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Analysis of Baseflow Trends Related to Upland Groundwater Pumping for Las Garzas, San Clemente, Potrero, and San Jose Creeks

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ANALYSIS OF BASEFLOW TRENDS RELATED TO UPLAND GROUNDWATER PUMPING FOR LAS GARZAS, SAN CLEMENTE, POTRERO, AND SAN JOSE CREEKS

A Thesis

Presented to the

Faculty of the

Division of Science and Environmental Policy

California State University Monterey Bay

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Coastal and Watershed Science and Policy

by

Zachary Croyle

Spring 2009

CALIFORNIA STATE UNIVERSITY MONTEREY BAY

The Undersigned Faculty Committee Approves the

Thesis of Zachary Croyle

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ANALYSIS OF BASEFLOW TRENDS RELATED TO UPLAND GROUNDWATER PUMPING FOR LAS GARZAS, SAN CLEMENTE, POTRERO, AND SAN JOSE CREEKS

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ABSTRACT

Analysis of Baseflow Trends Related to Upland Groundwater Pumping for Las Garzas, San Clemente, Potrero and San Jose Creeks
by
Zachary Croyle
Master of Science in Coastal and Watershed Science and Policy
California State University Monterey Bay, 2009

As Carmel River water supplies have become over-appropriated, new development projects have increasingly utilized groundwater from fractured rock aquifers found in the uplands of the Carmel River watershed. The Santa Lucia Preserve (SLP) is an example of a recent residential development project that has developed its water supply solely from upland fractured rock aquifers. The intensive use of groundwater by the SLP project has generated a great deal of concern because of the potential negative effects this may have by reducing dry season baseflows in Carmel River tributaries and San Jose Creek. Stream baseflows are critical in maintaining quality instream habitat for juvenile steelhead trout during the dry season (a listed species under the Endangered Species Act). This research aims to fill a demand for additional groundwater – surface water information by analyzing stream baseflows for declining trends associated with groundwater pumping by the SLP. This study used two complimentary multiple-regression model comparison techniques to test for trend at study streams (Las Garzas, San Clemente, Potrero, and San Jose Creek, originating on SLP land) and undeveloped reference streams. A sensitivity analysis was also conducted to test the ability of the analysis methods to detect a simulated reduction in baseflow for records of different lengths (6, 7, 9, and 16 years, representing lengths of available records used in this research). Analysis results provided no substantial evidence to support the hypothesis that declining baseflow trends are occurring in any of the study streams. However, results of the sensitivity analysis revealed that records greater than 9 years are needed to unambiguously detect a trend in baseflow. The sensitivity analysis also revealed that even if a declining baseflow trend is occurring, it cannot be detected using records of 9 years or less. Given that most study streams had records of 9 years or less, declining trends in baseflows cannot presently be ruled out. The methods used in this research will likely be able to produce more useful and unequivocal results on baseflow trends in Carmel River tributaries and San Jose Creek as more streamflow data becomes available in the near future.

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CHAPTER 1

INTRODUCTION

Carmel River Watershed

The Carmel River watershed, in Monterey County along California's central coast, is an area where increasing demand for water has exceeded limited supplies and resulted in numerous environmental and regulatory challenges. Water pumped from the Carmel River alluvial aquifer provides approximately 69% of the water supply for the Monterey Peninsula area (SWRCB 1995). The intensive use of this resource over many years in response to increased urban development led to a lowering of groundwater levels and decrease in dry season streamflows (Smith et al. 2004). Lowered groundwater levels caused mortality of riparian vegetation that resulted in bank erosion and channel widening in the lower reaches of the Carmel River (Kondolf and Curry 1986). Riparian vegetation along portions of the lower Carmel River must now be sustained by irrigation during summer months (MPWMD 2008a). The lower reaches of the river ordinarily stop flowing by July and isolated pools that remain gradually dry as groundwater elevations drop in response to pumping (NMFS 2002).

Reductions in streamflow and dewatering of the lower river have reduced available steelhead habitat during the dry season and made them more vulnerable to stranding and predation (NMFS 2002). The intensive use of Carmel River water resources, with the attendant effects on stream habitat, has been directly implicated in the decline of steelhead trout (*Oncorhynchus mykiss*) populations (DFG 1996; NMFS 2002). Carmel River steelhead populations are part of the California south-central coast Evolutionary Significant Unit (ESU) that was federally listed as threatened under the Endangered Species Act (ESA) in 1997 (NMFS 2007).

In 1995 the State Water Resources Control Board (SWRCB) concluded in Order 95-10 that excessive diversion and pumping of the Carmel River by California American Water Company (Cal-Am), the private utility that provides local water services, was causing direct adverse impacts to the riparian corridor below San Clemente Dam, to wildlife dependent on riparian habitat, and to steelhead trout and other fish (SWRCB 1995). SWRCB ruled that Cal-Am was taking 10,730 acre-feet annually in excess of their legal water right and was ordered to reduce its use of Carmel River water by 75% (SWRCB 1995). An interim cut of 20% was ordered while new water supplies must be found to offset the use of Carmel River water and achieve the ultimate goal of a 75% reduction (MPWMD 2008b).

Santa Lucia Preserve Project

With Carmel River water supplies over-appropriated, new development projects have had to find alternative sources of water. A source of water that is being increasingly utilized is the fractured rock aquifers found in the uplands of the Carmel River watershed. The Santa Lucia Preserve (SLP) is an example of a recent project that has developed an independent water supply relying solely on these upland fractured rock aquifers. SLP is on the 20,000 acre former Rancho San Carlos property located in the uplands of the Carmel River watershed. The property includes the headwaters of several important Carmel River tributaries and San Jose Creek (Figure 1).

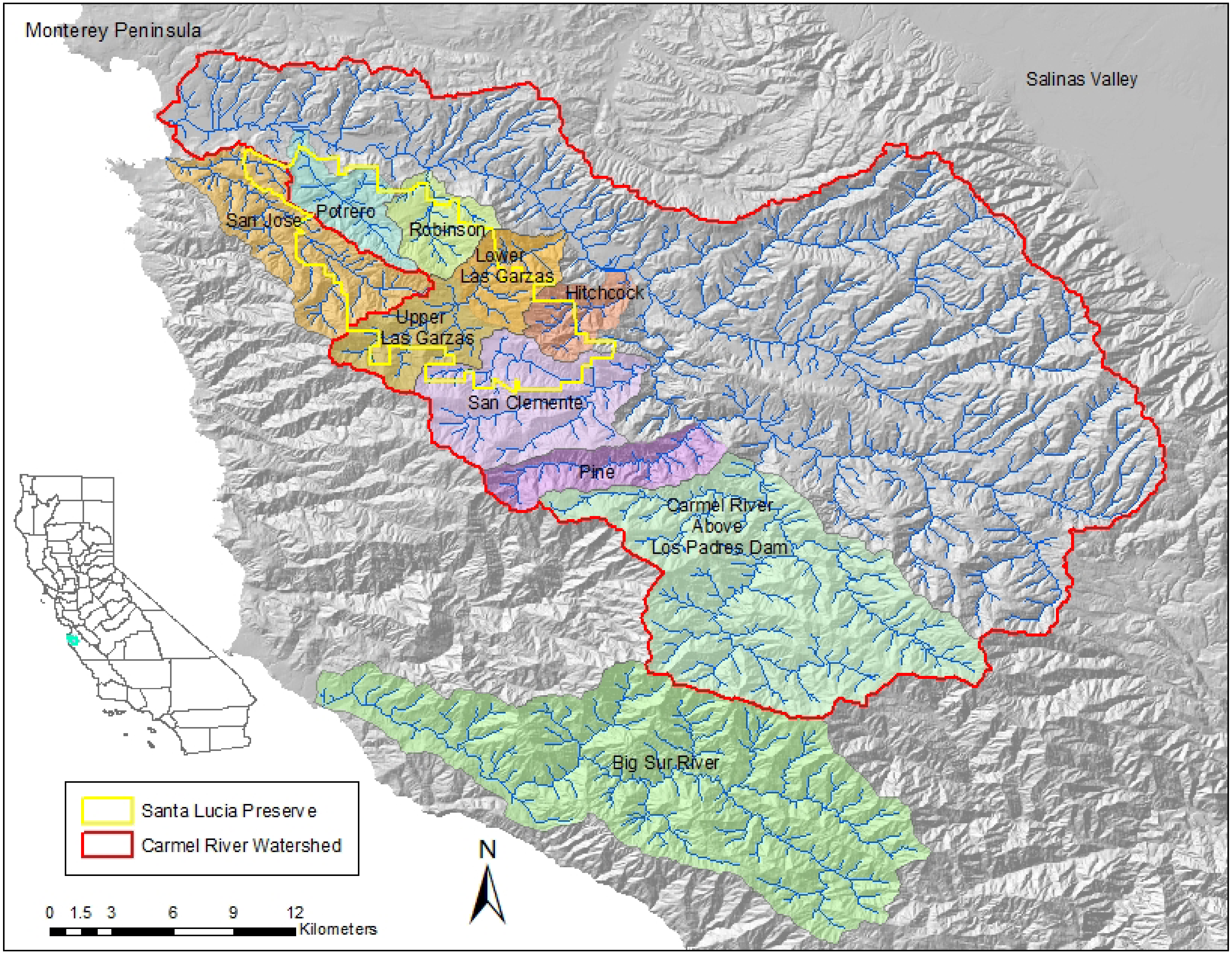


Figure 1. Map of Carmel River watershed and surrounding area, depicting the Santa Lucia Preserve and watersheds of interest

The SLP project involved the creation of a private community of low density housing, recreation facilities, and golf course, but with approximately 18,000 acres to be left undeveloped and managed as open space (SLC 2007).

Project Permitting History

Monterey County Planning and Building Inspection Department is the lead agency under the California Environmental Quality Act (CEQA) and oversees the preparation of Environmental Impact Reports (EIR) for projects occurring within the county. The original Comprehensive Development Plan submitted in 1994 created the SLP and "outlined resource protection principles and identified the location of development and preservation areas throughout the [Santa Lucia] Preserve" (Monterey County 2003). The Comprehensive Development Plan established the Santa Lucia Conservancy as a non-profit public organization and independent corporation that would manage the 18,000 acres of undeveloped lands it would own through fee titles and conservation easements (Monterey County 2003). The draft EIR for SLP was prepared and circulated in 1994 -1995 (Monterey County 2003). The final EIR (FEIR) was certified by the Board of Supervisors in 1996 along with the Comprehensive Development Plan and was subject to numerous Conditions of Approval (Monterey County 2003). The SLP project approved in 1996 included a provision to rezone 1,135 acres for the construction of a hotel and commercial development (Monterey County 2003). However, this rezoning provision was nullified through a voter referendum, Measure M (Monterey County 2003). In 1997 an addendum was approved that updated the FEIR to reflect the changes in the SLP project caused by the passage of Measure M and by the listing of California red-legged frog and steelhead trout under the ESA (Monterey County 2003). In 2003, a supplemental EIR was prepared as required to implement the Potrero Subdivision phase of the SLP project (Monterey County 2003). The final supplemental EIR (FSEIR) was certified by the Monterey County Board of Supervisors in 2005 (Monterey County 2005).

Potential Impacts of Upland Groundwater Use

The intensive use of groundwater by the SLP project and the potential negative effects this may have on tributary baseflow conditions and downstream water supplies in the Carmel River have generated a great deal of concern. The direct connection between groundwater from upland fractured rock aquifers and dry season tributary baseflows was noted in the FEIR (Monterey County 1995) and by other investigators (Woyshner et al. 2003; Smith et al. 2004), but has not been extensively studied. The connection between groundwater and surface water makes depletion of tributary baseflows from groundwater pumping highly likely (Monterey County 1995).

Steelhead are thought to utilize all major tributaries originating on SLP (Las Garzas, Potrero, San Clemente, San Jose) for spawning and rearing (Monterey County 1995). Minor tributaries (e.g. Hitchcock Canyon) are also utilized when hydrological conditions are optimal (Monterey County 1995). Dry season baseflows are critical in maintaining rearing conditions for juvenile steelhead during a time of year when habitat may be limited to isolated pools and discontinuous reaches of wetted channel (Monterey County 1995). The Carmel River watershed also contains significant populations of California Red-Legged frog (*Rana aurora draytonii*), another threatened species listed under ESA in 1996 (MPWMD 2004; USFWS 2007). Reductions in dry season tributary baseflows would reduce and degrade available aquatic habitat and could harm steelhead and red-legged frog populations (Monterey County 1995; DFG 1999; SWRCB 2003; Monterey County 2004).

Carmel River tributaries originating on SLP contributed 24% of the total annual streamflow for the Carmel River (at Highway 1 bridge) during WY 1993 – 2003 (James 2004). Reductions in tributary baseflows, as well as groundwater outflow, due to SLP groundwater use could result in less water available for Carmel River surface flows and recharge of its adjacent alluvial aquifer (Monterey County 1995; Smith et al. 2004).

Mitigation Measures

The high potential for project groundwater use to impact tributary baseflows and groundwater flow to recharge Carmel Valley aquifer was identified and discussed in the FEIR (Monterey County 1995). The FEIR was subject to a number of Conditions of Approval intended to prevent, detect, and mitigate project related impacts to tributary baseflow (Appendix A). The FEIR (Monterey County 1995) concludes implementation of these mitigation measures will result in negligible and fully mitigated impacts to summer baseflows.

Condition 14 requires daily monitoring of streamflow at Potrero, San Clemente, and Las Garzas Creeks near SLP property boundaries (Monterey County 2004b). In addition, Condition 14 requires an annual report on a survey evaluating pool and baseflow conditions conducted each September for all gaged streams and also San Jose Creek (Monterey County 2004). Condition 15 requires baseflows to be augmented by discharging water into the channel if the annual baseflow monitoring report demonstrates that baseflows in any of the streams have declined below October 1990 levels as a direct result of the project (Monterey County 2004). October 1990 baseflow conditions are used as a reference because they represent end of the dry season conditions after a severe 4 year drought and serve as a minimum flow management objective (Monterey County 1995). The FEIR (Monterey County 1995) states October 1990 conditions represent the "lowest flows that the aquatic habitat would probably have to endure in a 20- to 50- year period." Condition 11 requires monitoring of groundwater levels for all production wells to be reported annually and trends in groundwater hydrographs to be evaluated at least every 3 years (Monterey County 2004). Condition 12 requires that pumping of wells located within 1000 feet of Protected Baseflow Reaches be delayed between April 1 and November 1, unless the combined capacity of other wells is insufficient to meet project demand (Monterey County 2004). Protected Baseflow Reaches are defined as those reaches that contained pools or baseflow in October 1990 (Monterey County 1995). Condition 13 allows for the construction of new wells to be less than 1000 feet from Protected Baseflow Reaches, but limits pumping between April 1 and November 1 so that groundwater levels are not drawn down more than 2 feet in areas with riparian vegetation or 1 foot along a Protected Baseflow Reach (Monterey County 2004).

The Cattle Grazing Plan is another key component of the mitigation strategy and was included as part of the SLP project design largely for the beneficial effects on hydrology that are assumed will result from its implementation (Monterey County 1995). The Cattle Grazing Plans calls for grazing a limited fraction of the historic grazing lands at intensities one-fifth of historic levels (Monterey County 1995). Increased infiltration of precipitation resulting from reduced grazing intensity is expected to increase groundwater recharge, compared to in the past when SLP was more intensively grazed (Monterey County 1995). The FEIR (Monterey County 1995) claims the "Cattle Grazing

Plan would have a substantial beneficial impact on the groundwater balance that would probably more than offset the long-term effects of project water use on groundwater levels, subsurface outflow, stream base flow, and phreatophytic vegetation."

The potential impact to Carmel Valley water supplies resulting from decreases in tributary streamflow and groundwater outflow from SLP was considered less than significant and no mitigation measures were required (Monterey County 1995). Among the reasons potential impacts were considered less than significant was because decreases in surface and subsurface flow to Carmel Valley during critical droughts was estimated to be little more than 1% of annual groundwater use in Carmel Valley (Monterey County 1995).

Criticism of Mitigation Measures

Despite mitigation and monitoring requirements imposed on the SLP project, various government resource agencies, interest groups, and individuals have expressed concern that current measures are inadequate to mitigate impacts on stream baseflows and aquatic habitat, and are based on flawed analyses. It has been alleged that SLP groundwater use has resulted in reductions in dry season baseflows on Las Garzas, San Jose, and Potrero Creeks that have reduced and degraded habitat supporting steelhead trout and red-legged frogs (DFG 1999; SWRCB 2003; Monterey County 2004a; NMFS 2005). Condition 15 has been criticized because it requires mitigation through flow augmentation only if baseflows are depleted below severe drought levels (October 1990 conditions) and could conceivably result in stream baseflows being depleted down to extremely dry conditions every year (CRSA 1996; NMFS 2005). Because summer rearing habitat is a limiting factor for Carmel River steelhead, "maintaining summer creek [base]flows at multi-year drought levels will dramatically reduce the number of juvenile steelhead that survive each summer. . . [and] is likely to lead to the demise of the steelhead populations in all five of the steelhead streams on the [Santa Lucia] Preserve" (NMFS 2005). Critics note that streamflow gages were not installed as required by Condition 14 until 2001 and 2002, after project groundwater use had begun; this lack of pre-project streamflow data makes interpretation of post-project data subjective and precludes meaningful efforts at determining effects on baseflow from groundwater use (NMFS 2005). Critics claim the FEIR and FSEIR analyses were based on questionable assumptions about the SLP aquifer system (e.g. homogeneity, isotropy) and wrongly assumed impacts from groundwater use would be distributed evenly across SLP; instead critics believe available evidence indicates baseflow impacts will be highly localized (Monterey County 1995; NMFS 2005). The FEIR and FSEIR assumes the Cattle Grazing Plan will fully mitigate any impacts on groundwater levels and stream baseflow but critics point out these claims are not substantiated with any real data or analysis specific to SLP (NMFS 2005). Project proponents have countered the claims of critics and maintain the original analyses and mitigation measures conducted for the FEIR (Monterey County 1995) are valid. As evidence, they cite additional analyses conducted by project consultants for the FSEIR (Monterey County 2004) that concluded impacts to baseflow from groundwater pumping are negligible and mitigation measures are working (Monterey County 2004).

Need for Additional Research

Based on the concerns of government resources agencies, interest groups, and experts, it is clear there is a demand for further analyses of groundwater – surface water interactions for the SLP project. Demand for additional analyses reflects the high value of the aquatic resources at stake and the high potential for impacts to occur. There is disagreement between experts whether observed post-project tributary baseflow patterns reflect the impacts of SLP groundwater use or simply reflect the tributary baseflow responses to natural climatic variability. In particular, further investigation is needed to determine whether dry season baseflows in Carmel River tributaries and San Jose Creek have been depleted by groundwater use at SLP. An objective, quantitative analysis of baseflow trends is needed. The analysis should be able to account for natural variability so any observed trends in baseflow attributed to natural climatic variability can be differentiated from trends associated with other, non-climatic influences, such as groundwater use.

CHAPTER 2

ANALYSIS OF BASEFLOW TRENDS RELATED TO UPLAND GROUNDWATER PUMPING FOR LAS GARZAS, SAN CLEMENTE, POTRERO AND SAN JOSE CREEKS

Baseflow

Baseflow is the genetic component of streamflow originating primarily from groundwater, springs and seeps or other persistent, slowly varying sources (Hall 1968; Sophocleus 2002). Baseflow is distinguished from surface and/or shallow subsurface runoff (a.k.a. storm runoff, direct runoff, event flow, quick flow, interflow) which is generally assumed to be the direct output response to a given precipitation event (Chapman 1999). During the dry season, unmanaged streamflow may be composed entirely of baseflow and thus consist primarily of groundwater discharge (Smakhtin 2001) (Figure 2).

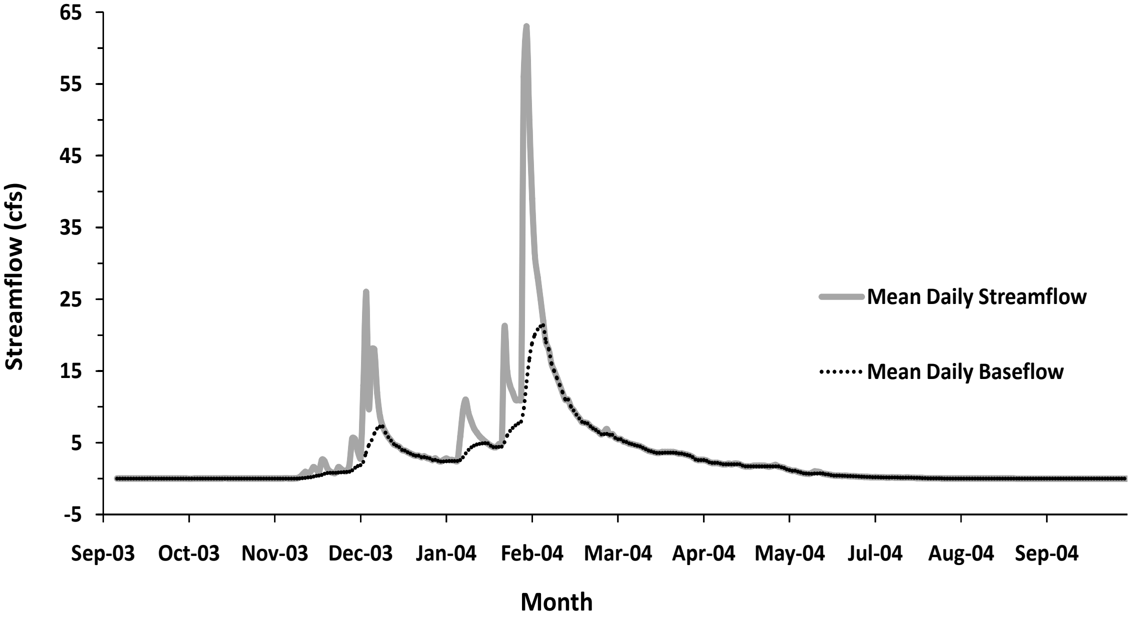


Figure 2. An annual hydrograph from Pine Creek showing that streamflow consists primarily of baseflow during during the dry season

Importance of Baseflow to Stream Habitat

Like most of California, the central coast receives little to no rain between May and October and consequently streamflows are dominated by baseflow for nearly half of each year. Baseflows are therefore critical in maintaining quality instream habitat for steelhead trout and other aquatic species during the dry season, particularly on the central coast where streamflows can become extremely low or intermittent (DFG 1996). Adequate baseflows are needed to maintain water temperatures in acceptable ranges. Steelhead trout prefer water temperatures in the range of 10 – 13 degrees C; temperatures exceeding 24 C can be fatal (Bjorn and Reiser 1991). Temperatures near the extremes of the suitable range can also cause reduced growth and behavioral changes in steelhead (Bjorn and Reiser 1991). High water temperature reduces dissolved oxygen solubility and can cause already low dissolved oxygen levels to drop further and adversely affect steelhead (Bjorn and Reiser 1991). Riparian vegetation provides shade, bank stability, and organic debris to streams and is sustained by baseflow and shallow groundwater (Mahoney and Erman 1984). Riparian vegetation provides the organic material to streams that feed the aquatic invertebrates on which fish rely as their main food source; in addition, fish also eat terrestrial invertebrates associated with riparian vegetation (Bjorn and Reiser 1991). Reduced baseflows due to human activities can contribute to mortality of riparian vegetation (Stine et al. 1984; Kondolf and Curry 1986). Loss of riparian vegetation reduces stream shade and results in increases in water temperature (Mahoney and Erman 1984). Bank erosion and channel instability can occur with loss of riparian vegetation and result in the introduction of excessive amounts of fine sediment to the channel (Kondolf and Curry 1986). Excess fine sediment degrade steelhead habitat by burying spawning substrate and filling in pools (DFG 1996).

Human Influences on Baseflow

Urbanization, groundwater pumping, and surface water diversion are examples of human activities that can affect stream baseflows. Increases in impervious surface and installation of sanitary and storm sewers that accompany urbanization result in less precipitation infiltrating into the soil to recharge groundwater; consequently, baseflows can decrease as less groundwater enters the stream (Simmons and Reynolds 1982; Ferguson and Suckling 1990). However, urbanization does not always decrease baseflows. Meyer (2001) found that mean annual baseflows did not show any significant decline for extensively urbanized watersheds, but the time distribution of the baseflows did change. Konrad and Booth (2002) did not find any consistent trends to indicate that baseflows had decreased as a result of urbanization. Urbanization can also cause increases in baseflow due to leakage of municipal water supply and sewer lines, discharge of treated waste water, and lowered evapotranspiration as formerly vegetated areas are converted to impervious cover (Brandes et al. 2005). Streamflow depletion from groundwater pumping is a common water resources problem worldwide and has been extensively studied (Fetter 1977; Sophocleous et al. 1995; Smakhtin 2001; Burt et al. 2002; Nyholm et al. 2002; Wittenberg 2003; Maimone 2004; Wen and Chen 2006). Groundwater pumping can deplete stream baseflows by capturing groundwater flow that would ordinarily discharge to the stream (Sophocleous et al. 1995). Groundwater pumping can also deplete stream baseflows by lowering the groundwater elevation near the stream so that the groundwater flow gradient is reversed and streamflow is drawn back into the aquifer (Sophocleous et al. 1995). Surface diversions reduce streamflow and can have a particularly marked effect on low flows, such as during the dry season when streamflow is primarily baseflow (Smakhtin 2001; Oki et al. 2006). Large impoundments such as dams can increase or decrease baseflows depending on operational procedures (Smakhtin 2001).

