DRAFT

Groundwater Budget and Approach to a Groundwater Management Plan Upper and Lower Ventura River Basin

(75% Complete)

Prepared for **Ventura County Watershed Protection District**

August 20, 2010

Daniel B. Stephens & Associates, Inc.

5951 Encina Road, Suite 208 • Goleta, California 93117

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Gregory Schnaar, PhD

John Dodge, PG

Jordan Kear, PG, CHg

Daniel B. Stephens & Associates, Inc.

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Executive Summary

The Upper and Lower Ventura River Groundwater Subbasins (the Subbasins) extend along the Ventura River Valley from the mouth of the river at the Pacific Ocean to just south of Matilija Canyon (Figure 1). The Subbasins comprise the Ventura River Valley Groundwater Basin, as delineated by the California Department of Water Resources. Water users in the Ventura River Watershed have no access to imported water, and are therefore dependent upon maintaining an adequate supply of usable quality local water resources. For this reason, protection of local groundwater is vital, and an adequate understanding of groundwater storage volume and water quality trends is necessary. This report presents a groundwater budget for the Subbasins and an approach to a groundwater management plan (GWMP), which constitute the first steps in building a sufficient understanding of groundwater resources and planning for long-term protection.

The general approach for the groundwater budget is to estimate, based on available data and hydrogeologic analyses, the magnitude of all groundwater inputs and outputs within each of the Subbasins. The resulting budget provides an estimate of the net gain or loss of the volume of groundwater in storage within the Subbasins per year. For the Upper Subbasin, a net annual loss of 3,240 acre-feet per year (ac-ft/yr) is estimated for the budgeted time period (water years 1997 through 2007). The primary inputs to groundwater in this Subbasin are infiltration and surface water recharge from Lake Casitas and the Ventura River, while the primary outputs are municipal and agricultural extractions. The observation of a net loss of storage is consistent with groundwater level data from select monitoring wells in the Upper Subbasin over the budgeted time period, which generally indicate groundwater level fluctuation over the budgeted time period with a net decline. Observations over a longer time period indicate that average groundwater levels within the Upper Subbasin are stable, with 5- to 10-year rise and decline cycles.

For the Lower Subbasin, a net annual loss of 1,971 ac-ft/yr is estimated for the budgeted time period. The primary inputs are infiltration and inflow from bedrock to the alluvial aquifer, while the primary outputs are groundwater discharge to surface water and discharge to the ocean.

There are currently no water levels monitored by Ventura County within the Lower Subbasin for comparison to the budget.

The intention of a GWMP is to provide a framework to manage groundwater to ensure a long-term sustainable, reliable, good-quality water supply suitable to the political, legal, institutional, hydrogeologic, and economic conditions and constraints that exist in the Ventura River Valley Groundwater Basin. This report presents an approach to development of a GWMP, including specifications for public participation, interagency involvement, coordination with the Ventura River Watershed Council, literature review and technical analysis, establishment of management objectives, and development of a monitoring program.

1. Introduction

The County of Ventura Watershed Protection District (VCWPD), in cooperation with the Watersheds Coalition of Ventura County (WCVC), has received funding in the form of a Proposition 50 grant, intended for implementation of priority projects to address water supply reliability, water quality improvement, and habitat protection. The top priority project for the Ventura River Watershed is the Ventura River Watershed Protection Plan, also known as the V-1 Project, as defined in the Ventura County Integrated Water Management Program (VCIRWMP) that served as the basis for the Proposition 50 Grant Funding. One identified priority project component of the V-1 Project is the development of a groundwater budget for the Ventura River Valley Groundwater Basin, which is further subdivided into the Upper Ventura River and Lower Ventura River Subbasins (the Subbasins) (Figure 1). Other V-1 components include water supply reliability, groundwater recharge, habitat restoration, water quality, and flood management. As part of the V-1 Project, Daniel B. Stephens & Associates, Inc. (DBS&A) has produced this groundwater budget and an approach for creation of a groundwater management plan (GWMP) for these two significant groundwater Subbasins. Section 2 of this report presents and describes the groundwater budget for the Subbasins. Section 3 discusses the approach for a GWMP.

1.1 Background

The Subbasins extend along the Ventura River Valley for approximately 15 miles from the mouth of the river at the Pacific Ocean to just south of Matilija Canyon, and include the area surrounding Lake Casitas and San Antonio Creek (Figure 1). The Subbasins comprise the Ventura River Valley Groundwater Basin, as delineated by the California Department of Water Resources (CDWR, 2004). Ventura County nomenclature defines these basins as separate; however, to comply with State-indicated requirements of groundwater management planning, this report refers to the system as a single basin consisting of two subbasins. Portions of the cities of Ventura, Oak View, Mira Monte, Meiners Oaks, and Ojai are located within the Subbasins.

The Upper Subbasin may be further delineated into eastern and western portions, with the Upper East Subbasin comprising the main stem of the Ventura River above Foster Park, and the Upper West Subbasin consisting of Lake Casitas and Coyote Creek drainage area. The Upper Subbasin is bounded on the south by the Lower Subbasin, on the east by the Ojai Valley Basin, and throughout the rest of its area by the Santa Ynez Mountain Range. The Coyote, Matilija, and San Antonio Creeks flow into the Ventura River, which drains the Upper Subbasin. The Lower Subbasin is bounded on the north by the Upper Subbasin, on the south by the Pacific Ocean, and on the east and west by the foothills of the local southern mainland portion of the transverse ranges, and is drained by the Ventura River. The alluvial groundwater subbasins consist of Holocene and Pleistocene age sand, gravel, and clay deposits of up to 100 feet in thickness (CDWR, 2004).

Surface water and groundwater flows in the Subbasins have been influenced by several major engineering projects. The Ventura River Project of the U.S. Bureau of Reclamation was completed in 1959, and is one of several projects designed to capture seasonal floodwaters that would otherwise ”waste to the sea” (USBR, 2009). The Ventura River Project consists of Casitas Dam and Reservoir on Coyote Creek, the Robles Diversion Dam on the Ventura River, the Robles-Casitas Canal, and a conveyance system (Figure 1). Casitas Dam is the main component of the project, and is located on Coyote Creek about 2 miles above the junction of the creek and the Ventura River. Lake Casitas, created by the dam and located along Coyote Creek, is a storage reservoir that is also fed by the Robles-Casitas Conduit, which diverts water from the Ventura River at the Robles Diversion Dam. Lake Casitas regulates flows along the lower reach of Coyote Creek, and supplies municipal and irrigation water to the Casitas Municipal Water District (CMWD).

The Foster Park Submerged Dam was constructed in 1907 at Casitas Narrows, along the Ventura River (Figure 1). The dam was built to intercept groundwater flow through alluvium below the river and bring it to the surface such that it would be available for diversion to municipal supply. The reinforced concrete dam contacts bedrock along its length, from depths of 6 to 50 feet below ground surface. Due to construction difficulties, a 300-foot gap exists in the dam at the eastern end of the alluvium (SBRA, 2002).

1.2 Groundwater Quantity Issues

Groundwater is extracted from the Subbasins for municipal, industrial, agricultural, and domestic uses. In the Upper Ventura Subbasin, the City of Ventura, Ventura River County Water District (VRCWD), CMWD, and Meiners Oaks County Water District (MOCWD) extract groundwater for municipal use. Hydrographs from wells within the Upper Subbasin indicate that groundwater levels are generally stable over long time periods, and fluctuate seasonally by about 5 to 20 feet. Gradual groundwater level decline and rise can also be observed for dry and wet weather cycles, of lesser amplitude compared to seasonal cycles. In the uppermost portion of the Upper Subbasin (5N/23W-33), upstream of Kennedy Narrows, a more steady decline is observed over the long term. This may be due to the high density of extraction wells in this portion of the basin. Ventura County regularly monitors key well 04N23W16C04S in the Upper Eastern Subbasin (Figure 1), and water level data are available beginning in 1949 (VCWPD, 2009). Analysis of trailing multiyear averages from this well indicate that overall groundwater levels have remained generally stable since measurements began (Figure 2). Water levels for the Lower Subbasin are not currently monitored by Ventura County.

1.3 Groundwater Quality Issues

Historically, the Subbasins have both had generally good water quality, with the exception of elevated concentrations of total dissolved solids (TDS) above the U.S. Environmental Protection Agency (EPA) secondary maximum contaminant level (MCL) of 500 milligrams per liter (mg/L) and nitrate concentrations in excess of the state MCL of 45 mg/L (as NO_3). TDS concentrations within the Upper Subbasin are reported to range from 500 to 1,240 mg/L (CDWR, 2004; VCWPD, 2009). For the Lower Subbasin, TDS concentrations are reported to typically range from 760 to 784 mg/L, but become elevated to as high as 3,000 mg/L during extended dry periods when there is less recharge of lower-TDS surface waters. Nitrate concentrations reach an areal maximum approaching 70 mg/L in the central portion of the Upper Subbasin. The Lower Subbasin has also exhibited elevated levels of hydrogen sulfide, hydrocarbons associated with oil seepage, sulfate, iron, and nitrate (CDWR, 2004; VCWPD, 2009). In sampling conducted by VCWPD in 2009, no samples from either subbasin exhibited levels of inorganic metals (i.e., Title 22 metals) above the EPA or state MCLs (VCWPD, 2009).

2. Groundwater Budget

Water users in the Ventura River Watershed have no access to imported water, and are therefore dependent upon maintaining an adequate supply of usable quality local water resources. For this reason, protection of local groundwater is vital, and an adequate understanding of groundwater storage volume and water quality trends is necessary. DBS&A has prepared a groundwater budget for the Upper and Lower Subbasins, with the objective to gain a better understanding of the groundwater inputs and withdrawals that govern groundwater availability.

2.1 Approach to the Groundwater Budget

The general approach for the groundwater budget is to estimate, based on available data and hydrogeologic analyses, the magnitude of all groundwater inputs and outputs within each of the Subbasins. The resulting budget provides an estimate of the net gain or loss of the volume of groundwater in storage within the Subbasins per year, over the time period of analysis. A general schematic of the hydrologic cycle and factors driving the groundwater budget is shown in Figure 3.

Groundwater inputs for a subbasin include infiltration of precipitation and irrigation water (I), inflow of groundwater from upgradient adjacent subbasins (GW_i), recharge of surface water to groundwater (SW_i), recharge of domestic water from domestic septic systems (S), and flux of groundwater from bedrock into the alluvium (B_i). Groundwater outputs include extractions for municipal (E_m), domestic (E_d), irrigation of agriculture (E_a), industrial (E_p) uses, groundwater outflow to downgradient basins or the ocean (GW_o), flux of groundwater in the alluvium to bedrock (B_o), and discharge to surface water (SW_o). Mathematically, the net groundwater budget (ΔGW_s) is represented by the following equation:

$$\Delta GW_s = [I + GW_i + SW_i + S + B_i] - [E_m + E_d + E_a + E_p + GW_o + B_o + SW_o] \quad (1)$$

In order to calculate the groundwater budget, additional watershed processes must be quantified. For example, the amount of infiltration to groundwater is a function of the amount of precipitation, irrigation, surface runoff, and evapotranspiration. In addition, quantifying surface water/groundwater interactions (SW_i, SW_o) requires budgeting of surface water inputs and outputs, including diversions, point sources of surface water (e.g., from wastewater treatment plants), and surface water evaporation.

As described below, the annual average magnitude of each of the parameters listed on the righthand side of Equation 1 was estimated or obtained from literature references for each of the Subbasins. Several of the groundwater budget estimates or calculations presented in this report are derived from the Ventura River Watershed Hydrology Model (VRWHM), an existing hydrologic routing model of the Subbasins and surrounding Ventura River Watershed (Tetra Tech, 2009). This earlier study was also sponsored by the VCWPD and funded under a Proposition 50 grant. The model represents the land area, land management areas, stream reaches, reservoirs, and water diversions within the entire area of the watershed, including impacts of land use changes and wildfires over time. The model was calibrated to seven different continuous flow gages and peak storm events from four additional gages. The model represents the surface water balance of the watershed and gaged flows. Results of the watershed balance are presented in the VRWHM report for water years 1997 through 2007 (i.e., October 1996 to September 2007). For this reason, the same time period was used in this report for determination of the groundwater budget (henceforth referred to as the budgeted time period). In addition, the delineation of the Subbasins is also consistent with the VRWHM (Figure 1).

2.2 Groundwater Inputs

This section describes calculations of estimates of inputs to groundwater within the Subbasins, including infiltration, surface water recharge to groundwater, recharge from septic systems within the basins, and influx from bedrock into the alluvial aquifers. As described below, these inputs were estimated using available data and hydrogeologic analyses. The final results of the groundwater budget for each of the Subbasins are provided in Section 2.4. Limitations are discussed below and summarized in Section 2.5.

