as part of the Santa Clara River and adjacent region (Figure 3-2). This study was an extension of the original DWR modeling described in Section 3.1, above (DWR, 1974a,b; 1976). The USGS developed a stochastic simulation-optimization model and used it to analyze a hypothetical 15-year planning period for the Santa Clara - Calleguas basin beginning in October 1989. In order to do so, Reichard (1995) applied the hydrogeological data that was included in the original digital Thiessan-Weber Polygon to be used with the USGS's recently-developed groundwater flow modeling code, MODFLOW (McDonald and Harbaugh, 1988). Like the original DWR modeling, this work simulated the multiple aquifers of the region using one or two model layers. The Upper Aquifer System (UAS) was the only layer represented in the Piru, Fillmore, Santa Paula, and Mound basins. The Lower Aquifer System (LAS) was the only layer represented in the Las Posas, Pleasant Valley, and Arroyo Santa Rosa Valley basins. The Oxnard Plain and Forebay basins were simulated with both the UAS and LAS present. Model cells were 0.5 mile x 0.5 mile in extent, and the system was modeled assuming heterogenous, isotropic confined flow in both layers. Previously simulated water levels representing 1967 (DWR, 1976) were used to represent initial conditions for a six-year transient simulation (using annual stress periods) from 1984 to 1989. The initial simulation used average measured pumping and artificial recharge over the simulated period. The final water level elevations from the six-year transient simulation were then used as initial conditions for Reichard's stochastic simulation-optimization modeling over the 15-year planning period which was constrained to meet demands (pumping and pipeline deliveries) across 13 "water-demand sectors" representative of 1984 – 1989 conditions on an annual basis. Reichard's (1995) work included uncertainty using probability distributions of streamflow within the Santa Clara River available for diversion and artificial recharge, and presented allocation alternatives for the region that optimized groundwater and surface water management strategies to satisfy the demands and minimize seawater intrusion.

3.2.2 RASA MODEL

Building upon Reichard's (1995) work, the USGS published a significant numerical modeling update for the Santa Clara River and Calleguas Creek watersheds in 2003 (Hanson and others, 2003; commonly referred to as "the USGS RASA model" due to its contribution to the USGS' RASA program). The domain was again discretized into 0.5 mile x 0.5 mile cells which included the Piru, Fillmore, Santa Paula, Mound, Oxnard Plain, Oxnard Forebay, Pleasant Valley, Santa Rosa, East Las Posas, West Las Posas, and South Las Posas basins, and extended farther offshore than the previous regional modeling domains (Figure 3-3). The USGS RASA model was also constructed using their groundwater flow modeling code, MODFLOW (McDonald and Harbaugh, 1988), but this time included two layers across the entire modeling domain in order to represent UAS and LAS aquifers within each basin (Figure 3-4). The USGS RASA model simulated the UAS as unconfined within the Piru, Fillmore, and Santa Paula basins, as well as the Oxnard Forebay, the Northeast Oxnard Plain, Las Posas Valley, and parts of Santa Rosa Valley (Figure 3-4, blue shaded area labeled as subareas with valley-floor recharge). In all other areas UAS aquifers were simulated as confined, and all basin LAS layers were simulated as confined. Additional modeling packages were included in order to simulate routing of streamflow (Prudic, 1989), land subsidence (Leake and Prudic, 1991), and faults as horizontal-flow-barriers to groundwater flow (Hsieh and Freckleton, 1993).

In the upper basins of the Santa Clara River Valley (Piru, Fillmore, and Santa Paula), data from shallow wells (depths less than 50 feet) were noted to have had higher observed water levels than water levels observed in nearby wells completed within the same upper aquifer system, but deeper in comparison (note: there are very limited wells this shallow). The USGS RASA report (Hanson and others., 2003; Page 69) commented that this "may indicate some degree of hydraulic separation between the Shallow (recent alluvium) aquifer and the underlying aquifer along the Santa Clara River." Observed water levels within the UAS of the Santa Paula and Piru basins were observed to be 10 – 25 feet higher than water levels in the LAS, which illustrates downward vertical gradients within those basins. Calibration within the Piru, Fillmore and Santa Paula basins were dependent on about a dozen wells across the LAS (4) and UAS (9) (Hanson and others., 2003; Page 99, Figures 13, 14, 15, and 21). This split between the targets available in the UAS and LAS calibrations was likely due to the availability of drilled wells being skewed toward shallower depths, given the relatively higher water-table and water production capacity of wells within those basins.

The USGS RASA model investigation included results from three model runs: one "historical" model and two "forward" model simulations to represent projected future groundwater conditions. The historical model scenario was simulated from 1891 – 1993 using estimated and reported pumping for agricultural, municipal and industrial users as well as estimated and measured streamflow and diversions. The historical model was used for calibration, with targets of estimated historical surface-water flows and measured groundwater levels during the period from 1891 –

1993. The years 1984 – 1993 were the only period when reported pumping records were available for most of the model domain. The initial conditions for transient calibration were derived from predevelopment steady-state conditions, which were considered adequate when having water levels of 40 to 50 feet above sea level near the coast, based on early hydraulic conditions previously reported (Freeman, 1968). The 103-year transient model simulation used 3-month stress periods in order to represent season changes, and 12 equal time-steps for each stress period in order to represent seasonal variability. Hydrologic budget components were estimated in the report, however, many were representative of the entire SCR-Calleguas domain, rather than detailed budgets for each basin. The Fillmore and Piru groundwater basins were often lumped with Santa Paula for analysis of the Santa Clara River Valley basins as a unit.

Following calibration efforts, the model was used to project future groundwater flows and to evaluate several alternatives to future groundwater flow, including six proposed water-supply projects. These future assessments were not focused on the upper basins, but rather were related to overdraft in the coastal basins and assessing the risk of increased seawater intrusion. The primary forward model scenario was based on historical hydrologic records for the years 1970 – 1993 in order to simulate a 24-year projection of future groundwater flows representing the years 1994 – 2017. The historical record period (1970 – 1993) contained 13 “dry” and 11 “wet” years, and the average wet and average dry pumping and streamflow values across the entire period were used for each individual wet and dry year, accordingly. In addition to the primary forward modeling approach, another approach was used for a 44-year projection of future groundwater flows representative of 1994 – 2037, that used statistical and time-series signal processing of long-term historical annual precipitation totals (1905 – 1993) in order to estimate precipitation into the future.

3.3 MODELING UPDATES SPONSORED BY UWCD

The USGS RASA model (Hanson and others., 2003) described in the previous section was an outcome of decades of geologic and hydrologic investigations within the Santa Clara River and Calleguas Creek watersheds. However, its use of only two model layers to represent the multiple aquifers within the UAS and LAS was a simplification that limited the degree to which it could be calibrated. This limitation prevented it from being able to evaluate impacts of future pumping/recharge scenarios on specific aquifers, particularly in coastal areas impacted by seawater intrusion.

Following the completion of the USGS RASA model, United went on to support subsequent efforts intended to further refine and enhance the model in order to apply it for better regional understanding and planning of water resources. These efforts extended over a period of about seven years in which United supported three different organizations for model updates and refinements, including:

- ETIC Engineering (2002 to 2006)
- CH2M HILL (early 2006)
- HydroMetrics: (mid 2006 – 2008)

The various refinements and modifications from the USGS RASA model were noted in the *Groundwater Management Plan* for the Fox Canyon Groundwater Management Agency (FCGMA and others, 2007), including:

- Refinement of cell size from 1/2 mile x 1/2 mile to 1/6 mile x 1/6 mile for the alluvial basins
(Figure 3-5, this report).
- Reduction in grid size. In the original USGS RASA model only 28% of the grid cells were active and in the modified model 47% of grid cells were active (ETIC, 2003).
- Extension of the historical and forward model to include 1994 to 2000 hydrology.
- Addition of a zone of lower hydraulic conductivity in the Lower Aquifer System extending in a linear trend from the Camarillo Hills to Port Hueneme.
- Addition of a third layer in the Piru, Fillmore and Santa Paula basins to better simulate the more permeable alluvium along the Santa Clara River, Sespe Creek, Santa Paula Creek and Piru Creek. In other words, this partitioned the UAS into two-separate UAS layers.
- Recalibration of the Forebay and Oxnard Plain portions of the model over the period 1983 to 1998 to better reflect the increased diversions and recharge that had occurred in this area since the USGS originally calibrated the model (HydroMetrics, 2006).
- Expansion of the forward model period to a full 55 years to reflect the climate and hydrology of the years 1944 to 1998. This period was a commonly-used base period because it starts and ends in very wet years, spans several dry cycles, and represents zero cumulative departure for rainfall across the period.

- Refinement of time discretization from 3-month stress periods to 1-month stress periods (using 300 time-steps per stress period).

As the various revisions and updates were completed, the regional groundwater flow model was used for several local studies related to proposed water projects and management strategies (FCGMA and others, 2007):

- Oxnard Plain LAS and UAS overdraft analysis – UWCD (2001)
- GREAT Project EIR – UWCD and City of Oxnard
- Las Posas Basin ASR project operations – Calleguas MWD
- City of Fillmore water supply planning – UWCD and City of Fillmore
- Pleasant Valley AB303 grant study – UWCD
- Fox Canyon Groundwater Management Agency Groundwater Management Plan – UWCD and FCGMA

3.4 LOWER SANTA CLARA RIVER SALT AND NUTRIENT PLAN

A consultant team consisting of Larry Walker Associates, in association with HydroMetrics, Carollo Engineers, Rincon Consultants, and Dr. Norm Brown (affiliated with University of California, Santa Barbara) prepared the Lower Santa Clara River (LSCR) Salt and Nutrient Management Plan (SNMP) under the direction of the Ventura County Public Works Agency's Watershed Protection District (LWA and others, 2015; Figure 3-6). The purpose of the SNMP was to understand the potential impacts of increased future use of recycled water upstream and within the basins containing the LSCR. The plan was created in order to satisfy the requirement set by the State Water Resources Control Board (State Water Board) following the State Water Board's adoption of the Recycled Water Policy (State Water Resources Control Board Resolution No. 2009-0011) in February 2009, which required the development of regional or sub-regional SNMPs for groundwater basins within California.

3.4.1 LSCR SNMP GROUNDWATER BASIN WATER BUDGETS

The LSCR SNMP provides the most recent summary of the water budgets for the Piru, Fillmore and Santa Paula groundwater basins based on numerical modeling. Because the area included in the LSCR SNMP is almost entirely dependent on groundwater for water supply, the SNMP was focused on sources and sinks related to the groundwater basins. The consultant team leveraged HydroMetrics' experience with the previous modeling updates supported by United, and as well as work HydroMetrics performed for United to acquire numerical modeling output from other entities relating to fluxes into and between the basins of the groundwater basins (see Section 4.2).

The hydrologic numerical modeling supporting the SNMP was based on the primary forward modeling run and relevant modifications of the USGS RASA model (Hanson and others, 2003) sponsored by United and described in Section 3.3, above. In the model, the Piru, Fillmore, and Santa Paula basins have three layers, with layers 1 and 2 defining the UAS and layer 3 defining the LAS (LWA and others, 2015, Section 7.1.2). The results represent surface water modeling and groundwater modeling over 17 total water years (WYs), from 1996 - 2012. Climatic statistics were calculated based the United-sponsored forward modeling run (see section 3.3) using 1944 – 1998 data. Each WY from 1996 – 2012 was then classified as wet, dry, or average, and forced with the values calculated from the historical climatic data accordingly. These transient groundwater flow results were then used to inform a steady-state mass balance model which calculated groundwater concentrations for certain salts the UAS each year, using surface water inflows and outflows and groundwater flow data available over the 1996 – 2012 simulation period. Each groundwater basin was divided into various subdomains in calculating the annual steady-state concentrations, and estimated flows were adjusted for each year to maintain equilibrium (inflows approximately equal to outflows). Results presented in this report are the average values of each water budget component considered, as summarized below in Tables 3-1 to 3-3 for the Piru, Fillmore, and Santa Paula groundwater basins.

Table 3-1. Piru Basin Salt and Nutrient Management Plan Water Budget; Average values of Water Years 1996 – 2012 (LWA and others, 2015; Tables 7-3, 7-4, and 7-5).

INFLOW	Component	RATE (AFY)
GW Flows	Upper Santa Clara River Aquifer Underflow	360
Non-Land Use Surface Flows	Managed Recharge	1150
	Precipitation Recharge	1990
	Santa Clara River and Tributaries	60670
	Mountain Front Recharge	2620
Land Use Surface Flows	Ag irrigation with SW	1240
	Ag irrigation with GW	2760
	Water Treatment Percolation Ponds	210
	Septic Systems	67
OUTFLOW		
GW Flows	Seepage to Santa Clara River	1990
	GW production	9210
	Upper Aquifer Underflow to Fillmore basin	10480
	Net Lower Aquifer Underflow to Fillmore basin[1]	25220

Table 3-2. Fillmore Basin Salt and Nutrient Management Plan Water Budget; Average values of Water Years 1996 – 2012 (LWA and others, 2015; Tables 7-6, 7-7, and 7-8).

INFLOW	Component	RATE (AFY)
GW Flows	Piru Upper Aquifer Underflow to Filmore Basin	10480
	Net Lower Aquifer Underflow to Fillmore[1]	25220
Non-Land Use Surface Flows	Precipitation	9170
	Santa Clara River and Tributaries	12470
	Mountain Front Recharge	3530
Land Use Surface Flows	Municipal irrigation	230
	Ag irrigation with GW	9480
	Water Treatment Percolation Ponds	1040
	Urban irrigation recycled water	50
	Septic Systems	210
OUTFLOW		
GW Flows	Underflow to Santa Paula Basin	16990
	Seepage to Santa Clara River	14420
	GW production	39470

Table 3-3. Santa Paula Basin Salt and Nutrient Management Plan Water Budget; Average values of Water Years 1996 – 2012 (LWA and others, 2015; Tables 7-9, 7-10, 7-11, and 7-12).

INFLOW	Component	RATE (AFY)
GW Flows	Santa Paula Aquifer Underflow from Fillmore Basin	16,990
Non-Land Use Surface Flows	Precipitation	8,770
	Santa Clara River and Tributaries	1,370
	Mountain Front Recharge	3,600
Land Use Surface Flows	Municipal irrigation	960
	Ag irrigation with GW	7,310
	Water Treatment Percolation Ponds	2,230
	Ag irrigation with SW	90
	Septic Systems	180
OUTFLOW		
GW Flows	Underflow to Oxnard Forebay Aquifer	8,090
	Underflow to Mound Aquifer	1,010
	GW production	41,040

4 PREVIOUS INVESTIGATIONS DETAILING SUBSURFACE UNDERFLOW ESTIMATES

In addition to the studies that focused on all three of the study area groundwater basins, there have been several investigations and numerical modeling efforts that have focused on: 1) The Santa Clara River Valley East basin, located directly upstream of the Piru basin and 2) the Santa Paula groundwater basin, with work related to technical support and resulting management and updates following adjudication of the basin. The following sections will provide some background related to the studies and detail the relevant water fluxes that were estimated by those studies.