Analysis of Baseflow

Given the importance of baseflows in maintaining high value aquatic habitat and their susceptibility for change due to human activities, the management of stream baseflows is an essential task for resource managers. Detecting temporal changes in baseflows that are directly related to human activities is critical to informing adaptive watershed management by providing a warning that an impact is occurring (Hartley and Funke 2001). If a change (e.g. reduction) in baseflow can be detected and attributed in large part to human activities, management actions can be taken to mitigate that impact on aquatic resources (Van Kirk and Naman 2008). High natural variability in hydro-meteorological variables and brief data records often make it difficult to detect changes (Smith and Rose 1991). It can also be difficult to distinguish whether a change in baseflow is due to human activities or due to a climatic trend (Chagnon and Demissie 1996; Van Kirk and Naman 2008).

A variety of statistical methods for detecting trends in baseflow and other hydrologic time series have been widely used. Statistical approaches have the advantages of being relatively simple, low cost, relying on readily available data such as precipitation and streamflow, and can be used to directly identify an impact that is occurring. Table 1 shows some parametric (regression) and nonparametric (Mann-Kendall) trend tests commonly used to detect monotonic trend in hydrologic time series.

Table 1. Classification of 5 parametric and non-parametric trend tests (adapted from Helsel and Hirsch 2002)

	Not Adjusted for X	**Adjusted for X**
Nonparametric	Mann-Kendall trend test on Y	Mann-Kendall trend test on Residuals from LOWESS of Y on X
Mixed	------	Mann-Kendall trend test on Residuals from regression of Y on X
Parametric	Regression of Y on T	Multiple-regression of Y on X and T

These tests are discussed in detail by Helsel and Hirsch (2002). The tests in the right hand column remove variation caused by the effect of a confounding, exogenous variable (e.g. precipitation) on the dependent variable of interest (e.g. baseflow) (Helsel and Hirsch 2002). LOWESS (Locally Weighted Scatterplot Smooth) is a nonparametric smoothing technique used in the trend test found in the upper right hand box of Table 1 (Helsel and Hirsch 2002). Many different studies have utilized versions of these tests to detect monotonic trends in streamflow/baseflow over time related to land use changes, particularly urbanization (Simmons and Reynolds 1982; Ferguson and Suckling 1990; Chagnon and Demissie 1996; Gebert and Krug 1996; Konrad and Booth 2002; Meyer 2002; Brandes et al. 2005; Meyer 2005), groundwater use (Fetter 1977; Dow 1999; Burt et al. 2002; Wen and Chen 2006), and climatic changes (Chagnon and Demissie 1996; Burn and Elnur 2002; Kahya and Kalayci 2004).

Nonparametric trend tests have advantages over parametric tests because they do not require assumptions of normality in the data, are resistant to outliers, invariant to transformations of the data, and well suited for studies with many data sets where detailed checking of model assumptions is not feasible (Hirsch et al. 1991; Helsel and Hirsch 2002). However, where detailed model checking is practical and normality assumptions can be met, parametric trend tests are generally more powerful than nonparametric methods (Hirsch et al. 1991; Helsel and Hirsch 2002). Parametric multiple regression that simultaneously includes both *time* and exogenous variables such as precipitation is generally more powerful than stagewise procedures, which first remove the effects of the exogenous variable and then test the residuals for trend (Alley 1988; Hirsch et al. 1991; Smith and Rose 1991; Helsel and Hirsch 2002).

The Santa Lucia Preserve Project: An Overview

The Santa Lucia Preserve (SLP) is located on the 20,000 acre former Rancho San Carlos property in the uplands of the Carmel River watershed. SLP is comprised of several important Carmel River tributaries (Las Garzas, Potrero, San Clemente) and San Jose Creek, as well as some minor ones (Robinson and Hitchcock Canyons) (Figure 3).

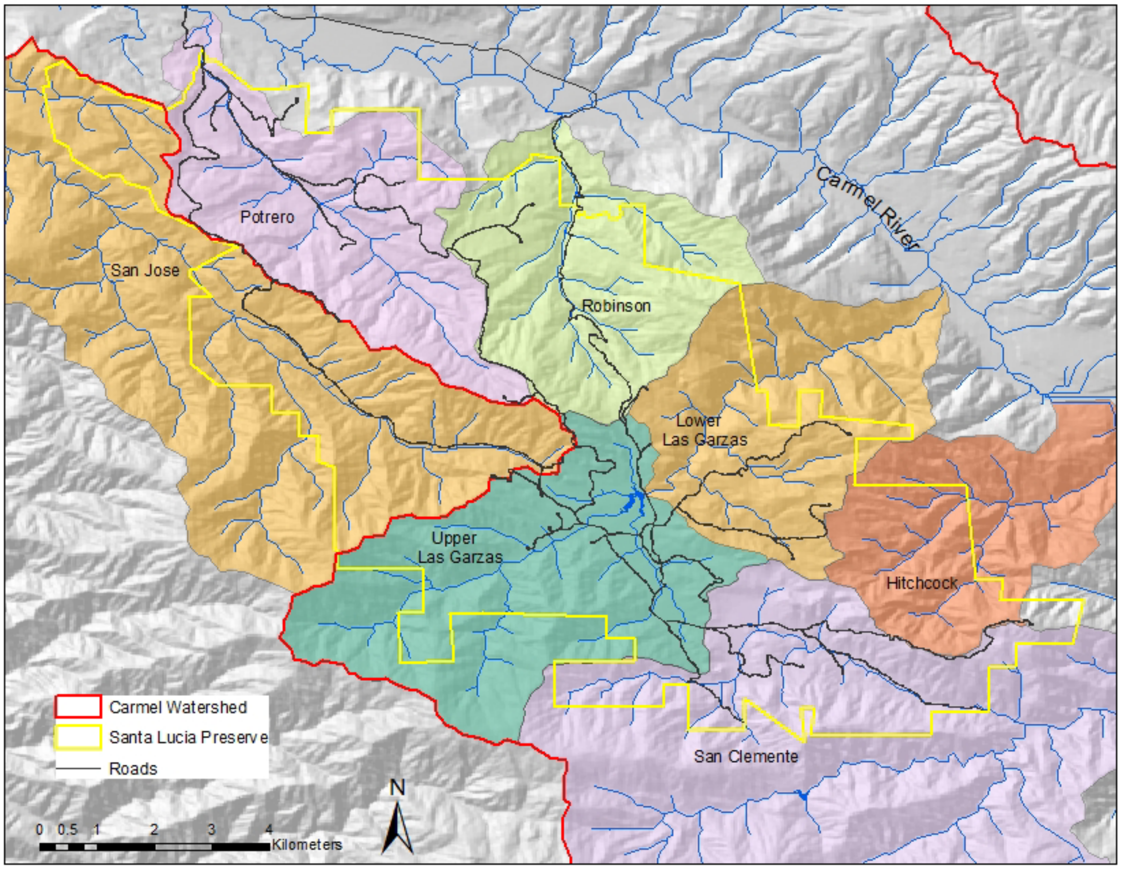


Figure 3. Map of Santa Lucia Preserve boundary and watersheds

The SLP project involved the creation of a private community of low density housing, recreation facilities, and golf course, but with approximately 18,000 acres to be left undeveloped and managed as open space (SLC 2007). As Carmel River water supplies have become over-appropriated, new development projects have had to find alternative sources of water. A source of water that is being increasingly utilized is the fractured rock aquifers found in the uplands of the Carmel River watershed. SLP is an example of a recent project that has developed an independent water supply relying solely on these upland fractured rock aquifers.

The intensive use of groundwater by the SLP project and the potential negative effects this may have on tributary baseflow conditions has generated a great deal of attention. Steelhead are thought to utilize all major tributaries originating on SLP (Las Garzas, Potrero, San Clemente, San Jose) for spawning and rearing, as well as minor ones (e.g. Hitchcock Canyon) when hydrological conditions are optimal (Monterey County 1995). Dry season baseflows are critical in maintaining rearing conditions for juvenile steelhead during a time of year when habitat may be limited to isolated pools and discontinuous reaches of wetted channel (Monterey County 1995). Reductions in dry season tributary baseflows would reduce and degrade available aquatic habitat and could harm steelhead and red-legged frog populations, both Endangered Species Act (ESA) listed species (Monterey County 1995; DFG 1999; SWRCB 2003; Monterey County 2004a).

The final Environmental Impact Report (FEIR) for the SLP project was subject to a number of Conditions of Approval intended to prevent, detect, and mitigate project related impacts to tributary baseflows (Monterey County 1995) (Table 2). The full text of these Conditions can be found in Appendix A.

Table 2. Summary of Mitigation Measures ("County Conditions") for SLP FEIR (Monterey County 1995) relevant to groundwater and stream baseflows.

County Condition	Description
11	Monitor groundwater levels in all supply wells at least weekly during June – August, and monthly rest of the year. Submit annual report of groundwater production monitoring, precipitation and streamflow. Evaluate water-level hydrographs for trends at least every three years.
12	Between April 1 and November 1 delay pumping of new and existing wells located within 1,000 feet of Protected Base Flow Reaches unless the combined capacity of other wells connected to the water supply system is insufficient to meet project demand.
13	New wells may be installed less than 1,000 feet from Protected Base Flow Reaches [designated reaches with perennial flow even during drought]. Limit pumping from new and existing wells during the dry season (April 1- November 1) so that draw-down does not exceed 2 feet in any nearby areas of riparian vegetation or 1 foot at any point along the Protected Base Flow Reach. Draw-down determined by County approved observation wells
14	Measure daily base flows in the Potrero Canyon, San Clemente and Las Garzas Creeks near SLP. Conduct annual survey of pools and base flow conditions in the gauged creeks and in San Jose Creek each September. Submit annual Base Flow Monitoring Report of base flow conditions to County and Ca. Dept. of Fish and Game.
15	If the Base Flow Monitoring Report demonstrates that the base flow in any of the four creeks has dropped below the October 1990 level as a direct result of the project, augment flow by discharging water into the creek near the upstream end of the affected Base Flow Reach. Rate of augmentation shall be of an amount sufficient to sustain pools and base flow approximately equal to conditions in October 1990. Maximum required combined augmentation for all four creeks is 30 gpm at the points where the augmented water reaches the protected base flow reaches. Proposed augmentation methods, rates, and locations shall be reviewed by County Water Resources Agency prior to implementation of this condition.

The FEIR (Monterey County 1995) concludes implementation of mitigation measures will result in negligible and fully mitigated impacts to dry season baseflows.

Despite mitigation and monitoring requirements imposed on the SLP project, various government resource agencies, interest groups, and individuals have expressed concern that current measures are inadequate to mitigate impacts on stream baseflows and aquatic habitat, and are based on flawed analyses. It has been alleged that SLP groundwater use has resulted in reductions in dry season baseflows on Las Garzas, San

Jose, and Potrero Creeks that have reduced and degraded habitat supporting steelhead trout and red-legged frogs (DFG 1999; SWRCB 2003; Monterey County 2004a; NMFS 2005). Project proponents have countered the claims of critics and maintain the original analyses and mitigation measures conducted for the FEIR (Monterey County 1995) are valid. As evidence, they site addition analyses conducted by project consultants for the Potrero Subdivision final Supplemental EIR (FSEIR) (Monterey County 2004) that concluded impacts to baseflow from groundwater pumping are negligible and mitigation measures are working.

Research Objectives

The primary goals of this research are to provide information to assist resource managers and meet a demand for further analyses of groundwater – surface water interactions for the SLP project by. Research will be focused on the central research questions:

- Has groundwater use at the SLP caused any measurable changes to dry season stream baseflows in Carmel River tributaries and San Jose Creek?
- If there are measurable changes, what is the magnitude of the change?

New information gained from this research may be used to help resource managers in a variety of ways. For example, if current patterns of groundwater use are demonstrated to affect baseflow, this information can provide the basis for developing alternate water supply management practices. This research may also provide information to help create more efficient and effective monitoring protocols. Alternately, this research may confirm and help to validate the effectiveness of the current baseflow monitoring and mitigation efforts. This research may also prove useful for planning of future projects as well as informing public discussion of natural resource management issues for this region.

CHAPTER 3

METHODS

Study Area Description

The Carmel River is a northwest trending watershed of high relief (1200 m), that is 43 km in length and encompasses an area of 656 km^2 (Table 3).

Table 3. Physical attributes of Carmel River watershed (adapted from Smith et al. 2004)

Physical Attribute	Description
Drainage area	656 km^2 (256 mi^2)
Axial trend	315°
Length	43 km (25.8 mi)
Highest peak (South Cone)	1514 m (4965 ft)
General divide elevation	1200 m (4000 ft)
Mouth elevation	Sea level at mouth of Carmel submarine canyon
Relief	1200 m (4000 ft)
Average slope	3%
Land-use	Wilderness, grazing, viticulture, golf-courses, sparse residential, suburban, urban, and light industrial.
Vegetative Ecosystems	Dominated by chaparral, grasslands, and oak woodland. Local conifer and redwood forests present.
Soil Series	Wide range

The Carmel River watershed has a generally mild, Mediterranean climate. Mean annual rainfall is spatially highly variable, ranging from approximately 14 inches on the coast to over 40 inches in the southernmost mountains (James 2004). More than 90% of annual precipitation occurs between November and April (James 2004). The 85-year mean annual precipitation at San Clemente Dam (located approximately in the center of the watershed) is approximately 21 inches (James 2004).

The Santa Lucia Preserve (SLP) encompasses approximately 20,000 acres of varied, rugged terrain within the Santa Lucia Range. Over the last 100 years, much of the SLP was used extensively for livestock grazing (Monterey County 2003). Currently 18,000 acres are managed as open space for recreation, livestock grazing, and resource conservation, while the remaining 2,000 acres are developed for dispersed housing, golf course, and recreational facilities (Monterey County 2003). SLP contains 13 habitat types including: coast live oak woodland (most widespread), coastal scrub, coast live oak savanna, Monterey Pine forest, redwood forest, coyote brush scrub, blue blossom scrub, chamise-manzanita chaparral, coast live oak-chamise-manzanita, coastal prairie, ruderal grassland, wetland/riparian, and disturbed (Monterey County 2003). The headwaters of numerous streams are within the SLP, including Potrero, Robinson Canyon, Las Garzas, Hitchcock Canyon, San Clemente (all tributaries of Carmel River), and San Jose (Figure 3). More detailed, individual maps for each SLP watershed are included in Appendix B.

The bedrock geology of SLP is dominated by quartz diorite, granodiorite, marine sandstones, and shale (Rosenberg 2001). Data indicate these formations are at least several thousand feet in depth (Monterey County 1995). Undifferentiated alluvial deposits of less than 100 feet in depth are found along the channels of San Jose, Potrero, and Upper Garzas creeks, as well as in the San Francisquito Flat area containing Moore’s Lake (Monterey County 1995; Rosenberg 2001). Five faults have been identified within SLP but there is no evidence of any recent fault activity (Monterey County 1995). Although alluvial deposits readily store and transmit groundwater, the limited extent of these deposits at SLP make their contribution to groundwater resources relatively small (Monterey County 1995). The majority of groundwater is extracted from fractured bedrock aquifers underlying SLP. Measured values for hydraulic conductivity of the fractured bedrock at SLP ranged from 0.02 to 13.60 (ga/day/ft^2), with most values falling between 0.02 and 2.0 (ga/day/ft^2) (Monterey County 1995). Aquifer storativity was estimated to be between 0.5% and 1.2% (Monterey County 1995).

Available data strongly suggest that streams at SLP are in direct hydraulic connection with adjacent fractured rock aquifers and dry season stream baseflows are sustained by discharge from these aquifers (Monterey County 1995). Groundwater levels at wells were found to generally follow land surface topography, indicating groundwater generally flows toward the nearest creek and discharges into the stream as baseflow, rather than flowing offsite (Monterey County 1995). Groundwater levels near streams were at or above stream bed elevation (Monterey County 1995). Data do not suggest the widespread presence of perched or vertically separate groundwater systems (Monterey County 1995).

Data Sources

For study streams, streamflow data used in this analysis came from continuously recording gaging stations operated by the Monterey Peninsula Water Management District (MPWMD) (Lower Garzas, Lower Garzas Canyon, San Clemente, San Jose) and the Santa Lucia Conservancy (Upper Garzas, San Clemente-SLP, Potrero) (Table 4).

Table 4. Streamflow gage station information for study streams

Watershed	Station	Record (WY)	Gaged Area (km^2)	Source	Comment
Las Garzas	Lower Garzas	1968 to78; 1992 to present	34.2	MPWMD	recording gage; mean daily discharge
	Lower Garzas Canyon	2001 to present	33.4	MPWMD	recording gage; mean daily discharge
	Upper Garzas	2001 to present	11.9	SLC	recording gage; mean daily discharge; Moore's Lake inflow
San Clemente	San Clemente	1992 to present	40.4	MPWMD	recording gage; mean daily discharge
	San Clemente-SLP	2002 to present	13.4	SLC	recording gage; mean daily discharge; gage near SLP property boundary
Potrero	Potrero	2002 to present	13.3	SLC	recording gage; mean daily discharge
San Jose	San Jose	1999 to present	36.8	MPWMD	recording gage; mean daily discharge

Records range from 6 to 16 years in length. Robinson Canyon and Hitchcock Canyon were not included in the analysis due to a lack of baseflow during the dry season. The Lower Garzas station uses a Stevens Type-F water level recorder/float system (James

2004). All other gaging stations for study streams use pressure transducers with electronic data loggers (Brown et al. 2003; James 2003). The stations operated by SLC also contain probes to measure water temperature and specific conductance (Brown et al. 2003). Study stream data are plotted in Figure 4.

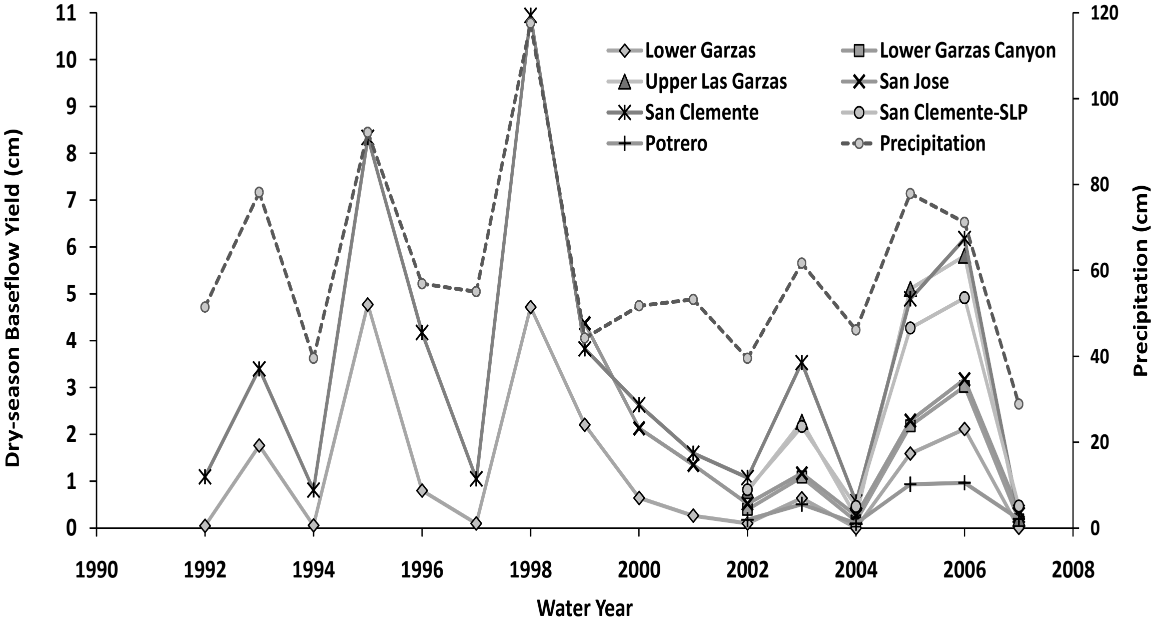


Figure 4. Dry-season baseflow at study sites and precipitation. Dry-season baseflow is defined as total streamflow from May through October, divided by watershed area

The gaging stations with the longest records (16 years) are Lower Garzas and San Clemente. Streamflow at both of these sites is affected by water management actions independent of SLP (James 2004). Lower Garzas streamflow is affected by groundwater withdrawals from the Carmel Valley alluvial aquifer, while San Clemente is influenced by diversions for storage in seasonal dams outside of SLP lands (James 2004). While providing valuable data, these sites are not the best ones to use for detecting trends in baseflow directly attributable to SLP groundwater use.

Streamflow gaging stations closest to the boundaries of SLP (Lower Garzas Canyon, Upper Garzas, Potrero, San Clemente-SLP) would be the most useful for detecting project related impacts to baseflow. Unfortunately, these gaging stations were not installed until Water Year (WY) 2001 and 2002, after project groundwater pumping had begun (SLP 2001). This lack of pre-project streamflow data at these sites severely hampers analyses of post-project related impacts to baseflows.

Pine Creek, Carmel River above Los Padres Dam (referred to from here on as "Los Padres"), and Big Sur were selected as reference streams for comparison with SLP streams. Reference streams were selected based on the following criteria: availability of relatively long term streamflow data; proximity to study streams; watershed is largely undeveloped; watershed has not been subjected to recent intensive groundwater use; streamflows are not regulated or diverted. Streamflow data for reference streams came from stations operated by MPWMD (Pine, Los Padres) and U.S. Geological Survey (USGS) (Big Sur River), with records ranging from 16 to 58 years (Table 5). More detailed, individual maps of reference watersheds are found Appendix B. Data at these sites are plotted in Figure 5.

Table 5. Streamflow gage station information for reference streams

Watershed	Station	Record (WY)	Gaged Area (km^2)	Source	Comment
Carmel above Los Padres Dam	Los Padres	1986 to present	116.0	MPWMD	monthly measurements taken during dry season by wading
Pine	Pine	1992 to present	20.2	MPWMD	recording gage; mean daily discharge
Big Sur	Big Sur	1950 to present	120.4	USGS	recording gage; mean daily discharge

Pine and Big Sur are both continuously recording stations (James 2004; USGS 2007). Pine uses a pressure transducer/electronic data logger system (James 2004), while Big Sur's system is unknown. Los Padres is a non-recording station, where manual measurements are taken monthly during the dry season using either a pygmy or AA type current meter (James 2004). Among reference streams chosen for this research, Pine Creek is the most suitable as a basis for comparison with SLP study streams because of its similarity to SLP streams in terms of watershed size and proximity. Los Padres and Big Sur are much larger watersheds and likely not as suitable for purposes of comparison with SLP streams; however, given the lack of streamflow data for other, more suitable watersheds, these sites represent the best available data after Pine.

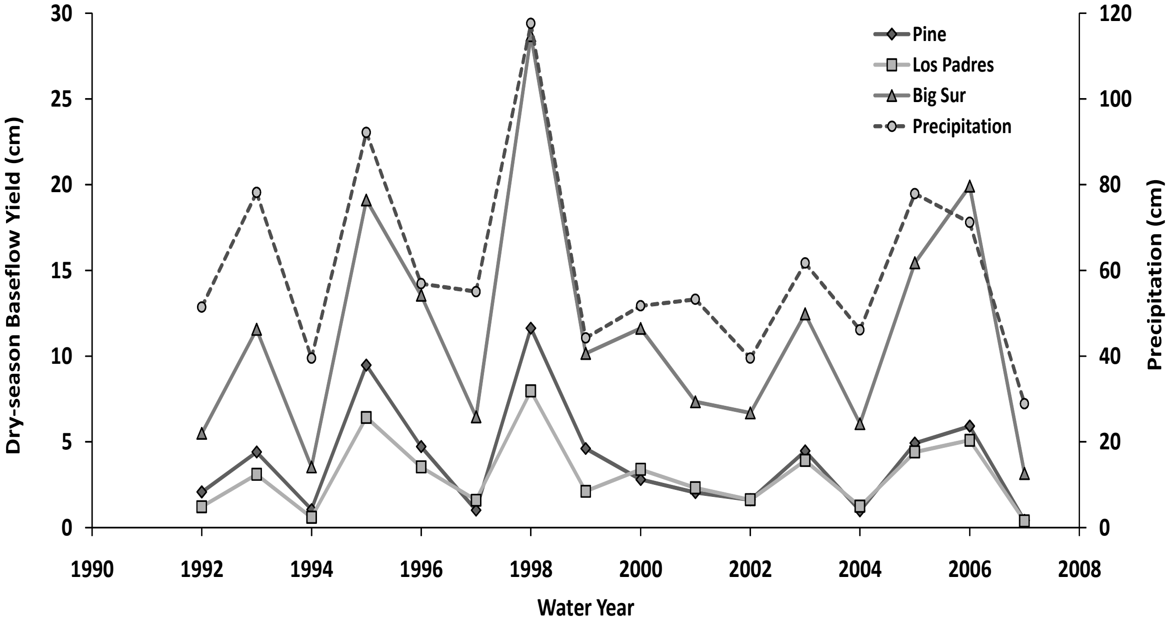


Figure 5. Dry-season baseflow at reference sites and precipitation. Dry-season baseflow is defined as total streamflow from May through October, divided by watershed area

Precipitation data used in this analysis are from the rain gage at San Clemente Dam operated by Cal-Am (James 2004). Precipitation has been recorded at this site continuously from 1922 (James 2004).