2.2.1 Precipitation

As discussed below, estimates of precipitation are required in order to estimate infiltration rates for each of the Subbasins. Total precipitation over the budgeted time period for the Subbasins was determined from precipitation data provided in the VRWHM report (Tetra Tech, 2009). Precipitation rates were calculated by summing the area contribution of each precipitation isocontour within each of the Subbasins (Figure 4). Annual average precipitation rates over the budgeted period were 3,661 acre-feet per year (ac-ft/yr) for the Upper West Subbasin, 17,659 ac-ft/yr for the Upper East Subbasin (total of 21,320 ac-ft/yr for the Upper Subbasin), and 4,946 ac-ft/yr for the Lower Subbasin (Tables 1 and 2).

2.2.2 Irrigation

Similar to precipitation, estimates of irrigation rates are required in order to estimate infiltration inputs to groundwater. Irrigation estimates within each of the Subbasins were developed using land use data acquired from the VRWHM report (Tetra Tech, 2009) and crop-specific annual water use estimates for Ventura County from CDWR (2010). The relevant crop types identified were orchards (including citrus and avocado), other truck vegetables, and pastures. Developed area vegetation was assumed to consist mostly of turf grass (i.e., pasture), but also contain trees, shrubs, and ornamental plants.

Areas for each land use group within each of the Subbasins were estimated using graphical analysis (e.g,. geographic information system [GIS]) of land uses reported in the VRWHM (Figure 5; Table 3). The relevant land use groups included irrigated agricultural, orchards and vineyards, parks/golf courses, and developed areas, which are further delineated as residential, commercial, industrial, or institutional areas. Developed areas were assumed to only be irrigated at areas of vegetated coverage. The fraction of vegetative coverage for developed areas ranges from 12 percent for commercial land use to 72 percent for low-density residential use (Brabec et al., 2002). The fraction of vegetative coverage for each developed land use within each of the Subbasins was multiplied by the total area for that land use to determine the irrigated area. A limitation of this approach is that it is assumed that all vegetated coverage within developed areas is irrigated, while in reality certain vegetated areas (e.g., low-impact landscaping) are not irrigated. This assumption will tend to overestimate irrigation and resulting estimates of infiltration.

Irrigation for agricultural areas, parks, and golf courses was estimated by multiplying the calculated land use areas by crop type water use estimates to arrive at annual irrigation totals for each land use within each of the Subbasins (Table 3). In developed land use areas, irrigation was estimated by multiplying the land use area by the crop water use estimate and by an additional factor for the fraction of vegetation within the land use area (acres of vegetation per acre of land use area). Within each of the Subbasins, the annual irrigation totals for each of the land use groups were summed to calculate annual Subbasin totals. Estimated irrigation rates are 12,865 ac-ft/yr for the Upper East Subbasin, 670 ac-ft/yr for the Upper West Subbasin (total of 13,535 ac-ft/yr for the Upper Subbasin), and 2,822 ac-ft/yr for the Lower Ventura Subbasin.

2.2.3 Infiltration

For the purposes of the groundwater budget, infiltration is considered to be influx of water from ground surface that recharges the alluvial aquifer, resulting from precipitation or irrigation, and not associated with a surface water body. Precipitation and irrigation water not routed to the atmosphere via evapotranspiration or routed to surface water bodies via surface runoff is considered to contribute to infiltration.

The percentage of precipitation and irrigation routed to infiltration was estimated by the VRWHM for portions of the watershed that contain the Upper and Lower Subbasins (Tetra Tech, 2009). The VRWHM-estimated infiltration factor (i.e., percentage of precipitation and irrigation routed to infiltration) was 4.27 percent for the Ventra River Mainstem, which contains the Upper East and Lower Subbasins, and 3.46 percent for the Coyote Creek/Lake Casitas drainage, which contains the Upper West Subbasin. These factors were applied to the total amount of precipitation and irrigation estimated for each of the Subbasins (Table 1, Sections 2.2.1 and 2.2.2).

A limitation of this approach is that the VRWHM estimates are provided for larger regions of the watershed that contain upland areas, and are not limited specifically to the Subbasins. The infiltration factors used herein were derived from the VRWHM for drainage areas that consist of both the Subbasins and upland areas. Infiltration in the Subbasins may be underestimated because infiltration rates tend to be greater in the lower-slope alluvial depositional areas that comprise the Subbasins, as compared to the low-permeability bedrock upland areas, and the infiltration factors used represent a composite of both areas.

Estimates of annual average infiltration over the budgeted period are presented in Tables 1 and 2 for the Upper and Lower Subbasins, respectively. Estimated infiltration inputs into the groundwater basins are 1,303 ac-ft/yr for the Upper East Subbasin, 150 ac-ft/yr for the Upper West Subbasin (total of 1,453 ac-ft/yr for the Upper Subbasin), and 332 ac-ft/yr for the Lower Subbasin.

2.2.4 Surface Water Recharge to Groundwater

Surface water bodies within the Subbasins, including Lake Casitas and portions of the Ventura River and San Antonio Creek, recharge groundwater. For analysis of surface water/ groundwater interactions, the Upper West Subbasin, which contains Lake Casitas, was analyzed separately from the Upper East Subbasin, which contains sections of the Ventura River and San Antonio Creek, and the Lower Subbasin, which contains a section of the Ventura River. Discussion of surface water/groundwater interactions for the Lower Subbasin are included in Section 2.3.5, as calculations indicated that there is a net flux of groundwater discharging to surface water in the Lower Subbasin. The Upper East Subbasin estimate is discussed below.

The VRWHM provides modeled estimates of reservoir loss from Lake Casitas in the Upper Western Basin, which includes recharge to groundwater and the net precipitation balance (Tetra Tech, 2009). The Casitas Reservoir Inventory Annual Summary, provided by CMWD (2010), was used herein to determine average annual lake evaporation and direct precipitation onto the lake in order to calculate the net precipitation balance.

The net precipitation balance was then subtracted from the VRWHM-calculated annual average reservoir loss in order to estimate surface water recharge to groundwater at Lake Casitas. The estimated annual average recharge from the lake to groundwater over the budgeted time period is 2,003 ac-ft/yr. Data and calculations associated with this estimate for the Upper West Subbasin are presented in Table 4.

For the Upper East Subbasin, the estimated surface water/groundwater balance of the Ventura River was estimated from an accounting of surface water flows within the river. The difference between inputs and outputs to the river along this section is assumed to recharge to groundwater. Inputs and outputs from the river are accounted for as follows:

$$\Delta SW = (Q_o + E + D_o) - (R + D_i + P + Q_i) \tag{2}$$

where ΔSW = the net surface water/groundwater balance

- Qo = the surface water flow at the downstream boundary of the Subbasin
- E = evaporation from the river
- D_o = diversions out of the river
- R = surface runoff into the river along the reach of the Subbasin
- D_i = point sources of water into the river
- P = direct precipitation into the river
- Q_i = the surface water flow at the upstream boundary of the Subbasin

For the section of the Ventura River within the Upper East Subbasin, there are no point sources into the river, and evaporation is considered negligible according to the VRWHM; therefore, Equation 2 simplifies to the following:

$$\Delta SW = (Q_o + D_o) - (R + P + Q_i) \tag{3}$$

Calculation of the net recharge to groundwater for the Upper Subbasin is presented in Table 5. U.S. Geological Survey (USGS) Gage 608 was used to provide river flow rates at the downstream boundary of the Upper Subbasin, and modeled flows from the VRWHM were used at the upstream boundary. Gage 608 is located downstream of the Foster Park Dam (Figure 1).

Estimates of surface runoff, direct precipitation, and diversions were also taken from the VRWHM. The calculated surface water recharge to groundwater for the Ventura River within the Upper East Subbasin is 1,321 ac-ft/yr.

A section of San Antonio Creek is also located within the Upper East Subbasin (Figure 1). Use of Equation 2 for determination of the groundwater/surface water balance was not applicable, however, because there are not sufficient stream flow gages present along the reach at this location. Therefore, a simpler approach was used based on the results of the VRWHM within the San Antonio Creek drainage. The VRWHM predicts a net recharge from the creek to groundwater of 2,204 ac-ft/yr along the entire length of the creek (Table 5). It was estimated based on GIS analysis that 44 percent of San Antonio Creek is located within the Upper East Subbasin. Therefore, it was assumed that 44 percent of the total San Antonio Creek recharge to groundwater, or 970 ac-ft/yr, occurs in the Upper East Subbasin. A limitation of this approach is that groundwater recharge and discharge rates may not be constant over the length of the Creek, as assumed here. As discussed in Section 2.5, obtaining model data from the VRWHM that is specific to the area of San Antonio Creek in the Upper East Subbasin will reduce uncertainty associated with this estimate.

2.2.5 Recharge from Domestic Septic Systems

For domestic water users that use individual septic systems, some of the household-consumed water is eventually recharged to groundwater. The amount of septic system recharge for each of the Subbasins was estimated using data from the County of Ventura Individual Sewage Disposal System Applications/Permits Database (Table 6). This database provides approved septic systems listed by the assessor's parcel number (APN). GIS parcel data were obtained from Ventura County, and were overlaid with the boundaries of the Subbasins to determine APNs within the boundaries of each of the Subbasins (Figure 6). This list was then cross-referenced against the Sewage Disposal System Applications/Permits Database in order to determine the number of approved septic systems within each of the Subbasins. Based on a study of septic system recharge within southern California, it was assumed that the recharge rate from individual septic systems is 150 gallons per day (gpd), or 0.16 ac-ft/yr (Hantzche and Finnemore, 1992). The resulting total recharge from all septic systems was 126 ac-ft/yr for the

Upper East Subbasin, 19 ac-ft/yr for the Upper West Subbasin (total of 145 ac-ft/yr for the Upper Subbasin), and 6 ac-ft/yr for the Lower Subbasin.

2.2.6 Inflow from Bedrock to the Alluvial Aquifer

Nine Tertiary (Eocene to Pliocene) bedrock formations underlie the Quaternary alluvium that comprises the aquifers of the Upper and Lower Subbasins. These formations also comprise a significant portion of the larger Ventura River Watershed. Regionally, numerous domestic, agricultural, and industrial wells extract groundwater from aquifers within these bedrock formations. Hydrogeologic data from these wells can be used to characterize the quantity (and quality) of groundwater available in each formation. In addition to working directly with property and well owners, DBS&A completed a review of available well data with literature data to estimate inflow from bedrock to alluvial aquifers (Table 7).

North to south, the bedrock formations that underlie the Upper Ventura River Basin are the Cozy Dell shale, Coldwater sandstone, Sespe Formation, Vaqueros sandstone, Rincon shale, and Monterey Formation. South of the Red Mountain Fault Zone, beneath the Lower Ventura River Basin, the younger Pico Formation, Las Posas sand, and Saugus Formation are present, from north to south. The thickness of bedrock formations underlying the basins was estimated from Dibblee (1987 and 1988) and AAPG (1956). Formation names used here and primary geologic structures identified in the area also follow AAPG (1956) and Dibblee (1987 and 1988).

The estimated widths (chiefly west to east) of the Ventura River Basin alluvium above the formations were multiplied by the formational thickness to estimate a formational cross-sectional area under the basins (A_b).

A percentage of the bedrock formation that is typically considered potential primary and/or secondary aquifer material was estimated from several hundred geophysical logs of water wells and oil wells (exploration and production) in the region, as available in the personal collections of the project team. Geophysical logs, published cross sections, and oil field data sets (CDOG, 1992) were also used to estimate the areal extent of the bedrock aquifers and base of fresh water therein.

Based on experience with water wells in the bedrock formations, a typical specific capacity was estimated using methods such as those presented by Driscoll (1986) and GRA (2004). Hydraulic conductivity (K_b) for each bedrock aquifer was then estimated from the specific capacity and aquifer thickness estimates (Table 7).

The hydraulic gradient between bedrock aquifers and basin aquifers (dh/dl) was estimated from typical grade elevations and groundwater levels in the bedrock aquifers, including flowing artesian conditions that occur in wells and springs. Darcy's Law was then used to estimate flux to the Subbasins from bedrock, as follows:

$$B_i = A_b \cdot K_b \cdot \frac{dh_b}{dl} \tag{4}$$

The inflow calculations result in an estimate of 256 ac-ft/yr to flow from bedrock aquifers to the Upper Ventura River Subbasin and 606 ac-ft/yr from bedrock aquifers to the Lower Ventura River Subbasin.

2.2.7 Groundwater Inflow from Upgradient Subbasins

The majority of groundwater flow in the alluvium between the Upper and Lower Subbasins is intercepted by the Foster Park Submerged Dam (Figure 1). However, a 300-foot gap exists in the dam on the eastern side (SBRA, 2002). The groundwater flux within the 300-foot channel comprises an inflow to the groundwater budget for the Lower Subbasin and an outflow for the groundwater budget of the Upper Subbasin. Groundwater flux was calculated using Darcy's Law, as follows:

$$GW_i = A_a \cdot K_a \cdot \frac{dh_a}{dl} \tag{5}$$

where A_a = the cross-sectional area of the alluvium in the gap, taken as the product of the thickness (b) and the width (w)

K_a = the hydraulic conductivity of the alluvium

dh_a/dl = the hydraulic gradient across the gap

The saturated alluvium thickness and hydraulic gradient for the Casitas Narrows were obtained from Turner (1971); the width was estimated by SBRA (2002) at 300 feet.