4.1 SANTA CLARITA VALLEY REGIONAL GROUNDWATER FLOW MODELING

The Santa Clarita Valley Regional Groundwater Flow Model (SCVRGFM) was developed as part of the work of scope contained in an August 2001 Memorandum of Understanding that was signed by the Upper Basin Water Purveyors in the Santa Clarita Valley of Los Angeles County and by United Water Conservation District in Ventura County. The final numerical model documentation was completed in April 2004 (CH2M HILL, 2004). This modeling effort used MicroFEM (Hemker and de Boer, 2003), a finite-element numerical modeling tool for the groundwater modeling. MicroFEM was used to calibrate and simulate a steady-state model over the calendar years 1980 – 1985, which provided the initial conditions to a transient model that was calibrated and simulated over the calendar years 1980 – 1999. The modeling extended over the Santa Clara River Valley East groundwater basin (Figure 4-1). The relevant information from this work related to the downstream Piru groundwater basin is the estimated groundwater underflow that moves between the basin near the Los Angeles/ Ventura County Line. The SCVRGFM estimated the groundwater underflow across the county line using a specified head boundary (805 feet) in the alluvial aquifer material based on groundwater elevation contours interpreted by Richard C. Slade (1986, 2002; using spring 2000 water table elevations). Estimates of subsurface underflow entering across the Los Angeles/ Ventura County Line for the steady-state and the transient model simulations are shown in Table 4-1, below. There are believed to be issues in the assumption made during this investigation that considered hydrogeologic conditions east of the Los Angeles/ Ventura County Line to be the same at the USGS County Line gage, where streamflow was compared. Because of this, subsurface underflow at the County Line and surface flows at the USGS County Line gage were essentially presented as being co-located, which is now understood to be problematic (Figure 4-2). For that reason, we present the underflow results from this investigation as being representative as the underflow entering across the Los Angeles/ Ventura County Line. These differences are described in more detail in Section 4.4. Lastly, streamflow was simulated in this investigation at the USGS County Line gage and monthly discharges were compared with observational records. Annual streamflow out of the modeling domain were not presented alone in the investigation's water budget summary, but as part of "total discharge", which included all discharge to the Santa Clara River, evapotranspiration, subsurface outflow, and pumping.

Table 4-1. Subsurface underflow at County Line related to initial Santa Clarita Valley regional groundwater flow modeling (CH2M HILL, 2004).

Model Run	Period	Subsurface underflow (AFY)
Steady-State	1980 - 1985	6,600
Transient, minimum	1980 - 1999	6,520
Transient, maximum	1980 - 1999	7,017
Transient, average	1980 - 1999	6,703
Transient, median	1980 - 1999	6,657

A calibration update to the SCVRGFM occurred within the following year (CH2M HILL, 2005), which extended the modeling period by a little more than 5 years for validation purposes. The original simulation period of January 1980 – December 1999 became a simulation period of January 1980 – February 2005. This revised transient simulation resulted in updated estimates of subsurface flow at the county line, which are shown in Table 4-2, below. From this update, subsurface underflow at the Los Angeles/ Ventura County Line increased nearly three-fold. As part of the calibration update, changes in the boundary condition representing underflow into their domain at the eastern portion of their model boundary were reported and a previously neglected underflow component from the upstream Acton basin was introduced following additional field visits along the Santa Clara River channel. This underflow component was estimated to be a considerable volume (average of 16,538 AFY from 1980 – 2005), which appears to have propagated down-gradient and significantly increasing in the estimated subsurface underflow outflowing downstream into Ventura County.

Table 4-2. Subsurface underflow at the County Line related to updated Santa Clarita Valley regional groundwater flow modeling (CH2M HILL, 2005).

Model Run	Period	Subsurface underflow (AFY)
Transient, minimum	1980 - 2005	18,059
Transient, maximum	1980 - 2005	18,802
Transient, average	1980 - 2005	18,324
Transient, median	1980 - 2005	18,315

4.2 UPPER SANTA CLARA RIVER TRANSPORT MODELING

Following finalization of SCVRGFM reports mentioned above, development of a new hydrologic model was completed for the eastern portions of the Santa Clara River watershed that would allow for improved simulation of the interaction between groundwater and surface water (CH2M HILL/HGL, 2006 and 2008). This work focused on simulating the fate and transport of chloride and total dissolved solids throughout the Santa Clara River Valley East groundwater basin, the Piru groundwater basin, and extended slightly into the Fillmore groundwater basin (Figure 4-3). This new effort was motivated by requirements set by the Los Angeles Regional Water Quality Control Board to perform several major studies related to a Total Maximum Daily Load for chloride within the Santa Clarita Valley. One of these major studies included the need to develop a Groundwater/Surface-water Interaction Model (GSWIM) in order to assess long-term impacts in the Piru basin.

For the GSWIM modeling effort, CH2M HILL collaborated with HydroGeoLogic, Inc. (HGL) and used a hydrologic modeling code called MODHMS (HGL, 2006). MODHMS was based on the USGS' MODFLOW model and was developed and enhanced by HGL in order to conduct simulations of fully-integrated groundwater and surface-water flow (including saturated and unsaturated flow) and solute transport. The model calibration started with a steady-state simulation using January 1975 for average boundary conditions (groundwater elevations, streamflow locations, and solute concentrations) throughout the modeling domain (CH2M HILL/HGL, 2008, Task 2B-1, Section 3.5). The steady-state groundwater elevation solution was then used as initial conditions for a transient integrated groundwater and surface water simulation over calendar years 1975 – 2005. Initial calibration was performed using monthly stress periods and without considering chloride concentrations, but the final calibration was performed using daily stress periods which allowed comparison of daily streamflow discharge rates and chloride concentrations to calibration targets. After GSWIM was calibrated at the daily temporal resolution, the model was used to simulate future scenarios in order to evaluate potential future basin conditions given the anticipated future loads of chloride and total dissolved solids within the watershed.

Like the previous Santa Clarita Valley modeling described in Section 4.1 above, the relevant groundwater information from this work that relates to the downstream Piru groundwater basin is the estimated groundwater underflow that moves between the basin near the Los Angeles County/Ventura County line. The results of calibrated underflow coming across the county line were not explicitly detailed within the numerical modeling report for this work (CH2M HILL and HGL, 2008). United contracted HydroMetrics to review the numerical modeling effort and report. As part of that analysis HydroMetrics requested additional data from the CH2M HILL team regarding the flow, both surface and subsurface, across the county line and into the Piru groundwater basin. From that work, HydroMetrics reported to United that the CH2M HILL/HGL numerical model simulated most of the water flux across the county line occurred as surface water, with relatively little water flowing into the Piru groundwater basins as subsurface flow within the underlying alluvium surrounding the streambed (Figure 4-4; HydroMetrics, 2008). Though not calculated by HydroMetrics, the plot referenced here suggests the CH2M HILL/HGL numerical modeling estimated annual average subsurface flow into the Piru groundwater basin at approximately 1,084 AFY. This value was computed for this document using an average daily value of 1.5 cfs for subsurface flow within the alluvium (from Figure 4-4) and converting that to AFY (1 cfs equates to approximately 1.98 AFD; 365 days within 1 year).

Additionally, HydroMetrics noted that the simulated surface water flows showed a good match with measured flows, but with slight overprediction during low-flow periods (Figure 4-5). If the overall estimate of flow in the Blue Cut area is correct, this overprediction of streamflow during summer baseflow periods could mean that actual subsurface flow in this area was less than what was simulated within the CH2M HILL/HGL (2008) numerical modeling.

During CH2M HILL/HGL's GSWIM model development, it was determined that United's numerical model used an estimated value of approximately 2,000 AFY flowing into the Piru groundwater basin as subsurface flow (CH2M HILL/HGL, 2006; Table C-1). Additionally, The USGS RASA model (2003) only specified stream inflow and mountain-front recharge into Piru basin and did not explicitly state that subsurface underflow from the Santa Clarita Valley was included.

4.3 SANTA PAULA SAFE YIELD

The Santa Paula groundwater basin is located downstream of the Fillmore basin. Several past studies have investigated hydrologic budget components within the Santa Paula basin, with the USGS numerical model and United-sponsored modifications thereafter providing the only estimates from numerical groundwater models.

The first report that documented the subsurface outflow from Fillmore basin to Santa Paula basin in the context of adjudication and legal decision making was the *Water Resources Evaluation Santa Paula Ground Water Basin Ventura County, California* (Law/Crandall, 1993). This report used wells near the basin boundaries which had corresponding water level measurements for most of the period 1973 – 1987. Using observed well tests for aquifer properties and hydraulic gradients, Darcy's Law was used to calculate the estimated average subsurface flow from the Fillmore basin to the Santa Paula basin as 3,914 AFY for the period 1956 – 1990. These methods were very similar to previous methods used by DWR (1956) and Mann (1959), and the report briefly mentioned subsurface outflow from Santa Paula basin and agreed with Mann (1959) that "the average subsurface outflow through the recent river deposits is approximately 1,800" AFY, mentioning that it was "consistent with their estimates of the transmissivity, outflow area, and local gradient."

The most-recent report that estimated the subsurface outflow from Fillmore basin to Santa Paula basin was the *Santa Paula Basin Hydrogeologic Characterization and Safe Yield Study Ventura County, California* (DBS&A and RCS, 2017). This report used observed well test results for hydraulic conductivity for both the undifferentiated alluvium and the more consolidated San Pedro Formation, as well as observed groundwater elevations from 2000, 2010, and 2013 to calculate groundwater flux using Darcy's Law (Figure 4-6). From this analysis, the average subsurface flow from the Fillmore basin to the Santa Paula basin was estimated to be 25,244 AFY. Within this report they also present the findings of a similar study from Bachman (2015), which estimated groundwater flux across the same basin boundary area to be 19,700 AFY. DBS&A and RCS (2017) also reported estimated subsurface outflow from the Santa Paula basin to be 7,349 AFY, using similar methodology to Santa Paula basin subsurface inflow calculation.

4.4 SUMMARY OF SUBSURFACE UNDERFLOW ESTIMATES

For the purpose of comparison, this section summarizes the previously estimated subsurface underflow budget components. Previous estimates of subsurface underflow into Piru groundwater basin ranges from 240 AFY to 18,300 AFY (Table 4-3). Previous estimates of subsurface underflow into Fillmore groundwater basin ranges from 17,200 AFY to 39,300 AFY (Table 4-4). Previous estimates of subsurface underflow into Santa Paula groundwater basin ranges from 3,900 AFY to 25,200 AFY (Table 4-5). Previous estimates of subsurface underflow out of Santa Paula groundwater basin ranges from 1,900 AFY to 9,100 AFY (Table 4-6).

Table 4-3: Summary of previous estimates made by various entities relating to average annual subsurface underflow into Piru groundwater basin

INFLOW (AFY)	Representative Years	Source
240	1936 – 1957	Mann, 1959
245	1957 – 1967	DWR, 1974a
6,703	1980 - 1999	CH2M HILL, 2004
18,324	1980 - 2005	CH2M HILL, 2005
2,084	1986 - 2000	UWCD (presented in CH2M HILL/HGL, 2006)
1,084	1975 - 2005	HydroMetrics (2008) review of CH2M HILL/HGL (2008)
360	1996 - 2012	SNMP (HydroMetrics), 2015

Table 4-4: Summary of previous estimates made by various entities relating to average annual subsurface underflow into Fillmore groundwater basin

INFLOW (AFY)	Representative Years	Source
20,600	1936 - 1951	DWR, 1956
17,200	1936 – 1957	Mann, 1959
44,287	1975 - 2005	CH2M HILL/HGL, 2008
35,700	1996 - 2012	SNMP (HydroMetrics), 2015

Table 4-5: Summary of previous estimates made by various entities relating to average annual subsurface underflow into Santa Paula groundwater basin

INFLOW (AFY)	Representative Years	Source
11,500	1936 - 1951	DWR, 1956
5,400	1936 – 1957	Mann, 1959
3,900	1956 - 1990	Law/Crandall, 1993
16,990	1996 - 2012	SNMP (HydroMetrics), 2015
19,700	1947 - 2014	Bachman, 2015*
25,244	1999 – 2012	DBS&A and RCS, 2017**

*Representative years weighted using of wet (2005), average (2010), and dry (2012) years, respectively, using spring and fall conditions for each

**Average value derived from representative median (2000), 75th percentile (2010), and 25th percentile (2012) water years, respectively, based on precipitation from rain gauges located in Saticoy and Ventura over the hydrologic base period of 1999 – 2012. Minimum value reported was 22,320 AFY and maximum value reported was 30,909 AFY.

Table 4-6: Summary of previous estimates made by various entities relating to average annual subsurface underflow out of Santa Paula groundwater basin

OUTFLOW (AFY)	Representative Years	Source
7,200	1936 - 1951	DWR, 1956
1,800	1936 – 1957	Mann, 1959
1,800	1956 - 1990	Law/Crandall, 1993
9,100	1996 - 2012	SNMP (HydroMetrics), 2015
7,350	1999 – 2012	DBS&A and RCS, 2017**

**Average value derived from representative median (2000), 75th percentile (2010), and 25th percentile (2012) water years, respectively, based on precipitation from rain gauges located in Saticoy and Ventura over the hydrologic base period of 1999 – 2012.

The various investigations described in the previous sections of this report all represented various time periods over the last century, and because of that we expect to see differences due to natural variability in water inputs into the systems as well as systematic changes in certain inputs (such as increased flows from Los Angeles County waste water due to increased development).

Related to the range of estimated inflowing subsurface underflow values reported for Piru basin, there is a significant issue in comparing these values because different studies estimated subsurface underflow at different locations. Most of the values were representative of flows entering into previous Piru basin boundary (Mann, 1959), prior to DWR's 2003 update (DWR, 2003) and the most recent 2019 modifications (DWR, 2019; Figure 4-7). The CH2M Hill (2004 and 2005) numerical modeling estimates are the only estimates affected by this discrepancy because of where their investigation terminated. An important concern related to the presentation of the CH2M Hill (2004 and 2005) underflow estimates is that the investigators made the assumption that the hydrogeologic conditions several miles east of the Los Angeles/ Ventura County Line also represented the conditions in an around the County Line gage (Figure 4-2). In fact, the Los Angeles/ Ventura County Line is located approximately 2/3-mile approximately upstream from the USGS County Line streamflow gage.

For context, when the CH2M Hill (2004 and 2005) projects were conducted, there was no groundwater well information in the County Line area and groundwater well data from several miles into the eastern groundwater basin within Los Angeles County was used to inform aquifer thickness in Ventura County. With subsequent investigations conducted related to the data gap in the County Line gage area (e.g. Geomatrix, 2006; CH2M Hill/HGL, 2008), thickness of water-bearing aquifer material within the County Line gage location was approximated to be 10 feet at the gage location. United staff estimate the thickness of water-bearing aquifer material increases to approximately 30 feet in the Newhall gage area where more groundwater well information is known (Figure 4-7). Therefore, the CH2M Hill (2004 and 2005) reported subsurface underflow values are likely largely overestimated for subsurface underflows at the County Line gage, but good initial estimates for subsurface underflow at the Los Angeles/ Ventura County Line as well as the recently updated Piru basin boundary (Figure 4-7).Following the field investigations near the County Line gage location, the CH2M HILL/HGL (2008) estimate into the Piru basin boundary (Mann, 1959) is believed to be the best approximation for the historical basin boundary given that additional information was known in the vicinity of the USGS County Line gage as well as the fact that no numerical model boundary conditions were located near this area of interest to affect estimates.