Data for annual production well pumping by subwatershed for WY 2001 - 2007 are presented in Appendix C. Plots of groundwater elevations at monitoring wells over time and a location map are included in Appendix D. These data were not used in the baseflow analysis but are included as relevant complimentary information that could prove useful for future, related analyses.

Baseflow Trend Analysis Methods

Two complimentary regression methods were used to detect and quantify monotonic trends in stream baseflows over time (Table 6).

Table 6. Comparison of the two regression methods used in analysis

	Method 1	**Method 2**
Response Variable	Annual baseflow yield	Annual baseflow yield (study site)
Explanatory Variables	• Annual precipitation • Annual precipitation, lagged (1-year, 2-years) • Time	• Annual baseflow yield (Reference site) • Time
Description	Inference of baseflow trend based on existence of non-zero, standardized *Time* coefficient, and differences in standardized coefficients between study and reference streams	Inference of baseflow trend based on existence of non-zero, standardized *Time* coefficient

The methods used in this analysis represent an extension of methods proposed in the project FEIR (Monterey County 1995). The FEIR recommends comparing the regression relationships between precipitation and dry season baseflows using historic and current data on Lower Las Garzas (Monterey County 1995). The FEIR also recommends regressing dry season baseflows on SLP streams against dry season baseflows in nearby, undeveloped streams such as Pine Creek (Monterey County 1995). Changes in regression relationships between historic and current data could be used as an indication of project related impacts on stream baseflow.

Method 1

The first method used a multiple linear regression model comparison approach to test for monotonic trends in dry season baseflow over time. The use of multiple linear regression for analysis of monotonic trend is described in Helsel and Hirsch (2002). Multiple regression allows for the effects of exogenous variables and trend to be modeled simultaneously and has been shown to be statistically more powerful than stepwise approaches that model exogenous variable effects and time trend in separate steps (Alley 1988; Smith and Rose 1991).

Because annual streamflow (and thus baseflow) is highly dependent on annual precipitation, the exogenous effects of precipitation on streamflow should be modeled in order to increase the power of detecting a time trend in streamflow due to non-climatic influences, such as groundwater use (Alley 1988; Helsel and Hirsch 2002). Previous studies of the Carmel River watershed have noted that years of high rainfall (e.g. WY 1998) can influence baseflows in subsequent years (Woyshner et al. 2003; Smith et al. 2004). Lagged precipitation (1 and 2 years) was included as an explanatory variable in order to more thoroughly model the exogenous effects of precipitation on baseflow and increase the chances of detecting a trend.

A set of candidate a priori regression models was constructed to explain dry season baseflow as a function of some combination of current and lagged annual precipitation, and time (to test for trend) (Table 7).

Table 7. Candidate a priori models used in Method 1. For streams with records beginning WY 2001 and 2002, a subset of models was used (lm0, lm1, lm2, lm4)

Model	Regression Equation	Description	Hypothesis
lm0	$Flow = \beta_0$	No relationship between Baseflow and Precip, Time; Baseflow is constant	*Null*
lm1	$Flow = \beta_0 + \beta_1 Precip$	Baseflow is a function of current year annual precipitation; No trend in Baseflow	*No-Trend*
lm2	$Flow = \beta_0 + \beta_1 Precip + \beta_2 Precip1$	Baseflow is a function of current and lagged (1 year) annual precipitation; No trend in Baseflow	*No-Trend*
lm3	$Flow = \beta_0 + \beta_1 Precip + \beta_2 Precip1 + \beta_3 Precip2$	Baseflow is a function of current and lagged (1 year and 2 year) annual precipitation; No trend in Flow	*No-Trend*
lm4	$Flow = \beta_0 + \beta_1 Precip + \beta_2 Time$	Baseflow is a function of current year annual precipitation and time; Trend in Baseflow (positive or negative) is present	*Trend*
lm5	$Flow = \beta_0 + \beta_1 Precip + \beta_2 Precip1 + \beta_3 Time$	Baseflow is a function of current and lagged (1 year) annual precipitation and time; Trend in Baseflow (positive or negative) is present	*Trend*
lm6	$Flow = \beta_0 + \beta_1 Precip + \beta_2 Precip1 + \beta_3 Precip2 + \beta_4 Time$	Baseflow is a function of current and lagged (1 year and 2 year) annual precipitation and time; Trend in Baseflow (positive or negative) is present	*Trend*

These models were constructed to represent the competing No-Trend, Trend, and Null hypotheses. Dry season baseflow (defined here as total streamflow during May 1 – September 30, divided by watershed area) was chosen as the independent variable of interest because reductions in stream baseflows due to groundwater pumping would most likely be detected during the dry season, when streamflow is dominated by groundwater sources and groundwater pumping is highest (SLP 2001 – 2007).

Each variable was standardized by subtracting its mean and dividing by its standard deviation. This was done to facilitate direct comparison of coefficient estimates for all variables in order to assess their relative influence on baseflow. A priori models were fitted to each study stream over its period of record. The same a priori models were fitted to reference streams for periods of record concurrent with those of each study stream. For analyses of study streams with short records (beginning WY 2001, 2002), a subset of the a priori models was used that were believed to model the most important effects. There were too few degrees of freedom in the shorter records to fit the most complex a priori models. Statistical operations were performed using *R* statistical software version 2.5.0 (R Foundation 2007); *R* code used in the analysis is available in Appendix E. Fitted a priori models for study and reference streams were evaluated and compared using techniques discussed in the following Statistical Analysis section.

In the absence of anthropogenic effects such as groundwater pumping, we would expect reference and study streams to yield similar modeling results. Differences between study and reference streams (e.g. trends in baseflow present in one group but not the other) were used as a basis to infer the presence of groundwater pumping effects on baseflows.

Method 2

The second approach to test for baseflow trend used multiple linear regression to model dry season baseflow at each study site as a function of dry season baseflow at a reference site and time. Regressing study site baseflows against reference site baseflows allows for the exogenous effects of climatic variability on baseflow to be accounted for and any trends present to be more easily detected (Alley 1988; Helsel and Hirsch 2002). A strong linear relationship was assumed to exist between study and reference site baseflows, in the absence of anthropogenic influences such as groundwater use.

Three candidate a priori models representing the competing No-Trend, Trend, and Null hypotheses fitted for each study stream over its period of record against each of the three reference streams. (Table 8).

Table 8. Candidate a priori models used in Method 2

Model	Regression Equation	Description	Hypothesis
lm0b	$Flow.Study = \beta_0$	Study site Baseflow is constant; No relationship between Study and Reference stream baseflow	*Null*
lm1b	$Flow.Study = \beta_0 + \beta_1 Flow.Ref$	Study site Baseflow is a function of reference site baseflow; No trend Study site in Baseflow	*No-Trend*
lm2b	$Flow.Study = \beta_0 + \beta_1 Flow.Ref + \beta_2 Time$	Study site Baseflow is a function of Reference site baseflow and time; Trend in Study site baseflow (positive or negative) is present	*Trend*

Statistical operations were performed using *R* statistical software version 2.5.0 (R Foundation 2007); *R* code used in the analysis is available in Appendix E. Fitted a priori models were evaluated using techniques discussed in the following Statistical Analysis section.

Sensitivity Analysis

A simple sensitivity analysis was conducted to provide information on the ability of both analysis methods to detect monotonic trends in dry season baseflows using available records of different lengths (6, 7, 9, and 16 years). The latter part of a stream's record was incrementally reduced to simulate a decreasing trend in order to determine at what level of baseflow reduction a trend would be detected for a record of a given length. For the sensitivity analysis with the WY 1992 -2007 record, baseflow was incrementally reduced over the years WY 2001 – 2007. For the sensitivity analyses with WY 1999 - 2007, WY 2001 – 2007, and WY 2002 – 2007 records, baseflow was incrementally reduced over the years WY 2005 – 2007. Streams chosen for use in the sensitivity analysis were those that showed little probability of trend in baseflow based on the results of the Method 1 and 2 analyses.

Using Method 1, the entire WY 1992 – 2007 record of Pine was analyzed for trend, while incrementally decreasing dry season baseflow during WY 2001 – 2007 by 10 – 80%. This procedure was repeated using the WY 1999 – 2007, WY 2001 – 2007, and WY 2002 – 2007 records from Pine while incrementally decreasing streamflow during

WY 2005 – 2007. Pine was chosen for the sensitivity analysis because results of Method 1 revealed little probability of trend for this stream.

This procedure was repeated using Method 2 on the following records: Lower Garzas vs. Pine (WY 1992 – 2007), Lower Garzas vs. Pine (WY 1999 – 2007), San Clemente vs. Big Sur (WY 2001 – 2007), and San Clemente vs. Big Sur (WY 2002 – 2007). These records were chosen because analysis results showed them to have the least likelihood of trend. Additional analyses (using Method 2) were performed on subsets of Lower Garzas' and San Clemente's record (study sites with the longest records) that were not part of the main research. This was done in order to find records for the periods WY 1999 – 2007, WY 2001 – 2007, and WY 2002 – 2007 to be used in the Sensitivity Analysis that had the least likelihood of trend. These records yielded results that had less probability of trend than results from the main Method 2 analysis. The main research focused on analyzing streams over their entire periods of record; this is why analyses of subsets of a stream's record were not included in the main results.

Statistical Analysis/Model Comparison

Akaike's Information Criteria (AIC), an information-theoretic approach to model selection, was used to identify the best of the fitted a priori models and make inferences based upon them. AIC selects the most parsimonious among fitted candidate a priori models by utilizing each model's log-likelihood as a measure of fit given the data and imposing a penalty for number of parameters (Burnham and Anderson 2002). AIC has numerous advantages over traditional hypothesis testing approaches to model selection in that: it yields consistent results, unlike traditional approaches to model selection that may perform differently depending on the method chosen (i.e. forward, backward, stepwise); it is theoretically justified by its foundation in maximum likelihood principles; it provides measures of strength of evidence and uncertainty for each model; it allows for inference and parameter estimation to be based on the entire set of candidate models rather than on a single best model (Burnham and Anderson 2002). The second order, small sample size version of AIC (AICc) was used, as is recommended when the ratio of sample size to number of parameters is approximately less than 40 (Burnham and Anderson 2002).
For each stream, candidate models were ranked based on their AICc scores, where the smallest AICc represents the best model. Models were then compared using three related

measures: delta AIC (Δ_i), Akaike weights (w_i), and Evidence Ratios (Burnham and Anderson 2002). Delta AIC (Δ_i) is the difference between a model's AICc score and the best model's AICc. Burnham and Anderson (2002) interpret a $\Delta_i \leq 2$ as substantial evidence in support of a model, a $4 \leq \Delta_i \leq 7$ as indicating a model has much less support, and $\Delta_i > 10$ indicating a model is very unlikely and essentially unsupported by the data. Akaike weights (w_i) are the ratio of a model's Δ_i relative to the sum of all candidate models' Δ_i and is scaled so the weights sum to 1 (Burnham and Anderson 2002). An Akaike weight (w_i) for a given model is the probability it is the (Kullback-Leibler) best model among the set of candidate models and given the data (Burnham and Anderson 2002; Anderson 2008). The details of this definition, such as what constitutes the "Kullback-Leibler best model," are explained by Anderson (2008). For example, a model with $w_i = 0.90$ is interpreted as meaning that model has a 90% probability of being the best model among the set of candidate models, given the data. The Evidence Ratio (ER) is simply the ratio of the best model's w_i relative to another candidate model's w_i and provides another way of conveying uncertainty in model selection (Burnham and Anderson 2002). For example, if the best model has a $w_1 = 0.70$ and another model has a $w_2 = 0.25$, the ER is 2.8 (i.e. 0.7 / 0.25 = 2.8) and indicates the best model is 2.8 times more likely, given the candidate models and data. In order to standardize the interpretation of this ratio, it is helpful within the context of a given study to define terms to guide interpretation of ranges of Evidence Ratios. For this study, ER's of models representing the competing *Trend*, *No-Trend*, and *Null* hypotheses were assigned a descriptive term (e.g. "decisive", "strong", "substantial", or "minimal") meant to convey the strength of evidence in favor of the competing hypotheses. The approximate ranges of ER's corresponding to each term are defined in Table 9. The origin of these specific terms is from the literature on Bayes Factors (Jeffreys 1961, as cited by Stauffer 2008); since Bayes Factors and Evidence Ratios are conceptually analogous, I borrow them here for use in describing Evidence Ratios. Burnham and Anderson (2002) and Anderson (2008) caution against such generalizations and dichotomies across all of science; however, this does not preclude the use of such terminology specific to a given study, provided it is recognized that the boundaries between terms are only approximate and not absolute. These terms enable generalizations to be made about the strength of evidence in favor of a best model and its corresponding hypothesis and provide a convenient and more intuitive means for conveying results, particularly for those unfamiliar with the type of statistics used in this research. All measures used to interpret modeling results are summarized in Table 9.

Table 9. Terminology used to interpret modeling results

Term	**Description**	**Interpretation**
AICc	A model's log-likelihood (measure of fit given the data), penalized for number of parameters; Candidate models ranked from best to worst based on AICc score	For a set of models: Lowest AICc = Best model Highest AICc = Worst model
Delta AICc (Δ_i)	Difference in AICc scores between the best model and another competing model from the same set of candidate models.	The relative merits of a model in a set can be assessed using the general guidelines: • $\Delta_i \leq 2$ model has substantial support (evidence) • $4 \leq \Delta_i \leq 7$ model has considerably less support • $\Delta_i > 10$ model has essentially no support
Akaike weight (w_i)	Model probabilities normalized so the sum of all candidate model w_i equals 1. Each model's w_i is interpreted as the probability a given model is the best among the set of candidate models and given the data.	Example: If Model 1 $w_1 = 0.90$, this is interpreted as meaning Model 1 has a 90% probability of being the best model in that set, given the data
Evidence Ratio (ER)	Ratio of best model's w_i relative to another model's w_i	Example: M1 $w_1 = 0.90$ M2 $w_2 = 0.05$ ER (M1/M2) = 0.90 / 0.05 = 18 Model 1 is 18 times more likely to be the best model than Model 2, given the candidate models and data
Descriptive Terms for Interpreting ER's	General guidelines used to interpret the strength of evidence of one model over another	An Evidence Ratio between 2 models is used and interpreted according to the definitions below (based on interpretation of Bayes Factor, from Jeffreys 1961, as cited in Stauffer 2008): ER (M1/M2) < 1/100: **decisive** evidence for M2 ER (M1/M2) < 1/10: **strong** evidence for M2 ER (M1/M2) < 1/√10: **substantial** evidence for M2 ER (M1/M2) < 1: **minimal** evidence for M2 ER (M1/M2) < √10: **minimal** evidence for M1 ER (M1/M2) < 10: **substantial** evidence for M1 ER (M1/M2) < 100: **strong** evidence for M1 ER (M1/M2) > 100: **decisive** evidence for M1 Using the ER(M1/M2) = 18 from the previous example, this is interpreted as ***strong*** evidence in favor of Model 1

In Method 1, Akaike weights were combined for models that included *Time* as an explanatory variable (Trend Models) and those without *Time* (No-Trend Models) in order to make generalizations about the probability the best model has a trend versus no trend. For example, if the combined w_i of all No-Trend models is 0.96, this is interpreted as meaning that there is a 96% probability a No-Trend model is the best and amounts to considerable support in favor of the hypothesis that no trend exists in baseflow.

In many cases, more than one candidate model can have $\Delta_i < 2$, indicating no one model is clearly the best. Model-averaging (a.k.a multi-model inference) was therefore used to calculate coefficient estimates and standard errors (SE) (Burnham and Anderson 2002) and thus assess the relative magnitudes of explanatory variables, most importantly *Time*. This approach bases inference on the entire set of candidate models rather than on a single best model and results in a more robust inference that reduces model selection bias and increases precision (Burnham and Anderson 2002; Johnson and Omland 2004).

CHAPTER 4

RESULTS AND DISCUSSION

Method 1

Each study stream was analyzed over its entire period of record; reference streams (Pine, Los Padres, Big Sur) were analyzed for the same concurrent periods. Results are presented by study streams; those having the same periods of record are presented together since both are being compared to reference streams over the same period. Complete AIC tables for all streams using Method 1 are found in Appendix F.

Study Sites: Lower Garzas, San Clemente (WY 1992 – 2007)
Reference Sites: Pine, Los Padres, Big Sur (WY 1992 – 2007)

The presentation of results begins with regression models for streams having data over the entire WY 1992 – 2007 record. Results suggest there is little evidence to support the hypothesis of a trend in dry season baseflow in Lower Garzas, San Clemente, and Pine during WY 1992 – 2007. Combined Akaike weights (w_i) of models that include the explanatory variable *Time* (Trend models) versus those without *Time* (No-Trend models) reveal that No-Trend models had much higher probabilities of being best models for Lower Garzas (No-Trend probability: 89%), San Clemente (No-Trend probability: 85%), and Pine (No-Trend probability: 89 %) (Table 10). Using the descriptive terms for interpreting Evidence Ratios defined in the Methods, these results amount to *substantial evidence* in favor of the No-Trend hypothesis (Table 10).

Table 10. Method 1 results for Lower Garzas, San Clemente, Pine, Los Padres, and Big Sur during WY 1992 - 2007

					Combined w_i for all Trend/No Trend models:			
Stream	**Record (WY)**	**Best model**	**Best model Coefficients**	**Best model Akaike w_i**	**Trend models Akaike w_i**	**No Trend models Akaike w_i**	**Null model Akaike w_i**	**Descriptive Terms for Interpreting Evidence Ratios**
Pine	1992 - 2007	*No Trend*	*P, P1*	0.61	0.11	0.89	0.00	**substantial** evidence in favor of ***No Trend*** hypothesis
Los Padres		*Trend*	*P, T*	0.40	0.51	0.49	0.00	**minimal** evidence in favor of ***Trend*** hypothesis; ***No Trend*** hypothesis nearly equally likely
Big Sur		*Trend*	*P, P1, T*	0.41	0.60	0.40	0.00	**minimal** evidence in favor of ***Trend*** hypothesis; ***No Trend*** hypothesis nearly equally likely
Lower Garzas		*No Trend*	*P, P1*	0.54	0.11	0.89	0.00	**substantial** evidence in favor of ***No Trend*** hypothesis
San Clemente		*No Trend*	*P, P1*	0.62	0.15	0.85	0.00	**substantial** evidence in favor of ***No Trend*** hypothesis

(Model coefficients: P = Annual precipitation; P1 = Annual precipitation lagged 1-year; P2 = Annual precipitation lagged 2-years; T = Time)

Results for Lower Garzas and San Clemente were very similar to those of Pine, both in terms of having similar levels of support for the same best model (*Precip*, *Precip1*) and also similar coefficient magnitudes. Strong support for this best model suggests dry season baseflow was highly related to both annual precipitation and lagged (1 year) annual precipitation in WY 1992 – 2007. The inclusion of lagged precipitation could be due to the influence on streamflow of two historically high rainfall years (WY 1995, 1998) that occurred during this period. Model-averaged coefficient magnitudes indicate dry season baseflow was more highly related to annual precipitation than 1-year lagged annual precipitation (Table 11).

Table 11. Coefficient estimates for Method 1 results for Lower Garzas, San Clemente, Pine, Los Padres, and Big Sur during WY 1992 - 2007

		Model Averaged Coefficient Estimates and Standard Errors							
Stream	**Record (WY)**	**Precip**	***SE***	**Precip1**	***SE***	**Precip2**	***SE***	**Time**	***SE***
Pine	1992 - 2007	0.963	*0.105*	0.180	*0.087*	0.004	*0.009*	0.002	*0.012*
Los Padres		0.955	*0.112*	0.031	*0.035*	0.015	*0.016*	0.090	*0.065*
Big Sur		0.983	*0.100*	0.172	*0.082*	0.010	*0.013*	0.116	*0.071*
Lower Garzas		0.915	*0.134*	0.205	*0.107*	0.015	*0.020*	-0.002	*0.015*
San Clemente		0.985	*0.094*	0.252	*0.086*	0.019	*0.022*	0.012	*0.017*

(Model coefficients: Precip = Annual precipitation; Precip1 = Annual precipitation lagged 1-year; Precip2 = Annual precipitation lagged 2-years)

The absence of effects in *Precip2* (2-year lagged precipitation) may indicate a lack of influence of annual precipitation on dry season baseflows beyond a year, or perhaps it is indicative of the lack of sensitivity in this method to detect those effects. For all streams, Akaike w_i for Null models was zero, indicating there was essentially no support for those models.

Results for both Los Padres and Big Sur minimally supported the hypothesis of a weak increasing trend in dry season baseflow during WY 1992 - 2007. Best models for both Los Padres (*Precip, Time)* and Big Sur (*Precip, Precip1, Time)* included *Time* (Table 10). The probability of a Trend model being the best was 51% for Los Padres and 60% for Big Sur (Table 10). Using the descriptive terms for interpreting Evidence Ratios defined in the Methods, this level of support amounts to *minimal evidence* in favor of the Trend hypothesis for both streams and means that Trend and No-Trend hypotheses are equally likely (Table 10). The positive value and magnitude of model-averaged *Time* coefficients for both Los Padres and Big Sur suggest a slight increasing trend in baseflows over the period of record (Table 11). For Big Sur, model-averaged coefficients for *Precip* and *Precip1* were similar to those of Pine, Lower Garzas, and San Clemente, suggesting a similar relationship between baseflow and annual precipitation. For Los Padres, the model-averaged coefficient for *Precip* was of similar magnitude as the other watersheds, but the lack of an effect in *Precip1* suggested dry season baseflow was not highly related to 1-year lagged precipitation at that site.

Increasing trends in dry season baseflows for the Los Padres and Big Sur watersheds could be explained by the 1999 Kirk Complex Fire that burned a total of 86,700 acres that included sizable portions of the Los Padres and Big Sur watersheds (USDA 2000). Temporary increases in streamflow/baseflow often occur due to decreased evapotranspiration that results when vegetation is destroyed by fire (Meixner and Wohlgemuth 2003). However, the weight of evidence for trend in baseflow at these sites is minimal and these results could have arisen due to random error from a variety of sources (e.g. microclimatic or hydrogeologic variability; error in streamflow gaging or estimation of areal precipitation using a single gage).

In light of the higher probability of trend in baseflow, it would seem that Los Padres and Big Sur are unsuitable for use as reference streams. Pine is likely the best reference watershed among the three due to its low probability of trend. Therefore, inferences drawn from comparisons between study sites and Pine should be considered the most valid. Discussion of results for the remaining study sites focus primarily on comparisons to Pine.

Study Site: San Jose (WY 1999 – 2007)
Reference Sites: Pine, Los Padres, Big Sur (WY 1999 – 2007)

Results suggest there is little evidence to support the hypothesis of trend in dry season baseflow for San Jose, Pine, Los Padres, and Big Sur during WY 1999 – 2007. Probabilities favoring No-Trend models as best were very high for all reference sites (Pine: 94%; Los Padres: 96%; Big Sur: 97%) and amounted to *strong evidence* in favor of the No-Trend hypothesis (Table 12). San Jose differed somewhat from the reference sites in less strongly supporting its No-Trend model (No-Trend model probability: 69%) and having considerable support for its Null model (Null model probability: 26%) (Table 12).

Table 12. Method 1 results for San Jose, Pine, Los Padres, and Big Sur during WY 1999 - 2007

Stream	Record (WY)	Best model	Best model Coefficients	Best model Akaike w_i	Combined w_i for all Trend/No Trend models: Trend models Akaike w_i	Combined w_i for all Trend/No Trend models: No Trend models Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
Pine	1999 - 2007	*No Trend*	*P, P1*	0.53	0.02	0.94	0.04	**strong** evidence in favor of ***No Trend*** hypothesis
Los Padres		*No Trend*	*P*	0.94	0.03	0.96	0.00	**strong** evidence in favor of ***No Trend*** hypothesis
Big Sur		*No Trend*	*P*	0.84	0.02	0.97	0.01	**strong** evidence in favor of ***No Trend*** hypothesis
San Jose		*No Trend*	*P, P1*	0.57	0.05	0.69	0.26	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely

(Model coefficients: P = Annual precipitation; P1 = Annual precipitation lagged 1-year; P2 = Annual precipitation lagged 2-years; T = Time)

Results for San Jose provide only *minimal evidence* in favor of the No-Trend hypothesis and indicate the Null hypothesis is nearly as likely (Table 12).

Although results for San Jose and Pine were comparable to each other in having similar levels of support (Pine: 53%; San Jose: 57%) for the same best model (*Precip*, *Precip1*) and little support for Trend models (Pine: 2%; San Jose: 5%), results also indicated that there were fundamental differences between Pine and San Jose. Perhaps the most important difference was that San Jose's Null model (Null model probability: 26%) was much more likely than Pine's (Null model probability: 4%) (Table 12). San Jose's model-averaged coefficients for *Precip* and *Precip1* indicated that lagged (1-year) and annual precipitation were nearly equal in their influence on annual baseflow (Table 13).