Because local measurements of hydraulic conductivity are unavailable, a literature hydraulic conductivity value of 100 feet per day for sand and gravels was obtained from Fetter (2001). Hydraulic gradient estimates are shown on Table 8. Groundwater flux into the Lower Subbasin from the Upper Subbasin was calculated to be 80 ac-ft/yr (Table 8). There are no alluvial subbasins upgradient of the Upper Subbasin.

2.3 Groundwater Outputs

This section describes calculations of outputs to groundwater within the Subbasins, including extractions, discharge to surface water, and outflow of groundwater from the Upper Subbasin to the Lower Subbasin, and outflow from the Lower Subbasin to the ocean. As described below, these outputs were estimated using available data and hydrogeologic analyses. The final results of the groundwater budget for each of the Subbasins are provided in Section 2.4. Limitations are discussed below, and are summarized in Section 2.5.

2.3.1 Municipal Groundwater Extractions

Several active municipal groundwater extraction wells exist within the Upper East Subbasin (Figure 7). Municipal groundwater extractions were provided by water purveyors for the Upper East Subbasin, and annual average withdrawals over the budgeted period were calculated (Table 9). The City of Ventura extracts groundwater for municipal use at the Foster Park well field, which is located at the southern terminus of the Upper East Subbasin. Additionally, the VRCWD, CMWD, and MOCWD extract groundwater in the Upper East Subbasin. A total average extraction rate of 7,385 ac-ft/yr was estimated over the budgeted time period from the Upper East Subbasin. No municipal groundwater extractions occur within the Lower Subbasin or Upper West Subbasin.

2.3.2 Domestic Groundwater Extractions

The locations of active domestic groundwater wells were obtained from the Ventura County Well Database, and GIS was used to determine how many active wells exist within each of the Subbasins (Figure 7; Table 10). A total of 86 active domestic wells are located within the Upper East Subbasin, 8 within the Upper West Subbasin, and 5 within the Lower Subbasin. An average annual domestic water use for private well users in California of 225 gpd (0.25 ac-ft/yr) was obtained from the USGS (2000). It was assumed that each domestic well serves one household. The resulting calculated domestic groundwater extraction was 22 ac-ft/yr for the Upper East Subbasin, 2 ac-ft/yr for the Upper West Subbasin (total of 24 ac-ft/yr for Upper Subbasin), and 1 ac-ft/yr for the Lower Subbasin.

2.3.3 Agricultural Groundwater Extractions

Irrigation water supply within the Subbasins (Sec. 2.2.2) is supplied from both groundwater and surface water sources. However, agricultural groundwater withdrawals from individual wells are not currently available. For the purpose of the groundwater budget, agricultural extraction was estimated from existing land use data and the locations of active agricultural wells within the Subbasins, available from the Ventura County Well Database. Active agricultural well locations were overlaid on the land use map for the Subbasins (Figure 5). Those land use areas designated as irrigated agriculture or orchard/vineyard, for which active agricultural wells were either co-located or reasonably proximal, were assumed to provide all irrigation via groundwater extraction. These land use areas were then multiplied by water application rates for the land use types available from CDWR (Table 11). Estimated agricultural extraction rates using this method are 1,898 ac-ft/yr for the Upper East Subbasin and 522 ac-ft/yr for the Lower Subbasin. There are no active agricultural wells located in the Upper West Subbasin.

A limitation of this approach is that active agricultural wells that are not located near agricultural land uses were assumed to extract no groundwater from the Subbasins. This may be a reasonable assumption considering that wells are listed as ”active” within the Ventura County database if employed as little as 8 hours per year. In addition, this method assumes that all irrigation for those areas co-located or proximal to agricultural wells is supplied by groundwater, while both surface water and groundwater supplies may be used. Therefore, agricultural extractions comprise a source of uncertainty for the groundwater budget.

For this reason, an alternative approach was also used to estimate agricultural extraction within the Subbasins as a check (Table 11). A representative annual average extraction from each well of 79 ac-ft/yr was applied to each active agricultural well within the basin. This annual average was calculated from reported agricultural withdrawals in the adjacent Ojai Basin, reported to the Ojai Basin Groundwater Management Agency (OBGMA) (SGD, 1992), where irrigation practices are similar to elsewhere in the Ventura River Watershed and often conducted by the same management teams. The resulting alternative estimates of agricultural extraction were 3,397 ac-ft/yr for the Upper East Subbasin and 474 ac-ft/yr for the Lower Subbasin. Although the estimated extraction rates compare well for the two different methods for the Lower Subbasin, the estimated extraction rate for the Upper East Subbasin is significantly greater using the alternative approach. The discrepancy in the Upper East Subbasin is due to the large number of active agricultural wells that are not co-located with agricultural land uses in that Subbasin (Figure 5).

2.3.4 Industrial Groundwater Extraction

Groundwater is extracted from the alluvium of the Lower Subbasin, which is associated with oil extraction activities by Aera Energy and its predecessors, including Shell Oil, in deeper zones (i.e., bedrock) (Figure 7). However, groundwater extraction rates associated with oil extraction by Aera are not currently available, and were not included in the groundwater budget. This is identified as a current limitation of the groundwater budget, although effects are small, as major groundwater extraction from these wells appears to have ceased several years ago following the cessation of steam/waterflood injection practices in the Ventura Oil Field. There are no active industrial wells within the Upper Subbasin.

2.3.5 Groundwater Discharge to Surface Water

Calculations of surface water/groundwater interaction, as described in Section 2.2.4, indicate that there is a net discharge of groundwater to surface water within the Lower Subbasin. Similar to the Upper East Subbasin, the estimated surface water/groundwater balance for the Lower Subbasin was estimated from an accounting of surface water flows within the Ventura River at the upstream and downstream boundaries of the subbasin, while also accounting for other inputs and outputs from the river (Table 5).

For the Lower Subbasin, because there are no diversions out, and evaporation is considered negligible according to the VRWHM, Equation 2 simplifies to the following:

$$\Delta SW = Q_o - \left(R + D_i + P + Q_i\right) \tag{6}$$

Calculation of the net groundwater discharge to surface water for the Lower Subbasin is presented in Table 5. USGS Gage 608 was used to provide river flow rates at the upstream boundary of the Subbasin, and modeled flows from the VRWHM were used at the downstream boundary. Estimates of surface runoff, direct precipitation, and input to the river from the Ojai Wastewater Treatment Plant (Figure 1) were also taken from the VRWHM. The calculated groundwater discharge to surface water in the Lower Subbasin is 1,254 ac-ft/yr.

2.3.6 Groundwater Outflow

Groundwater flow into downgradient Subbasins or the Pacific Ocean is an important groundwater output. As discussed in Section 2.2.7, groundwater flows out of the Upper Subbasin and into the Lower Subbasin at an estimated rate of 80 ac-ft/yr (Table 8).

For the Lower Subbasin, Darcy's Law (Equation 5), was used to estimate the groundwater flux to the Pacific Ocean (Table 8). The saturated alluvium thickness was obtained from Turner (1971). Because local measurements of hydraulic conductivity are unavailable, a literature hydraulic conductivity value for sand and gravels was obtained from Fetter (2001). Publically available water level measurements from two nearby contaminated sites within the Lower Subbasin were used to calculate the hydraulic gradient. Water level measurements from AT Systems, Inc. (188 W. Santa Clara) and Former BJ Services (2509 N. Ventura Ave) were used because groundwater level measurements were collected contemporaneously (September 2008), and the sites are placed favorably within the Lower Subbasin for estimation of the hydraulic gradient. Groundwater flux out of the Lower Subbasin was calculated to be 1,218 ac-ft/yr (Table 8).

This estimate has a significant impact on the calculated groundwater budget for the Lower Subbasin (Table 2), and is recognized as a source of uncertainty in the budget. For example, varying hydraulic conductivity within reasonable ranges varies the estimated outflow from the Lower Subbasin.

2.4 Results of the Groundwater Budget

Final results of the groundwater budget for the Upper and Lower Subbasins are provided in Tables 1 and 2, respectively. These budgets represent reasonable estimates based on available data and hydrogeologic analyses. Limitations to the analyses and resulting uncertainty are discussed in Section 2.5.

For the Upper Subbasin, because there are no inputs from upgradient alluvial subbasins, industrial extractions, groundwater discharge to surface water, or loss of alluvial groundwater to bedrock, Equation 1 simplifies to the following:

$$\Delta GW_s = \left[I + SW_i + S + B_i\right] - \left[E_m + E_d + E_a + GW_o\right] \quad (7)$$

A net annual loss of 3,240 ac-ft/yr is estimated for the budgeted time period for the Upper Subbasin (Table 1). The primary inputs to groundwater are infiltration and surface water recharge from Lake Casitas and the Ventura River, while the primary outputs are municipal and agricultural extractions. The observation of a net loss of storage is consistent with groundwater level data from select monitoring wells in the Upper Subbasin over the budgeted time period (e.g., Figures 8a, 8b, and 8d), which generally indicate groundwater level fluctuation over the budgeted time period with a net decline. Other wells, however, exhibited net groundwater level rise over the budgeted time period (e.g., Figure 8c), which may be due to local factors, such as increases in local recharge and/or reductions in groundwater extraction. Observations over a longer time period indicate that average groundwater levels within the Upper Subbasin are stable, with 5- to 10-year rise and decline cycles (Figure 2). It is expected that the results of the groundwater budget presented herein are specific to the budgeted time period (water years 1997 through 2007); a different outcome (e.g., net increase in groundwater storage) would likely occur over an alternative time period.

For the Lower Subbasin, because there is no net surface water recharge to groundwater, municipal or industrial extractions, or net loss of alluvial groundwater to bedrock, Equation 1 simplifies to the following:

$$\Delta GW_s = \left[I + GW_i + S + B_i\right] - \left[E_d + E_a + GW_o + SW_o\right] \tag{8}$$

A net annual loss of 1,971 ac-ft/yr for the Lower Subbasin is estimated for the budgeted time period (Table 2). The primary inputs are infiltration and inflow from bedrock to the alluvial aquifer, while the primary outputs are groundwater discharge to surface water and discharge to the ocean. There are currently no Ventura County-monitored water levels within the Lower Subbasin for comparison to the budget.

2.5 Limitations and Recommendations

As discussed above, there are several limitations to the groundwater budget presented in this report. The limitations are summarized here, along with an estimation of their potential impact on the final budget. These groundwater budgets constitute the first step in building a sufficient understanding of groundwater resources within the Subbasins; recommendations for further analyses are provided below.

- *Use of the VRWHM:* Several calculations presented in this report rely on reported results of the VRWHM. As discussed in the VRWHM report (Tetra Tech, 2009), similar to any hydrologic model, the VRWHM is prone to uncertainty stemming from assumptions in the mathematical formulation, data uncertainty, and parameter specifications. Recommendations are provided in the VRWHM documentation for reducing uncertainty with the VRWHM (Tetra Tech, 2009).

Recommendation: Following any revisions to the VRWHM that reduce model uncertainty, revise the groundwater budgets presented in this report to reflect those changes.

Recommendation: Develop a groundwater model of the Subbasins. As discussed in the VRWHM documentation (Tetra Tech, 2009), uncertainty with the surface water hydrology model will be reduced via development of a groundwater model for the Subbasins, and coupling of the groundwater and surface water models. Development and application of a groundwater model would also reduce uncertainty with estimation of the groundwater budget within the Subbasins.

- *Infiltration (Section 2.2.3):* Precipitation and applied irrigation within the Subbasins are estimated using values provided in the VRWHM for areas of the watershed that contain the Subbasins. However, infiltration may be underestimated, as infiltration rates tend to be greater in the lower-slope areas covered by the Subbasins, and the infiltration factors used herein represent a composite of both areas.

  Recommendation: Obtain output from the VRWHM that is specific to model areas within the Subbasins. With model output data specific to the Subbasins, uncertainty of infiltration rates will be reduced.

- *Groundwater Flow Calculations (Sections 2.2.7 and 2.3.5):* Groundwater flow calculations using Darcy's Law are dependent on values of hydraulic conductivity, hydraulic gradient, and aquifer cross-sectional area. For both of the Subbasins, locally measured values of hydraulic conductivity are unavailable, and literature values were used for representative gravels. A previous groundwater study has also had to rely on literature values for hydraulic conductivity within the Subbasins (Entrix, 2001). Resulting uncertainty in these calculations may be significant, particularly for the Lower Subbasin, where groundwater discharge to the ocean is a primary component of the groundwater budget.

Recommendation: Obtain local measurements of hydraulic conductivity via aquifer tests or other methods. Additionally, development of a groundwater model, as discussed above, would reduce uncertainty with hydraulic conductivity and hydraulic gradient estimation.

- *Agricultural Groundwater Extractions (Section 2.3.3):* Because extraction data from agricultural wells within the Subbasins are not available, agricultural extraction was estimated based on co-location of active wells and agricultural land uses. An alternative method was also used based on the total number of active agricultural wells and a representative extraction rate per well. Estimates using the alternative method agreed well for the Lower Subbasin, but were significantly greater for the Upper Subbasin, highlighting the uncertainty associated with agricultural extraction.