Related to the range of estimated inflowing subsurface underflow values reported for Fillmore basin, the estimates for the average have variability that could be explained by the various time periods examined. The CH2M Hill/HGL (2008) estimates ranged from 23,345 AFY to 111,205 AFY, with the upper range representative of 2005, which was an extremely wet year. The implementation of a specified head boundary condition that completed their modeling domain was located just downstream of the Piru and Fillmore basin boundary and set to a constant elevation of 10 feet below the surface of the Santa Clara River channel. Their subsurface underflow estimate should also be viewed as having potential issues because the proximity of the boundary condition to the water budget component of interest as well as the implementation of a specified head boundary condition which could be influencing the gradient across the basin to conditions that are not present during a given wet or dry period. Specifically, the upper value of 111,205 AFY of subsurface underflow during 2005 is likely to be greatly overestimated because the specified head boundary just downstream of this boundary creates a sink that results is a large amount of water draining out of the Piru basin when really the basins would be extremely full during this exceptionally wet period.

Finally, related to the range of estimated inflowing and outflowing subsurface underflow values reported for Santa Paula basin, the estimates for the averages have variability that could be explained by the various time periods examined. Although more recent numerical modeling estimates are not available to detail these components, Bachman (2015) and DBS&A and RCS (2017) did both look at these values during more recent time periods, and produced similar results in line with earlier estimates.

5 GROUNDWATER BASIN BOUNDARY MODIFICATIONS

This section briefly describes and illustrates recent changes to the DWR groundwater basin boundaries. The historical boundaries that have been used in the previous studies discussed in this report differ from the new boundaries. A comparison of the new basin boundaries to the older boundaries is warranted, as the most recent boundaries will be used in upcoming and future numerical modeling reports from United and the GSAs in their reporting to DWR for the Piru, Fillmore, and Santa Paula basins.

5.1 BACKGROUND AND MODIFICATIONS

The groundwater basin boundaries for the Piru, Fillmore, and Santa Paula basins were first presented in DWR's Bulletin 46 (1933). DWR (1956) updated these and Mann (1959) refined the basin boundaries presented by DWR (1956). Most of the studies previously discussed in this report utilized these Mann (1959) boundaries, or close variations, for their own studies and water budget component estimates (Mann, 1959; Hanson and others., 2003; LWA and others, 2015).

Figure 5-1 shows the groundwater basin boundaries that have historically been used by United and others during investigations along the Santa Clara River within Ventura County. These basin boundaries are all largely based on the delineation presented by Mann (1959). DWR updated their basin boundaries in 2003 (DWR, 2003) , which saw: 1) the expansion of Piru basin to include lower Piru Creek as well as extend east toward the Ventura/Los Angeles County line, 2) expansion of Fillmore basin up the hillslopes where aquifer material outcrops beyond the extent of alluvial deposits, and 3) expansion of Santa Paula basin up the hillslopes where aquifer material outcrops and to include Santa Paula Creek. The update to Santa Paula basin aligned it more closely, but not exactly, with the settlement boundary (see Section 2.6).

With the development of the GSA and defining their boundaries, DWR revised their Bulletin 118 groundwater basin boundaries from 2003 (DWR, 2003) and released the updated extents for review and requests for modifications in 2016 (DWR, 2016). Local agencies that were in the process of forming the GSAs for those basins were tasked with reviewing the revised DWR boundaries and submit requests for modifications. DWR was to accept modifications that were either scientifically or jurisdictionally motivated and based on relevant geologic and geographic data. Two separate rounds of modifications (2016 and 2018) were used by DWR to finalize the extents of the forming GSAs groundwater basin boundaries in February of 2019 (DWR, 2019).

For the Fillmore and Piru basins, United played the lead role in the analysis and submission of requests for modifications to the updated boundaries. Mound Basin GSA requested modifications for the shared boundary between the Santa Paula and Mound basins. Four notable modifications were made relating to the connection between these basins: 1) Scientific Internal modification of the Fillmore Basin and Piru subbasins, which better reflected the location of hydrologic connection manifested at the surface between the Fillmore and Piru basins (rising groundwater into the Santa Clara River); 2) Scientific External modification along the northern and southern portions of the Fillmore and Piru subbasins boundaries, which edited some misplaced geologic contacts as well as included alluvial deposits running upward in various canyons that drain into the basins; 3) a Jurisdiction Internal modification of the Santa Paula and Fillmore subbasins boundaries, which aligned the western end of the Fillmore Basin with the stipulated judgment boundary of the Santa Paula Basin; 4) a Jurisdiction Internal modification of the Mound and Santa Paula subbasins boundaries, which aligned the eastern end of the Mound subbasin with the stipulated judgment boundary of the Santa Paula Basin The formal documentation of the accepted modifications requests can be found on the DWR website at (last accessed: November 2020):

https://sgma.water.ca.gov/basinmod/modrequest/preview/191

and

https://sgma.water.ca.gov/basinmod/modrequest/preview/230

A comparison of the representative previous basin boundaries (Mann, 1959) to the current and official basin boundaries (DWR, 2019) can be seen in Figure 5-1 and Table 5-1, below.

Table 5-1: Piru, Fillmore and Santa Paula groundwater basin boundary modifications areal comparison

Groundwater Basin Area (acres)			
	Mann (1959)	DWR (2019)	% increase
Piru	7,201	10,896	51
Fillmore	18,497	22,583	22
Santa Paula	14,205	22,110	56

From the DWR 2003 update and the 2019 modifications to the DWR boundaries, there was a noticeable increase in size for the Piru, Fillmore, and Santa Paula groundwater basins when compared to the Mann (1959) delineations. As mentioned above, the Piru basin increase was largely due to the inclusion of lower Piru Creek. The Fillmore basin increase was primarily from the extension of the groundwater basin up into areas of alluvial deposits at the base of the mountain slopes, including Timber Canyon to the north, and areas where the Saugus Formation outcrops along the margins of the basin. However, due to changes in the groundwater basin areal extents, future basin-specific hydrologic budgets will also be different compared to all previous investigations due to changes in total inflows, outflow, and available storage. Santa Paula's increase was a combination of the extension of the groundwater basin up into alluvial deposits at the base of the mountain slopes as well as the inclusion of Santa Paula Creek on the north, and where the San Pedro/Saugus Formation outcrops. Along the valley floor the DWR (2019) Piru/Fillmore boundaries were modified to align with the Mann (1959) delineation. Likewise, the DWR (2019) Fillmore/Santa Paula and Santa Paula/Mound basin boundaries were also were modified to align with the Mann (1959) delineation, which also coincides with the Santa Paula settlement boundary (see Section 2.6) that relied on Mann's work.

5.2 WATER BUDGET IMPACTS

With the majority of previous modeling efforts and reported water budgets based on analysis of the Piru, Fillmore, and Santa Paula basins as delineated by Mann (1959), water budgets that are estimated moving forward using the DWR (2019) basin boundaries are expected to have some differences. As mentioned above, the DWR (2019) modifications adjusted the previous DWR basin boundaries for the Piru/Fillmore shared boundary (scientific internal modification), Fillmore/Santa Paula shared boundary (jurisdiction internal modification) and the Santa Paula/Mound shared boundary (jurisdiction internal modification). These modifications brought the shared boundaries to coincide with those that Mann (1959) delineated, which allows for no changes moving forward at the boundary compared to most previous studies for these basins.

Several water budget components that would be expected to increase with the expanded basin boundaries include: 1) increased areal recharge from precipitation and applied water from groundwater and surface water sources, 2) increased groundwater extractions, and 3) increased groundwater and surface water exchange with the inclusion of creek deposits. As mentioned in the section above, the largest changes in these basins occurred by adding deposits underlying Creeks (Lower Piru Creek and Santa Paula Creek) as well as including the furthest extent of the outcrop and alluvial deposits extending up the hillslopes. With Mann's basin delineations having captured most of the water bearing and productive alluvial deposits and underlying aquifers along the valley floor, the effect on overall water budgets in not expected to be much from the additions. Relating to the addition of the creeks, Piru Creek is expected to have some groundwater and surface water interaction. Santa Paula Creek was previously believed to be a source of recharge for the Santa Paula basin, but more recent analysis has suggested that changes in the channel from flood control projects in the late 1990s have potentially reduced the recharge within Santa Paula Creek to be very minor (UWCD, 2013, 2019b). Relating to the addition of the hillslope alluvial deposits, not much change impact is expected from these additional areas because the water sources and uses within these areas were previously included in previous studies (estimated recharge from the hillslopes) or are minor (only a handful of wells are located in these higher elevation areas). As mentioned above, additional applied water will be included for these areas that were previously not considered to be within part of the groundwater basins, and the applied water is in some cases sourced from small creek diversions that capture storm flows draining from the northern hillslopes.

A significant change in the water budget estimates due to basin boundary changes between Mann (1959) and DWR (2019) is expected to be the location of Piru Creek's eastern basin boundary near the Ventura/Los Angeles County Line and the impacts it has on the underflow estimates moving from the Eastern basin into Piru basin. With the underflow estimates increasing substantially when Mann's Piru basin boundary was moved to the east for the DWR update (2003) and modifications (2019) because the water-bearing material is much thicker at the Ventura/Los Angeles County Line location compared to the previous boundary locations where alluvial deposits of limited depth and width are present. This was Piru basin change was detailed in Section 4.4, above.

6 OTHER NOTABLE CHANGES TO CONSIDER

As Section 5 details, Mann (1959), or very similar, basins boundaries were used for many of the studies from the 1950s through the more recent, which helps in the comparison of values. However, land use changes have occurred within the groundwater basins since the periods that the DWR (1956) and Mann (1959) reports considered (1937 – 1957), which affect water budgets in these basins and must be considered when comparing results from investigations during later periods. Several changes include: 1) the construction of Santa Felicia Dam on Piru Creek and related water conservation activities, 2) moderate urbanization and development within the groundwater basins, 3) changes in agricultural practices (e.g. crop changes, crop locations, and available water efficiency technology), and 4) significant urbanization and development within upstream Santa Clara groundwater basins.

Another change over time and perhaps the most systematic change that has affected Piru, Fillmore, and Santa Paula groundwater basins average annual water budgets components following construction of Santa felicia Dam is related to base flows arriving from the Eastern basin in Los Angeles County. Beginning in 1980, State Water Project water was imported to the eastern Santa Clara River Valley groundwater basin, augmenting local groundwater resources to meet increasing water demands by extensive urbanization. Large portions of this increased water use have historically been discharged as treated wastewater effluent into the Santa Clara River, resulting in increased streamflow and subsurface underflow entering Piru basin, compared to periods prior to 1980. The increased in water use upstream could explain the increase from about 240 AFY estimated in DWR (1956) and Mann (1959) to approximately 1100 AFY in CH2M HILL/HGL (2008) numerical modeling (HydroMetrics, 2008; analysis for United) for underflow near the Mann (1959) eastern Piru basin boundary. As such, changes in water use and demand upstream in Los Angeles County (e.g. increased development, potential increased recycled water) is expected to affect the water budgets of Piru and the remaining downstream groundwater basins within Ventura County.

7 SUMMARY AND CONCLUSIONS

Extensive efforts by various entities have provided foundational knowledge of the hydrology of the Piru, Fillmore, and Santa Paula groundwater basins as well as provided detailed datasets and estimates of various water budgets components for each basin. Table E-1 summarizes the hydrologic investigations which contributed water budget components related to the groundwater basins that make up the current study area. Table E-2 summarizes the range of reported water budget component values for each of the groundwater basins which were presented in the previous hydrologic studies that are listed in Table E-1.

The majority of the values presented in Table E-2 were extracted from DWR (1956) or Mann (1959), with other primary sources being CH2M HILL (2004, 2005), CH2M HILL/HGL (2008), LWA and others (2015) and DBS&A and RCS (2017). Values of lower and upper ranges were sourced from all the investigations reported. Each of the reports used for this review are representative of varying, sometimes overlapping, climatic periods and conditions (Table E-1). Since the values reported from DWR (1956) and Mann (1959) provided the most complete summaries of water budgets, most of the lower and upper bounds of the reported range for many of the components, presenting the results in this way is considered appropriate, and helpful, for comparison purposes.

In relation to United's efforts in the expansion of United's active numerical groundwater flow model, reviewing all available previous water budget component estimates helps during the numerical modeling development and calibration in order to ensure values of water budget components from the new model are reasonable. Additionally, it highlights where less information is known from a quantitative perspective and where additional monitoring and/or coordination with neighboring agencies can help further inform during the development process. With this review of previous water budgets estimates, United staff is continuing its ongoing numerical groundwater model expansion efforts that will support United's ability of regional water management planning, with the most immediate need satisfied through supporting local GSAs in developing GSPs.

Based on this review, United offers the following conclusions related to the previous studies and reported water budgets for the Piru, Fillmore, and Santa Paula groundwater basins:

- There are extensive previous studies available for these basins that were based on field, analytical, and numerical studies, dating back to the 1920s (Table E-1).
- The most significant inflows to each basin consist of recharge from streamflow (Santa Clara River) percolation, areal recharge from precipitation and applied water from groundwater and surface water sources, and incoming subsurface underflow from upstream groundwater basins.
- The most significant outflows to each basin consist of groundwater extractions for beneficial use and outgoing subsurface underflow to downstream groundwater basins.
- With the Santa Clara River (SCR) being the largest source of recharge (especially for Piru and Fillmore Basins), these basins are highly variable due to the dependence on local

rainfall within the SCR watershed. This variability and dependence on surface water inflows leads to the large range observed in the previously reported water budget components (Table E-2). This dependence to surface water flows is expected to continue in the future, resulting in variable water budgets of similar ranges.

- Basin boundary modifications have recently been adopted that expanded the extent of the Piru, Fillmore, and Santa Paula groundwater basins. The majority of the studies reviewed for this document utilized boundaries that captured most of the water-bearing and productive alluvial deposits and underlying aquifers along the valley floor, and the overall effect on the ranges for many of the water budget components is not expected to be significant. Changes to the upstream extent of the Piru basin will however result in an increase in the subsurface underflow into Piru basin from the east. This value is expected to increase using the Department of Water Resources (DWR, 2019) boundary moving forward due to the substantial increase in saturated aquifer thickness near the Los Angeles County line compared to the downstream locations used in previous studies. The increased area will also result in increased recharge to the underlying aquifers due to precipitation.