Table 13. Coefficient estimates for Method 1 results for San Jose, Pine, Los Padres, and Big Sur during WY 1999 - 2007

		Model Averaged Coefficient Estimates and Standard Errors							
Stream	**Record (WY)**	**Precip**	***SE***	**Precip1**	***SE***	**Precip2**	***SE***	**Time**	***SE***
Pine	1999 - 2007	0.845	*0.199*	0.249	*0.146*	0.000	*0.001*	-0.004	*0.006*
Los Padres		0.932	*0.138*	0.001	*0.005*	0.000	*0.000*	-0.003	*0.006*
Big Sur		0.889	*0.174*	0.034	*0.036*	0.000	*0.000*	-0.001	*0.005*
San Jose		0.477	*0.204*	0.562	*0.222*	0.026	*0.026*	-0.018	*0.019*

(Model coefficients: Precip = Annual precipitation; Precip1 = Annual precipitation lagged 1-year; Precip2 = Annual precipitation lagged 2-years)

In contrast, coefficients for Pine showed annual precipitation to be more than 3 times more influential on baseflow than 1-year lagged precipitation during the WY 1999 – 2007 period (Table 13). These results reflect a minimal level of support for San Jose's best (No Trend) model and may also reflect a fundamental lack of dependence of baseflow on annual and lagged precipitation for San Jose. These results for San Jose could reflect physical differences from Pine in terms of watershed/groundwater characteristics or be indicative of anthropogenic influences such as diversions and/or groundwater use. In addition, these results could have arisen due to random error from a variety of sources (e.g. hydro-climatic variability; error in streamflow gaging or estimation of areal precipitation using a single gage; small sample size).

Study Site: Upper Garzas (WY 2001 – 2007)

Reference Sites: Pine, Los Padres, Big Sur (WY 2001 – 2007)

Results for all sites during WY 2001 – 2007 were very similar in terms of having virtually zero support for the hypothesis of trend in baseflow (Table 14). All sites had the same best No-Trend model (*Precip*) and all had No-Trend model probabilities ≥ 93% (Table 14). Null models received little support, with probabilities ranging from 1% to 7% (Table 14). Using the descriptive terms for interpreting Evidence Ratios defined in the Methods, the level of support in these results amounted to *strong evidence* in favor of the No-Trend hypothesis for Pine, Big Sur, and Upper Garzas, and *decisive evidence* in favor of the No-Trend hypothesis for Los Padres (Table 14). Model-averaged coefficients for *Precip* were of similar magnitude for all streams, indicating a similar, strong relationship between baseflow and annual precipitation (Table 15).

Table 14. Method 1 results for Upper Garzas, Pine, Los Padres, and Big Sur during WY 2001 - 2007

					Combined w_i for all Trend/No Trend models:			
Stream	**Record (WY)**	**Best model**	**Best model Coefficients**	**Best model Akaike w_i**	**Trend models Akaike w_i**	**No Trend models Akaike w_i**	**Null model Akaike w_i**	**Descriptive Terms for Interpreting Evidence Ratios**
Pine	2001 - 2007	*No Trend*	*P*	0.96	0.00	0.96	0.04	**strong** evidence in favor of ***No Trend*** hypothesis
Los Padres		*No Trend*	*P*	0.99	0.00	0.99	0.01	**decisive** evidence in favor of ***No Trend*** hypothesis
Big Sur		*No Trend*	*P*	0.93	0.00	0.94	0.06	**strong** evidence in favor of ***No Trend*** hypothesis
Upper Garzas		*No Trend*	*P*	0.91	0.01	0.93	0.07	**strong** evidence in favor of ***No Trend*** hypothesis

(Model coefficients: P = Annual precipitation; P1 = Annual precipitation lagged 1-year; P2 = Annual precipitation lagged 2-years; T = Time)

Table 15. Coefficient estimates for Method 1 results for Upper Garzas, Pine, Los Padres, and Big Sur during WY 2001 - 2007

		Model Averaged Coefficient Estimates and Standard Errors							
Stream	**Record (WY)**	**Precip**	***SE***	**Precip1**	***SE***	**Precip2**	***SE***	**Time**	***SE***
Pine	2001 - 2007	0.892	*0.167*	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*
Los Padres		0.942	*0.138*	0.000	*0.000*	0.000	*0.000*	0.000	*0.000*
Big Sur		0.864	*0.178*	0.002	*0.002*	0.000	*0.000*	0.000	*0.001*
Upper Garzas		0.847	*0.184*	0.005	*0.006*	0.000	*0.000*	0.001	*0.002*

(Model coefficients: Precip = Annual precipitation; Precip1 = Annual precipitation lagged 1-year; Precip2 = Annual precipitation lagged 2-years)

Results for the WY 2001 – 2007 analysis period seem to provide strong, unambiguous support for the of No-Trend hypothesis in baseflow for Upper Garzas, Pine, Los Padres, and Big Sur. However, with the very small sample size available here, a trend in baseflow cannot be ruled out as conclusively as the results would suggest.

Study Sites: Lower Garzas Canyon, San Clemente-SLP, Potrero (WY 2002 – 2007) Reference Sites: Pine, Los Padres, Big Sur (WY 2002 – 2007)

Results were inconsistent and varied widely for both reference and study sites during the WY 2002 – 2007 analysis period (Table 16). All sites had zero support for Trend models and sizable probabilities for Null models ranging from of 10% to 66% (Table 16). Results for Pine and Los Padres had the most support for No-Trend models (Pine No-Trend model probability: 79%; Los Padres No-Trend model probability: 90%) and amounted to *substantial evidence* in favor of the No-Trend hypothesis (Table 16). Results for Big Sur less strongly supported the No-Trend model (Big Sur No-Trend model probability: 73%) and amounted to only *minimal evidence* in favor of the No-Trend hypothesis over the Null hypothesis (Table 16). Results for Lower Garzas Canyon favored the Null model (Null model probability: 66%) over the No-Trend model and amounted to *minimal evidence* in favor of the Null hypothesis over the No-Trend hypothesis (Table 16). Results for San Clemente-SLP and Potrero weakly favored No-Trend models (San Clemente No-Trend model probability: 61%; Potrero No-Trend model probability: 57%) and amounted to only *minimal evidence* in favor of the No-Trend hypothesis over the Null hypothesis (Table 16). Model-averaged coefficients indicate the relationship between baseflow and annual precipitation is fairly strong for Pine and Los Padres, but ranges from weak to nearly non-existent for all other streams (Table 17).

Table 16. Method 1 results for Lower Garzas Canyon, San Clemente-SLP, Potrero, Pine, Los Padres, and Big Sur during WY 2002 -2007

					Combined w_i for all Trend/No Trend models:			
Stream	**Record (WY)**	**Best model**	**Best model Coefficients**	**Best model Akaike w_i**	**Trend models Akaike w_i**	**No Trend models Akaike w_i**	**Null model Akaike w_i**	**Descriptive Terms for Interpreting Evidence Ratios**
Pine	2002 - 2007	*No Trend*	*P*	0.79	0.00	0.79	0.21	**substantial** evidence in favor of ***No Trend*** hypothesis
Los Padres		*No Trend*	*P*	0.90	0.00	0.90	0.10	**substantial** evidence in favor of ***No Trend*** hypothesis
Big Sur		*No Trend*	*P*	0.73	0.00	0.73	0.27	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely
Lower Garzas Canyon		*Null*		0.66	0.00	0.34	0.66	**minimal** evidence in favor of ***Null*** hypothesis; ***No Trend*** hypothesis nearly equally likely
San Clemente-SLP		*No Trend*	*P*	0.61	0.00	0.61	0.39	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely
Potrero		*No Trend*	*P*	0.57	0.00	0.57	0.43	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely

(Model coefficients: P = Annual precipitation; P1 = Annual precipitation lagged 1-year; P2 = Annual precipitation lagged 2-years; T = Time)

Table 17. Coefficient estimates for Method 1 results for Lower Garzas Canyon, San Clemente-SLP, Potrero, Pine, Los Padres, and Big Sur during WY 2002 -2007

		Model Averaged Coefficient Estimates and Standard Errors							
Stream	**Record (WY)**	**Precip**	***SE***	**Precip1**	***SE***	**Precip2**	***SE***	**Time**	***SE***
Pine	2002 - 2007	0.735	*0.209*	0.000	*0.000*	NA	NA	0.000	*0.000*
Los Padres		0.857	*0.161*	0.000	*0.000*	NA	NA	0.000	*0.000*
Big Sur		0.682	*0.226*	0.000	*0.000*	NA	NA	0.000	*0.000*
Lower Garzas Cyn		0.300	*0.214*	0.000	*0.000*	NA	NA	0.000	*0.000*
San Clemente-SLP		0.554	*0.250*	0.000	*0.000*	NA	NA	0.000	*0.000*
Potrero		0.522	*0.252*	0.000	*0.000*	NA	NA	0.000	*0.000*

(Model coefficients: Precip = Annual precipitation; Precip1 = Annual precipitation lagged 1-year; Precip2 = Annual precipitation lagged 2-years)

The inconsistent and inconclusive results obtained for Lower Garzas Canyon, San Clemente-SLP, and Potrero during the WY 2002 – 2007 analysis are not unexpected given the extremely small sample sizes used. The available data are more than likely inadequate to support the more complex (i.e. more parameters) Trend model over the No-Trend model, or even to support the No-Trend model over the Null model in some cases. This would make detection of a baseflow trend next to impossible even if present.

Method 2

Dry season baseflows at each study stream were analyzed over their entire period of record against reference site (Pine, Los Padres, Big Sur) baseflows in concurrent years. Results are presented by study stream, starting with those having the longest record. Complete AIC tables for all streams using Method 2 are found in Appendix G.

Lower Garzas (WY 1992 – 2007)

Results for Lower Garzas during WY 1992 – 2007 with Pine as the reference site strongly supported the No-Trend model (probability: 85%) over the Trend model (probability: 15%) and provide *substantial evidence* in favor of the No-Trend hypothesis using the descriptive terms for interpreting Evidence Ratios defined in the Methods (Table 18). Null models received zero support (Table 18). The model-averaged *Reference Baseflow* coefficient magnitude indicated baseflows at Pine and Lower Garzas were highly related during WY 1992 – 2007 (Table 19). When Los Padres and Big Sur were used as references, the No-Trend model was less strongly favored (No-Trend model probability: 71% with Los Padres; 64% with Big Sur) over the Trend model (Trend model probability: 29% with Los Padres; 36% with Big Sur), indicating a greater uncertainty about whether or not a trend is present in Lower Garzas baseflow (Table 18). This level of evidence would be characterized as *minimal* in favor of the No-Trend hypothesis and means the Trend hypothesis is nearly as likely. Null models received zero support (Table 18). *Reference Baseflow* coefficient magnitudes indicated baseflows at Lower Garzas were highly related to those at both Los Padres and Big Sur during WY 1992 – 2007 (Table 19).

Table 18. Method 2 results for Lower Garzas during WY 1992 - 2007

Study Stream	Reference Stream	Record (WY)	Best model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
Lower Garzas	*Pine*	1992 - 2007	*No Trend*	0.15	0.85	0.00	**substantial** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*No Trend*	0.29	0.71	0.00	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Trend*** hypothesis nearly equally likely
	Big Sur		*No Trend*	0.36	0.64	0.00	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Trend*** hypothesis nearly equally likely

Table 19. Coefficient estimates for Method 2 results for Lower Garzas during WY 1992 - 2007

			Model-Averaged Coefficient Estimates and Standard Errors			
Study Stream	**Reference Stream**	**Record (WY)**	**Reference Baseflow**	***SE***	**Time**	***SE***
Lower Garzas	*Pine*	1992 - 2007	0.956	*0.079*	-0.004	*0.012*
	Los Padres		0.879	*0.127*	-0.046	*0.049*
	Big Sur		0.874	*0.129*	-0.067	*0.062*

The difference in results using Los Padres and Big Sur as references could be explained by the probability of increasing trends in baseflow at these sites that were observed for this period in the Method 1 analysis. Because no trend was previously detected in Pine in the Method 1 analyses, the analysis comparing Lower Garzas with Pine should be considered to be more valid than those using Los Padres and Big Sur as references. Therefore, results obtained (using Pine) that strongly support the hypothesis of no trend in baseflow in Lower Garzas during WY 1992 – 2007 should be given the most weight.

San Clemente (WY 1992 – 2007)

Results for San Clemente varied among the different reference sites (Table 20). Results with Pine as the reference site favored the Trend model (probability: 75%) over the No-Trend model (probability: 25%), which amounted to *minimal evidence* in favor of the baseflow trend hypothesis for San Clemente (Table 20). Coefficient magnitude for *Reference Baseflow* indicated a strong relationship between baseflows for San Clemente and Pine, while the *Time* coefficient indicated the existence of a weak increasing trend in baseflow for San Clemente during WY 1992 – 2007 (Table 21). Results using Los Padres as the reference site were just the opposite and favored the No-Trend model (probability: 77%) over the Trend (probability: 23%) and amounted to *substantial evidence* in favor of the hypothesis of no trend in baseflow (Table 20). Trend (probability: 49%) and No-Trend (probability: 51%) models were nearly equally likely using Big Sur, although providing *minimal evidence* in support of the no trend hypothesis (Table 20). Coefficient magnitudes for *Reference Baseflow,* with both Los Padres and Big Sur as reference sites, indicated a strong relationship between baseflows at these sites and at San Clemente during WY 1992 – 2007 (Table 21).

Table 20. Method 2 results for San Clemente during WY 1992 - 2007

Study Stream	Reference Stream	Record (WY)	Best model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
San Clemente	*Pine*	1992 - 2007	*Trend*	0.75	0.25	0.00	**minimal** evidence in favor of ***Trend*** hypothesis; ***No Trend*** hypothesis nearly equally likely
	Los Padres		*No Trend*	0.23	0.77	0.00	**substantial** evidence in favor of ***No Trend*** hypothesis
	Big Sur		*No Trend*	0.49	0.51	0.00	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Trend*** hypothesis nearly equally likely

Table 21. Coefficient estimates for Method 2 results for San Clemente during WY 1992 - 2007

Study Stream	Reference Stream	Record (WY)	Model-Averaged Coefficient Estimates and Standard Errors			
			Reference Baseflow	*SE*	Time	*SE*
San Clemente	*Pine*	1992 - 2007	1.000	*0.032*	0.054	*0.026*
	Los Padres		0.969	*0.066*	-0.015	*0.019*
	Big Sur		0.977	*0.056*	-0.048	*0.036*

The results with Pine that support the possibility of a weak, increasing trend in San Clemente baseflow would probably be the most valid, given the higher probability of trends in Los Padres and Big Sur baseflows, as previously discussed. However, the strength of evidence in favor of the baseflow trend hypothesis is *minimal* and the magnitude of the trend is small. In addition, numerous sources of error exist, both natural (e.g. microclimatic variability) and anthropogenic (e.g. streamflow gaging error); therefore, results supporting the hypothesis of an increase in San Clemente dry season baseflow during WY 1992 – 2007 should not be considered definitive.

San Jose (WY 1999 – 2007)

Results for San Jose differed substantially for each reference site used (Table 22). Results with Pine as the reference favored the No-Trend model (probability: 79%) over both the Trend model (probability: 10%) and Null model (probability: 11%) and provided *substantial evidence* in favor of the hypothesis of no trend in baseflow for San Jose (Table 22). The *Reference Baseflow* coefficient suggested a moderately strong relationship between baseflows from San Jose and Pine (Table 23). Results with Los Padres as the reference site favored the Null model (probability: 70%) over both the No-Trend model (probability: 28%) and Trend model (probability: 2%) (Table 22). These results provided *minimal evidence* in favor of the null hypothesis (i.e. no relationship between San Jose and Los Padres baseflows) (Table 22). Results with Big Sur provided only *minimal evidence* in favor of the no trend hypothesis over the null hypothesis (No-Trend model probability: 46%; Null model probability: 45%; Trend model probability: 8%) (Table 22). Both *Reference Baseflow* coefficients with Los Padres and Big Sur as reference sites reflect the lack of relationship between baseflows at these reference sites and those of San Jose (Table 23).

Table 22. Method 2 results for San Jose during WY 1999 - 2007

Study Stream	Reference Stream	Record (WY)	Best model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
San Jose	*Pine*	1999 - 2007	*No Trend*	0.10	0.79	0.11	**substantial** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*Null*	0.02	0.28	0.70	**minimal** evidence in favor of ***Null*** hypothesis; ***No Trend*** hypothesis nearly equally likely
	Big Sur		*No Trend*	0.08	0.46	0.45	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely

Table 23. Coefficient estimates for Method 2 results for San Jose during WY 1999 - 2007

			Model-Averaged Coefficient Estimates and Standard Errors			
Study Stream	**Reference Stream**	**Record (WY)**	**Reference Baseflow**	***SE***	**Time**	***SE***
San Jose	*Pine*	1999 - 2007	0.704	*0.218*	-0.032	*0.036*
	Los Padres		0.160	*0.148*	-0.009	*0.012*
	Big Sur		0.352	*0.223*	-0.035	*0.038*

This lack of relationship in baseflows could be attributed to the possible trends in Los Padres and Big Sur baseflow identified in Method 1, although trends were not detected in these streams during the WY 1999 – 2007 record.

Upper Garzas (WY 2001 – 2007)

Support for No-Trend models was very high (No-Trend model probabilities ≥ 97%) across all reference sites (Table 24). This level of support amounted to *strong evidence* using Pine and Los Padres and *decisive evidence* using Big Sur, all in favor of the hypothesis of no trend in Upper Garzas baseflow (Table 24). The high level of support is reflected in the *Reference Baseflow* coefficients that all show a strong relationship between baseflows at Upper Garzas and all reference sites (Table 25).

Table 24. Method 2 results for Upper Garzas during WY 2001 - 2007

Study Stream	Reference Stream	Record (WY)	Best model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
Upper Garzas	*Pine*	2001 - 2007	*No Trend*	0.00	0.98	0.02	**strong** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*No Trend*	0.01	0.97	0.02	**strong** evidence in favor of ***No Trend*** hypothesis
	Big Sur		*No Trend*	< 0.01	0.99	< 0.01	**decisive** evidence in favor of ***No Trend*** hypothesis

Table 25. Coefficient estimates for Method 2 results for Upper Garzas during WY 2001 - 2007

			Model-Averaged Coefficient Estimates and Standard Errors			
Study Stream	**Reference Stream**	**Record (WY)**	**Reference Baseflow**	***SE***	**Time**	***SE***
Upper Garzas	*Pine*	2001 - 2007	0.925	*0.150*	0.000	*0.000*
	Los Padres		0.918	*0.154*	0.002	*0.002*
	Big Sur		0.962	*0.117*	0.000	*0.000*

The virtually complete support for the No- Trend model would seem to unambiguously support the hypothesis that there was no trend in Upper Garzas baseflow during WY 2001 - 2007. However, with the very small sample sizes available here, a trend in baseflow cannot be ruled out conclusively.

Lower Garzas Canyon, San Clemente – SLP, and Potrero: (WY 2002 – 2007)

Results for Lower Garzas Canyon using Pine as the reference site favored the No-Trend model (probability: 77%) over the Null model (probability: 23%), and provided *substantial evidence* in favor of the no trend hypothesis for Lower Garzas Canyon (Table 26). Results were similar using Los Padres as the reference site (No-Trend model probability: 71%; Null model probability: 29%), although the slightly lower level of support for the No-Trend model amounted to only *minimal evidence* in favor of the no trend hypothesis (Table 26). Results contained less uncertainty with Big Sur as the reference site and provided *strong evidence* in favor of the no trend hypothesis (No-Trend model probability: 98%; Null model probability: 2%) (Table 26). The higher levels of uncertainty in results (i.e. larger probabilities of Null models) using Pine and Los Padres are reflected in the *Reference Baseflow* coefficients that show moderately strong relationships (and higher SE’s) between baseflows at Lower Garzas Canyon and these reference sites (Table 27). The *Reference Baseflow* coefficient using Big Sur shows a much stronger relationship between study and reference site baseflows (Table 27).

Table 26. Method 2 results for Lower Garzas Canyon, San Clemente-SLP, and Potrero during WY 2002 - 2007

Study Stream	Reference Stream	Record (WY)	Best model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i	Descriptive Terms for Interpreting Evidence Ratios
Low. Garzas Cyn	*Pine*	2002 - 2007	*No Trend*	0.00	0.77	0.23	**substantial** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*No Trend*	0.00	0.71	0.29	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely
	Big Sur		*No Trend*	0.00	0.98	0.02	**strong** evidence in favor of ***No Trend*** hypothesis
San Clemente-SLP	*Pine*	2002 - 2007	*No Trend*	0.00	0.85	0.15	**substantial** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*No Trend*	0.00	0.82	0.18	**substantial** evidence in favor of ***No Trend*** hypothesis
	Big Sur		*No Trend*	0.00	0.97	0.03	**strong** evidence in favor of ***No Trend*** hypothesis
Potrero	*Pine*	2002 - 2007	*No Trend*	0.00	0.80	0.20	**substantial** evidence in favor of ***No Trend*** hypothesis
	Los Padres		*No Trend*	0.00	0.74	0.26	**minimal** evidence in favor of ***No Trend*** hypothesis; ***Null*** hypothesis nearly equally likely
	Big Sur		*No Trend*	0.00	0.85	0.15	**substantial** evidence in favor of ***No Trend*** hypothesis

Table 27. Coefficient estimates for Method 2 results for Lower Garzas Canyon, San Clemente-SLP, and Potrero during WY 2002 - 2007

			Model-Averaged Coefficient Estimates and Standard Errors			
Study Stream	**Reference Stream**	**Record (WY)**	**Reference Baseflow**	***SE***	**Time**	***SE***
Low. Garzas Cyn	*Pine*	2002 - 2007	0.715	*0.216*	0.000	*0.000*
	Los Padres		0.667	*0.229*	0.000	*0.000*
	Big Sur		0.949	*0.116*	0.000	*0.000*
San Clemente-SLP	*Pine*	2002 - 2007	0.803	*0.184*	0.000	*0.000*
	Los Padres		0.774	*0.195*	0.000	*0.000*
	Big Sur		0.940	*0.122*	0.000	*0.000*
Potrero	*Pine*	2002 - 2007	0.751	*0.204*	0.000	*0.000*
	Los Padres		0.687	*0.225*	0.000	*0.000*
	Big Sur		0.804	*0.183*	0.000	*0.000*

Results for San Clemente-SLP were similar for all reference sites in favoring the No-Trend model (probabilities 82% to 97%) over the Null model and providing *substantial* to *strong evidence* in favor of the no trend in San Clemente-SLP baseflow (Table 26). These results are reflected by all *Reference Baseflow* coefficients showing strong relationships between study and reference site baseflows (Table 27).

Results for Potrero using Pine and Big Sur provided *substantial evidence* in favor of the no trend hypothesis (Pine No-Trend model probability: 80%; Big Sur No-Trend model probability: 85%), while results with Los Padres provided only *minimal evidence* in favor of the no trend hypothesis over the null (Table 26). These differing levels of support are reflected in the *Reference Baseflow* coefficients that showed a moderate to strong relationship between baseflows at Potrero and those of the reference sites (Table 27).

Results for study streams with WY 2002 – 2007 records were all similar in generally strongly supporting the No-Trend model while having zero support for the Trend model. As discussed previously with Upper Garzas, this would seem to provide fairly unambiguous support for the hypothesis that there was no trend in baseflow at these sites during WY 2002 - 2007. However, with the very small sample sizes available here, it may be unlikely or even impossible with the current data to support a Trend model that would indicate the existence of a trend. Therefore, a trend in baseflow cannot be ruled out conclusively. In addition, the significant support for Null models contained in many of the results means there is a sizable probability no relationship even exists between study site baseflows and those at references sites for WY 2002 – 2007 data.

Sensitivity Analysis

A sensitivity analysis using Method 1 was performed on Pine for WY 1992 – 2007, WY 1999 – 2007, WY 2001 – 2007, and WY 2002 – 2007. Pine was used because results of Method 1 indicated an absence of trend. Results using the longest record (WY 1992 – 2007) show the Trend model becoming increasingly likely and finally more likely than the No-Trend model when baseflow reduction (of WY 2001 – 2007) reaches 60% (Table 28). There is no support for the Null model at any level of reduction with this record (Table 28). With the WY 1999 – 2007 record, the Trend model reaches its highest probability (33%) at 20% baseflow reduction, but never becomes the most likely (best) model at any level of reduction. Starting at 40% reduction, the Null model becomes the most likely model while probability for a Trend model never surpasses 11% (Table 28). With the WY 2001 – 2007 record, support for the No-Trend model starts high (probability: 96%) and decreases until the Null model is the most likely starting at 50% baseflow reduction (Table 28). With the WY 2002 – 2007 record, support for the No-Trend model starts less high (probability: 79%) and decreases until the Null model is the most likely, starting at 30% reduction (Table 28). For both WY 2001 – 2007 and WY 2002 – 2007, there is no support for the Trend model at any level of reduction.