  Recommendation: Obtain agricultural extractions from individual well owners within the Subbasins.

- *Industrial Groundwater Extraction (Section 2.3.4):* Groundwater extraction rates associated with oil production or other uses in the Lower Subbasin are not currently available, and may be a significant additional groundwater output.

  Recommendation: Obtain extraction rates from wells associated with oil production in the Lower Subbasin.

- *Groundwater/Surface Water Balance Calculations (Sections 2.2.4 and 2.3.5):* The net groundwater/surface water balances presented for each of the Subbasins rely on estimates of surface water inputs and outputs for sections of the Ventura River Watershed that contain the Subbasins.

  Recommendation: Obtain output from the VRWHM that is specific to model areas within the Subbasins that contain surface water bodies. With model output data specific to these specific reaches, uncertainty of the surface water/groundwater balance will be reduced.

Recommendation: Install additional surface water gages along San Antonio Creek within the area of the Subbasins, and upstream, in order to better quantify groundwater/surface water interactions along that reach.

- *Comparison of the groundwater budget to observed groundwater levels in the Lower Subbasin (Section 2.4):* There are currently no Ventura County-monitored water levels within the Lower Subbasin for comparison to the budget (VCWPD, 2009). Water level measurements within the Lower Subbasin would also be important for development of a groundwater model, and water samples could also be collected from these wells to evaluate groundwater quality trends.

  Recommendation: Identify several wells within the Lower Subbasin for inclusion in a groundwater level and groundwater quality monitoring program.

3. Approach to a Groundwater Management Plan (GWMP)

The intention of a GWMP is to provide a framework to manage groundwater to ensure a long-term sustainable, reliable, good-quality water supply suitable to the political, legal, institutional, hydrogeologic, and economic conditions and constraints that exist in the Ventura River Valley Groundwater Basin. The following outline provides an approach to development of a GWMP.

Component 1. Develop a map showing the area of the Basin, as defined by CDWR Bulletin 118, with the area that will be subject to the GWMP, as well as the boundaries of other local agencies that overlie any portion of the Basin. As a delineated groundwater basin with two delineated groundwater subbasins, maps of the basins have been developed by both the state and county agencies, and are incorporated in this report (Figure 1).

Component 2. Provide a written statement to the public describing the manner in which interested parties may participate in development of the GWMP. The statement should be provided to the public via local newspapers and/or other media, with distribution throughout the Basin. Documentation of public notification will be included in the GWMP.

Component 3. Establish a plan to involve other agencies whose boundaries overlie the Basin in development of the GWMP. This may include involvement via agency representative participation in the Ventura River Watershed Council (VRWC) (see Component 4).

Component 4. Establish process for the VRWC to serve as the designated advisory committee of stakeholders (interested parties) within the plan area that will help guide the development and implementation of the GWMP and provide a forum for resolution of controversial issues.

Component 5. Describe, in detail, the area to be managed under the GWMP, including (1) the physical structure and characteristics of the aquifer system underlying the plan area in the context of the overall basin, (2) a summary of the availability of historical data, (3) issues of concern, and (4) a general discussion of historical and projected water demands and supplies.

Component 6. Establish management objectives (MOs) for the groundwater basin that is subject to the plan.

Component 7. For each MO in Component 6, describe how meeting the MO will contribute to a more reliable supply for long-term beneficial uses of groundwater in the plan area, and describe existing or planned management actions to achieve MOs.

Component 8. Adopt monitoring protocols for the monitoring and management of groundwater levels, groundwater quality, potential inelastic land surface subsidence, and changes in surface flow and surface water quality that directly affect groundwater levels or quality.

Component 9. Describe the monitoring program, including the following:

- A map indicating the general locations of any applicable monitoring sites for groundwater levels, groundwater quality, subsidence stations, or stream gages.

- A summary of monitoring sites indicating the type (groundwater level, groundwater quality, subsidence, stream gage) and frequency of monitoring. For groundwater level and groundwater quality wells, indicate the depth interval(s) or aquifer zone monitored and the type of well (public, irrigation, domestic, industrial, or monitoring).

- A quality assurance project plan (QAPP) for monitoring in the Basin.

- Standard operating procedures (SOPs) for monitoring in the Basin.

Component 10. Describe any current or planned actions by the local managing entity to coordinate with other land use, zoning, or water management planning agencies or activities.

Component 11. Provide for periodic report(s) summarizing groundwater basin conditions and groundwater management activities. The report(s), prepared annually or at other frequencies as determined by the WCVC, should include the following:

- Summary of monitoring results, including a discussion of historical trends

- Summary of management actions during the period covered by the report

- A discussion, supported by monitoring results, of whether management actions are achieving progress in meeting MOs

- Summary of proposed management actions for the future

- Summary of any plan component changes, including addition or modification of MOs, during the period covered by the report

- Summary of actions taken to coordinate with other water management and land use agencies, and other government agencies

Component 12. Provide for the periodic reevaluation and updating of the plan by the VRWC.

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Figures

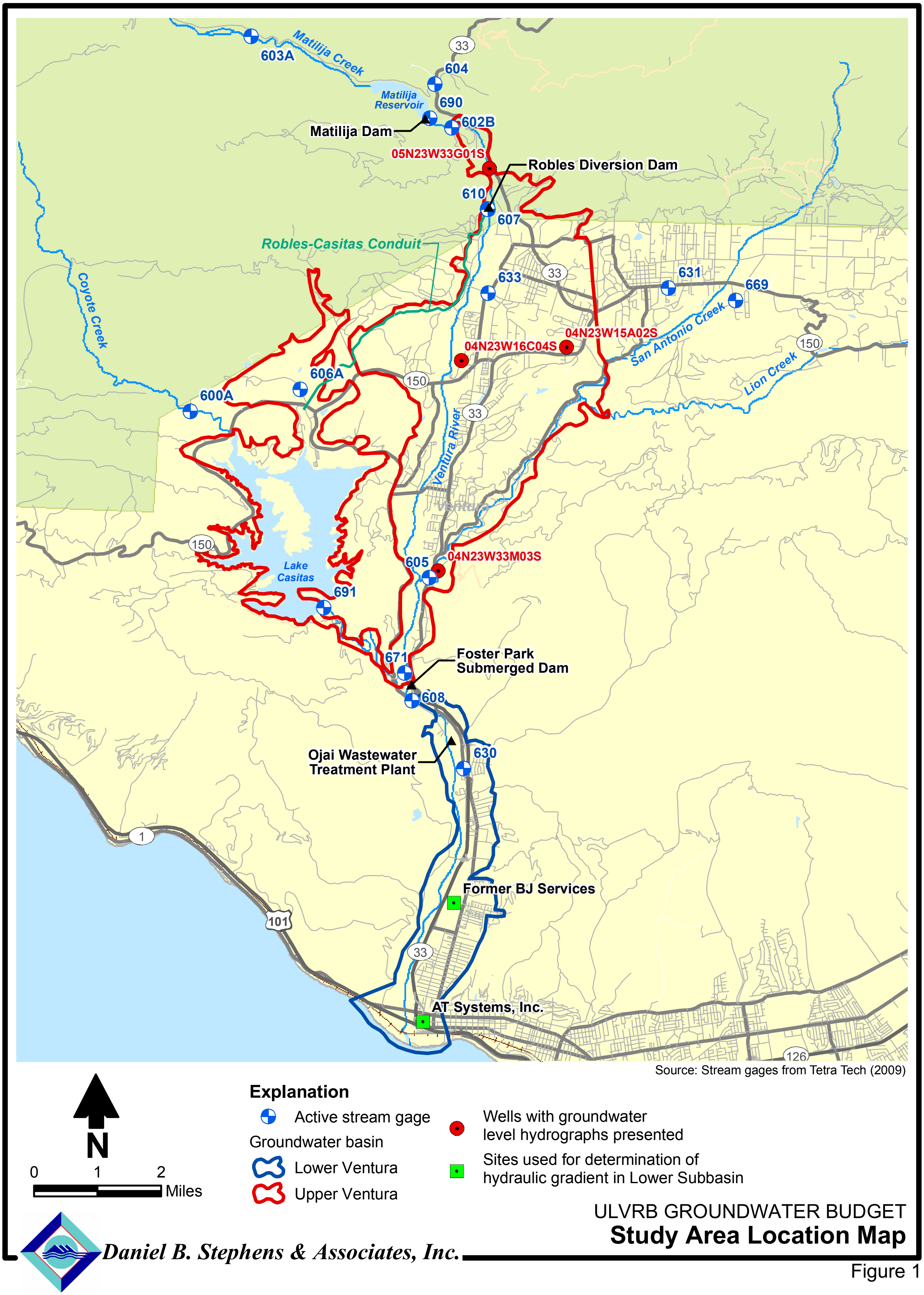
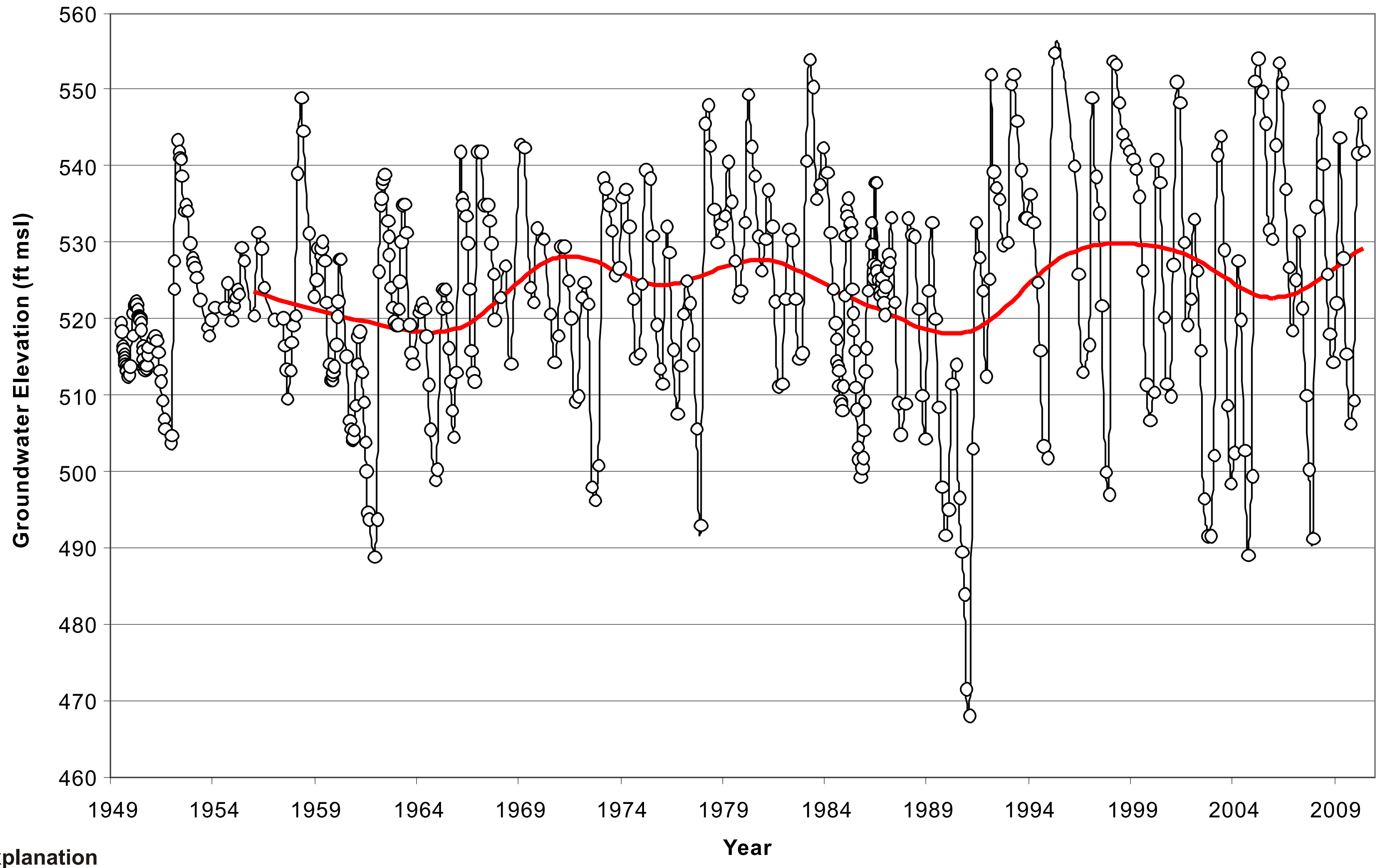

Matilija Creek
603A
604
690
602B
Matilija Reservoir
Matilija Dam
05N23W33G01S
Robles Diversion Dam
610
607
Robles-Casitas Conduit
Coyote Creek
633
631
669
San Antonio Creek
04N23W15A02S
04N23W16C04S
606A
600A
Lion Creek
Ventura River
Lake Casitas
605
04N23W33M03S
691
671
Foster Park
Submerged Dam
608
Ojai Wastewater
Treatment Plant
630
Former BJ Services
AT Systems, Inc.
33
150
1
101
126
Source: Stream gages from Tetra Tech (2009)
N
0
1
2
Miles
Explanation
Active stream gage
Groundwater basin
Lower Ventura
Upper Ventura
Wells with groundwater
level hydrographs presented
Sites used for determination of
hydraulic gradient in Lower Subbasin
ULVRB GROUNDWATER BUDGET
Study Area Location Map
Daniel B. Stephens & Associates, Inc.