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FIGURES

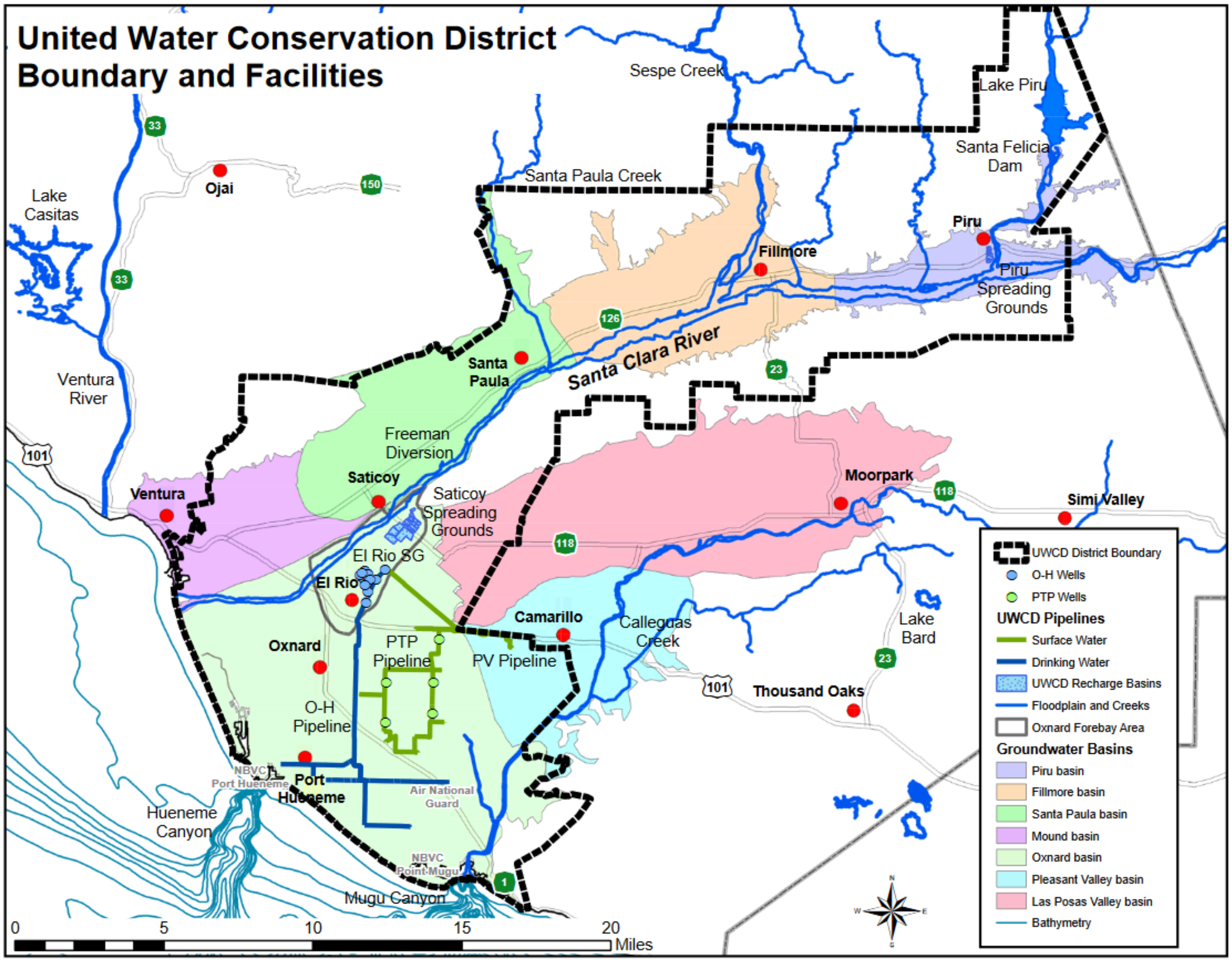

Figure 1-1. United's district boundaries, major recharge and conveyance facilities and groundwater basins.

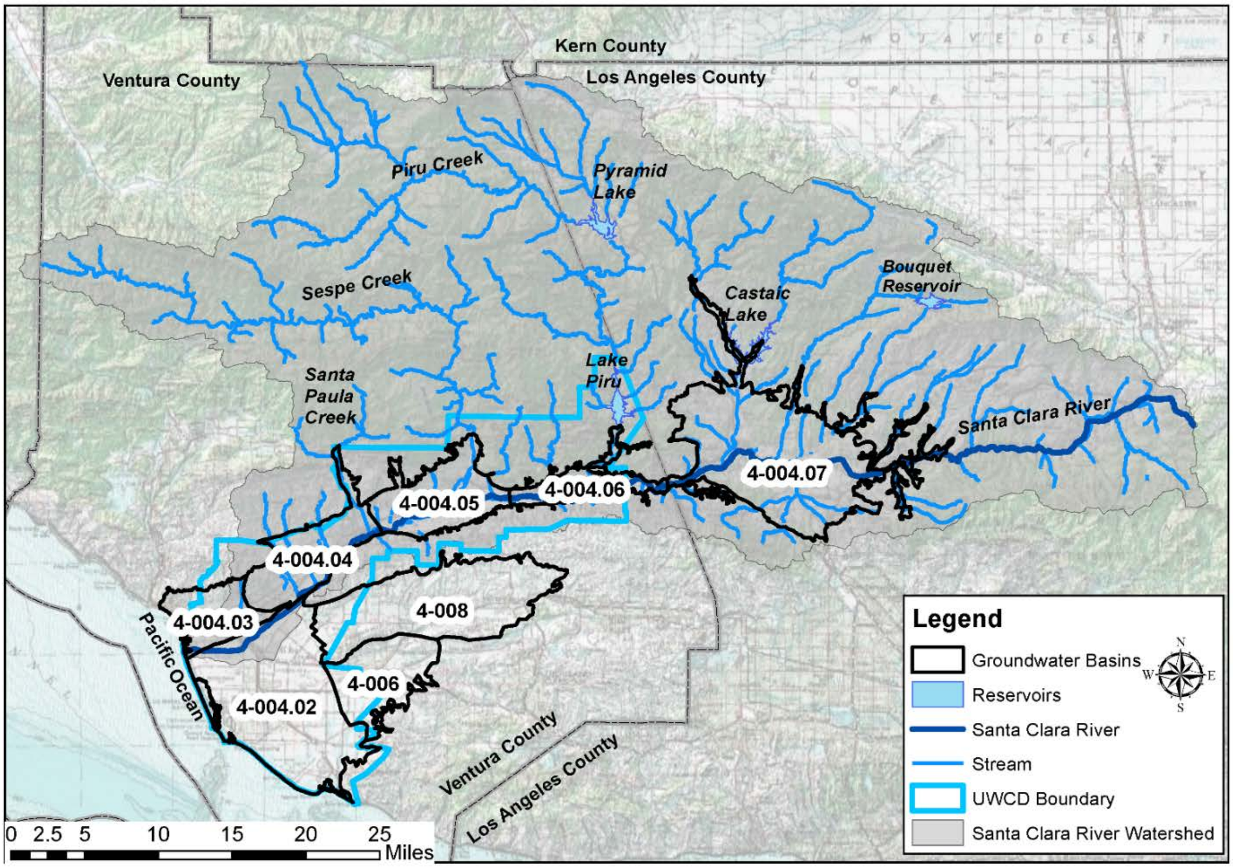

Figure 1-2. Study area and adjacent basins, with California Department of Water Resources groundwater basin boundary numbering.

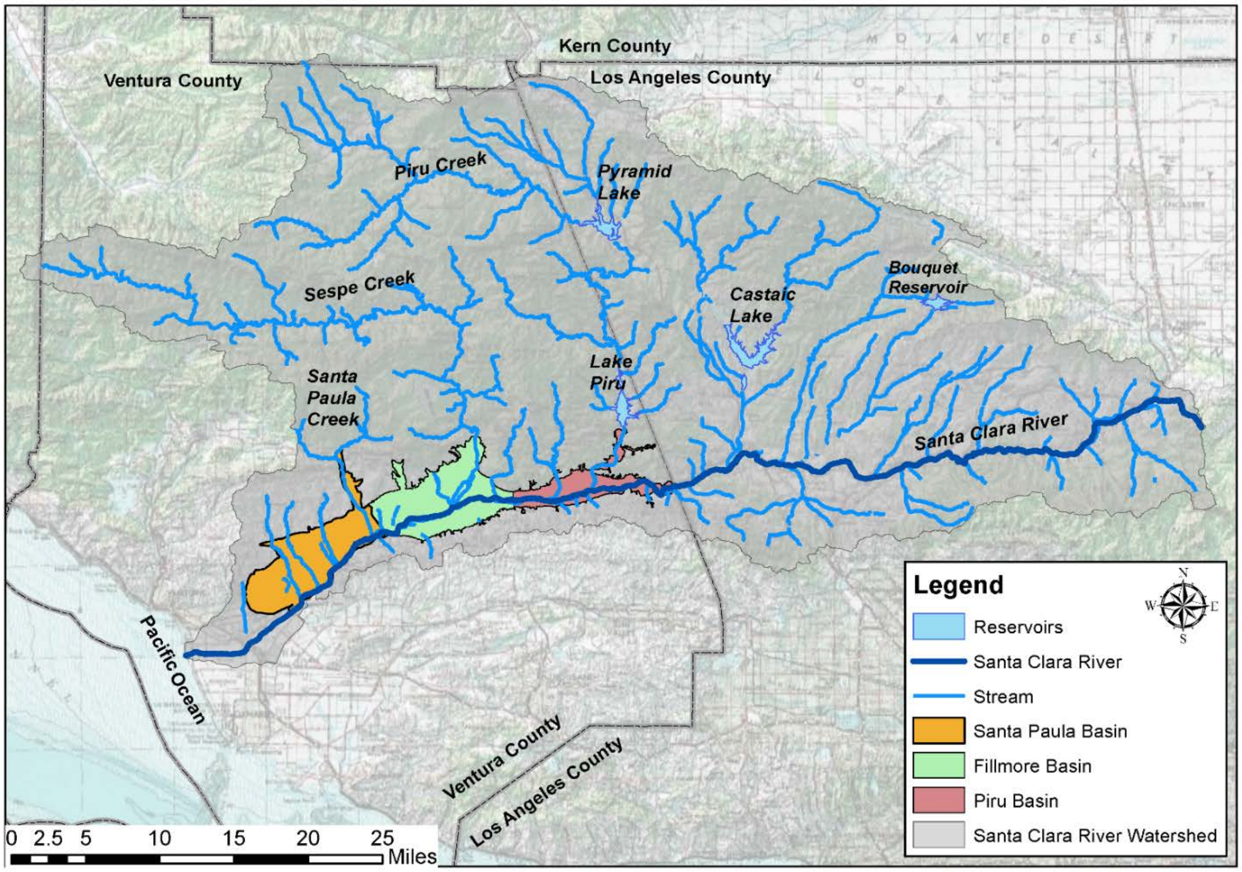

Figure 1-3. Watershed of the Santa Clara River, and the Piru, Fillmore and Santa Paula groundwater basins.

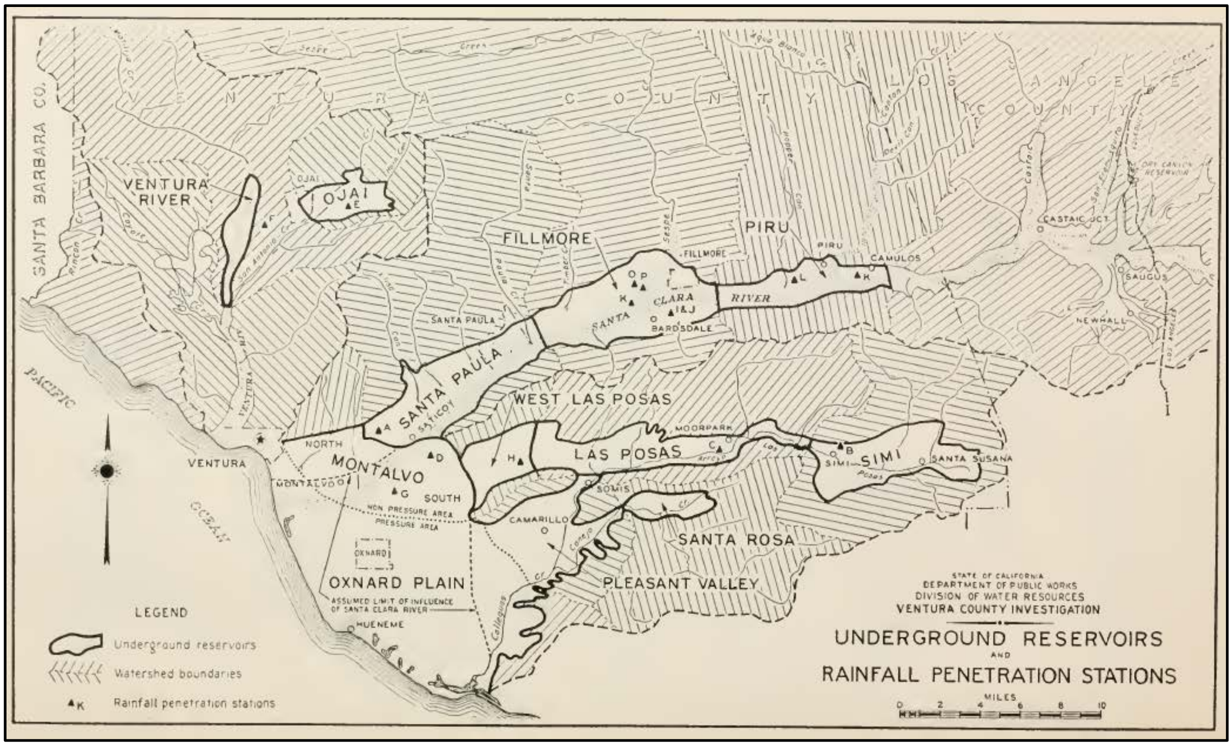

Figure 2-1. Underground reservoirs and rainfall penetration stations as of 1932 (DWR 1933, Plate 1).

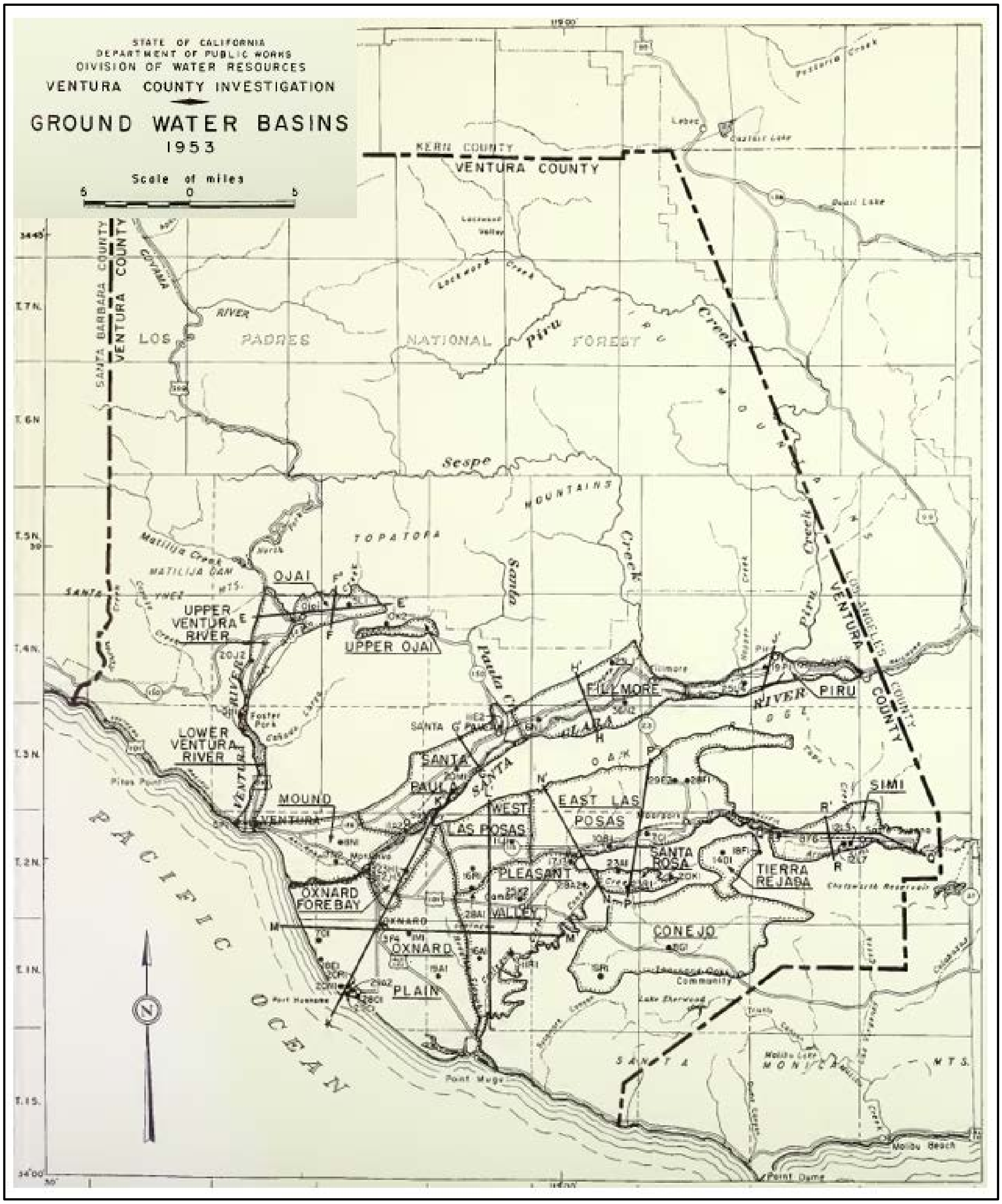

Figure 2-2. Ventura County groundwater basins as of 1953 (DWR, 1956, Plate 11).