Table 28. Sensitivity analysis results using Method 1

						Combined w_i for all Trend/No Trend models:		
		Years	**Baseflow**		**Best model**	**Trend models**	**No trend models**	**Null Model**
Stream	**Record (WY)**	**Reduced**	**Reduction (%)**	**Best Model**	**Akaike w_i**	**Akaike w_i**	**Akaike w_i**	**Akaike w_i**
Pine	1992 - 2007	2001 - 2007	0	No Trend	0.61	0.11	0.89	0.00
			10	No Trend	0.60	0.11	0.89	0.00
			20	No Trend	0.55	0.15	0.85	0.00
			30	No Trend	0.48	0.21	0.79	0.00
			40	No Trend	0.38	0.30	0.70	0.00
			50	No Trend	0.29	0.41	0.59	0.00
			60	***Trend***	0.27	0.51	0.49	0.00
			70	***Trend***	0.30	0.60	0.40	0.00
			80	***Trend***	0.32	0.68	0.32	0.00
Pine	1999 - 2007	2005 - 2007	0	No Trend	0.53	0.02	0.94	0.04
			10	No Trend	0.52	0.03	0.87	0.10
			20	No Trend	0.38	0.33	0.63	0.03
			30	No Trend	0.45	0.07	0.53	0.40
			40	***Null***	0.58	0.08	0.33	0.58
			50	***Null***	0.71	0.09	0.20	0.71
			60	***Null***	0.78	0.09	0.13	0.78
			70	***Null***	0.81	0.10	0.09	0.81
			80	***Null***	0.81	0.11	0.08	0.81
Pine	2001 - 2007	2005 - 2007	0	No Trend	0.96	0.00	0.96	0.04
			10	No Trend	0.95	0.00	0.95	0.05
			20	No Trend	0.91	0.00	0.91	0.09
			30	No Trend	0.80	0.00	0.80	0.20
			40	No Trend	0.56	0.00	0.56	0.44
			50	***Null***	0.72	0.00	0.28	0.72
			60	***Null***	0.87	0.00	0.13	0.87
			70	***Null***	0.94	0.00	0.06	0.94
			80	***Null***	0.96	0.00	0.04	0.96
Pine	2002 - 2007	2005 - 2007	0	No Trend	0.79	0.00	0.79	0.21
			10	No Trend	0.71	0.00	0.71	0.29
			20	No Trend	0.54	0.00	0.54	0.46
			30	***Null***	0.68	0.00	0.32	0.68
			40	***Null***	0.86	0.00	0.14	0.86
			50	***Null***	0.94	0.00	0.06	0.94
			60	***Null***	0.97	0.00	0.03	0.97
			70	***Null***	0.99	0.00	0.01	0.99
			80	***Null***	0.99	0.00	0.01	0.99

A sensitivity analysis using Method 2 was performed on Lower Garzas vs. Pine (WY 1992 – 2007), Lower Garzas vs. Pine (WY 1999 – 2007), San Clemente vs. Big Sur (WY 2001 – 2007), and San Clemente vs. Big Sur (WY 2002 – 2007). These records were chosen because results obtained with Method 2 indicated a low probability of trend in baseflow. Results with Lower Garzas vs. Pine (WY 1992 – 2007) show the Trend model becoming increasingly likely until it becomes equally likely as the No-Trend model at 80% reduction; the Null models received no support (Table 29). With the Lower Garzas vs. Pine (WY 1999 – 2007) record, the Null model becomes most likely, and the Trend model reaches its greatest probability (15%), at 70% baseflow reduction (Table 29). Results for both San Clemente vs. Big Sur for WY 2001 – 2007 and WY 2002 – 2007 are similar in that support for the Null model increases with increasing levels of baseflow reduction, while there is no support for the Trend model (Table 29). The Null model becomes most likely beginning at 60% baseflow reduction for WY 2001 – 2007 and 50% baseflow reduction for WY 2002 – 2007.

Table 29. Sensitivity analysis results using Method 2

Study Stream	Reference Stream	Record (WY)	Years Reduced	Baseflow Reduction (%)	Best Model	Trend model Akaike w_i	No Trend model Akaike w_i	Null model Akaike w_i
Lower Garzas	*Pine*	1992 - 2007	2001 - 2007	0	No Trend	0.15	0.85	0.00
				10	No Trend	0.17	0.83	0.00
				20	No Trend	0.20	0.80	0.00
				30	No Trend	0.24	0.76	0.00
				40	No Trend	0.29	0.71	0.00
				50	No Trend	0.35	0.65	0.00
				60	No Trend	0.40	0.60	0.00
				70	No Trend	0.45	0.55	0.00
				80	***Trend/No Trend***	0.50	0.50	0.00
Lower Garzas	*Pine*	1999 - 2007	2005 - 2007	0	No Trend	0.03	0.97	0.01
				10	No Trend	0.03	0.96	0.01
				20	No Trend	0.04	0.94	0.02
				30	No Trend	0.06	0.89	0.04
				40	No Trend	0.09	0.81	0.10
				50	No Trend	0.12	0.68	0.20
				60	No Trend	0.14	0.50	0.35
				70	***Null***	0.15	0.34	0.51
				80	***Null***	0.14	0.23	0.64
San Clemente	*Big Sur*	2001 - 2007	2005 - 2007	0	No Trend	0.00	1.00	0.00
				10	No Trend	0.00	1.00	0.00
				20	No Trend	0.00	1.00	0.00
				30	No Trend	0.00	1.00	0.00
				40	No Trend	0.00	0.97	0.03
				50	No Trend	0.00	0.78	0.22
				60	***Null***	0.00	0.35	0.65
				70	***Null***	0.00	0.11	0.89
				80	***Null***	0.00	0.05	0.95
San Clemente	*Big Sur*	2002 - 2007	2005 - 2007	0	No Trend	0.00	1.00	0.00
				10	No Trend	0.00	1.00	0.00
				20	No Trend	0.00	1.00	0.00
				30	No Trend	0.00	0.96	0.04
				40	No Trend	0.00	0.76	0.24
				50	***Null***	0.00	0.32	0.68
				60	***Null***	0.00	0.09	0.91
				70	***Null***	0.00	0.03	0.97
				80	***Null***	0.00	0.01	0.99

Sensitivity analysis results suggest Method 1 may be more sensitive in detecting trend than Method 2. With Method 1, Trend models have higher probabilities at lower levels of baseflow reduction in comparison to Method 2. For example, with the WY 1992 – 2007 record the Trend model becomes the most probable model at 60% baseflow reduction using Method 1. With Method 2, the Trend model reaches its highest probability at 80% baseflow reduction for the WY 1992 – 2007 record.

Sensitivity analysis results with both methods are similar in terms of demonstrating how the ability of these methods to detect trend decreases greatly from records of 16 years to 9 years, and are completely unable to detect trends in sample sizes of 6 and 7 years. For records of 9 years and less, as baseflow is reduced the Null model becomes increasingly likely until it becomes the best model, while the Trend model receives relatively little support with 9 year records, and zero support with 6 and 7 year records, even at high levels of baseflow reduction. This can be explained as follows. Reducing baseflow diminishes the likelihood of the No-Trend model because it has no mechanism for explaining baseflow reduction that is unrelated to precipitation (i.e. the explanatory variable for Method 1 No-Trend models) or Reference Site baseflows (i.e. explanatory variable for the Method 2 No-Trend model). With a sufficiently large sample size, one might expect the Trend model to become more likely because it does incorporate a mechanism (the *Time* variable) for explaining baseflow reduction. Because AICc imposes an increasingly large penalty for additional parameters as sample size decreases, the additional parameter included in the Trend model is penalized so severely at such small sample size, its likelihood is reduced below that of the other models. Therefore, the Null model wins by default, since the No-Trend model has no mechanism to account for baseflow reduction and the Trend model is too complex to receive strong support at such small sample sizes.

Results of the sensitivity analysis provide important insights into the research results, particularly for records of 9 years or less. The sensitivity analysis reveals that, although trends may very well be present, at small sample sizes the data are inadequate to support the more complex Trend models and therefore trends cannot be detected. Sensitivity analysis results with records of 9 years or less show that the Null model becomes increasingly likely as baseflow reduction increases, while the Trend model receives little or no support; this suggests that research results where the Null model is likely and the Trend model receives little or no support does not necessarily mean that a baseflow trend is not occurring. Two examples of this situation were observed at San Jose (9 year record) and Lower Garzas Canyon (7 year record) in the Method 1 analysis. San Jose had much higher support for its Null model (probability: 26%) in comparison to the reference streams (all Null models probabilities ≤ 4%). For Lower Garzas Canyon, the Null model was the most likely (probability: 66%), while Null models for reference streams had much lower probabilities (from 10% - 27%). The high support for the Null models in comparison to Null model support among reference streams could be an indication of trend in San Jose and Lower Garzas Canyon baseflows; however, the results are not clear and could also be the result of random variation from other sources.

The sensitivity analysis results do not necessarily reflect a deficiency in the methods, but rather reflects the fact that there is not enough information contained in brief records to support more complex explanations of the data, i.e. those involving a trend. These findings suggest that records greater than 9 years are needed to unambiguously detect trends.

CHAPTER 5

CONCLUSION

The primary goal of this research was to analyze Carmel River tributaries (Las Garzas, San Clemente, Potrero) and San Jose Creek for declining trends in dry season baseflows that may be occurring as the result of intensive groundwater use at SLP. Research results yielded no conclusive evidence that would support the hypothesis that baseflows are declining on Upper and Lower Las Garzas, Potrero, San Clemente, and San Jose Creeks. Research results from both analysis methods are summarized in (Table 30).

Table 30. Summary of results for study streams using Method 1 and Method 2. Method 2 results shown are those obtained using Pine as the reference site

		METHOD 1			**METHOD 2**		
Study Sites	**Record (WY)**	**Best Model**	**Probability (%)**	**Strength of Evidence in favor of:**	**Best Model**	**Probability (%)**	**Strength of Evidence in favor of:**
Lower Garzas	1992 - 2007	*No Trend*	89	substantial	*No Trend*	85	substantial
San Clemente	1992 - 2007	*No Trend*	85	substantial	*Trend*	75	minimal
San Jose	1999 - 2007	*No Trend*	69	minimal	*No Trend*	79	substantial
Upper Garzas	2001 - 2007	*No Trend*	93	strong	*No Trend*	98	strong
Lower Garzas Canyon	2002 - 2007	*Null*	66	minimal	*No Trend*	77	substantial
San Clemente-SLP	2002 - 2007	*No Trend*	61	minimal	*No Trend*	85	substantial
Potrero	2002 - 2007	*No Trend*	57	minimal	*No Trend*	80	substantial

The sensitivity analysis results provided crucial insights into the main research results. Sensitivity analysis results indicated that Method 1 may be more sensitive (and thus a better method) in detecting monotonic baseflow trends than Method 2. The sensitivity analysis also revealed that records greater than 9 years in length are necessary in order to unambiguously detect a trend. With records of 9 years and less, the Trend model will receive little to no support and therefore a trend will not be detected, even if a substantial trend exists. Instead, with small sample sizes, the Null model will receive increasingly large support as the trend becomes larger.

Although no decisive evidence was found supporting the existence of declining baseflow trends at the study sites, this does not mean baseflow trends are not occurring. In light of the sensitivity analysis results, the brief data records currently available at most study sites are inadequate to support a more complex Trend model that would indicate the existence of a baseflow trend. Therefore, inferences based on analysis results for records of 9 years or less are of limited value and should be considered incipient at best. The research results confirmed that trend can be detected given an adequate sample size (e.g. 16-year records: Los Padres and Big Sur with Method 1). The methods used in this research will likely be able to produce more useful and unequivocal results on baseflow trends in Carmel River tributaries and San Jose Creek as more streamflow data becomes available in the near future.

REFERENCES

Alley WM. 1988. Using exogenous variables in testing for monotonic trends in hydrologic time series. Water Resources Research 24(11): 1955 – 1961.

Anderson DR. 2008. Model based inference in the life sciences: a primer on evidence. Springer, New York.

Bjornn TC and Reiser DW. 1991. Habitat requirements of salmonids in streams. *In* Influences of Forest and Rangeland Management. Ed. W.R. Meehan. American Fisheries Society Special Publication 19. Bethesda, MD 1991.

Brandes D, Cavallo GJ, Nilson ML. 2005. Base flow trends in urbanizing watersheds of the Delaware River Basin. Journal of the American Water Resources Association. December: 1377 – 1391.

Burn DH, Hag Elnur MA. 2002. Detection of hydrologic trends and variability. Journal of Hydrology 255:107-122.

Burnham KP, Anderson D. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer, New York.

Burt OR, Baker M, Helmers GA. 2002. Statistical estimation of streamflow depletion from irrigation wells. Water Resources Research 38(12):1296

Chagnon SA and Demissie M. 1996. Detection of changes in streamflow and floods resulting from climate fluctuations and land use drainage changes. Climatic Change 32: 411 – 421.

Chapman T. 1999. A comparison of algorithms for stream flow recession and baseflow separation. Hydrological Processes 13:701-714.

[CRSA] Carmel River Steelhead Association. 1996. Santa Lucia Preserve: concern with final conditions. [Internet] [cited 2008 October 15]. Available from: http://www.carmelriverwatershed.org/crsa1221996.pdf

[DFG] CA Department of Fish and Game. 1996. Steelhead restoration and management plan for California. [Internet]. [cited 2007 May 05]. Available from: http://www.dfg.ca.gov/nafwb/pubs/swshplan.pdf

[DFG] CA Department of Fish and Game. 1999. DFG Letter. [Internet]. [cited 2007 May 05]. Available from: http://www.carmelriverwatershed.org/coulswrcb.pdf

Dow CL. 1999. Detecting base flow impacts in coastal plain streams. Journal of the American Water Resources Association 35(2): 349 – 362.

Ferguson BK and Suckling PW. 1990. Changing rainfall-runoff relationships in the urbanizing Peachtree Creek watershed, Atlanta, Georgia. Journal of the American Water Resources Association 26(2): 313 – 322.

Fetter CW. 1977. Statistical analysis of the impact of groundwater pumpage on low-flow hydrology. Journal of the American Water Resources Association 13(2): 309 – 323.

Gebert WA and Krug WR. 1996. Streamflow trends in Wisconsin's driftless area. Journal of the American Water Resources Association 32(4): 733 – 744.

Hall FR. 1968. Base-flow recessions: a review. Water Resources Research 4(5):973-983.

Hartley DM and Funke DE. 2001. Techniques for detecting hydrologic change in high resource streams. Journal of the American Water Resources Association 37(6): 1589 – 1595.

Helsel DR, Hirsch RM. 2002. Statistical methods in water resources. Techniques of water resource investigations of the USGS: Book 4-hydrologic analysis and interpretation. USGS.

Hirsch RM, Alexander RB, Smith RA. 1991. Selection of methods for detection and estimation of trends in water quality. Water Resources Research 27(5): 803 - 813.

James GW. 2004. Carmel River Basin: surface water resources data report, water years 2000 – 2003. Monterey Peninsula Water Management District.

Jeffreys H. 1961. [cited in Stauffer 2008]. The theory of probability. 3rd edition. Oxford University Press.

Johnson JB and Omland KS. 2004. Model selection in ecology and evolution. TRENDS in ecology and evolution 19(2): 101 – 108.

Kahya E, Kalayci S. 2004. Trend analysis of streamflow in Turkey. Journal of Hydrology 289:128-144.

Kondolf GM and Curry RR. 1986. Channel erosion along the Carmel River, Monterey County, California. Earth surface processes and Landforms: 11: 307 - 319.

Konrad CP and Booth DB. 2002. Hydrologic trends associated with urban development for selected streams in the Puget Sound Basin, western Washington. Water-Resources Investigations Report 02-4040. US Geological Survey.

Mahoney DL and Erman DC. 1984. The role of streamside buffer strips in the ecology of aquatic biota. In: California riparian systems: ecology, conservation, and productive management. Warner RE and Hendrix KM, editors. 1984. University of California Press, Berkeley. Available from: http://www.escholarship.org/editions/view?docId=ft1c6003wp

Maimome M. 2004. Defining and Managing Sustainable Yield. Groundwater 42(6):809-814.

Meixner T and Wohlgemuth PM. 2003. Climate variability, fire, vegetation, recovery, and watershed hydrology. *In*: Proceedings of first inter-agency conference on research in the watersheds. Benson, Arizona, October 28-30, 2003.

Meyer SC. 2001. Investigation of impacts of urbanization on base flow and recharge rates, northeastern Illinois: summary of year 2 activities. In: Proceedings of the Annual Illinois Groundwater Consortium Conference, Illinois Groundwater Consortium, Carbondale, Illinois. Available: http://www.siu.edu/orda/igc/proceedings/02/meyer.pdf. Accessed in September 2005.

Meyer SC. 2005. Analysis of base flow trends in urban streams, northeastern Illinois, USA. Hydrogeology Journal. 13:871-885.

[Monterey County]. Monterey County Planning and Building Inspection Department. 1995. Santa Lucia Preserve final EIR.

[Monterey County]. Monterey County Planning and Building Inspection Department. 2003. Draft supplemental environmental impact report for the Potrero area subdivision. Available from: http://www.co.monterey.ca.us/pbi/docs/eirs/potrero/potreroDEIR.pdf

[Monterey County]. Monterey County Planning and Building Inspection Department. 2004a. Final supplemental environmental impact report for the Potrero area subdivision. Available from: http://www.co.monterey.ca.us/pbi/docs/eirs/potrero/FSEIR_PLN010001.pdf

[Monterey County]. Monterey County Planning and Building Inspection Department. 2004b. Monterey County Subdivision Committee meeting July 29, 2004. Available from: http://www.co.monterey.ca.us/planning/cca/sub/2004/07-29-04/PLN010001SUB2.pdf

[Monterey County]. Monterey County Planning and Building Inspection Department. 2005. Monterey County zoning administrator meeting February 22, 2007. [Internet] [cited 2008 October 20]. Available from: http://www.co.monterey.ca.us/planning/cca/za/2007/02-22-07/PLN060510ZA4.pdf

[MPWMD] Monterey Peninsula Water Management District. 2004. Environmental and biological assessment of portions of the Carmel River watershed, Monterey County, California. [Internet]. [cited 2008 September 10]. Available from: http://www.mpwmd.dst.ca.us/programs/river/watershed_assessment/TOC.htm

[MPWMD] Monterey Peninsula Water Management District. 2008a. MPWMD mitigation program 2005 – 2006 annual report. [Internet]. [cited 2008 September 10]. Available from: http://www.mpwmd.dst.ca.us/programs/mitigation_program/annual_report/2006/fullreport2005_06.htm

[MPWMD] Monterey Peninsula Water Management District. 2008b. State Water Resources Control Board Order 95-10 reducing water supplies to Cal-Am customers. [Internet]. [cited 2008 September 10]. Available from: http://www.mpwmd.dst.ca.us/issues/rolewmd/role_wmd_pg3.htm

[NMFS] National Marine Fisheries Service Southwest Region. 2002. Instream flow needs for steelhead in the Carmel River: bypass flow recommendations for water supply projects using Carmel River waters.

[NMFS] National Marine Fisheries Service. 2005. Assessment of the adequacy of the environmental impacts analysis and required mitigation and monitoring programs, of the final and supplemental environmental impact report prepared for the Santa Lucia Preserve and Potrero subdivision. MPWMD Carmel River advisory committee meeting February 10, 2005. [Internet] [cited 2008 October 15]. Available from: http://www.mpwmd.dst.ca.us/programs/river/crac/meetings/2005/0210/02102005_CRAC_PACKET_2.pdf

[NMFS] National Marine Fisheries Service. 2007. Recovery of salmon and steelhead in California and southern Oregon. [Internet]. [cited 2007 May 05]. Available from: http://swr.nmfs.noaa.gov/recovery/Steelhead_SCCS.htm

Nyholm T, Christensen S, Rasmussen KR. 2002. Flow depletion in a small stream caused by groundwater abstraction from wells. Groundwater 40(4):425-437.

Oki DS, Wolff RH, Perreault JA. 2006. Effects of surface-water diversion and ground-water withdrawal on streamflow and habitat, Punaluu Stream, Oahu, Hawaii. U.S. Geological Survey, Scientific Investigations Report 2006-5153, 104 p.

R Foundation. 2007. R version 2.5.0 (2007-4-23). The R foundation for statistical computing.

Rosenberg LI. 2001. Geologic resources and constraints, Monterey county, California: a technical report for the Monterey county 21st century general plan update program. County of Monterey, environmental policy department. Salinas, California.

Simmons DL and Reynolds RJ. 1982. Effects of urbanization on base flow of selected south-shore streams, Long Island, New York. Journal of the American Water Resources Association. 18(5): 797 – 805.

[SLC] Santa Lucia Conservancy. [date unknown]. [Internet]. [cited 2007 May 05]. Available from: http://www.slconservancy.org/slconservancy-Pages/AboutUs.asp

[SLP] Santa Lucia Preserve. 2001. Santa Lucia Preserve water system annual water report for year 2001. Santa Lucia Preserve. Unpublished report.

-------- 2002. Santa Lucia Preserve water system annual water report for year 2002. Santa Lucia Preserve. Unpublished report.

-------- 2003. Santa Lucia Preserve water system annual water report for year 2003. Santa Lucia Preserve. Unpublished report.

-------- 2004. Santa Lucia Preserve water system annual water report for year 2004. Santa Lucia Preserve. Unpublished report.

-------- 2005. Santa Lucia Preserve water system annual water report for year 2005. Santa Lucia Preserve. Unpublished report.

-------- 2006. Santa Lucia Preserve water system annual water report for year 2006. Santa Lucia Preserve. Unpublished report.

-------- 2007. Santa Lucia Preserve water system annual water report for year 2007. Santa Lucia Preserve. Unpublished report.

Smakhtin VU. 2001. Low flow hydrology: a review. Journal of Hydrology 240:147-186.

Smith EP and Rose KA. 1991. Trend detection in the presence of covariates: stagewise versus multiple regression. Environmetrics 2(2): 153 - 168.

Smith D, Newman W, Watson F, Hameister J. 2004. Physical and hydrologic assessment of the Carmel River watershed, California. The Watershed Institute, California State University Monterey Bay, Publication No. WI-2004-05/2. Available from: http://ccows.csumb.edu/pubs/reports/CCoWS_CRWC_CarmAssPhysHyd_041101.pdf

Sophocleus M, Koussis A, Martin JL, Perkins SP. 1995. Evaluation of simplified stream-aquifer depletion models for water rights administration. Groundwater 33(4): 579-589.

Sophocleus M. 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal 10:52–67.

Stauffer HB. 2008. Contemporary Bayesian and frequentist statistical research methods for natural resource scientists. John Wiley & Sons, Inc. New Jersey.

Stine S, Gaines D, Vorster P. 1984. Destruction of riparian systems due to water development in the Mono Lake watershed. In: California riparian systems: ecology, conservation, and productive management. Warner RE and Hendrix KM, editors. 1984. University of California Press, Berkeley. Available from: www.escholarship.org/editions/view?docId=ft1c6003wp

[SWRCB] State Water Resources Control Board. 1995. Order on four complaints filed against the California American Water Company, Carmel River, Monterey County: Order 95-10. State of California.

[SWRCB] State Water Resources Control Board. 2003. Complaint of Ventana chapter of the Sierra Club and the Carmel River Steelhead Association against the Rancho San Carlos Partnership. [Internet]. [cited 2007 May 05]. Available from: http://www.carmelriverwatershed.org/SWRCB_complaint.html

[USDA] US Department of Agriculture. 2000. Policy implications of large fire management: a strategic assessment of factors influencing cost. US Department of Agriculture Forest Service.

[USFWS] US Fish and Wildlife Service. 2007. The California red-legged frog. [Internet].[cited 2007 May 05]. Available from: www.fws.gov/endangered/features/rl_frog/rlfrog.html

[USGS] US Geological Survey. 2007. Big Sur streamflow gage information. [Internet]. [cited 2007 November 03]. Available from: http://waterdata.usgs.gov/nwisweb/local/state/ca/text/11143000-manu.html

Van Kirk RW and Naman SW. 2008. Relative effects of climate and water use on base-flow trends in the lower Klamath basin. Journal of the American Water Resources Association 44(4): 1035 – 1052.

Wen F and Chen X. 2006. Evaluation of the impact of groundwater irrigation on streamflow in Nebraska. Journal of Hydrology. 327: 603 – 617.

Wittenberg H. 2003. Effects of season and man-made changes on baseflow and flow recession: case studies. Hydrological Processes 17:2113-2123.

Woyshner M, Hecht B, Brown S. 2003. Dry-season hydrologic and geomorphic conditions on Lower Las Garzas Creek, Monterey County, California, 2002. Prepared for the Santa Lucia Preserve by Balance Hydrologics, Inc.

Yue S, Pilon P, Cavadias G. 2002. Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrologic series. Journal of Hydrology 259:254-271.