Figure 1



Explanation

Measurements

Trailing 5-year average

Source: Ventura County Well Database

ULVRB GROUNDWATER BUDGET

Hydrograph for Ventura County Key Well 04N23W16C04S

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Figure 2

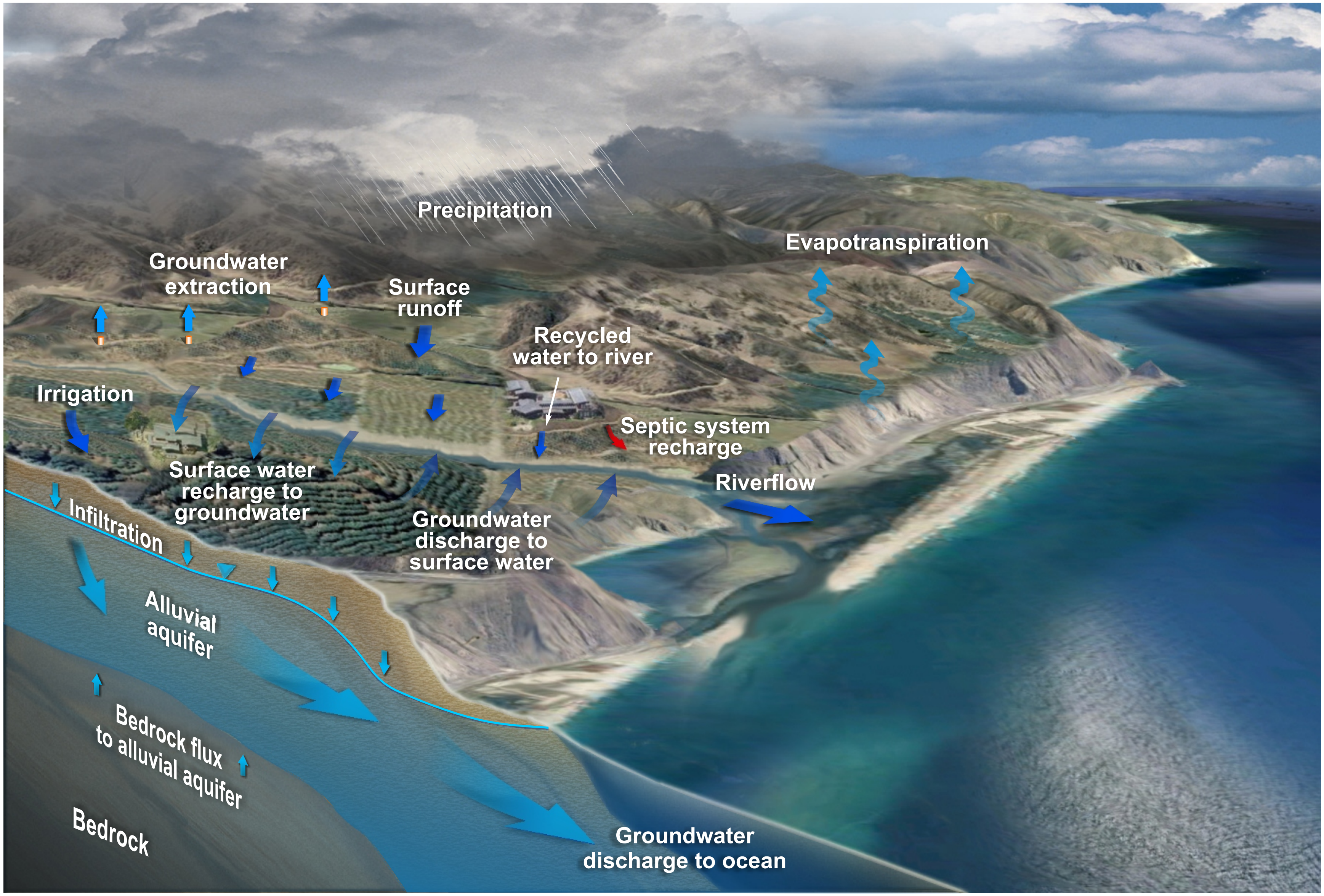

Figure 3

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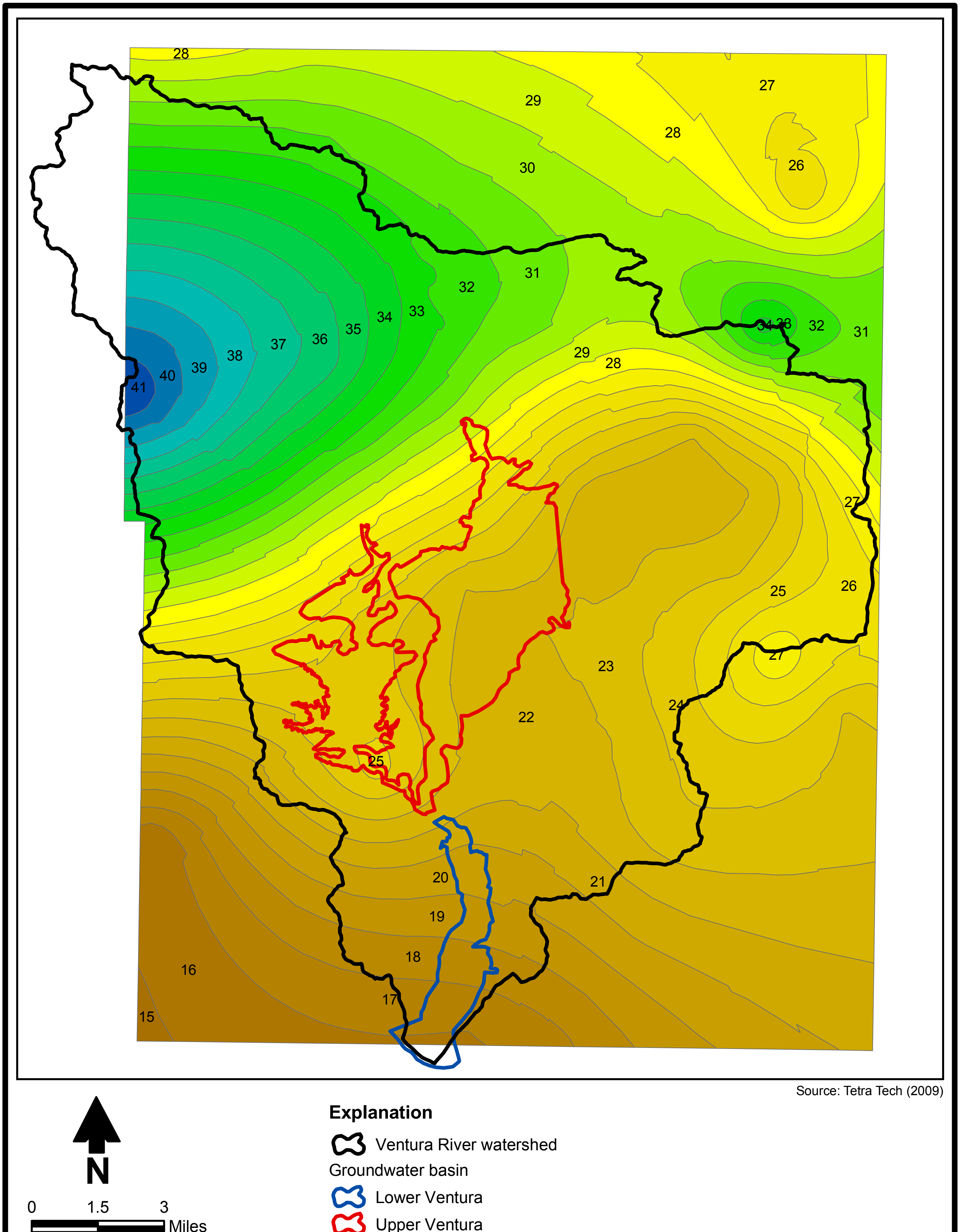
ULVRB GROUNDWATER BUDGET

Schematic Hydrologic Cycle



ULVRB GROUNDWATER BUDGET

Isohyets of Annual Average Precipitation

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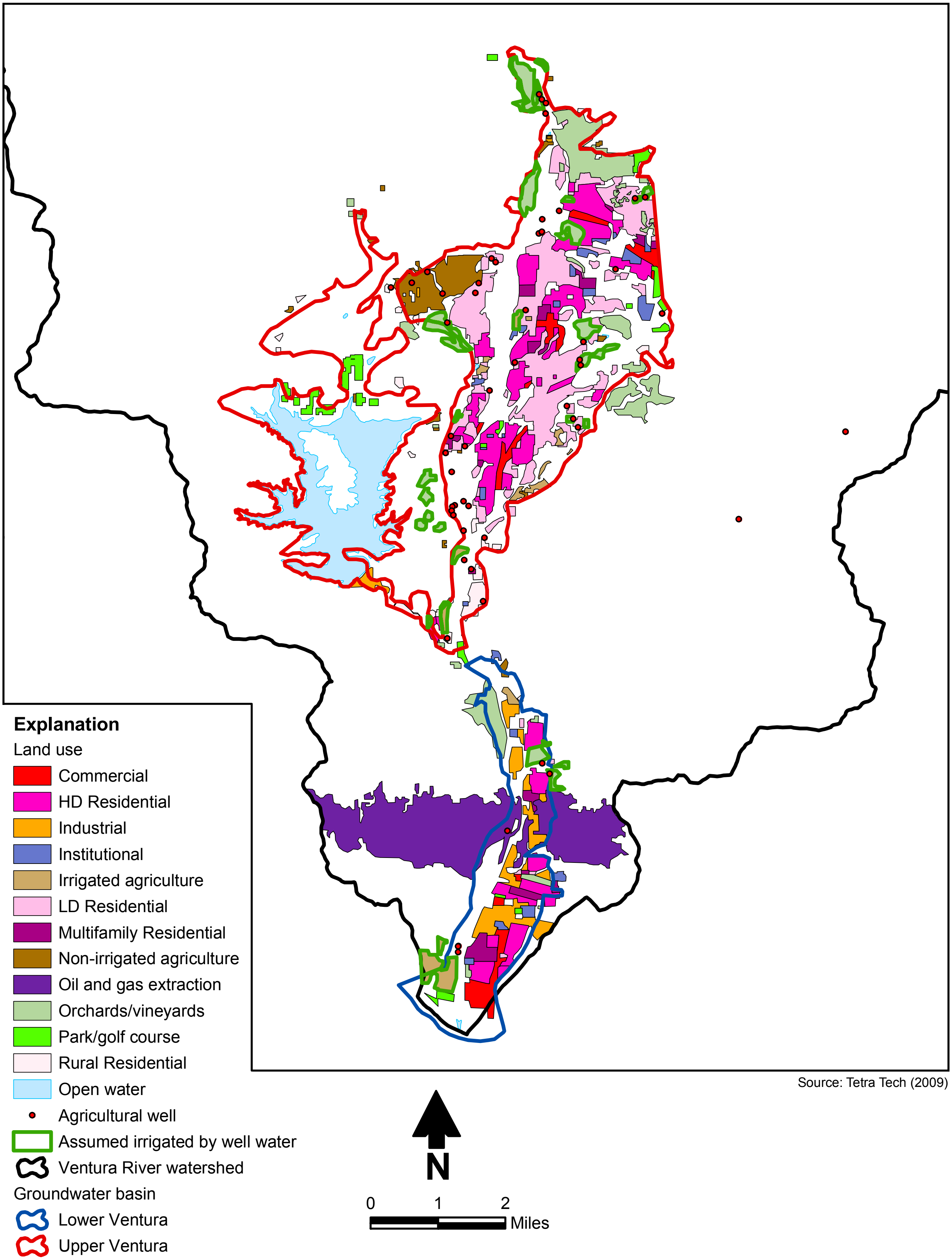
Figure 4