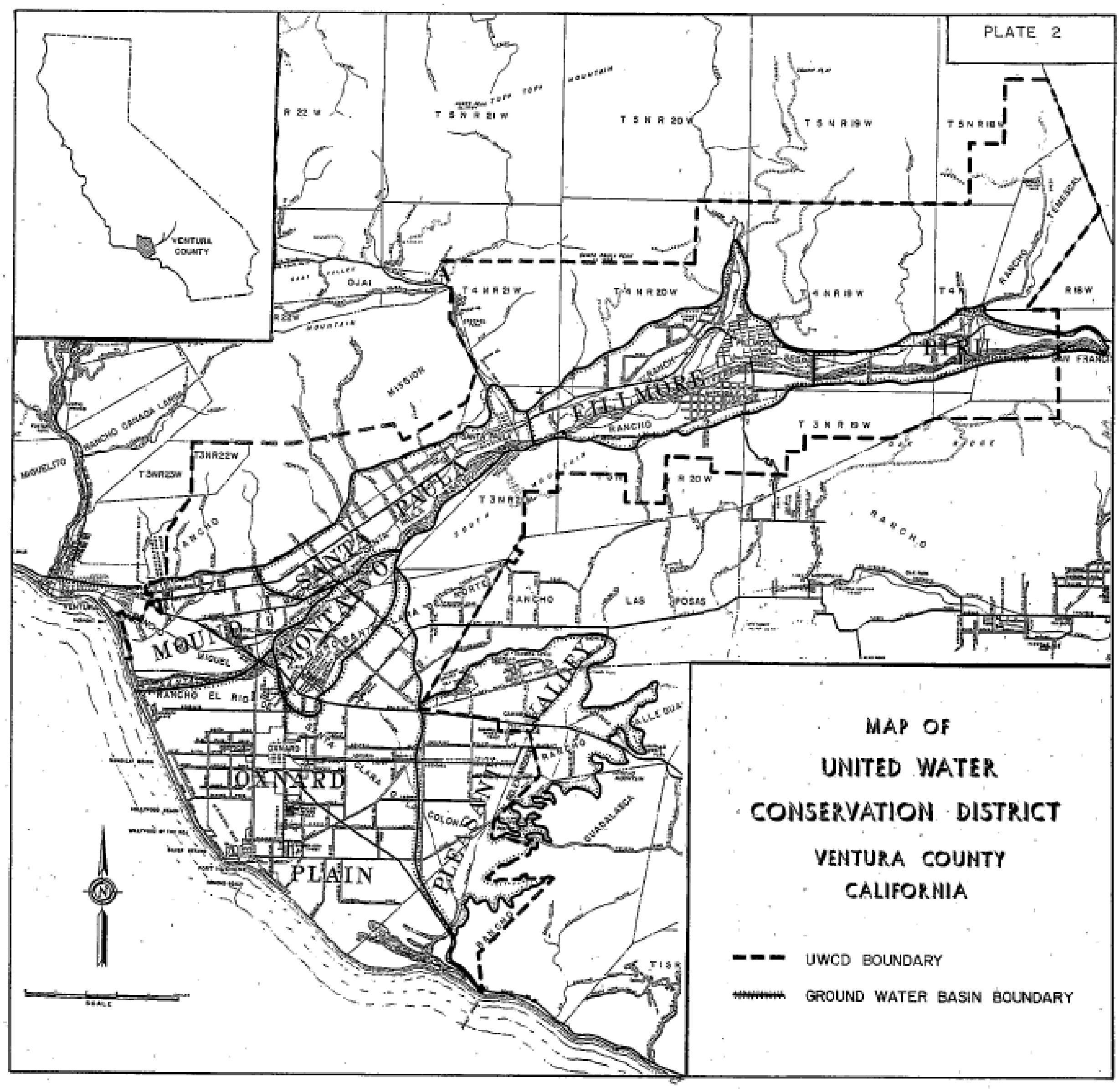

Figure 2-3. Map of United Water Conservation District and groundwater basins as described by (Mann, 1959; Plate 2). *Note: "Oxnard Forebay" groundwater basin presented in Bulletin 12 (DWR, 1956) is called "Montalvo." Like Bulletin 12, Mound basin is now identified.*

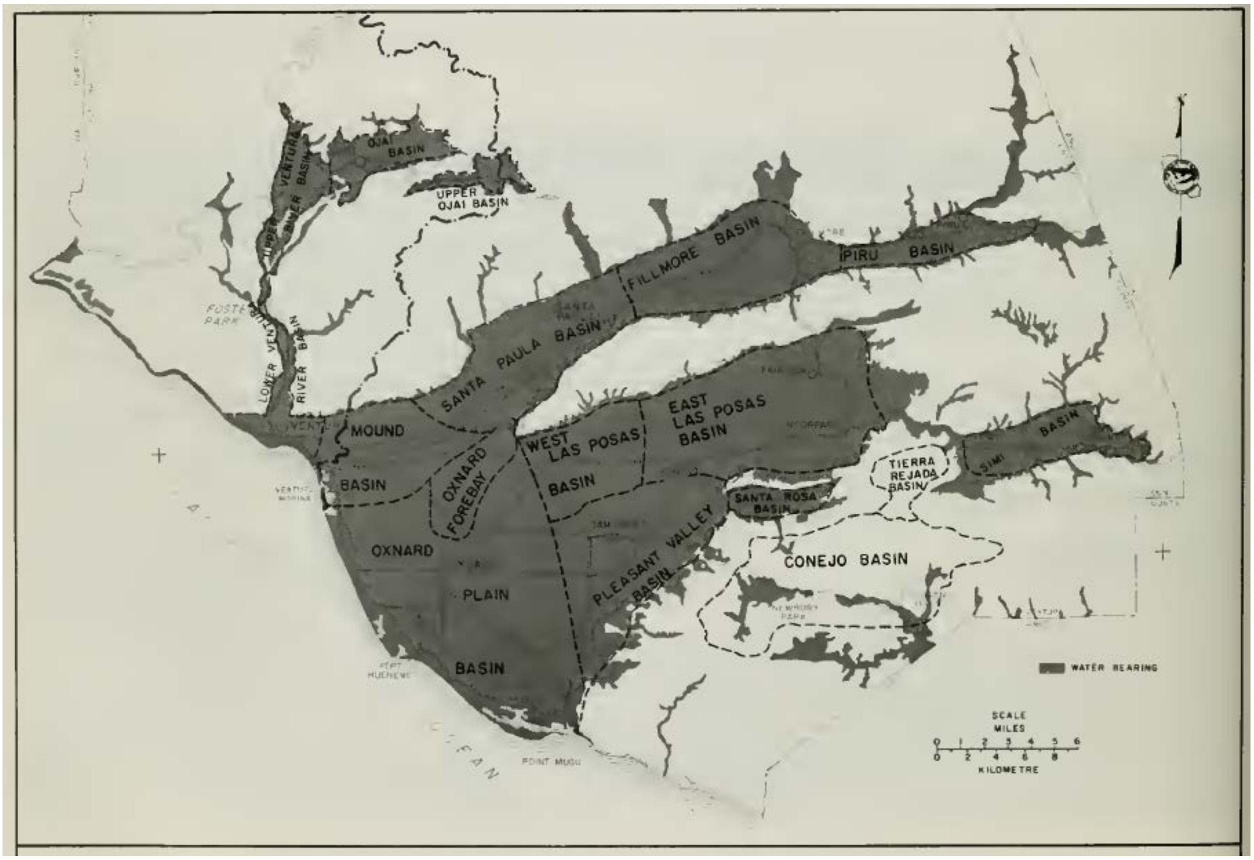

Figure 2-4. Groundwater basins (DWR, 1976; Figure 8).

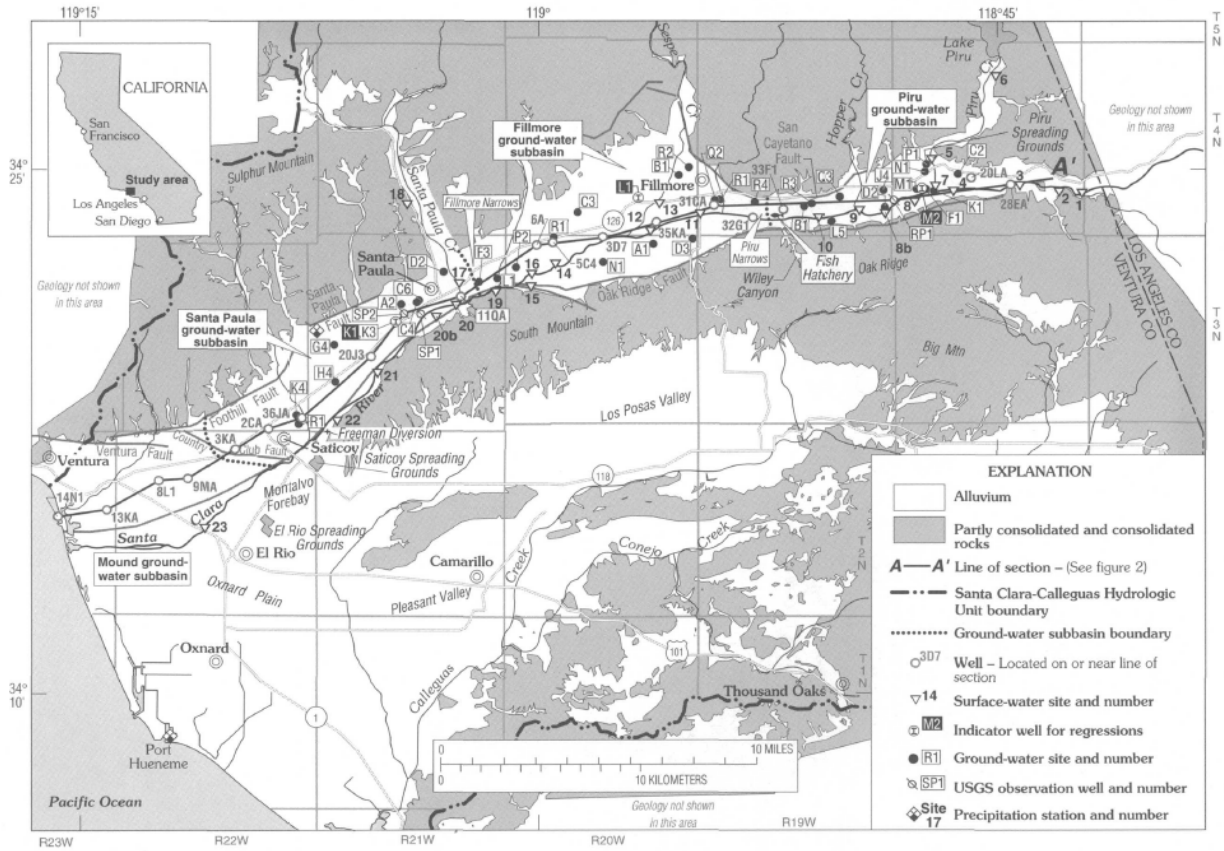

Figure 2-5. Surface water and groundwater sampling sites in the study area, Santa Clara River basin, Ventura County, California (Reichard and others, 1999; Figure 1).

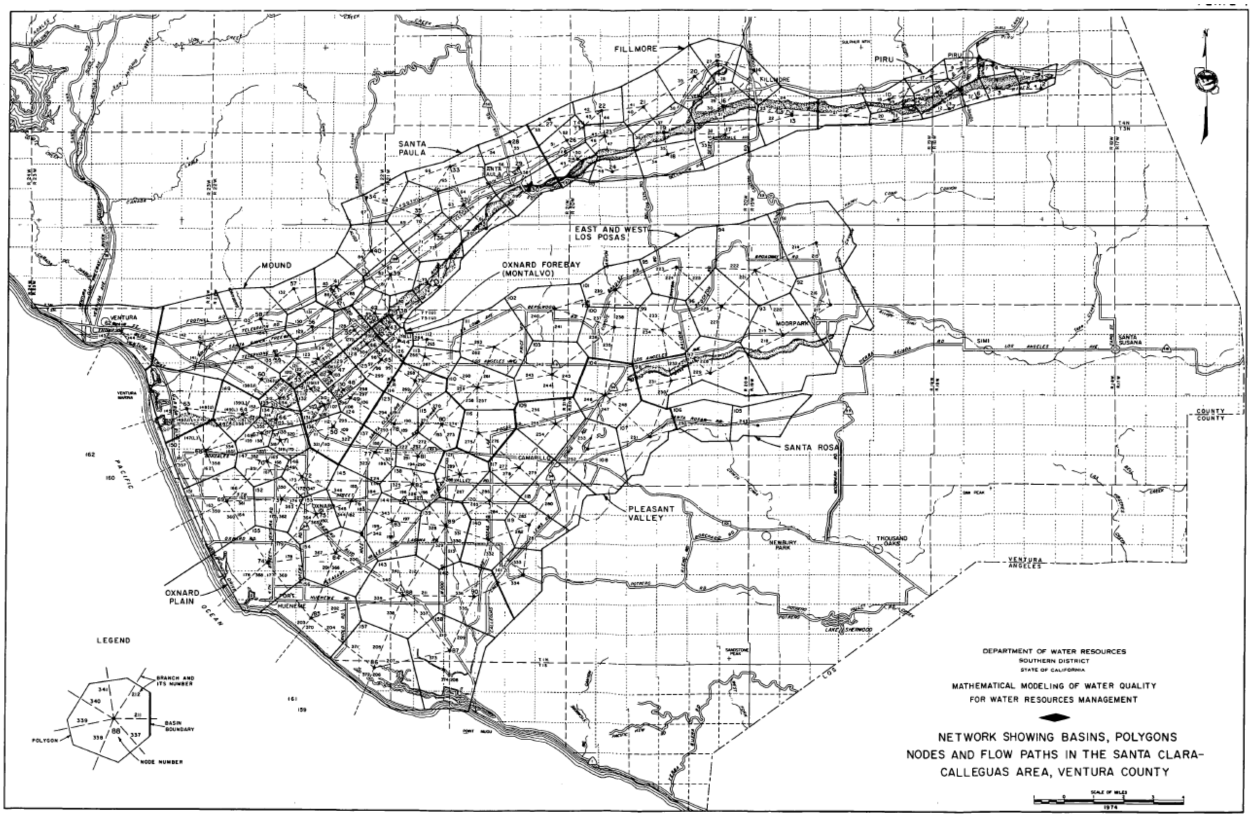

Figure 3-1. Network showing basins, polygons nodes and flow paths in the Santa Clara-Calleguas area, Ventura County based in DWR modeling (DWR 1974a; Plate 1).