APPENDICES

Appendix A

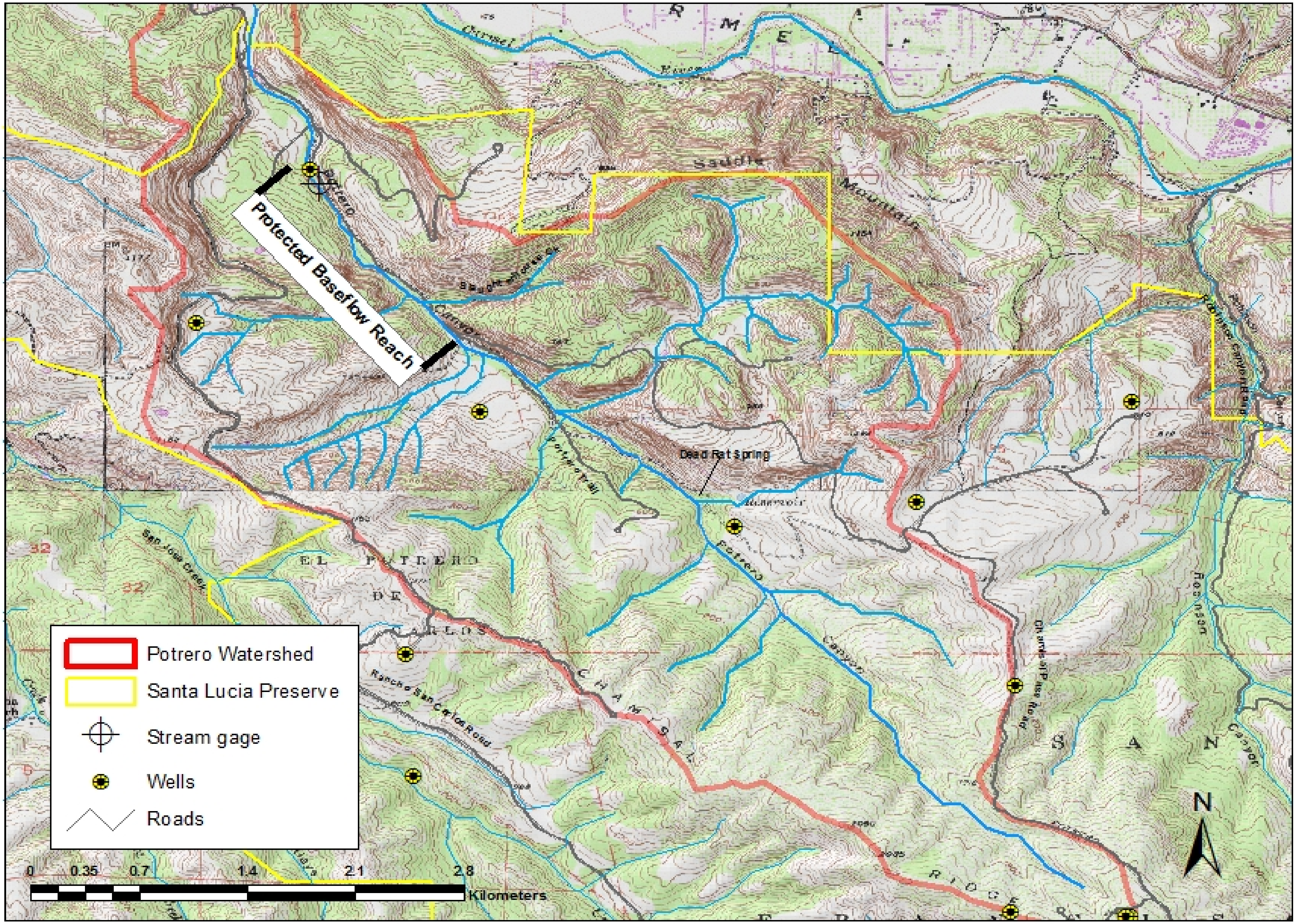
County Conditions/Mitigations Measures relevant to stream baseflows

County Condition	Description
11	Groundwater levels in all of the project water supply wells shall be monitored at least weekly during the maximum demand season (June-August) and monthly during the balance of the year. Wellhead elevations shall be surveyed at all wells so that water levels can be reported as elevation above sea level. An annual report containing the results of groundwater production monitoring, precipitation and streamflow shall be produced and filed with the County of Monterey Water Resources Agency and Environmental Health Department. Water-level hydrographs shall be plotted and data evaluated for trends (at least every three years). This monitoring program shall continue for at least 20 years or as long as the base flow monitoring program is required.
12	Between April 1 and November 1 delay pumping of new and existing wells located within 1,000 feet of Protected Base Flow Reaches (SLP EIR Figure 8-4a) unless the combined capacity of other wells connected to the water supply system is insufficient to meet project demand.
13	New wells may be installed less than 1,000 feet from Protected Base Flow Reaches (SLP EIR Figure 8-4a). Pumping from new and existing wells during the dry season (between April 1 and November 1) shall be limited so that draw down does not exceed 2 feet in any nearby areas of riparian vegetation or 1 foot at any point along the protected base flow reach. The draw-down shall be determined by observation wells. The location, number, and design of the observation wells shall be subject to the review and approval of the Director of Environmental Health and Water Resources Agency.
14	Measured daily base flows in the Potrero Canyon, San Clemente and Las Garzas Creeks shall be recorded at approved locations near the boundaries of Rancho San Carlos. An annual survey of pools and base flow conditions in the gauged creeks and in San Jose Creek shall be conducted in September of each year. At least every year, a Base Flow Monitoring Report for evaluating base flow conditions shall be prepared and filed with Environmental Health, Water Resources Agency, The Department of Fish and Game, and the Monterey County Planning and Building Inspection Department
15	If the Base Flow Monitoring Report demonstrates that the base flow in any of the four creeks has dropped below the October 1990 level as a direct result of the project, flow shall be augmented by discharging water into the creek near the upstream end of the affected Base Flow Reach. The rate of augmentation shall be of an amount sufficient to sustain pools and base flow approximately equal to conditions in October 1990. The maximum required combined augmentation for all four creeks is 30 gpm at

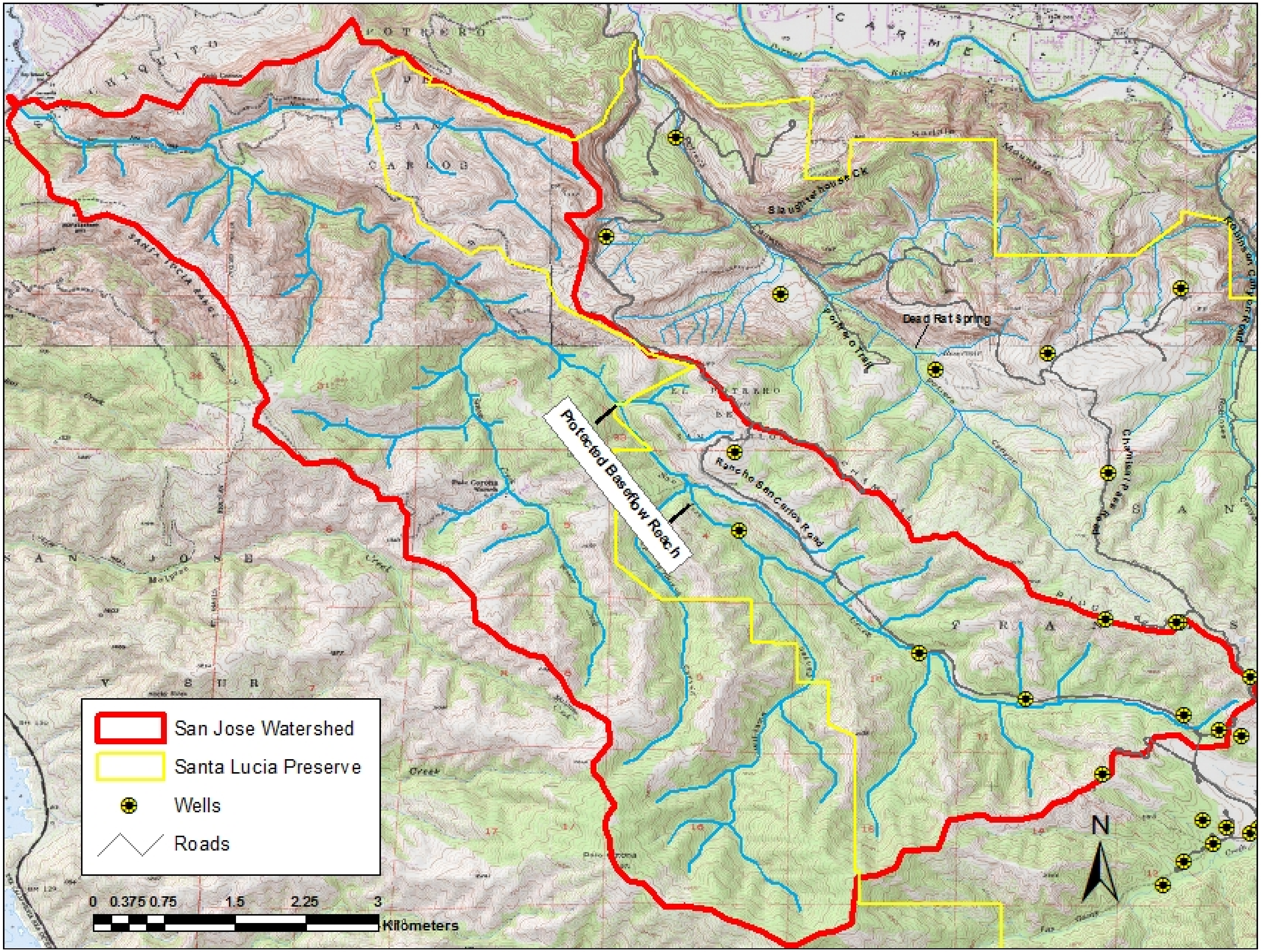
	the points where the augmented water reaches the protected base flow reaches. The proposed augmentation methods, the actual rate(s) of augmentation and the location(s) of augmentation shall be reviewed with the Water Resources Agency prior to implementation of this condition.

APPENDIX B

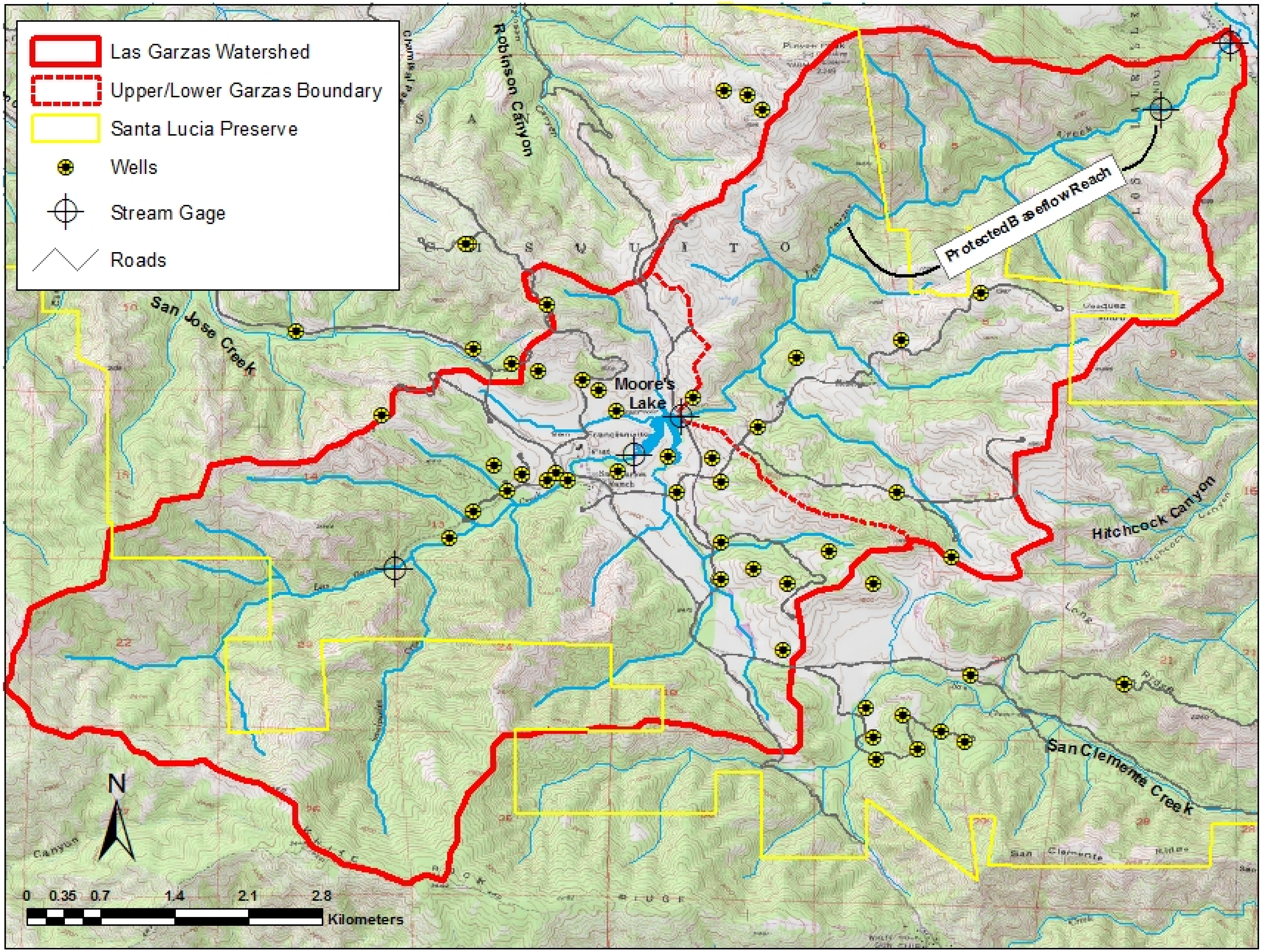
INDIVIDUAL MAPS OF SANTA LUCIA PRESERVE AND REFERENCE WATERSHEDS



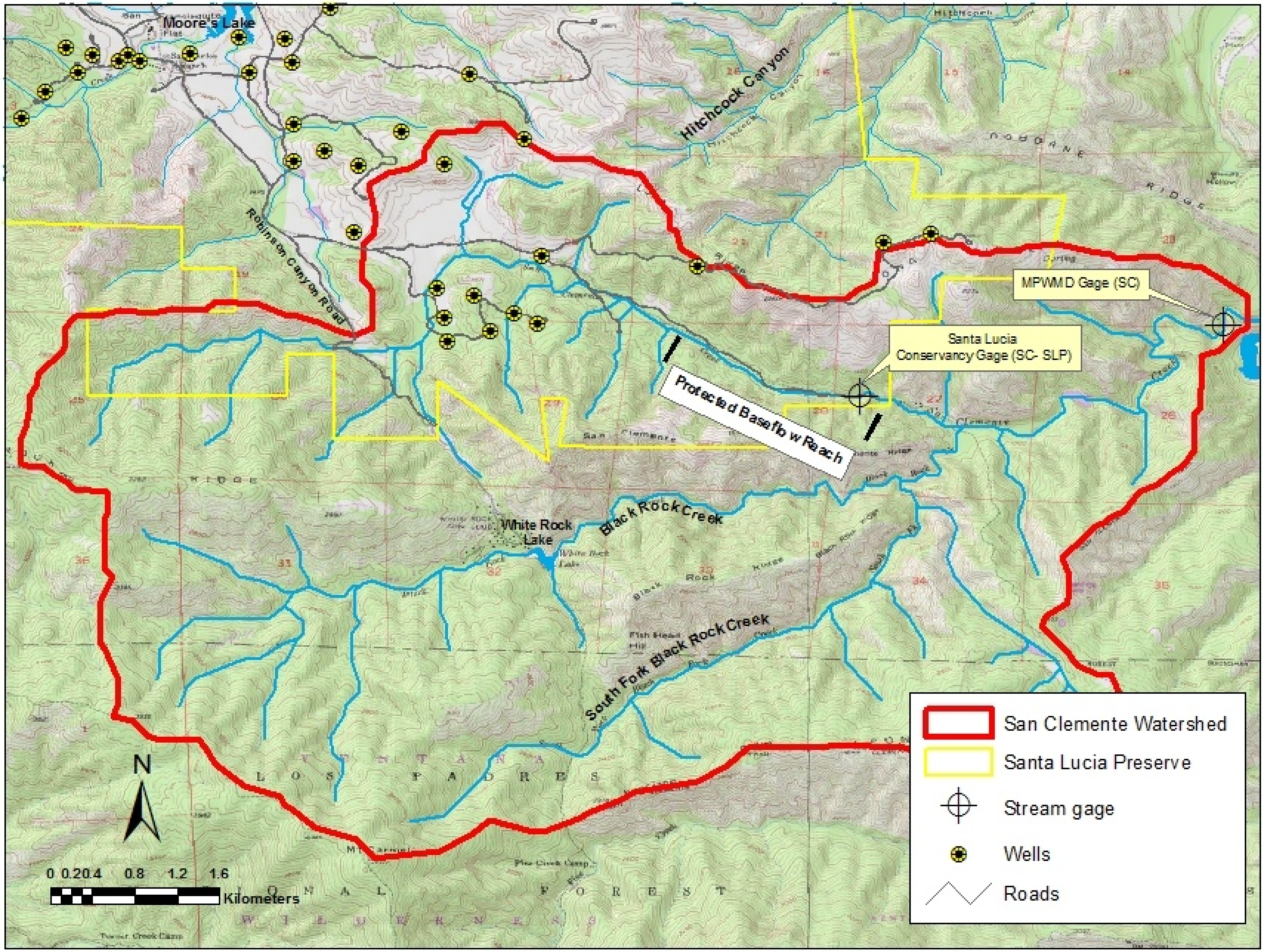
Appendix B-1. Map of Potrero Canyon watershed



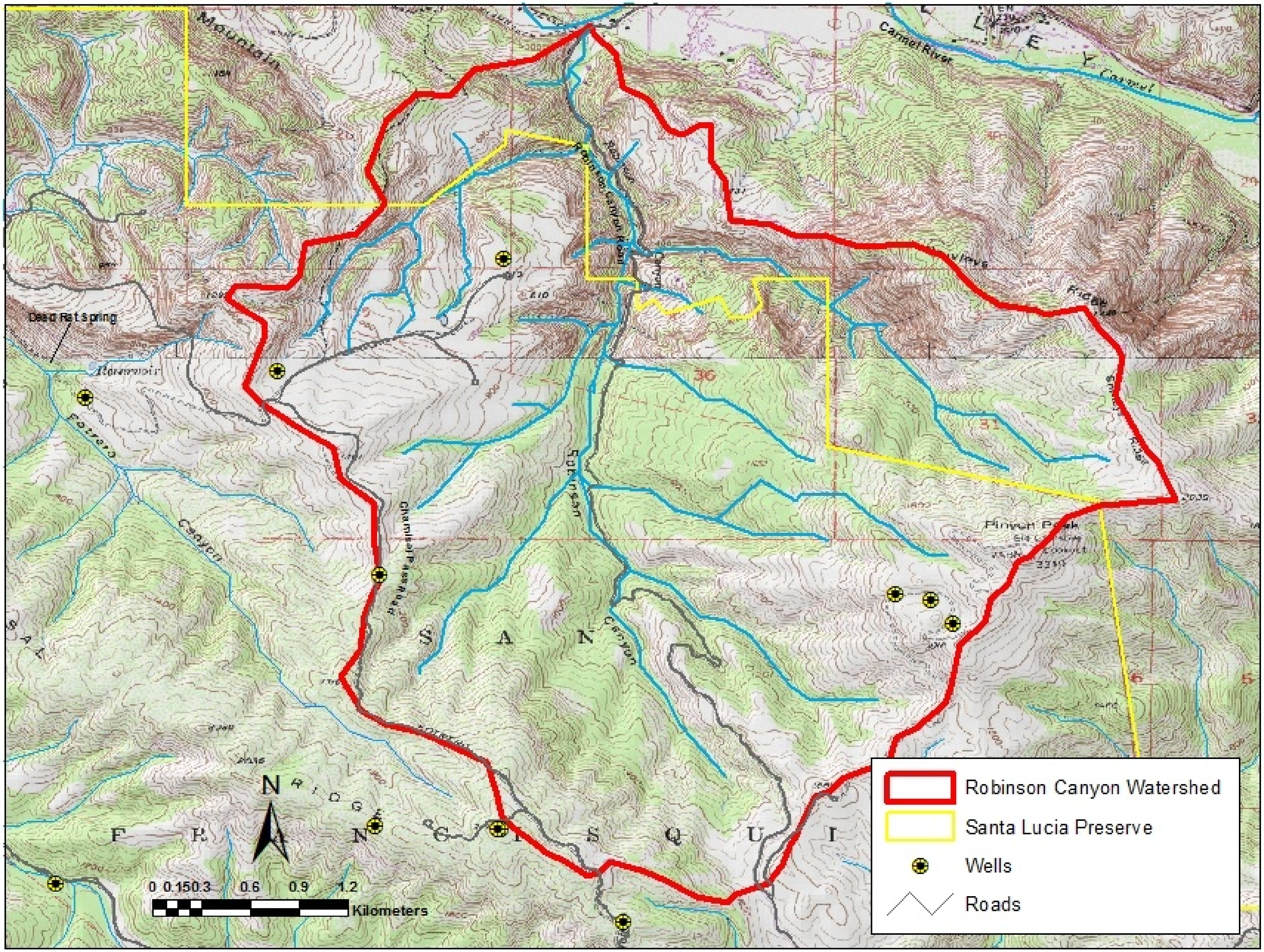
Appendix B-2. Map of San Jose Creek watershed



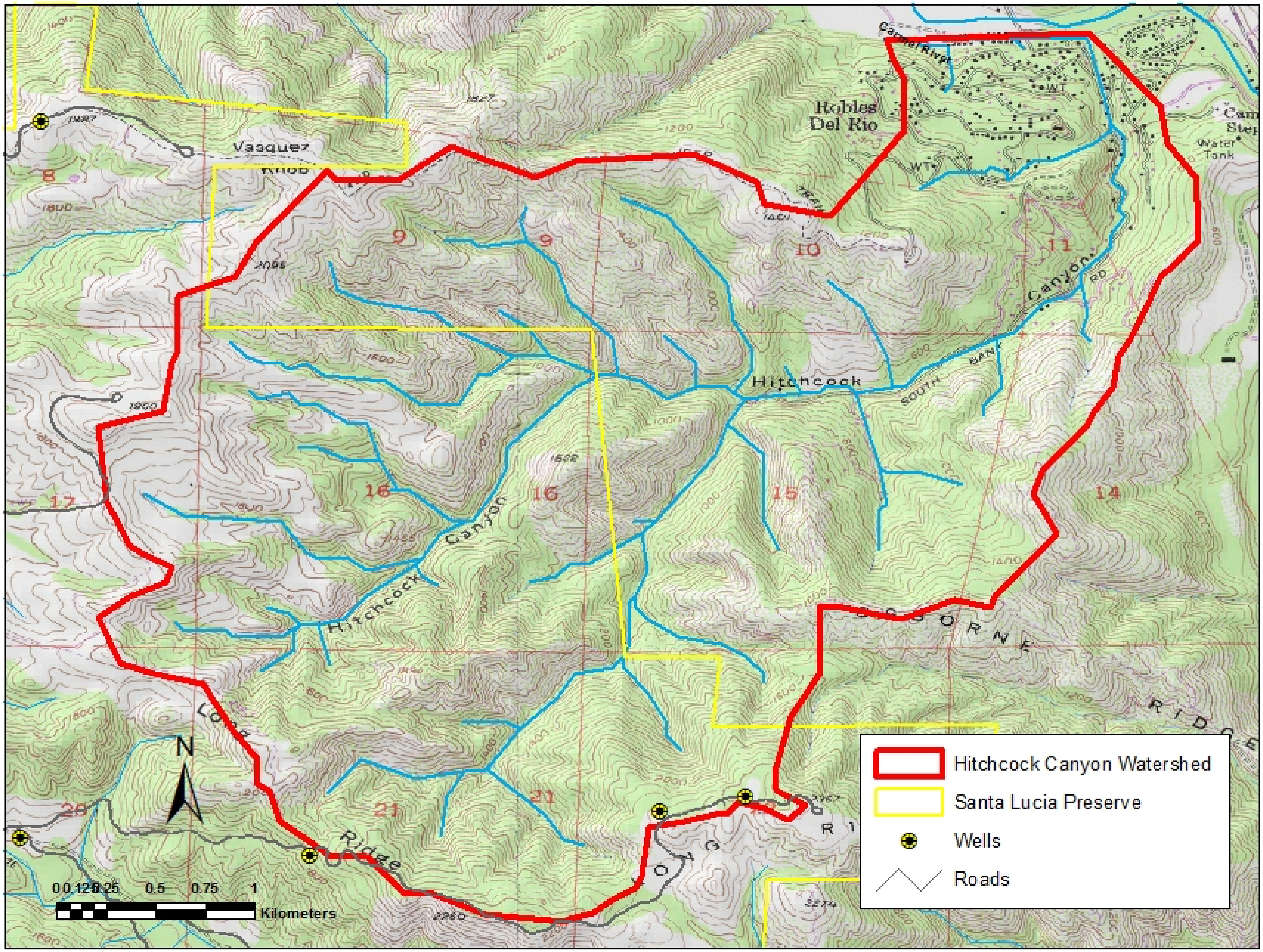
Appendix B-3. Map of Las Garzas Creek watershed