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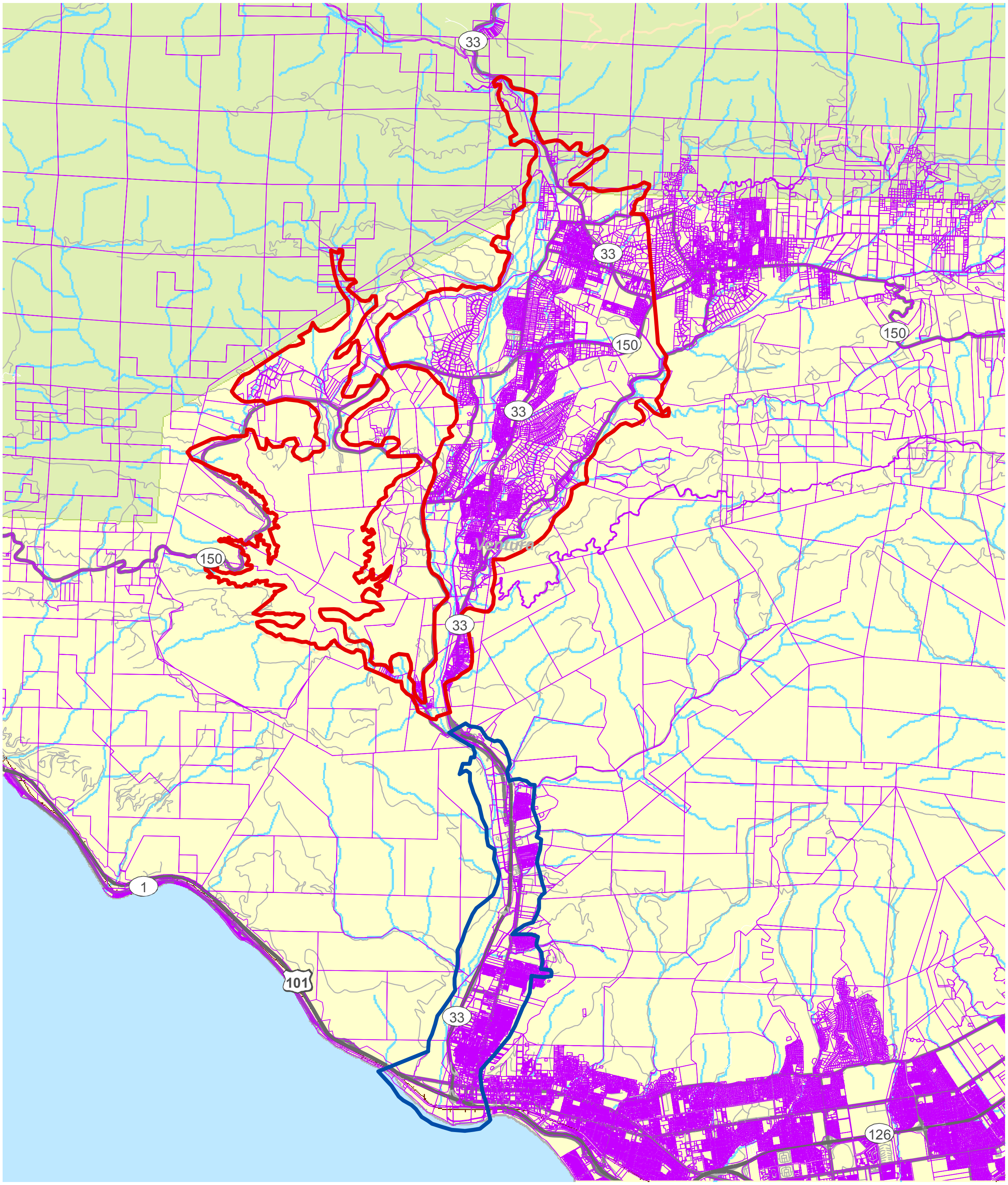
ULVRB GROUNDWATER BUDGET
Land Use

Figure 5



Source: County of Ventura GIS parcel data (http://gis.countyofventura.org/maps_data.htm)

N

0 1 2 Miles

Explanation

Groundwater basin

Lower Ventura

Upper Ventura

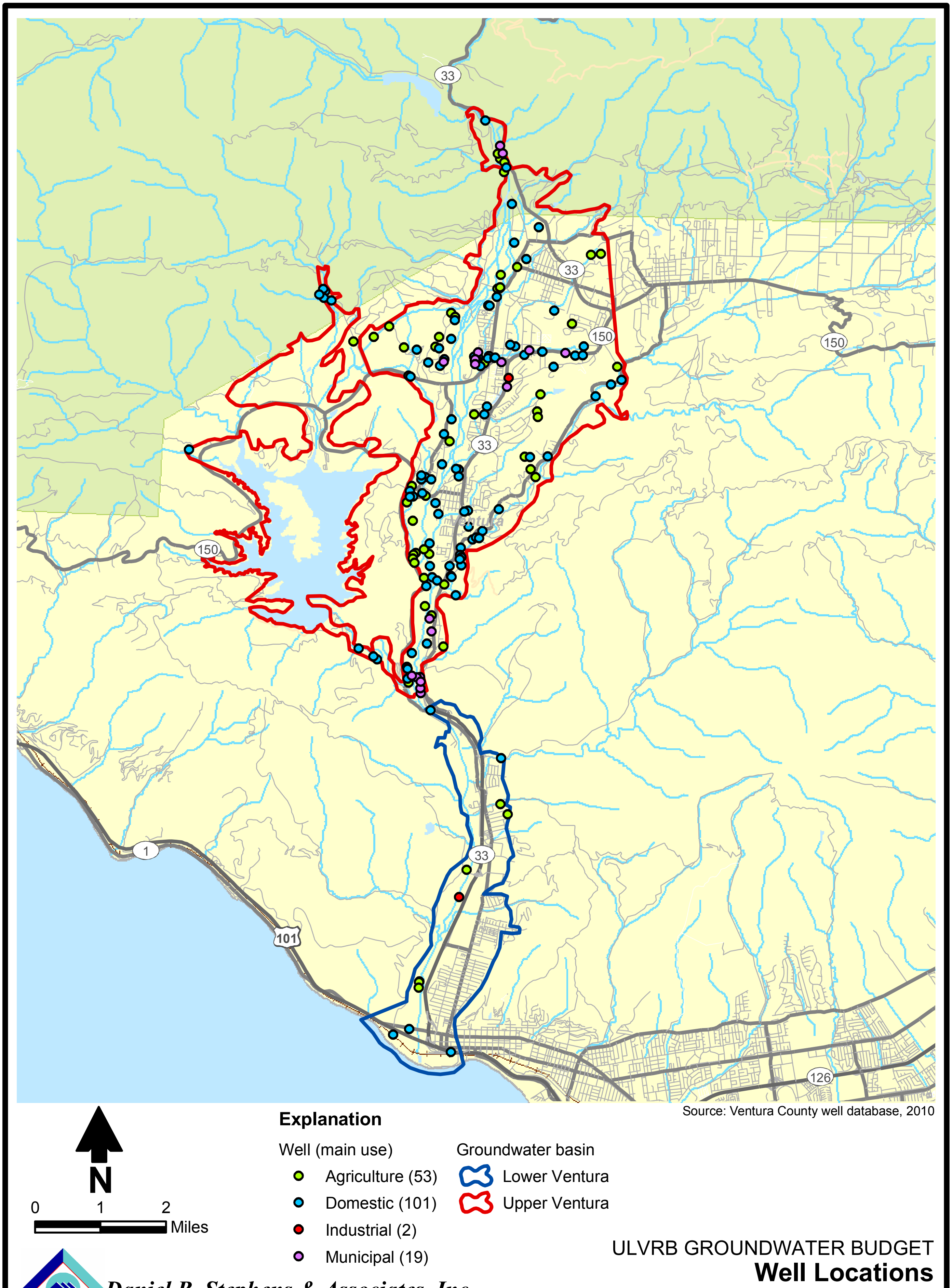
Parcels

ULVRB GROUNDWATER BUDGET

Parcels

Daniel B. Stephens & Associates, Inc.

Figure 6



ULVRB GROUNDWATER BUDGET

Well Locations

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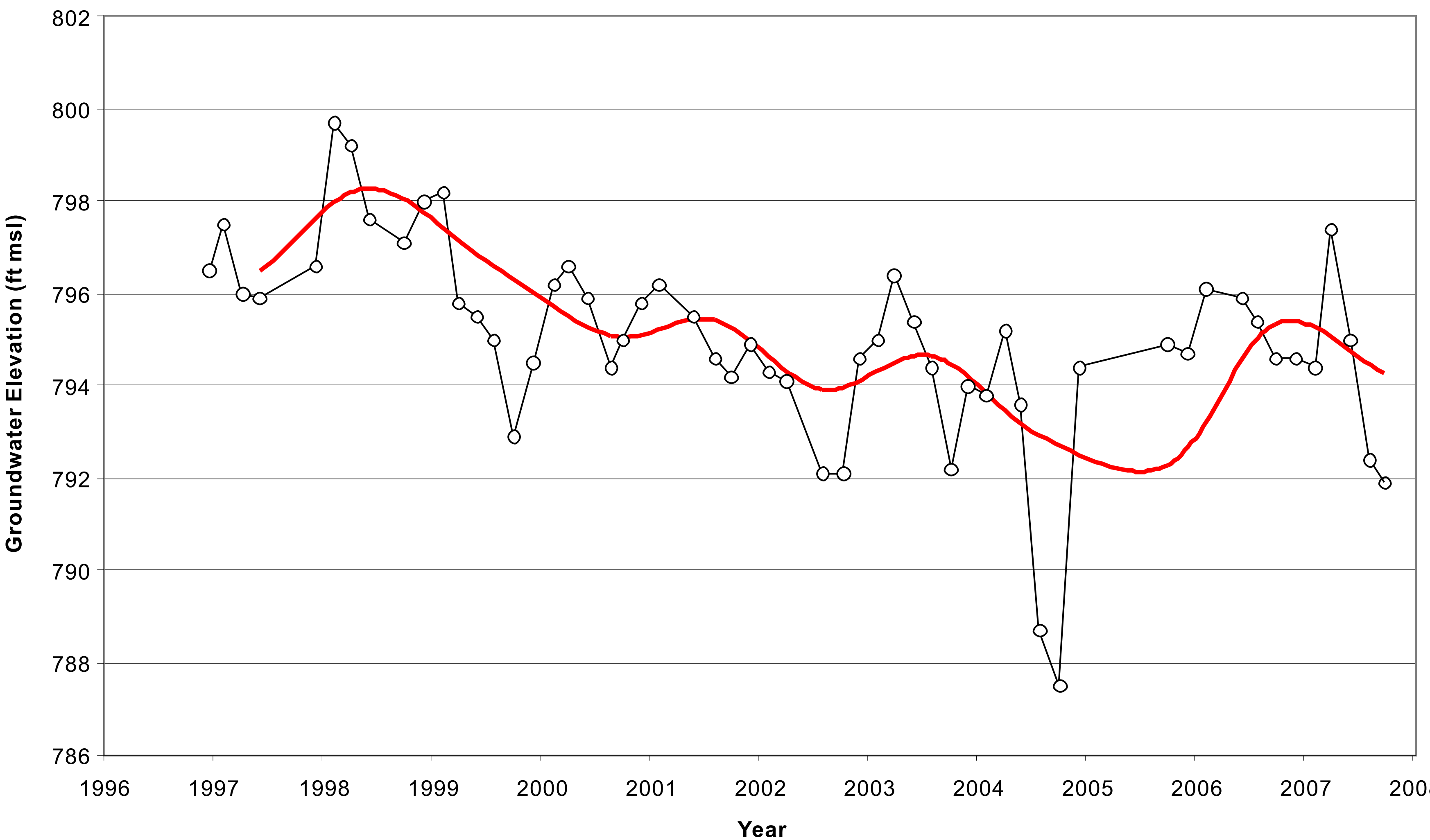
Figure 7