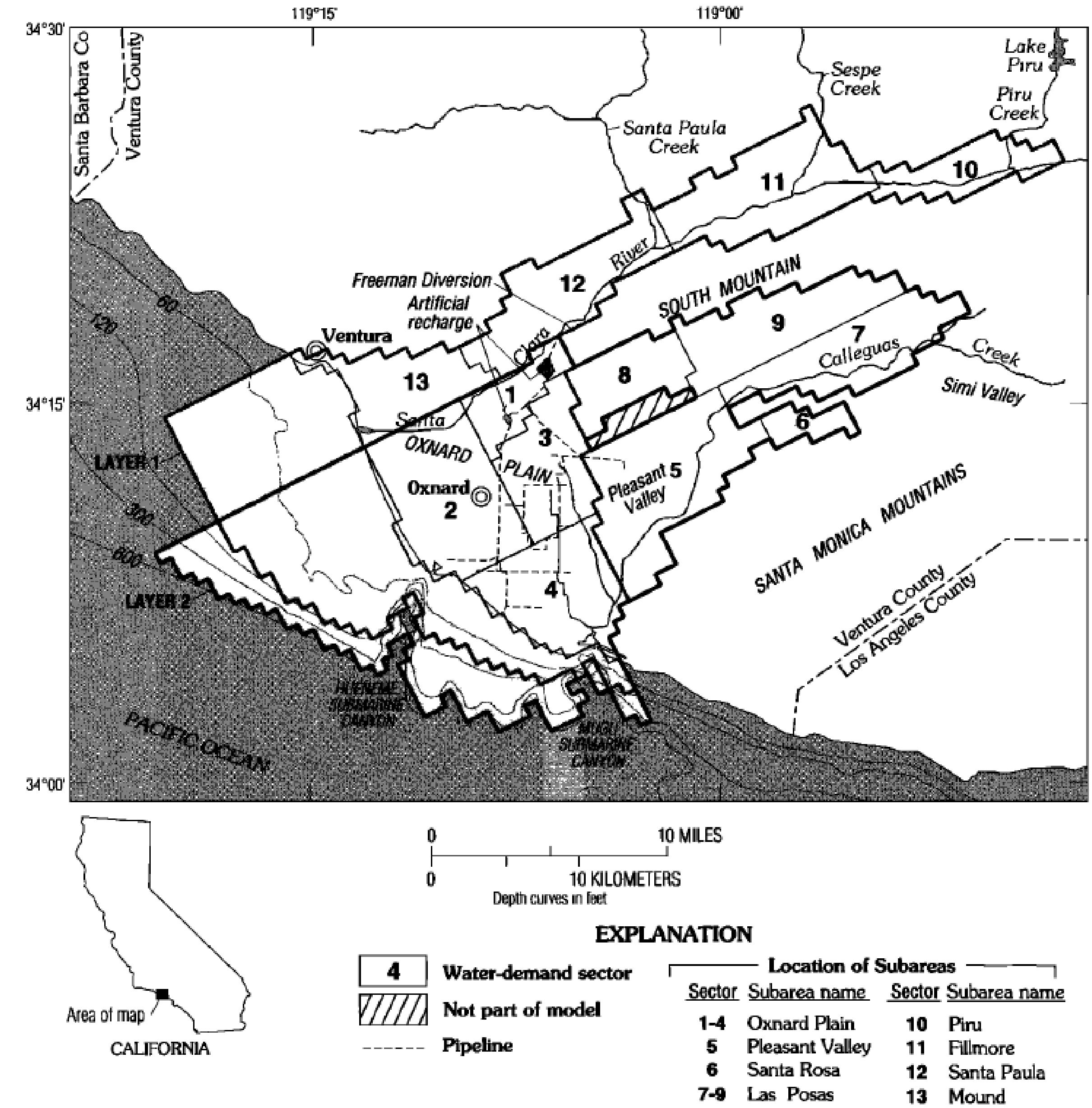

Figure 3-2. Santa Clara-Calleguas basins used by Reichard (1995; Figure 1).

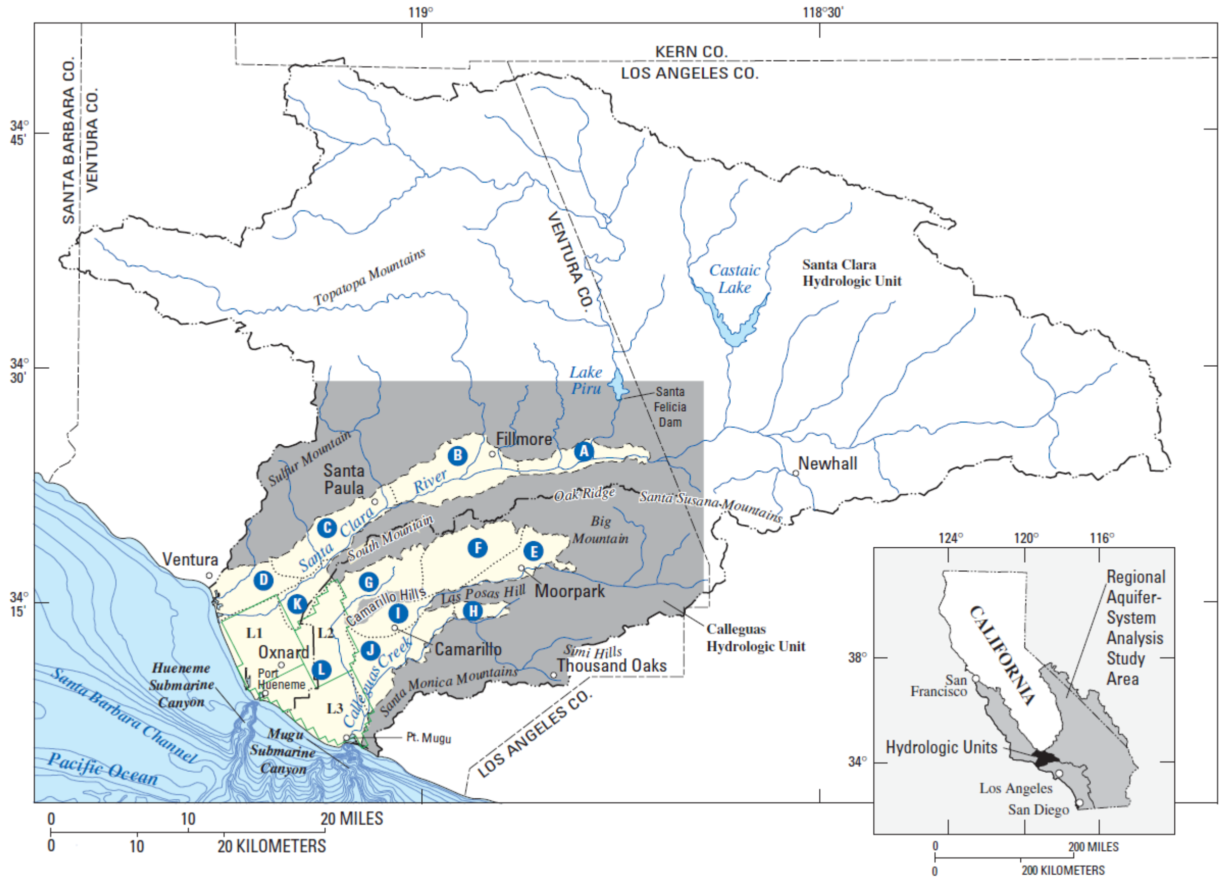

Figure 3-3. Santa Clara-Calleguas hydrologic unit and groundwater basins, (Hanson and others, 2003; Figure 1).

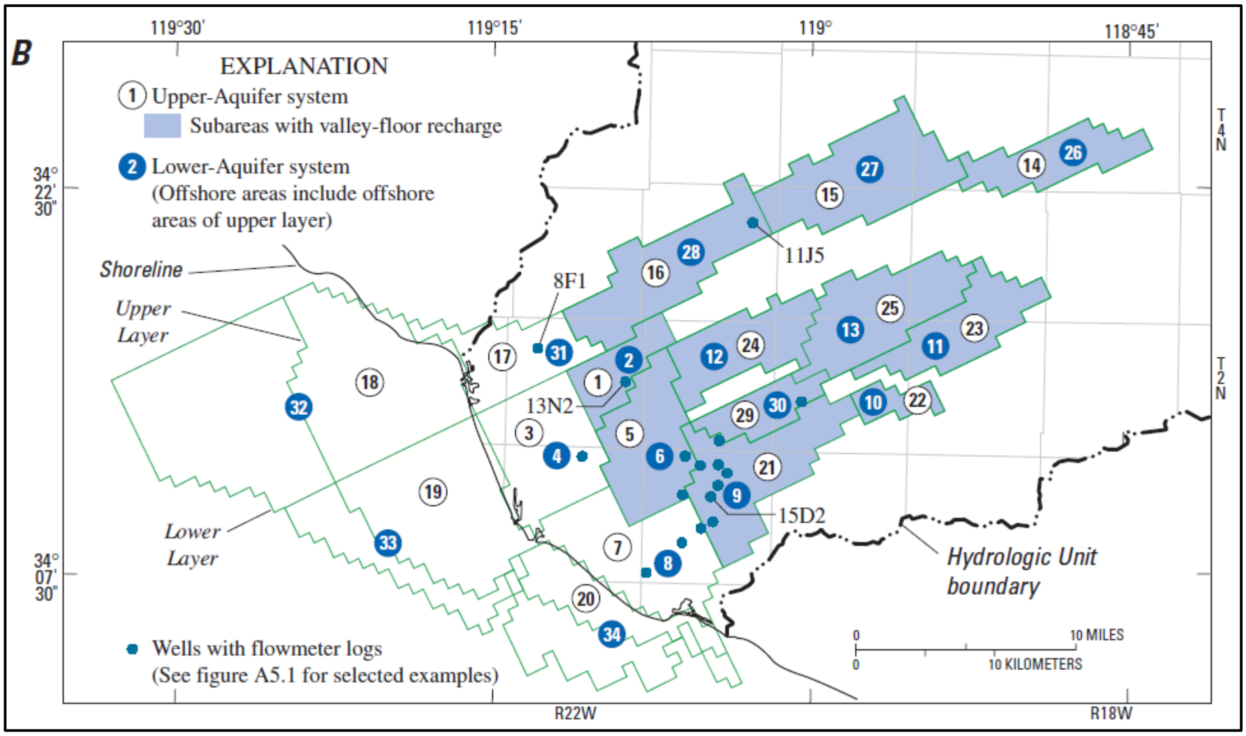

Figure 3-4. Modeled subareas for the upper-and lower-aquifer systems (Hanson and others., 2003; Figure 17B).

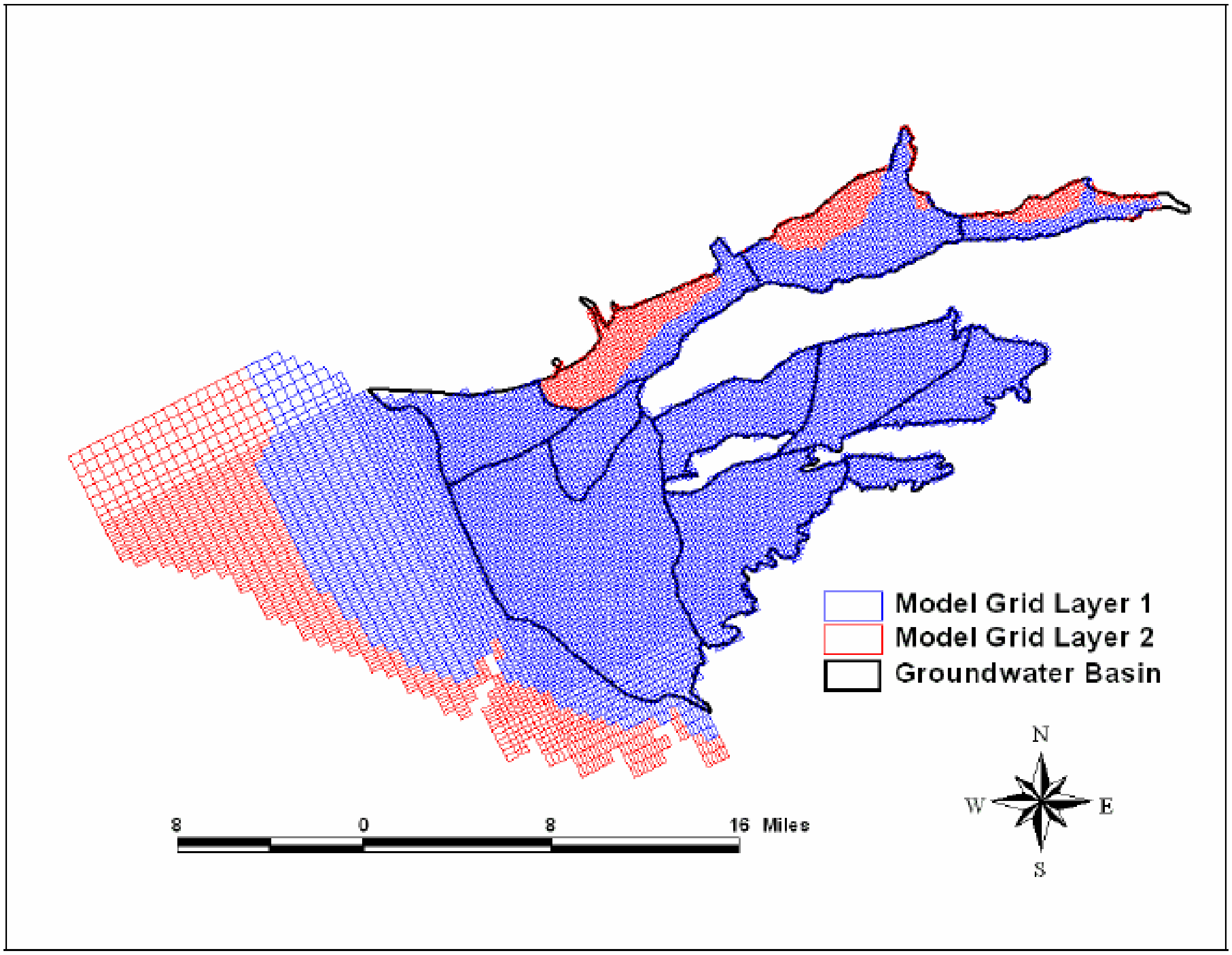

Figure 3-5. Updated model grid for Ventura Regional Groundwater Model (FCGMA and others, 2007; Figure 57).