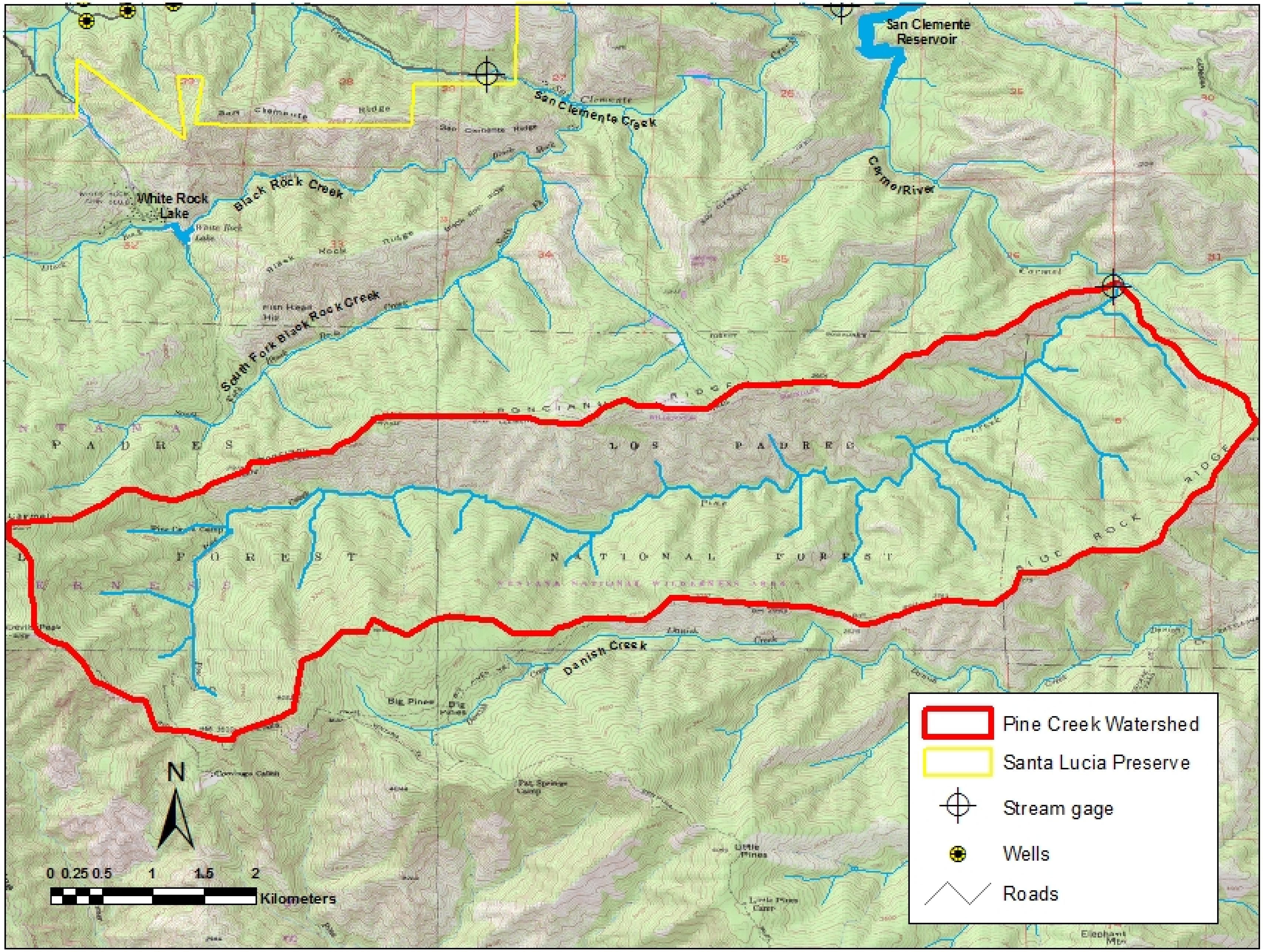
Appendix B-4. Map of San Clemente Creek watershed



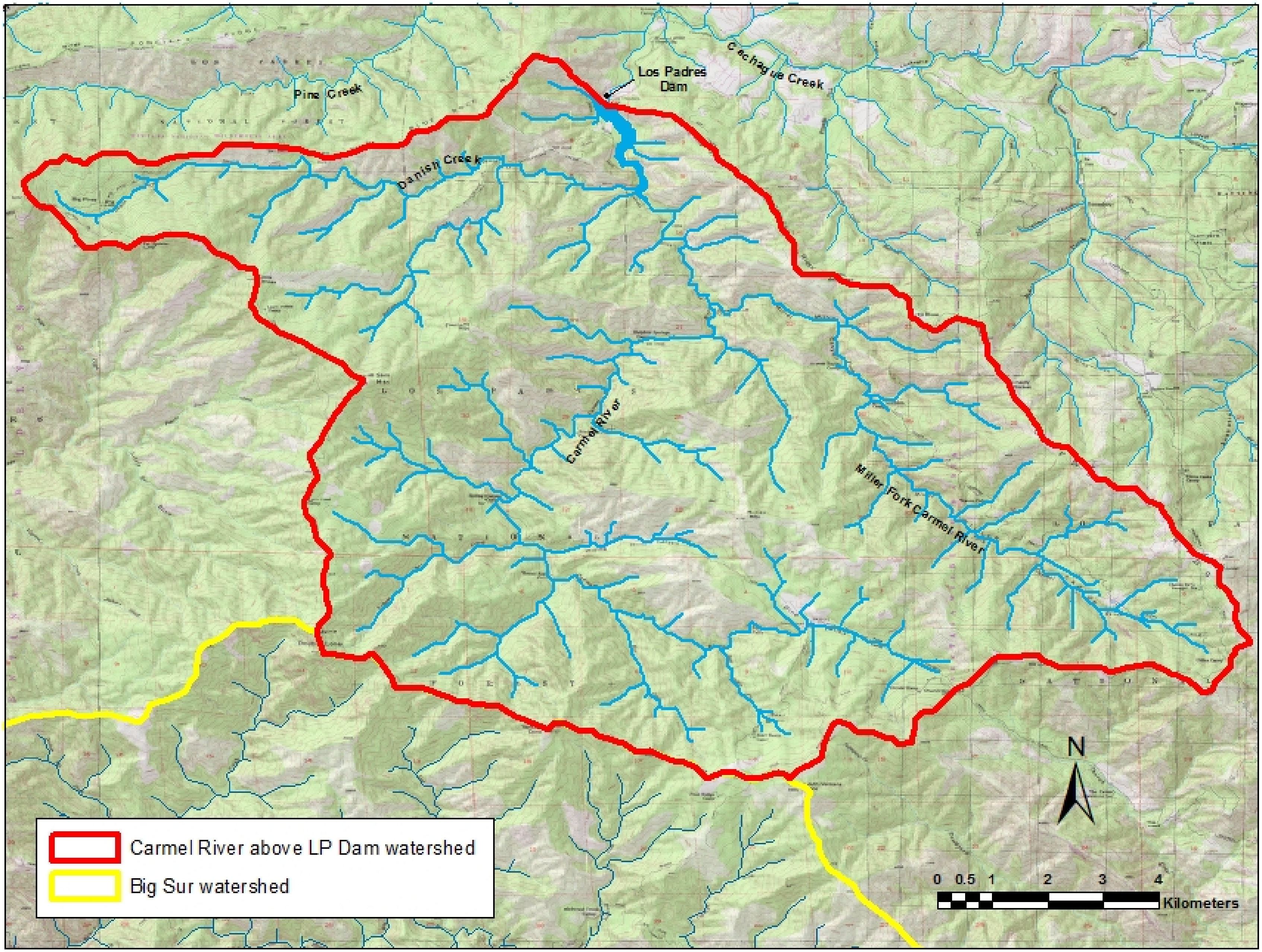
Appendix B-5. Map of Robinson Canyon watershed



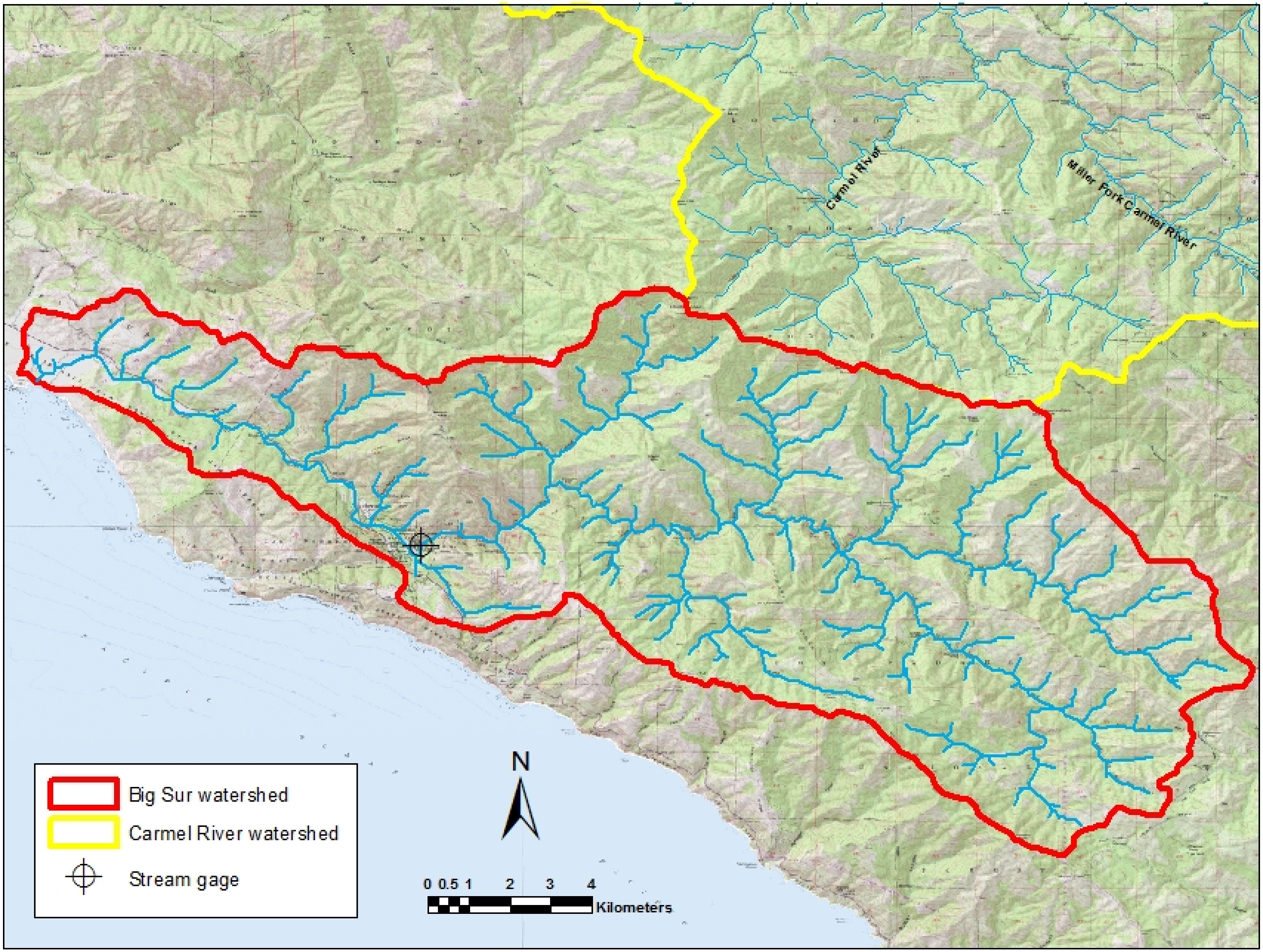
Appendix B-6. Map of Hitchcock Canyon watershed



Appendix B-7. Map of Pine Creek watershed



Appendix B-8. Map of the Carmel River watershed above Los Padres Dam (referred to as “Los Padres” in this study)



Appendix B-9. Map of the Big Sur River watershed

APPENDIX C

SLP GROUNDWATER WELL PRODUCTION BY SUBWATERSEHD

Annual production well pumping (acre-feet per year) by subwatershed. Data were compiled from annual water use reports (SLP 2001 – 2007).

Water Year	Subwatershed	Groundwater Pumped (af)
2001[1]	Upper Garzas (Moore's Lake inflow)[2]	26.1
	Upper Garzas (remainder)[3]	38.1
	Lower Garzas (below Moore's lake)[4]	3.6
	Potrero	10.6
	San Jose	19.0
	San Clemente	60.3
	Robinson	13.3
	Hitchcock	12.9
	Total	***183.9***
2002	Upper Garzas (Moore's Lake inflow)	45.3
	Upper Garzas (remainder)	39.6
	Lower Garzas (below Moore's lake)	3.6
	Potrero	3.1
	San Jose	24.2
	San Clemente	48.2
	Robinson	14.6
	Hitchcock	14.9
	Total	***193.5***
2003	Upper Garzas (Moore's Lake inflow)	34.1
	Upper Garzas (remainder)	36.2
	Lower Garzas (below Moore's lake)	7.1
	Potrero	0.9
	San Jose	30.7
	San Clemente	50.4
	Robinson	14.8
	Hitchcock	15.4
	Total	***189.5***
2004	Upper Garzas (Moore's Lake inflow)	41.5
	Upper Garzas (remainder)	58.0
	Lower Garzas (below Moore's lake)	8.2
	Potrero	4.0
	San Jose	36.7
	San Clemente	45.6
	Robinson	15.6

	Hitchcock	16.9
	Total	***226.5***
2005	Upper Garzas (Moore's Lake inflow)	19.1
	Upper Garzas (remainder)	22.9
	Lower Garzas (below Moore's lake)	2.4
	Potrero	0.9
	San Jose	9.9
	San Clemente	53.6
	Robinson	8.1
	Hitchcock	10.0
	Total	***126.9***
2006	Upper Garzas (Moore's Lake inflow)	29.7
	Upper Garzas (remainder)	28.7
	Lower Garzas (below Moore's lake)	1.2
	Potrero	6.2
	San Jose	14.4
	San Clemente	44.2
	Robinson	9.9
	Hitchcock	10.0
	Total	***144.3***
2007	Upper Garzas (Moore's Lake inflow)	50.0
	Upper Garzas (remainder)	37.3
	Lower Garzas (below Moore's lake)	7.7
	Potrero	6.8
	San Jose	15.1
	San Clemente	57.7
	Robinson	11.3
	Hitchcock	9.4
	Total	***195.3***

[1] - *WY 2001 partial record, begins January 1, 2001*

[2] - "*Upper Garzas (Moore's Lake inflow)*" refers to the portion of the Las Garzas watershed that enters Moore's Lake from Las Garzas Creek.

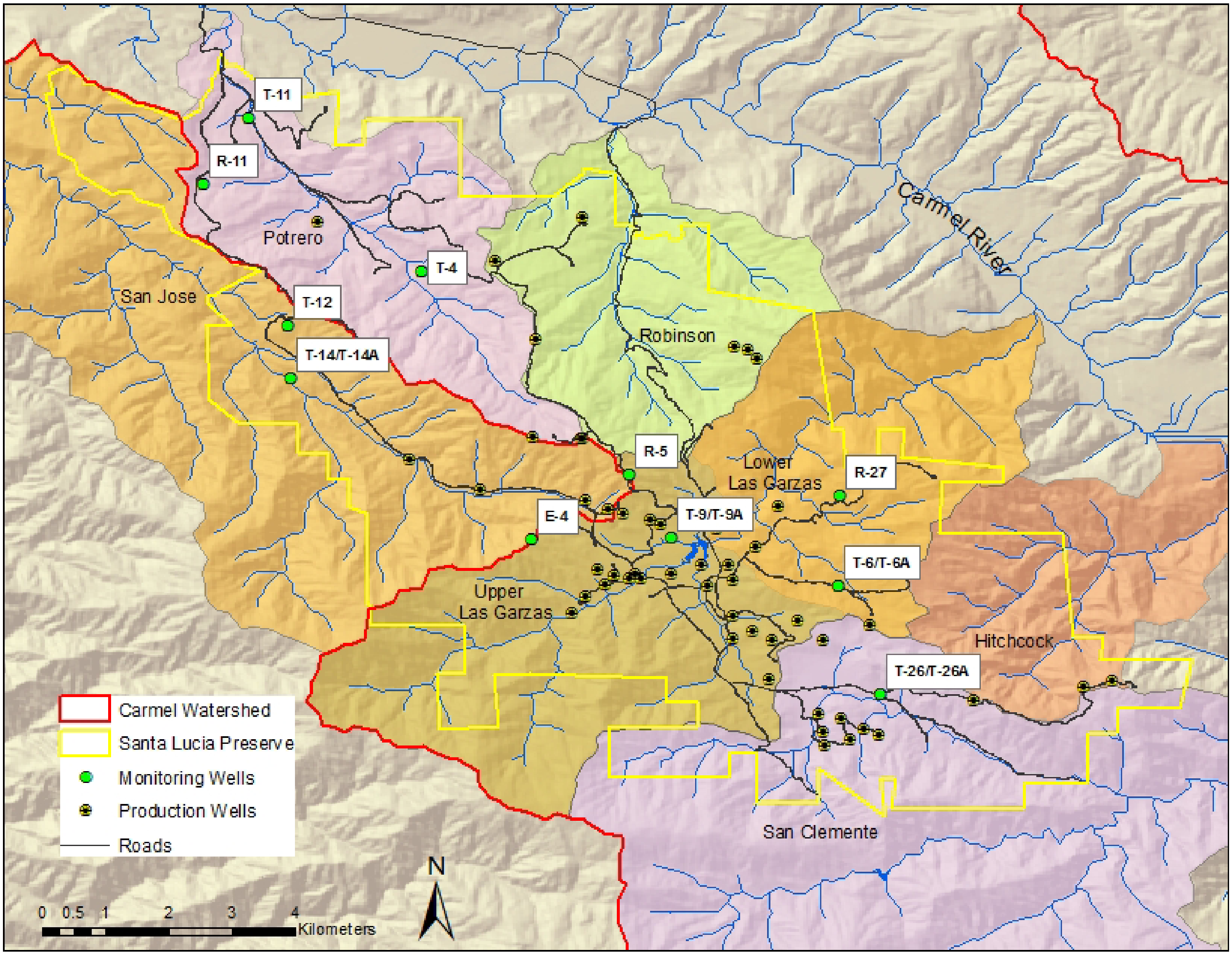
[3] - "*Upper Garzas (remainder)*" refers to the remainder of the Upper Garzas subwatershed that drains into Moore's Lake via other tributaries.

[4] - "*Lower Garzas (below Moore's lake)*" refers to the Las Garzas subwatershed below the Moore's Lake dam.

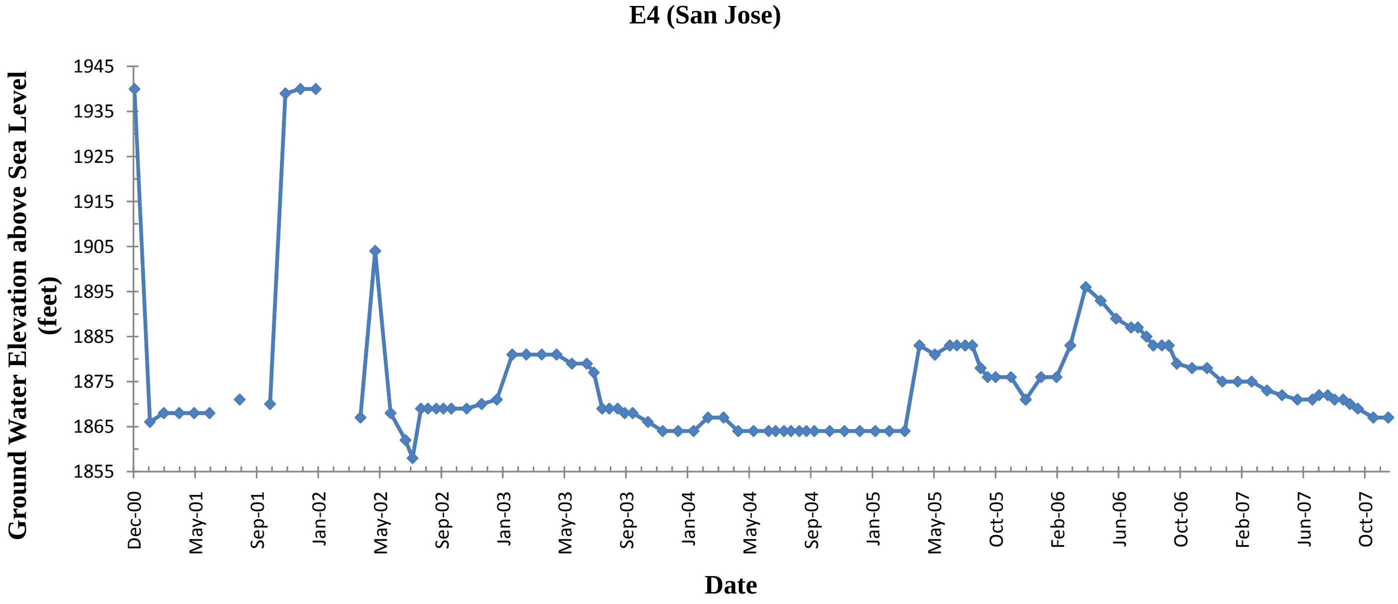
APPENDIX D

GROUNDWATER ELEVATIONS AT SLP MONITORING WELLS

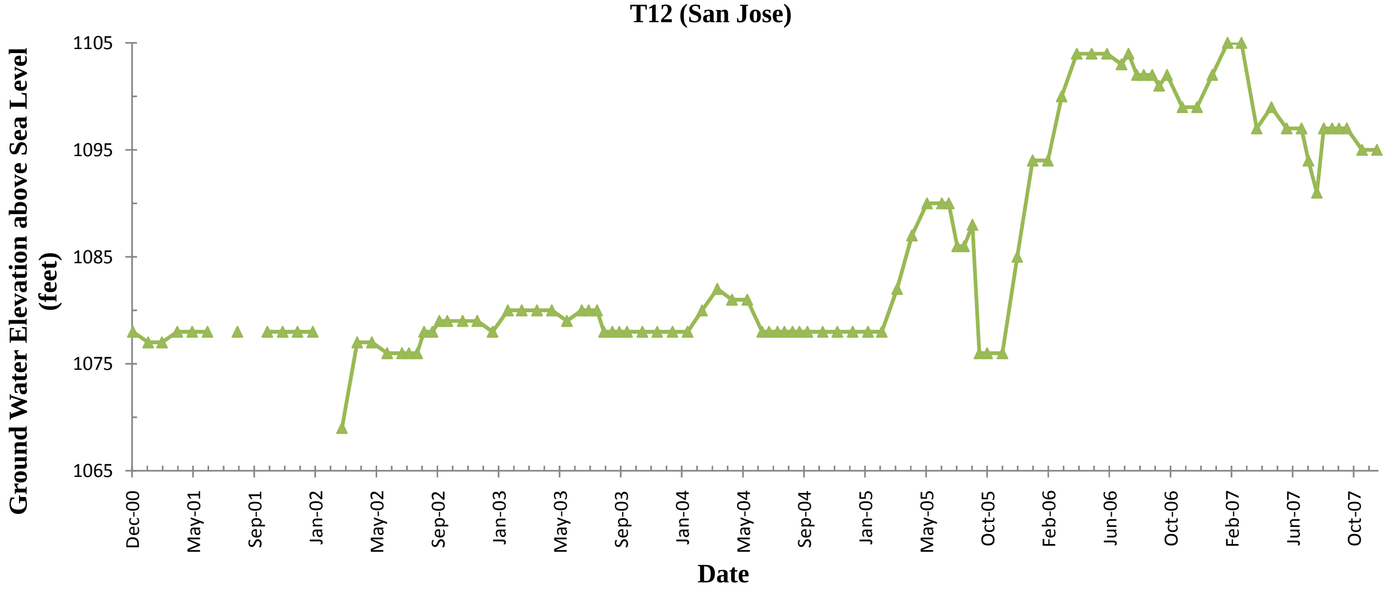
Groundwater elevation data was compiled from annual reports (SLP 2001 – 2007).