Explanation

Measurements

Trailing 1-year average

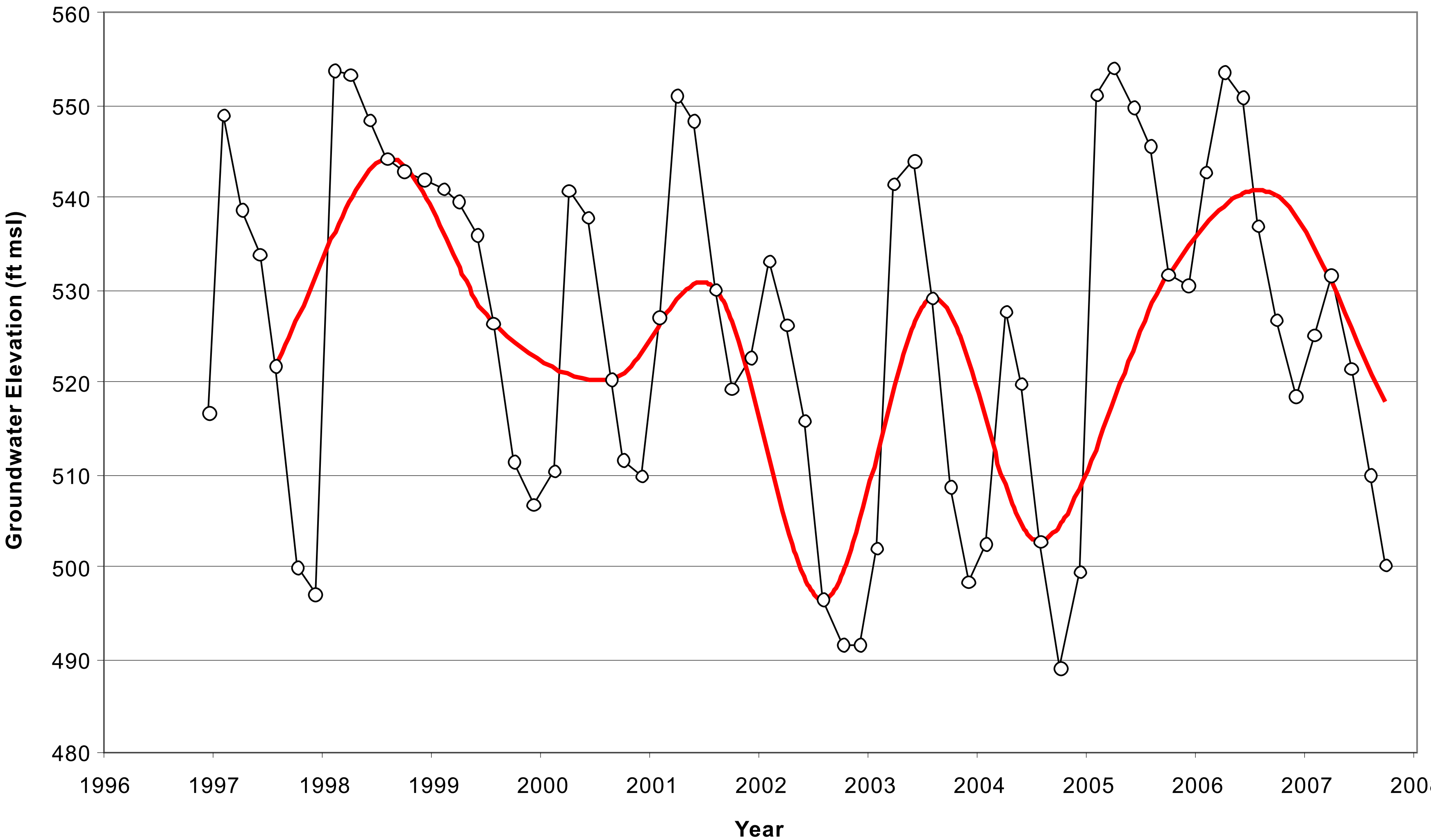
Source: Ventura County Well Database

ULVRB GROUNDWATER BUDGET

Hydrograph for 05N23W33G01S
Water Years 1997-2007

Daniel B. Stephens & Associates, Inc.

Figure 8a



Explanation

Measurements

Trailing 1-year average

Source: Ventura County Well Database

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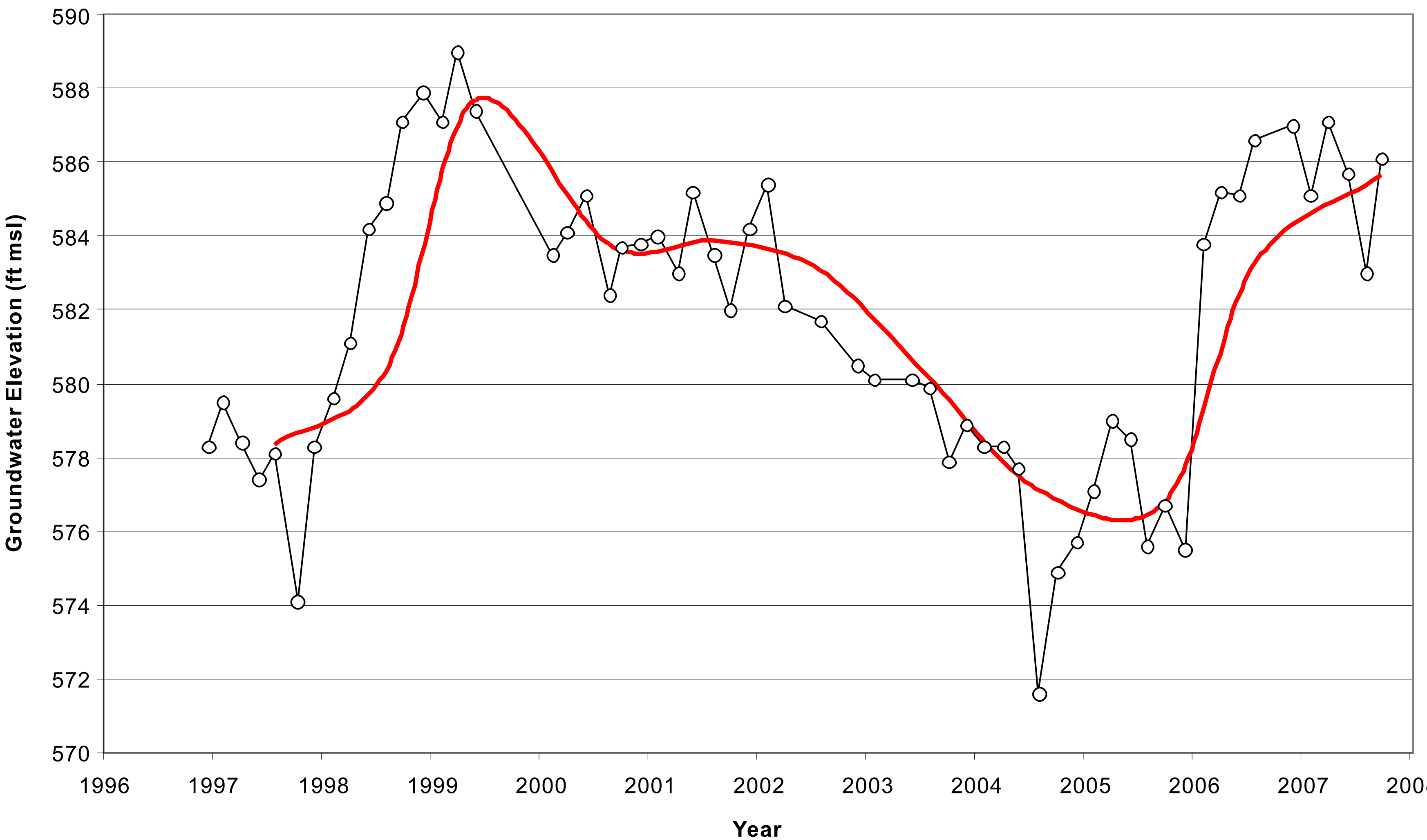
ULVRB GROUNDWATER BUDGET

Hydrograph for 04N23W16C04S
Water Years 1997-2007

Figure 8b



Explanation

Measurements

Trailing 1-year average

Source: Ventura County Well Database

ULVRB GROUNDWATER BUDGET

Hydrograph for 04N23W15A02S
Water Years 1997-2007

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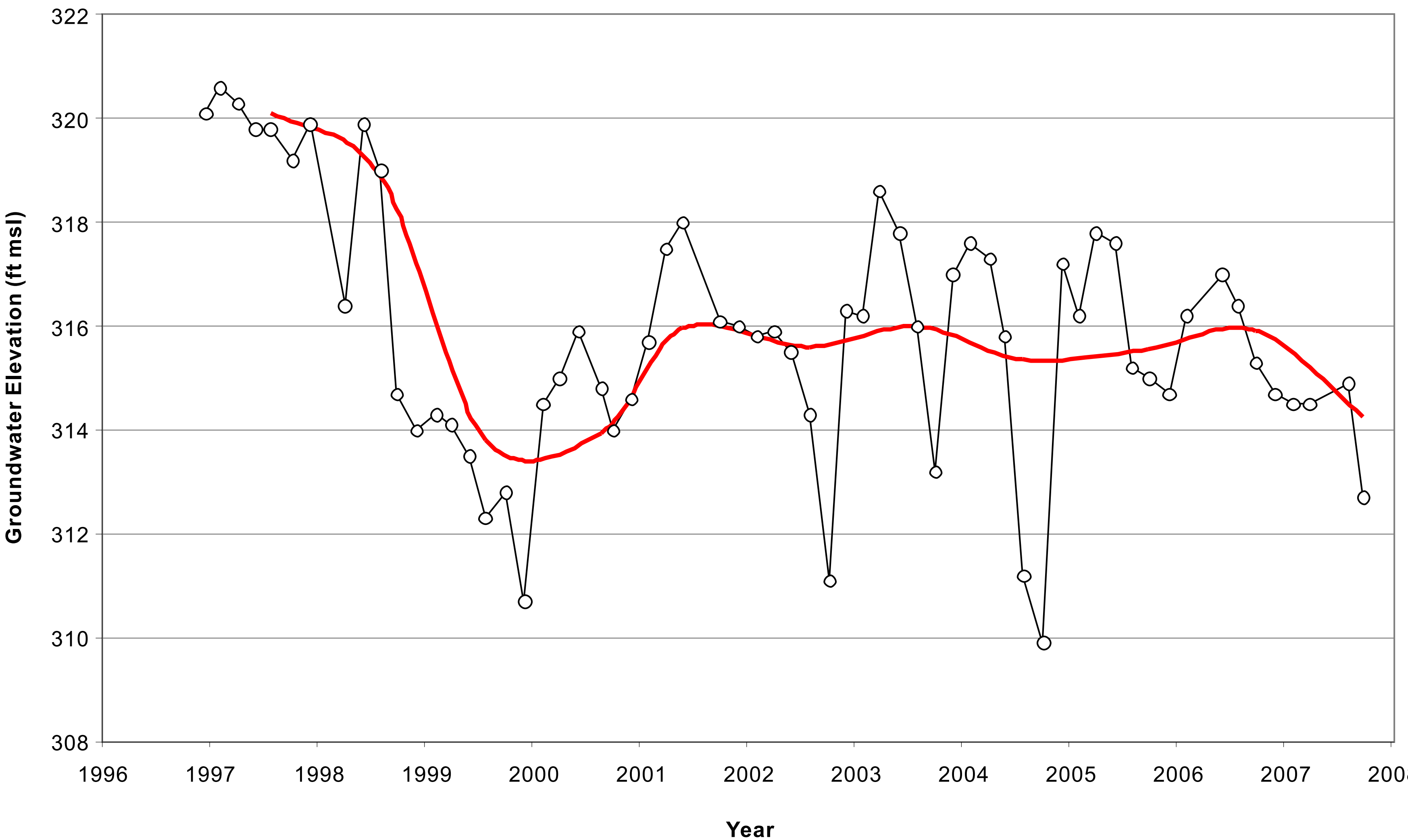
Figure 8c



Explanation

Measurements

Trailing 1-year average

Source: Ventura County Well Database

ULVRB GROUNDWATER BUDGET

Hydrograph for 04N23W33M03S
Water Years 1997-2007

Daniel B. Stephens & Associates, Inc.

Figure 8d

Tables

Table 1. Groundwater Balance
Upper Ventura Subbasin

Category	Parameter	Value (ac-ft/yr)		
		Upper West	Upper East	Upper (Combined)
Basin inputs	Precipitation	3,661	17,659	21,320
	Irrigation	670	12,865	13,535
Groundwater inputs	Infiltration	150	1,303	1,453
	Net surface water to groundwater	2,003	2,290	4,293
	Septic system recharge	19	126	145
	Bedrock to alluvial	—	—	256
Groundwater outputs	Extractions (domestic)	2	22	24
	Extractions (municipal)	—	7,385	7,385
	Extractions (agricultural)	—	1,898	1,898
	Groundwater outflow to Lower Subbasin	—	—	80
			Final balance [a]	–3,240

Source: Tables 3 through 11
[a] Sum of groundwater inputs minus sum of groundwater outputs.

ac-ft/yr = Acre-feet per year
— = Not applicable

Table 2. Groundwater Balance
Lower Ventura Subbasin

Category	Parameter	Value (ac-ft/yr)
Basin inputs	Precipitation	4,946
	Irrigation	2,822
Groundwater inputs	Infiltration	332
	Septic system recharge	6
	Bedrock to alluvial	606
	Groundwater inflow from Upper Subbasin	80
Groundwater outputs	Groundwater discharge to surface water	1,254
	Extractions (domestic)	1
	Extractions (agricultural)	522
	Downgradient out	1,218
	Final balance [a]	–1,971

Source: Tables 3 through 11 ac-ft/yr = Acre-feet per year

[a] Sum of groundwater inputs minus sum of groundwater outputs.