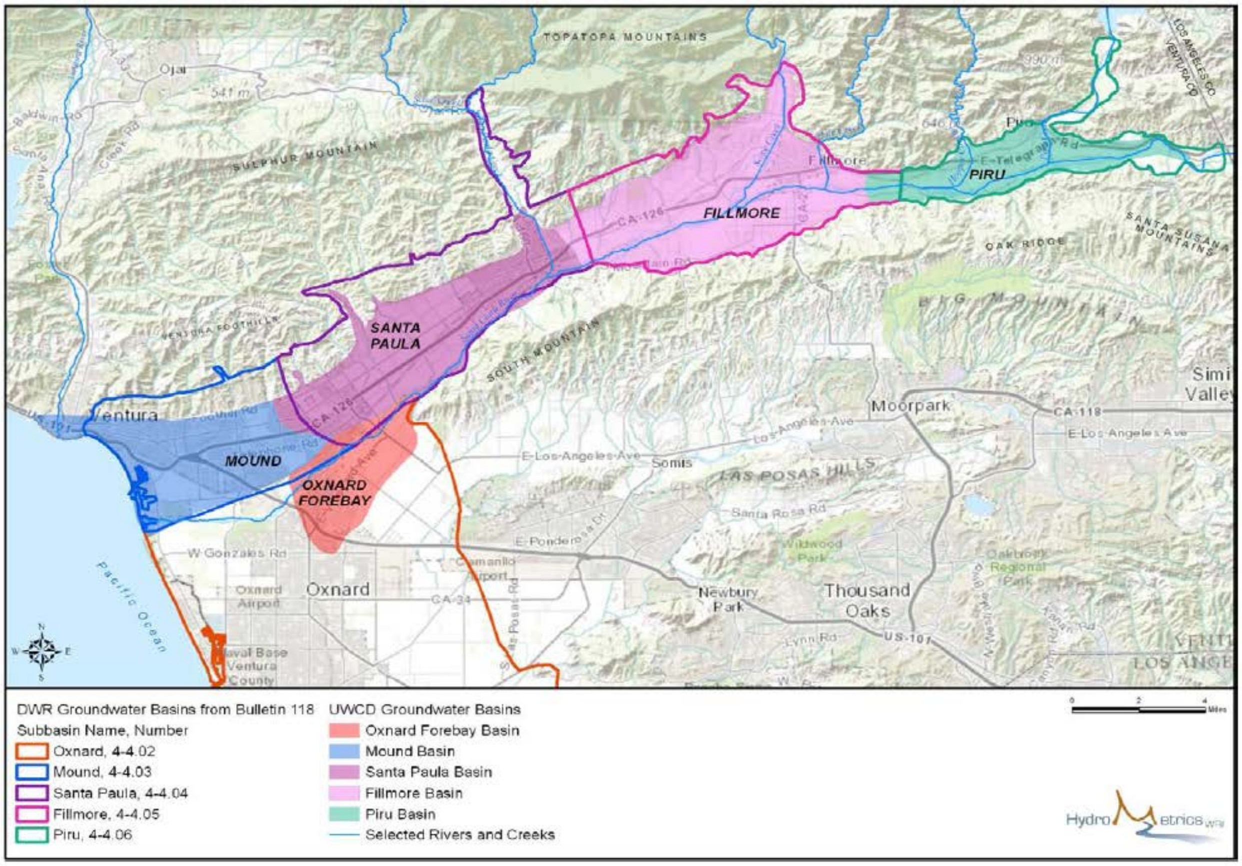

Figure 3-6. Lower Santa Clara River SNMP area comparison of DWR (Update 2003) and UWCD groundwater basins delineations (LWA and others, 2015; Figure 3-2). Note: LWA and others (2015) used United's basin boundaries for analysis.

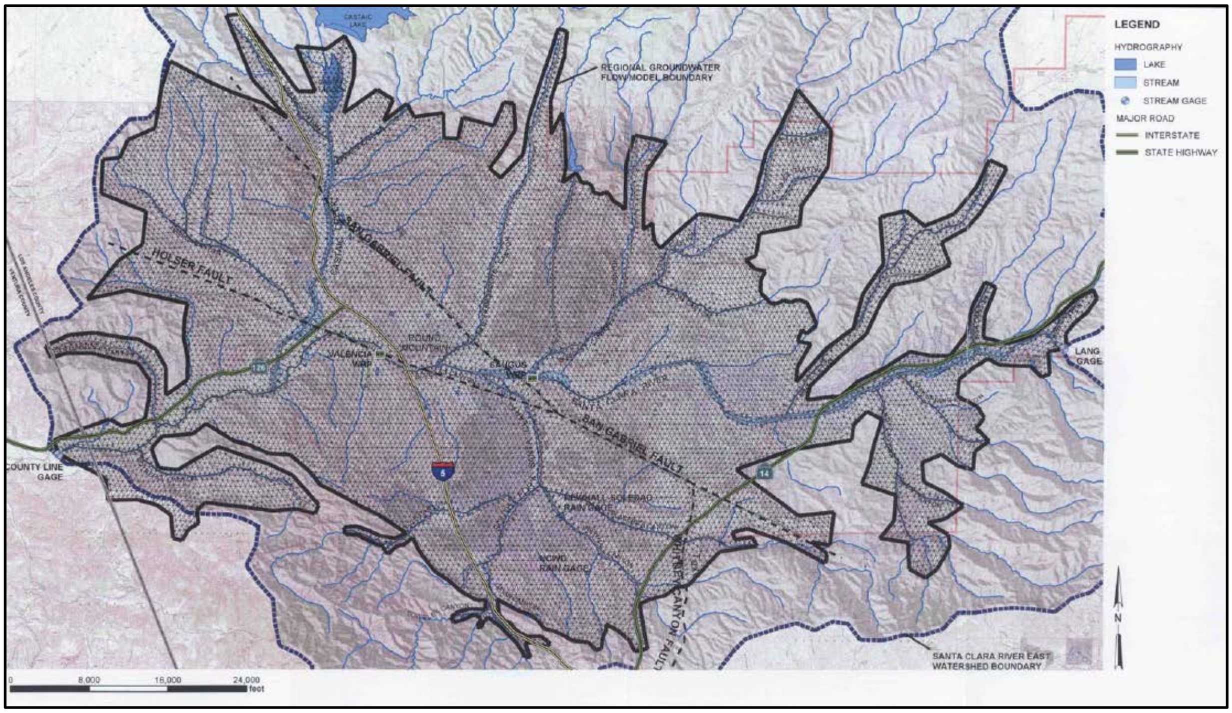

Figure 4-1. Groundwater flow model grid for the Santa Clarita Valley, (CH2M HILL, 2004; Figure 3-1).

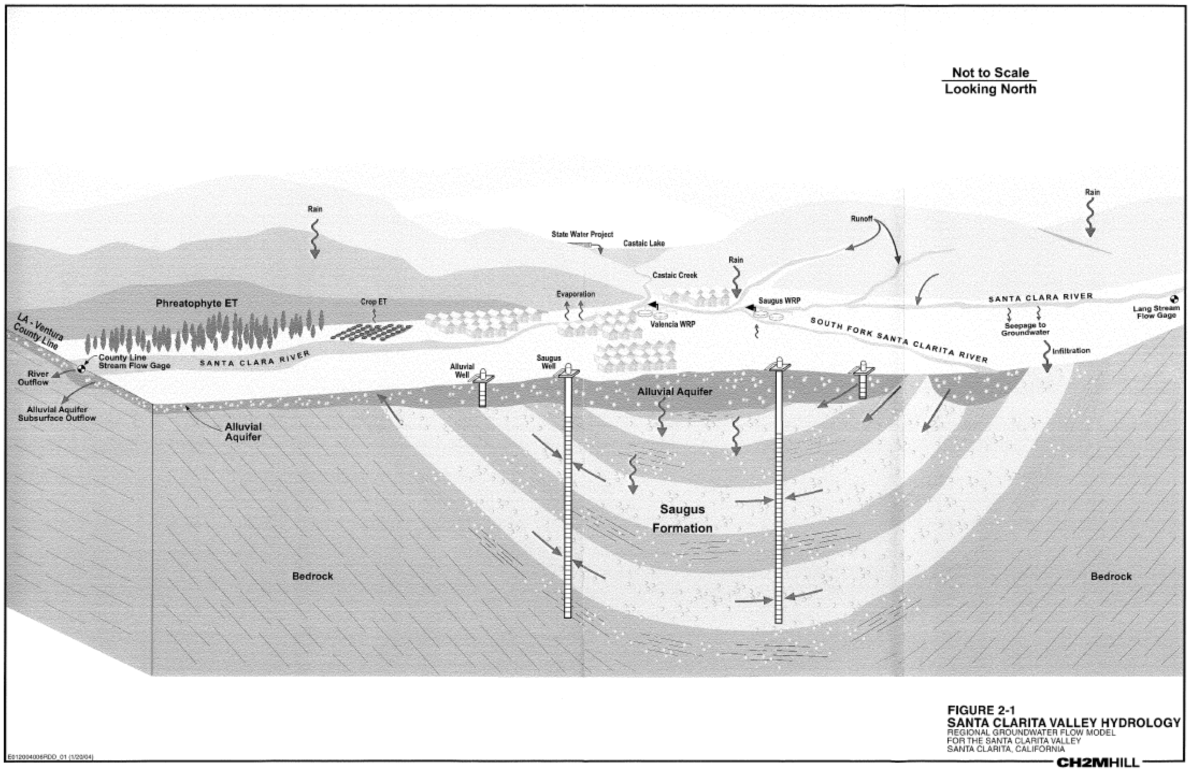

Figure 4-2. Santa Clarita Valley hydrology (CH2M HILL, 2004; Figure 2-1).

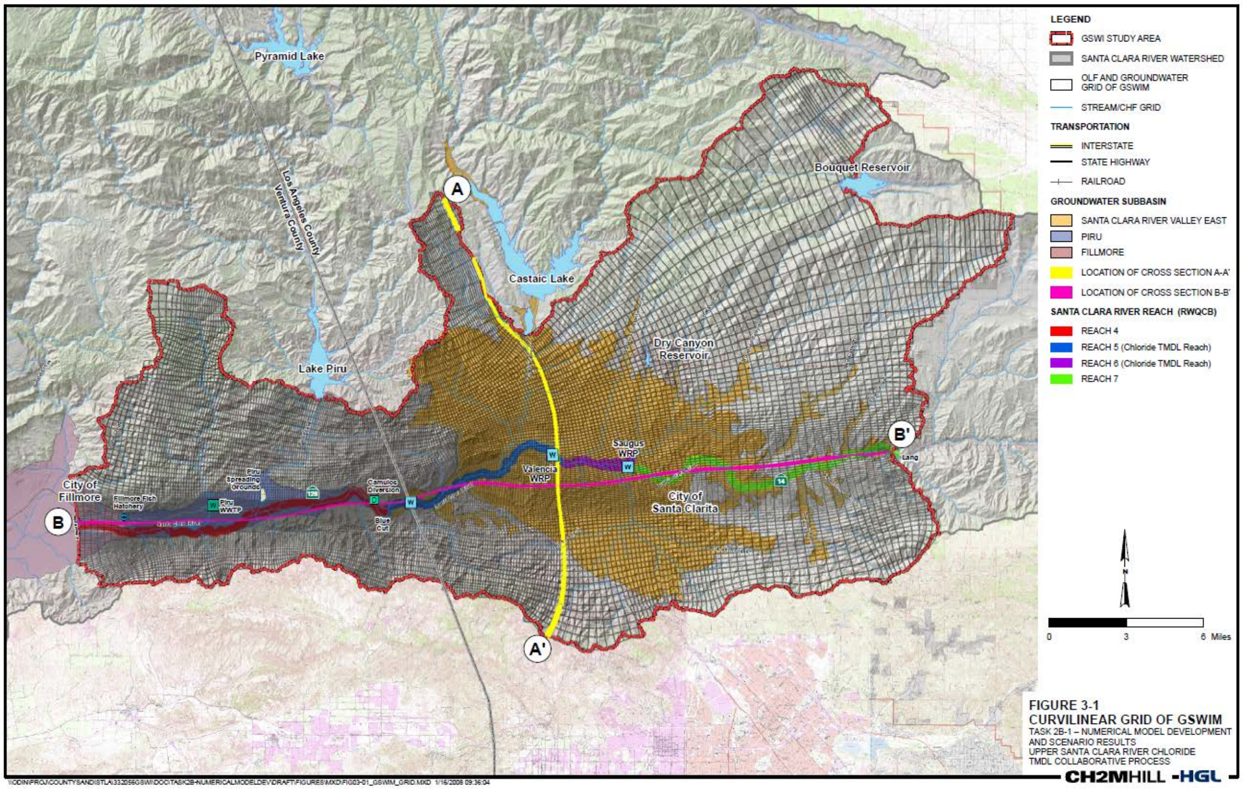

Figure 4-3. Curvilinear grid of GSWIM (CH2M HILL/HGL, 2008; Figure 3-1).

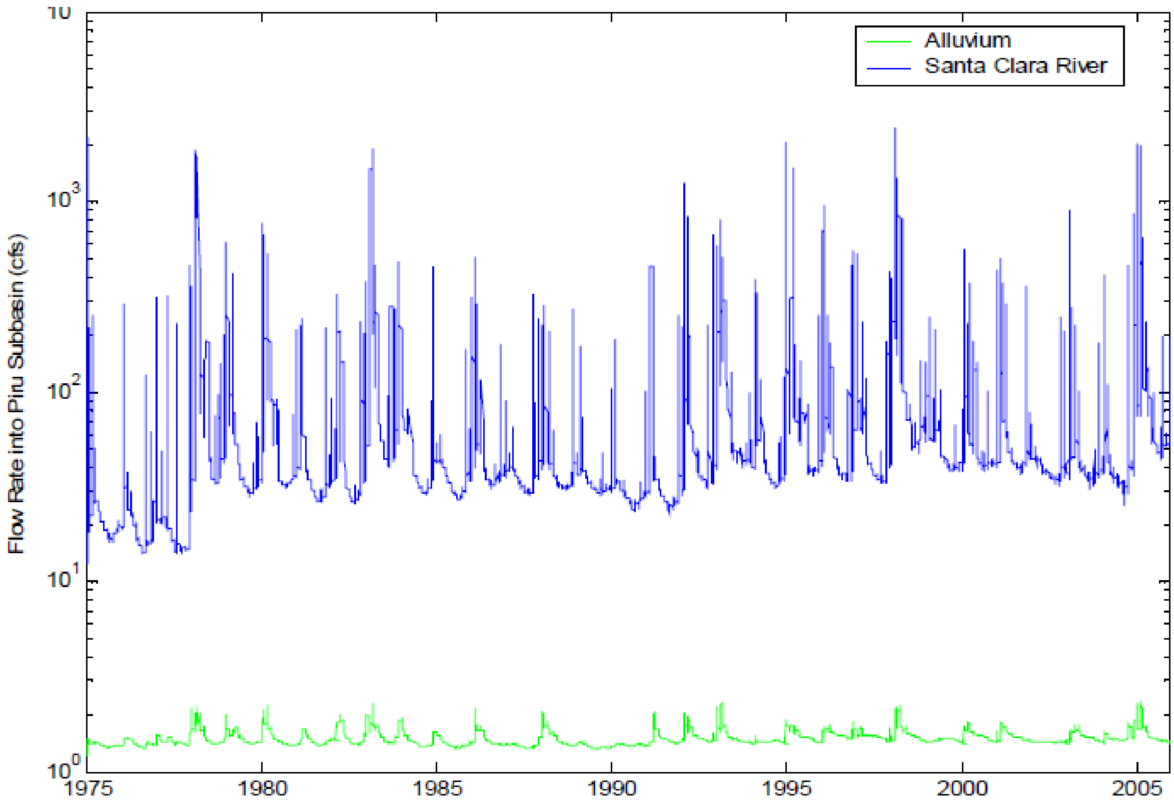

Figure 4-4. CH2M HILL and HGL modeled flow rates into Piru groundwater basin (CH2M HILL, 2008), modified from the HydroMetrics report (2008; Figure 2).

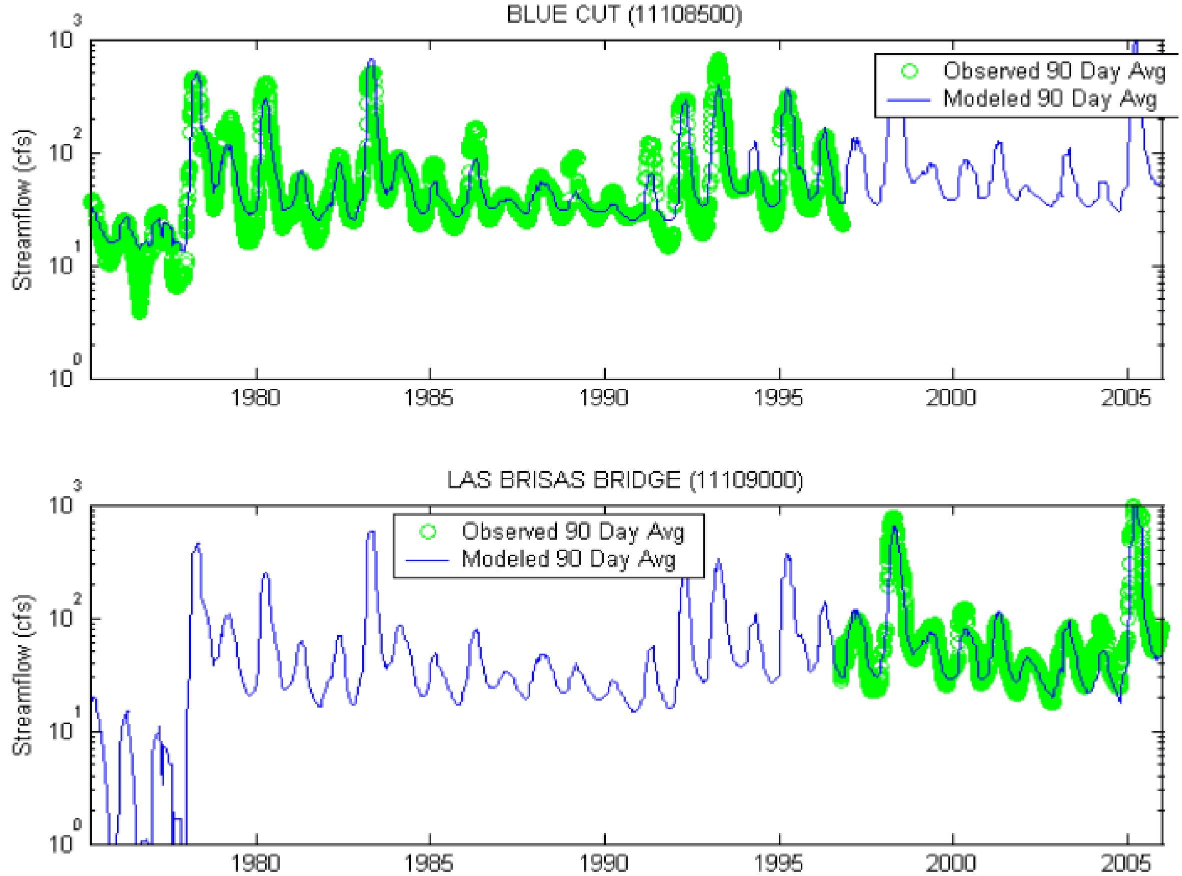

Figure 4-5. CH2M HILL/HGL 90-day averages of modeled versus observed streamflows at Blue Cut (CH2M HILL/HGL, 2008). modified from the HydroMetrics report (2008; Figure 2). *Note: that Blue Cut and Las Brisas Bridge are the two USGS streamflow locations near the Los Angeles and Ventura County Line. The USGS moved the official gaging location from Blue Cut to Las Brisas in October 1996.*

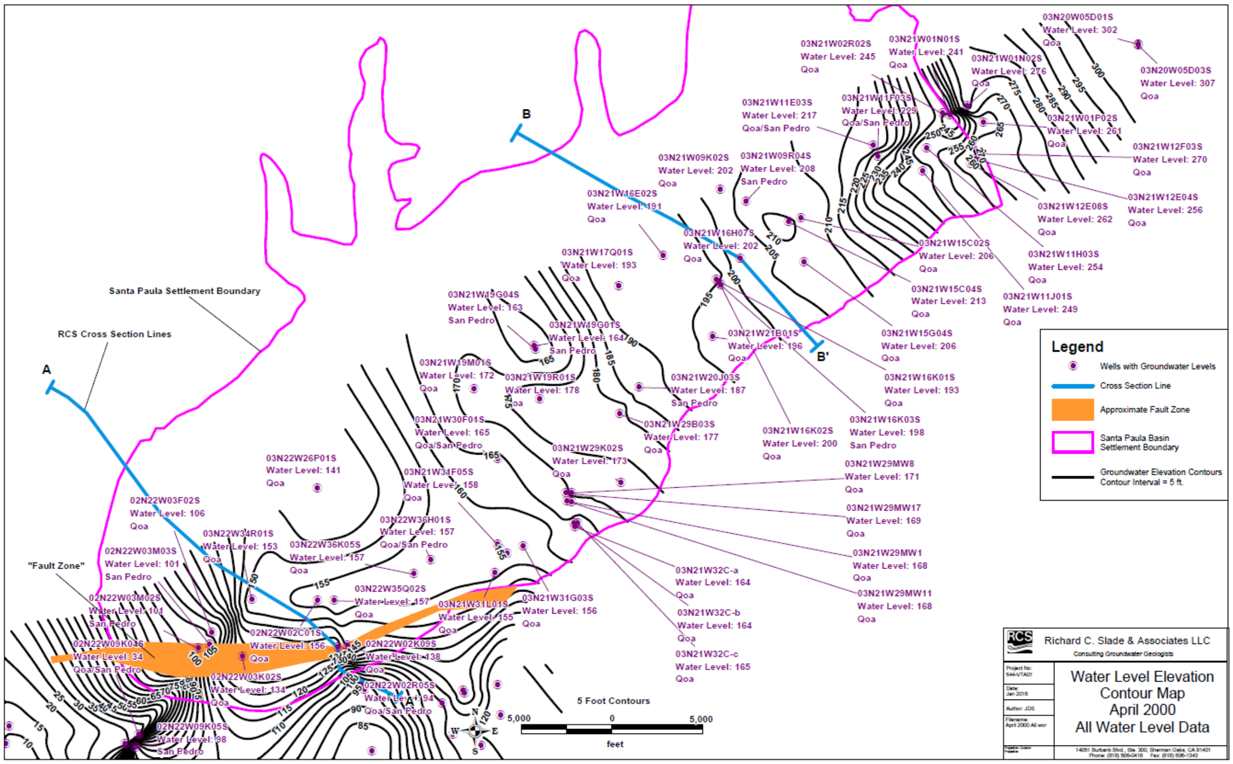

Figure 4-6. Water level elevation contour map, April 2000, all water level data (DBS&A and RCS, 2017; Figure 1 in Appendix F).

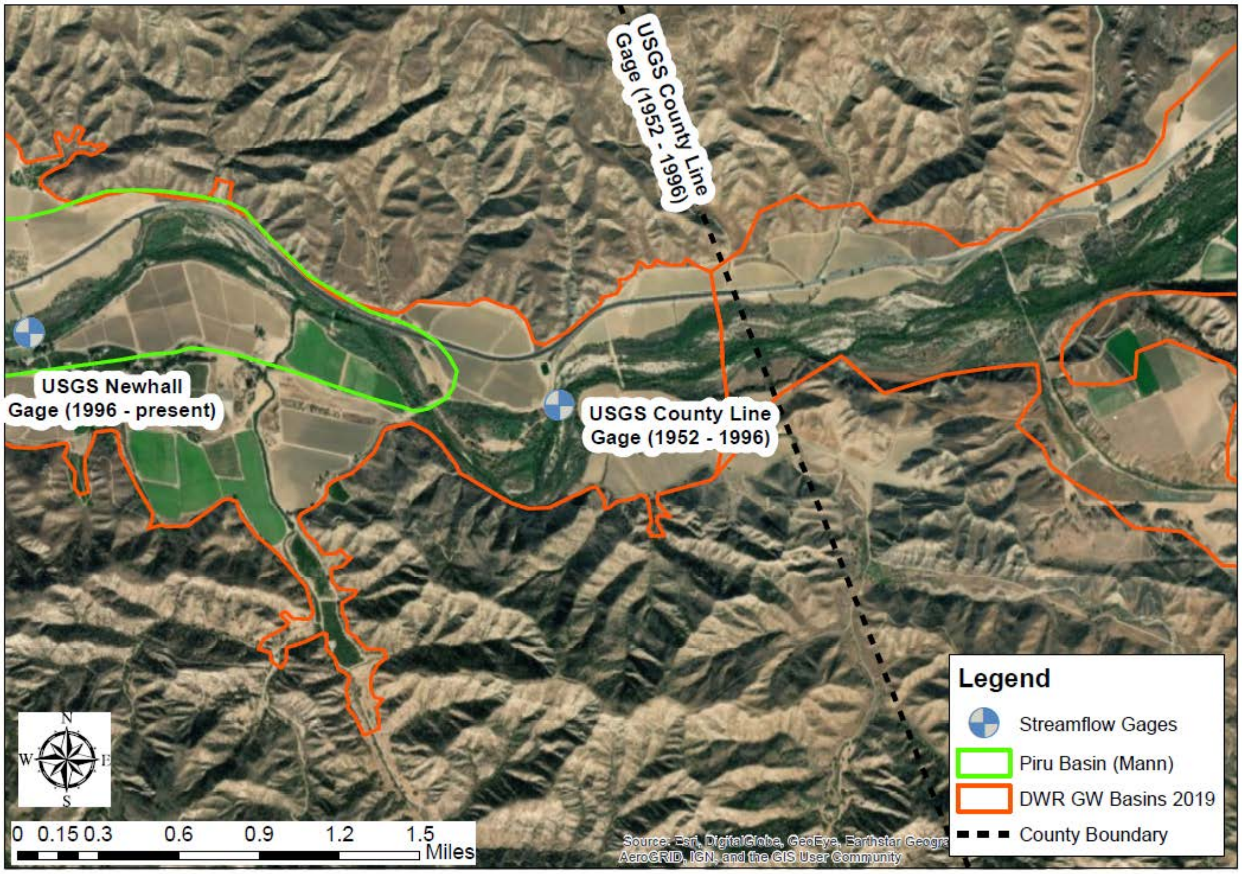

Figure 4-7. Site location of Piru Basin boundaries from Mann (1959) and DWR (2019) as well as streamgages and the Ventura/Los Angeles County Line.

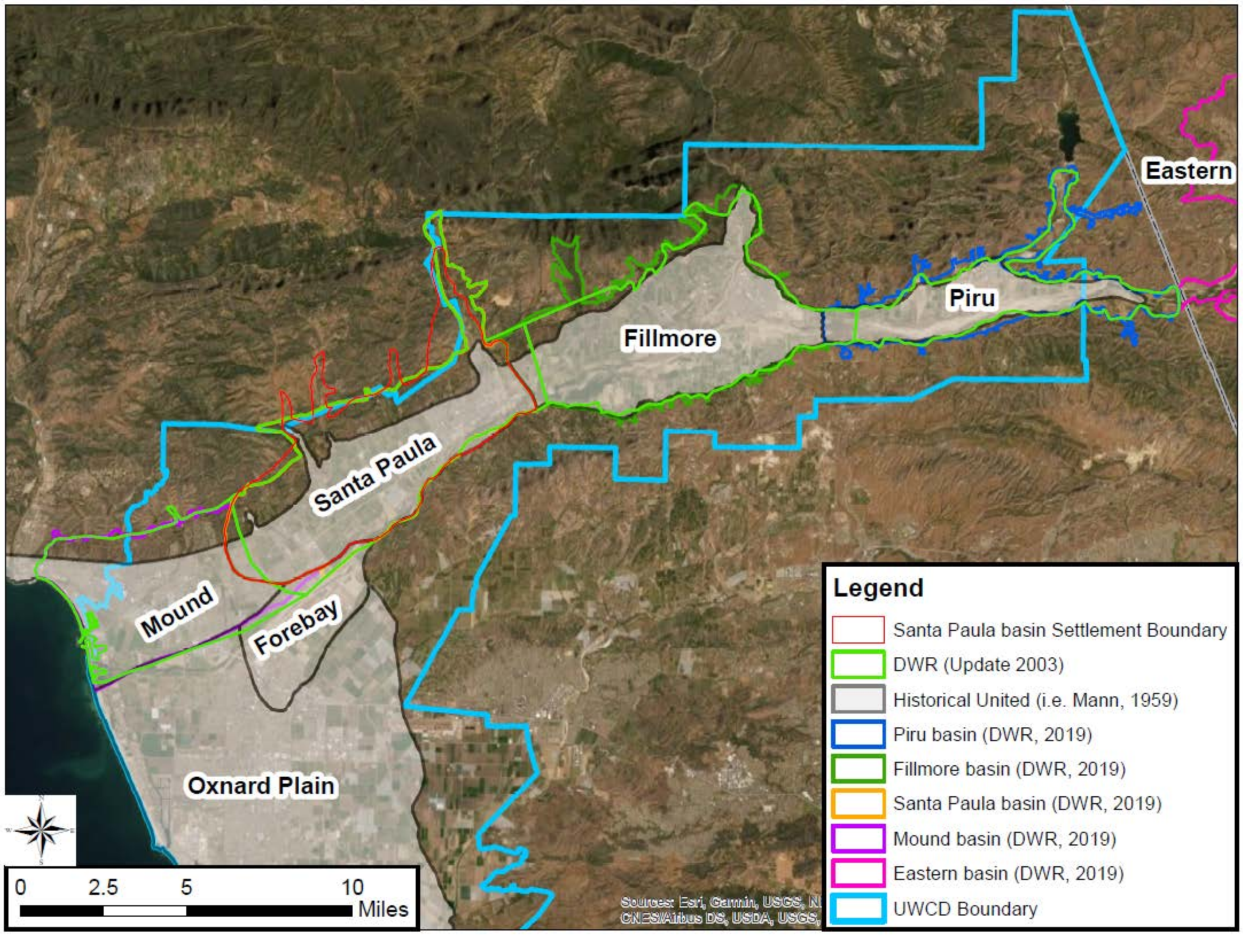

Figure 5-1. Comparison of groundwater basin boundaries along the Santa Clara River within Ventura County.