Table 3. Estimated Irrigation Rates, Upper and Lower Subbasins

Land Use	Area [a] (acres)	Fractional Coverage as Vegetation [b]	Water Application [c] (ac-ft/yr)	Irrigation (ac-ft/yr)
Lower Ventura				
Commercial	184.3	0.12	3.96	90
High-density residential	430.9	0.55	3.96	942
Industrial	407.3	0.26	3.96	412
Institutional	50.1	0.50	3.96	99
Irrigated agriculture	104.4	—	1.96	205
Low-density residential	16.9	0.72	3.96	48
Multifamily residential	149.8	0.33	3.96	196
Orchards/vineyards	204.4	—	3.36	687
Park/golf course	36.4	—	3.96	144
			Total	2,822
Upper Ventura West				
Commercial	0.0	0.12	3.96	0
High-density residential	11.2	0.55	3.96	24
Industrial	34.0	0.26	3.96	34
Institutional	0.0	0.50	3.96	0
Irrigated agriculture	4.9	—	1.96	10
Low-density residential	0.0	0.72	3.96	0
Multifamily residential	0.0	0.33	3.96	0
Orchards/vineyards	11.1	—	3.36	37
Park/golf course	142.5	—	3.96	564
			Total	670
Upper Ventura East				
Commercial	224.9	0.12	3.96	110
High-density residential	1,189.3	0.55	3.96	2,600
Industrial	7.6	0.26	3.96	8
Institutional	170.7	0.50	3.96	338
Irrigated agriculture	139.1	—	1.96	273
Low-density residential	1,986.8	0.72	3.96	5,667
Multifamily residential	153.3	0.33	3.96	200
Orchards/vineyards	966.2	—	3.36	3,247
Park/golf course	106.8	—	3.96	423
			Total	12,865

Sources:
[a] Tetra Tech (2009)
[b] Brabec et al. (2002)
[c] CDWR (2010)

ac-ft/yr = Acre-feet per year
— = Not applicable

DRAFT

**Table 4. Surface Water/Groundwater Interaction
Upper Ventura Subbasin (West)**

Water Year	Component (ac-ft/yr)	
	Evaporation [a]	Precipitation [a]
1997	11,062	4,304
1998	9,503	12,632
1999	10,224	2,295
2000	9,801	5,134
2001	8,379	6,693
2002	8,286	2,718
2003	7,985	3,583
2004	7,783	4,897
2005	7,242	7,798
2006	7,649	5,534
2007	8,571	2,253
Average	8,771	5,258
Modeled reservoir loss	5,516	
Net precipitation [b]	–3,513	
Estimated recharge to water [c]	2,003	

[a] Source: CMWD (2010)
[b] Average precipitation minus average evaporation
[c] Modeled reservoir loss plus net precipitation

ac-ft/yr = Acre-feet per year

Table 5. Surface Water/Groundwater Interaction
Upper Ventura Subbasin (East) and Lower Ventura Subbasin

Designator	Parameter	Calculation	Value (ac-ft/yr [a])
A	Ventura River length, Upper East Subbasin	—	9.9 miles
B	Ventura River length, Lower Subbasin	—	6.1 miles
C	Fraction Ventura River length, Upper East Subbasin	A / (A+B)	0.62
D	Fraction Ventura River length, Lower Subbasin	B / (A+B)	0.38
E	Average modeled flows, USGS Gage 608 1997-2007	—	71,523
Reported total, Ventura River Mainstem			
F	Modeled runoff	—	25,013
G	Modeled upstream input	—	58,129
H	Modeled point source (Ojai WWTP)	—	2,491
I	Modeled direct precipitation	—	198
J	Modeled downstream out	—	84,880
K	Modeled diversions out	—	885
Estimated, Upper East Subbasin			
Ventura River			
L	Runoff	F ∗ C	15,477
G	Upstream input	—	58,129
M	Direct precipitation	I ∗ C	123
K	Diversions out	—	885
O	Estimated balance (net river to groundwater)	(E+K) – (L+G+M)	–1,321
San Antonio Creek			
P	Modeled groundwater to creek (entire creek)	—	349
Q	Modeled creek to groundwater (entire creek)	—	2,553
R	Modeled net creek to groundwater (entire creek)	Q – P	2,204
S	Fraction length of creek within Upper East Subbasin	—	0.44
T	Estimated balance (net creek to groundwater)	–(S ∗ R)	–970
Total Upper East Subbasin			
U	Estimated balance (net surface water to groundwater)	T + O	–2,290
Estimated, Lower Subbasin (Ventura River)			
V	Runoff	F ∗ D	9,536
W	Point source (Ojai WWTP)	—	2,491
X	Direct precipitation	I ∗ D	76
Y	Estimated balance (net groundwater to river)	J – (V+W+X+E)	1,254

Source: Modeled data (Tetra Tech, 2009)
[a] Unless otherwise noted

ac-ft/yr = Acre-feet per year
USGS = U.S. Geological Survey
WWTP = Wastewater treatment plant

Table 6. Estimate of Recharge from Septic Systems

Basin	Number of Approved Septic Systems [a]	Recharge (ac-ft/yr)
Estimated average recharge per septic system [b]		0.17 [c]
Upper Ventura West	115	19
Upper Ventura East	749	126
Lower Ventura	34	6

[a] Source: County of Ventura Individual Sewage Disposal Systems Applications/Permits Database
[b] Source: Hantzche and Finnemore (1992)
[c] 150 gallons per day

ac-ft/yr = Acre-feet per year

Table 7. Bedrock Inflow to Alluvial Subbasins
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Formation (North to South)	Structure	Thickness across Ventura River Basins [a] (feet)	Width Under Basins (feet)	Percentage of Formation Aquifer [b]	Bedrock Aquifer Thickness [c] (feet)	Bedrock Aquifer Area under Ventura River Subbasins [c] (ft^2)	Typical Specific Capacity (Q/s) [d] (gpm/ft)	Hydraulic Conductivity [e] (gpd/ft^2)	Head (feet)	Flux to Basin (gpd)	Flux to Basin (ac-ft/yr)
Upper Subbasin											
Cozy Dell Shale	Matilija Overturn	5,500	1,000	20%	1,100	1,100,000	0.2	0.18	0.2	40,000	44.92308
Coldwater Sandstone	Matilija Overturn	5,000	500	60%	3,000	1,500,000	0.5	0.17	0.15	37,500	42.11538
Sespe Formation	Ojai Syncline	19,000	4,000	20%	3,800	15,200,000	0.1	0.03	0.03	12,000	13.47692
Vaqueros Sandstone	Oak View Folds and Flexural Slip faults	500	2,000	80%	400	800,000	0.5	1.25	0.03	30,000	33.69231
Rincon Shale	Oak View Folds and Flexural Slip faults	3,000	2,000	20%	600	1,200,000	0.2	0.33	0.03	12,000	13.47692
Monterey Shale	Oak View Folds and Flexural Slip faults	3,000	2,000	40%	1,200	2,400,000	0.2	0.17	0.03	12,000	13.47692
Rincon Shale	Oak View Folds and Flexural Slip faults	1,000	2,000	20%	200	400,000	0.2	1.00	0.03	12,000	13.47692
Monterey Shale	Oak View Folds and Flexural Slip faults	5,000	1,000	40%	2,000	2,000,000	0.2	0.10	0.03	6,000	6.738462
Rincon Shale	Oak View Folds and Flexural Slip faults	4,000	1,000	20%	800	800,000	0.2	0.25	0.03	6,000	6.738462

[a] Source: Dibblee (1987 and 1988); AAPG (1956)
[b] Based on geophysical logs from water and oil exploration wells in the region
[c] Percentage of formation aquifer thickness times thickness across Ventura River Subbasins
[d] Width under basins times bedrock aquifer thickness
[e] Source: Kear Groundwater, professional experience with wells in bedrock formations in region
[f] $\frac{Q/s * 1{,}000}{b}$

where Q = Flow in well per unit time (gpm)
s = Drawdown (feet)
b = aquifer thickness (feet)

[g] Hydraulic conductivity times head times bedrock aquifer area under Ventura River Subbasins

ft^2 = Square feet
gpm/ft = Gallons per minute per foot
gpd/ft^2 = Gallons per day per square foot
gpd = Gallons per day
ac-ft/yr = Acre-feet per year

Table 7. Bedrock Inflow to Alluvial Subbasins

Formation (North to South)	Structure	Thickness across Ventura River Basins [a] (feet)	Width Under Basins (feet)	Percentage of Formation Aquifer [b]	Bedrock Aquifer Thickness [c] (feet)	Bedrock Aquifer Area under Ventura River Subbasins [c] (ft^2)	Typical Specific Capacity (Q/s) [d] (gpm/ft)	Hydraulic Conductivity [e] (gpd/ft^2)	Head (feet)	Flux to Basin (gpd)	Flux to Basin (ac-ft/yr)
Upper Subbasin (cont.)											
Vaqueros Sandstone	Oak View Folds and Flexural Slip faults	300	1,000	80%	240	240,000	0.5	2.08	0.03	15,000	16.84615
Sespe Formation	Red Mountain Anticline	6,000	800	20%	1,200	960,000	0.1	0.08	0.05	4,000	4.492308
Vaqueros Sandstone		100	500	80%	80	40,000	0.5	6.25	0.1	25,000	28.07692
Rincon Shale	Red Mountain Fault Zone	1,000	800	20%	200	160,000	0.2	1.00	0.1	16,000	17.96923
	Total (Upper Subbasin)										**256**
Lower Subbasin											
Pico Formation	Ventura Anticline	19,000	2,000	60%	11,400	22,800,000	0.4	0.04	0.15	120,000	134.7692
Las Posas Sand		1,000	3,000	80%	800	2,400,000	1	1.25	0.1	300,000	336.9231
Saugus Formation	Marine Terrace	1,000	3,000	40%	400	1,200,000	0.8	2.00	0.05	120,000	134.7692
	Total (Lower Subbasin)										**606**

[a] Source: Dibblee (1987 and 1988); AAPG (1956)
[b] Based on geophysical logs from water and oil exploration wells in the region
[c] Percentage of formation aquifer thickness times thickness across Ventura River Subbasins
[d] Width under basins times bedrock aquifer thickness
[e] Source: Kear Groundwater, professional experience with wells in bedrock formations in region
[f] $\frac{Q/s * 1{,}000}{b}$

where Q = Flow in well per unit time (gpm)
s = Drawdown (feet)
b = aquifer thickness (feet)

[g] Hydraulic conductivity times head times bedrock aquifer area under Ventura River Subbasins

ft^2 = Square feet
gpm/ft = Gallons per minute per foot
gpd/ft^2 = Gallons per day per square foot
gpd = Gallons per day
ac-ft/yr = Acre-feet per year

Table 8. Groundwater Flux Between Subbasins and to Ocean

Designator	Parameter	Calculation	Value	Units
A	Hydraulic conductivity of alluvium [a]	—	100	ft/d
B	Thickness of saturated alluvium [b]	—	50	feet
Groundwater flux from Upper to Lower Subbasin				
C	Width of alluvium (gap in Foster Park Dam) [c]	—	300	feet
D	Hydraulic gradient [b]	—	0.0064	unitless
E	Groundwater flux	B ∗ C ∗ A ∗ D	9,600	ft^3/d
			80	ac-ft/yr
Groundwater flux from Lower Subbasin to Pacific Ocean				
F	Average groundwater elevation, AT Systems, Inc, 9/2008 [d]	—	6.86	ft msl
G	Average groundwater elevation, Former BJ Services, 9/2008 [e]	—	64.78	ft msl
H	Distance, AT Systems, Inc to Former BJ Services	—	10,138	feet
I	Width of alluvium (Lower Subbasin) [f]	—	5,089	feet
J	Hydraulic gradient	(G – F) / H	0.0057	unitless
K	Groundwater flux	B ∗ I ∗ A ∗ J	145,379.7	ft^3/d
			1,218	ac-ft/yr

Sources:
[a] Fetter (2001)
[b] Turner (1971)
[c] SBRA (2002)
[d] H2 Environmental (2008)
[e] EnviroSolve (2010)
[f] USGS (1951)

— = Not applicable
ft/d = Feet per day
ft^3/d = Cubic feet per day
ac-ft/yr = Acre-feet per year
ft msl = Feet above mean sea level

**Table 9. Municipal Groundwater Withdrawals (Upper East Subbasin)
2000 Through 2007**

District	Average Withdrawals (ac-ft/yr)
City of Ventura/Foster Park	4,603
Ventura River County Water District	1,399
Casitas Municipal Water District/Mira Monte Well	206
Meiners Oaks County Water District	1,177
Total Upper Ventura East	7,385

Source: Pumping records provided by applicable water districts

ac-ft/yr = Acre-feet per year

Table 10. Domestic Groundwater Withdrawals

Basin	Number of Active Domestic Wells [a]	Extraction (ac-ft/yr)
Estimated average domestic withdrawals per well [b]		*0.25* [c]
Upper Ventura West	8	2
Upper Ventura East	86	22
Lower Ventura	5	1

[a] Source: Ventura County Well Database
[b] Source: USGS (2000)
[c] 225 gallons per day

ac-ft/yr = Acre-feet per year

Table 11a. Agricultural Groundwater Withdrawals Based on Land Use and Agricultural Well Placement Within Subbasins

Basin	Land Use Type	Land Use Area [a] (acres)	Water Application (ac-ft/yr)	Irrigation (ac-ft)
Lower Ventura River	Irrigated agriculture	147.6	1.96	289
	Orchards/vineyards	69.4	3.36	233
			Total Irrigation	522
Upper Ventura East	Irrigated agriculture	70.3	1.96	138
	Orchards/vineyards	523.9	3.36	1,760
			Total Irrigation	1,898

[a] Interpreted from Tetra Tech (2009)
[b] Source: CDWR (2000)
ac-ft/yr = Acre-feet per year

Table 11b. Agricultural Groundwater Withdrawals Based on Number of Agricultural Wells and an Average Extraction Rate

Basin	Number of Active Wells [a]	Withdrawals (ac-ft/yr)
Estimated average agricultural withdrawals per well [b]		*79*
Lower Ventura River	6	474
Upper Ventura East	43	3,397

[a] Source: Ventura County Well Database
[b] Estimated from SGD (1992)
ac-ft/yr = Acre-feet per year