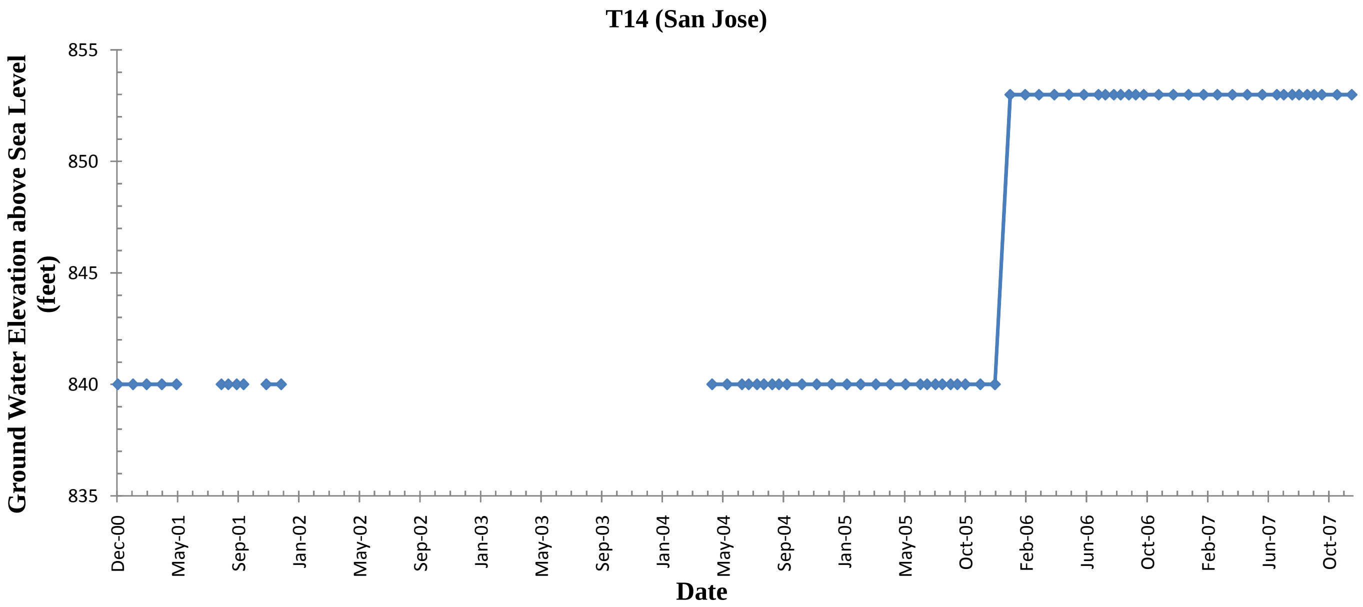
Appendix D – 1. Location map of groundwater production and monitoring wells



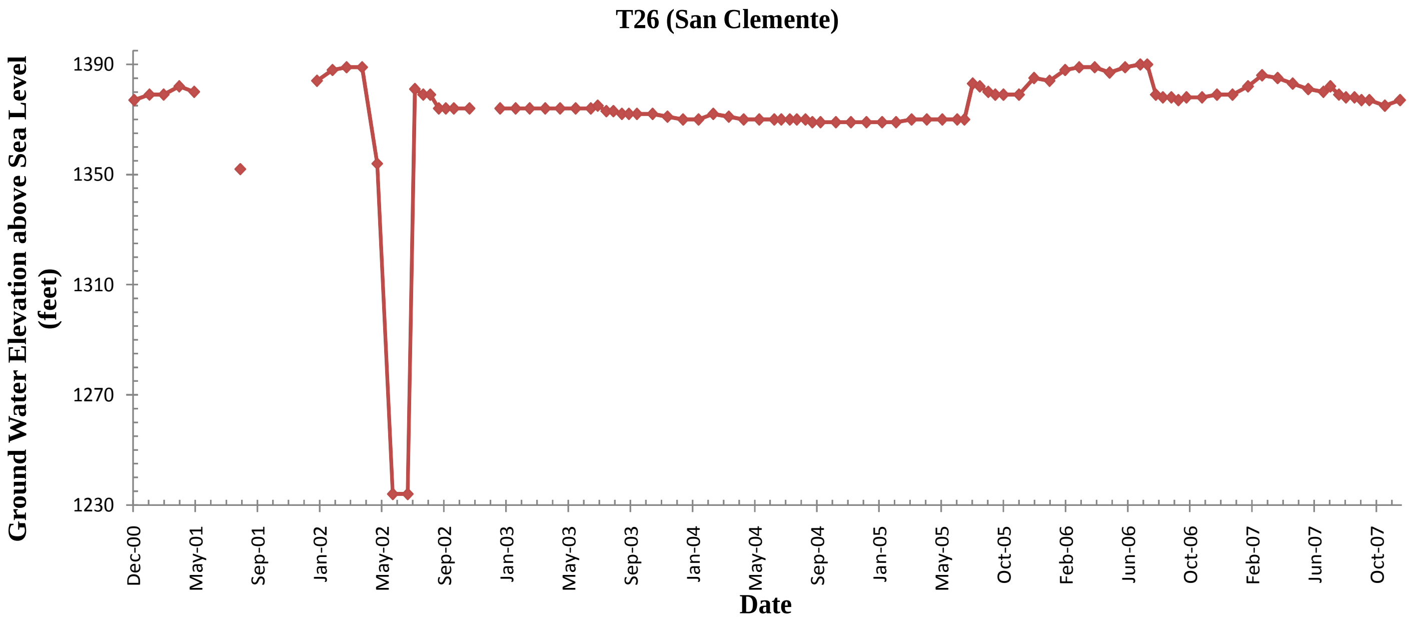
Appendix D – 2. Plot of groundwater elevation at E-4 monitoring well located in the San Jose watershed. Wellhead elevation was changed from 1960 feet to 1965 feet in 2006.



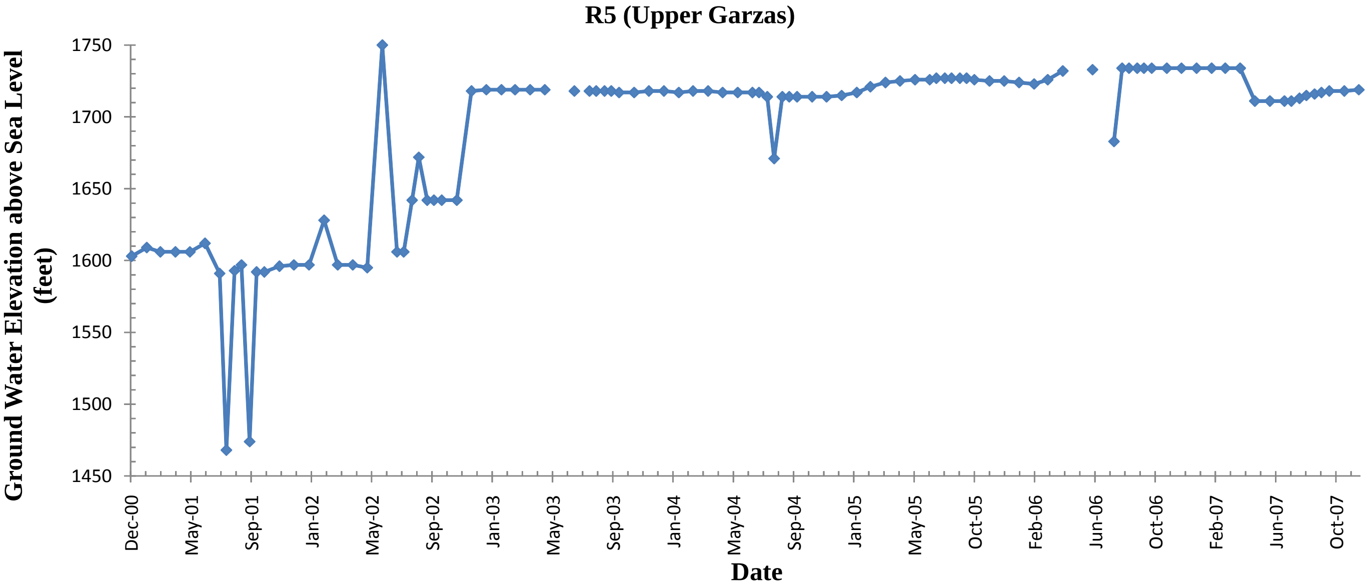
Appendix D – 3. Plot of groundwater elevation at T-12 monitoring well located in the San Jose watershed. Wellhead elevation was changed from 1172 feet to 1181feet in 2006.



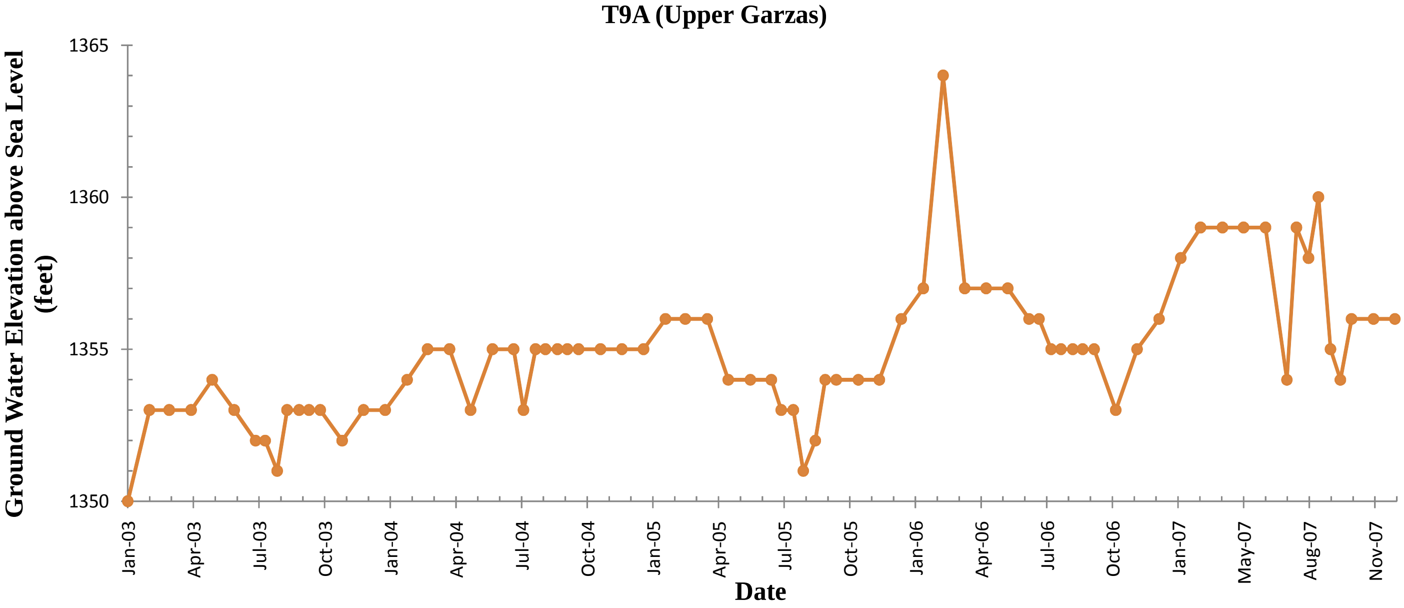
Appendix D – 4. Plot of groundwater elevation at T-14 monitoring well located in the San Jose watershed. Wellhead elevation was changed from 840 feet to 853 feet in 2006. The 2004 report states this well is always artesian, is not pumped and all measurements continue to be zero.



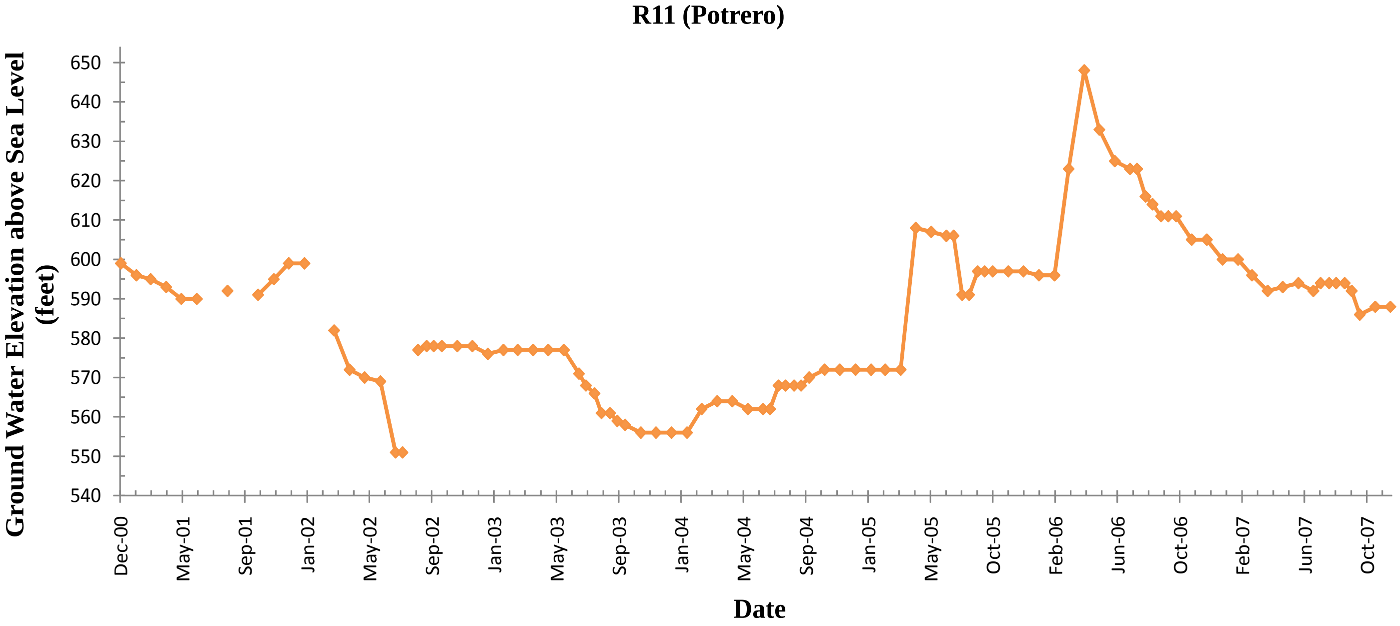
Appendix D – 5. Plot of groundwater elevation at T-26 monitoring well located in the San Clemente watershed.



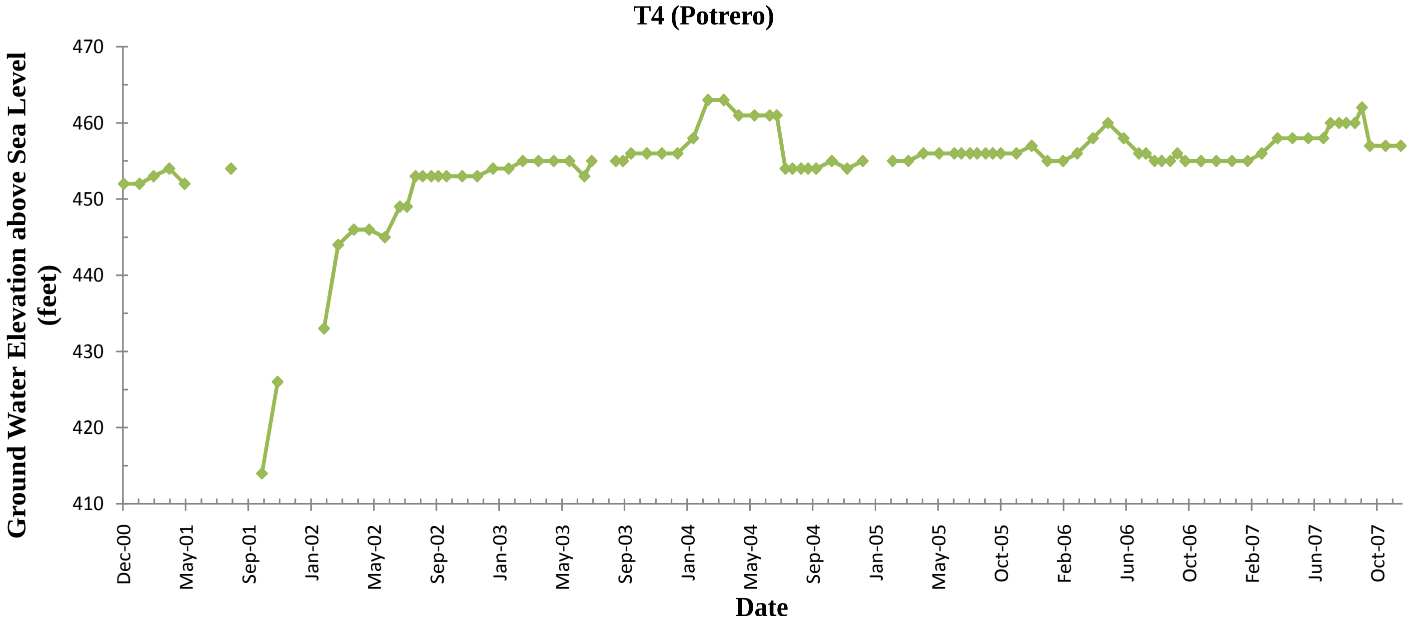
Appendix D – 6. Plot of groundwater elevation at R-5 monitoring well located in the Upper Garzas watershed. Wellhead elevation was changed from 1992 feet to 1990 feet in 2006. No pumping reported in 2003 and 2006, and very little pumping in 2004. Highest pumping occurred in 2007 starting in May.



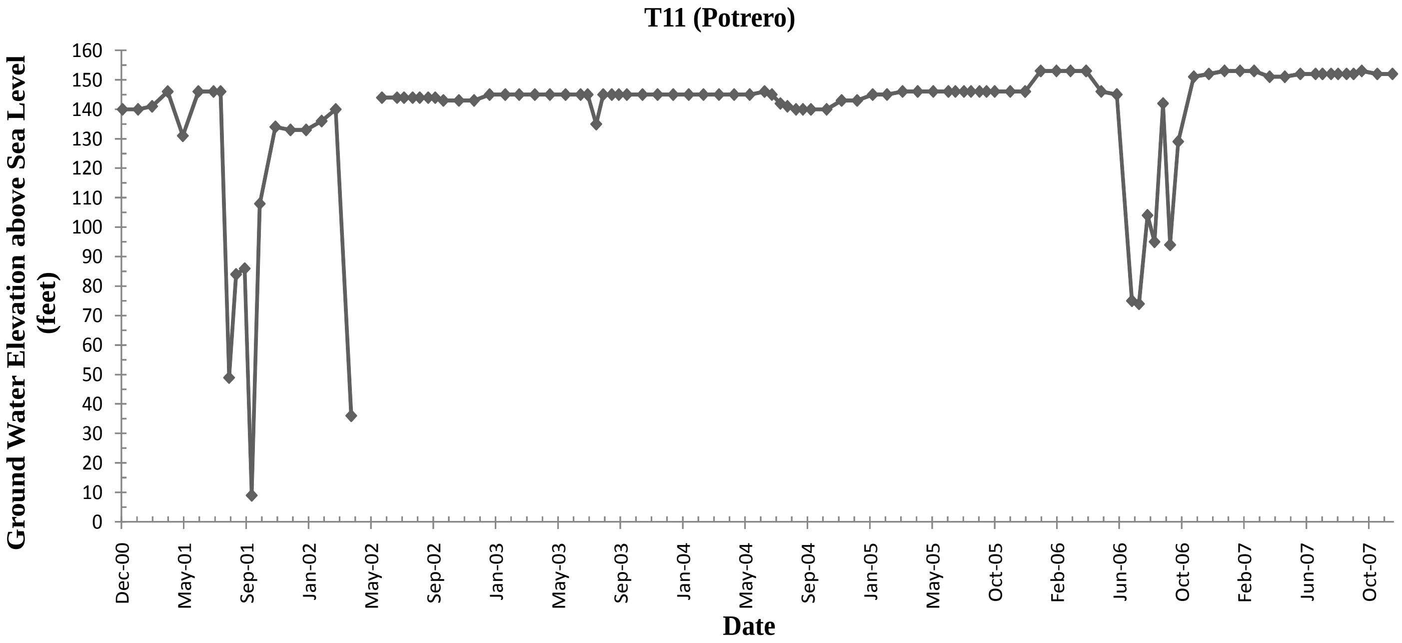
Appendix D – 7. Plot of groundwater elevation at T-9A monitoring well located in the Upper Garzas watershed. Wellhead elevation was changed from 1362 feet to 1364 feet in 2005.



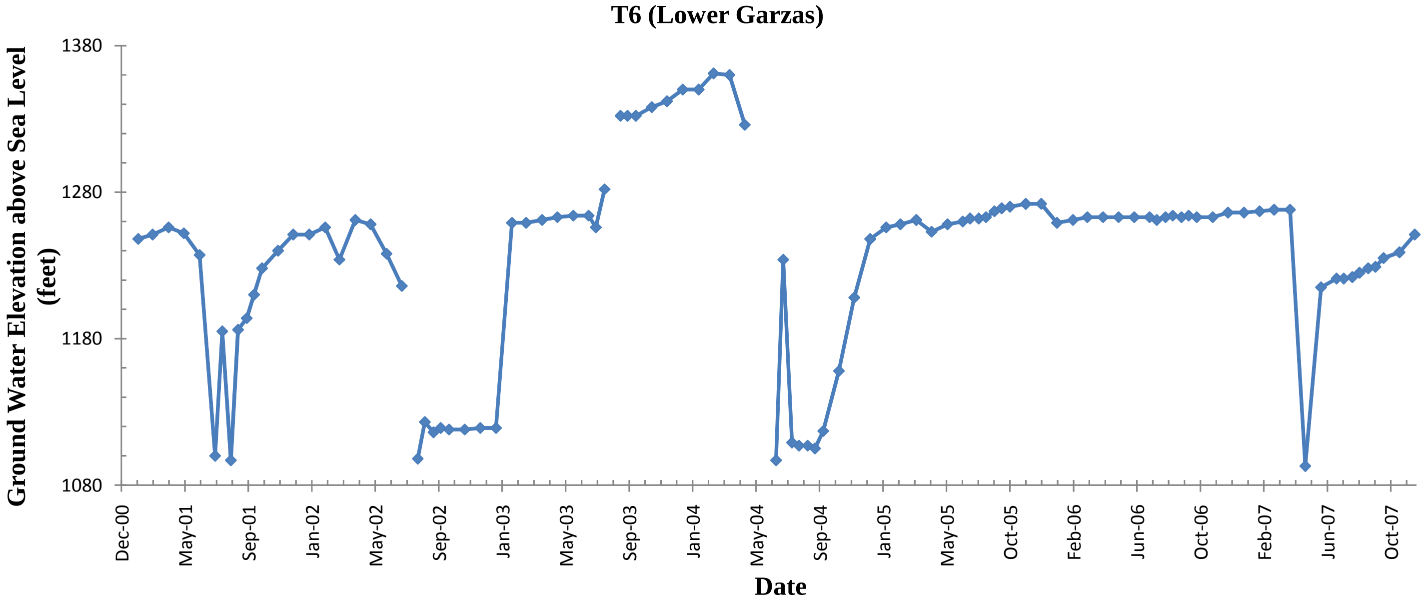
Appendix D – 8. Plot of groundwater elevation at R-11 monitoring well located in the Potrero watershed. Wellhead elevation was changed from 742 feet to 744 feet in 2006.



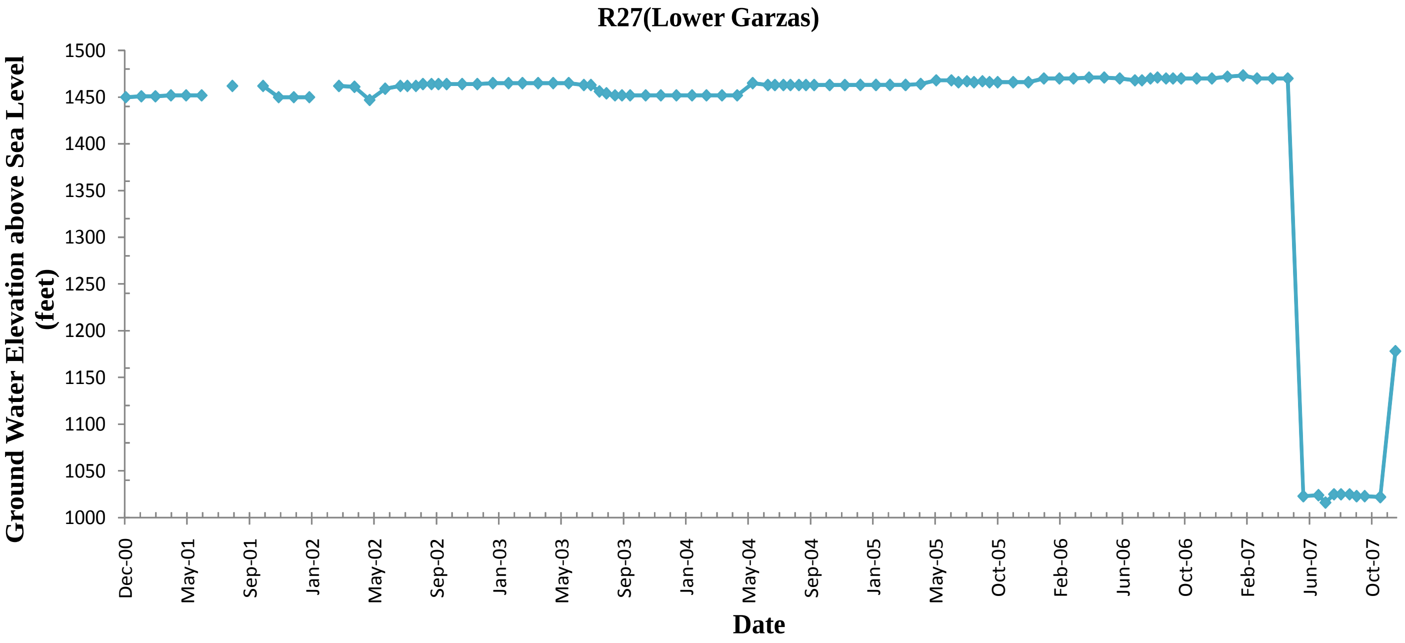
Appendix D – 9. Plot of groundwater elevation at T-4 monitoring well located in the Potrero watershed. Wellhead elevation is 552 feet. Only pumping reported occurred in October 2001.



Appendix D – 10. Plot of groundwater elevation at T-11 monitoring well located in the Potrero watershed. Wellhead elevation was changed from 146 feet to 153 feet in 2006. No pumping was reported during 2005.



Appendix D – 11. Plot of groundwater elevation at T-6 monitoring well located in the Lower Garzas watershed. Wellhead elevation was changed from 1592 feet to 1579 feet in 2007. No pumping was reported during 2006.



Appendix D – 12. Plot of groundwater elevation at R-27 monitoring well located in the Lower Garzas watershed. Wellhead elevation was changed from 1512 feet to 1516 feet in 2006. First pumping of this well occurred in June 2007.

APPENDIX E

R CODE USED IN STATISTICAL ANALYSES

Method 1

```
#standardization function- puts all coefficients on common scale to facilitate direct comparison of coefficient estimates
 std<-function(x){(x-mean(x))/sd(x)}

# all covariates were standardized
sDry.Flow<-std(Dry.Flow)        #dry season baseflow
sPrecip.t<-std(Precip.t)        # annual precipitation
sPrecip.t1<-std(Precip.t1)      #lagged 1-year annual precipitation
sPrecip.t2<-std(Precip.t2)      #lagged 2-year annual precipitation
sTime<-std(Time)                #water year- time trend


#candidate a priori models- lm0 is Null model; lms1 – 3 are No-Trend models; lms4 – 6 are Trend models; for records beginning in WY 2001 or 2002, only models lm0, lm1, lm2, and lm4 were used.
lm0 <-lm(sDry.Flow~1)
lm1 <-lm(sDry.Flow~sPrecip.t)
lm2 <-lm(sDry.Flow~sPrecip.t+sPrecip.t1)
lm3 <-lm(sDry.Flow~sPrecip.t+sPrecip.t1+sPrecip.t2)
lm4 <-lm(sDry.Flow~sPrecip.t+sWater_Year)
lm5 <-lm(sDry.Flow~sPrecip.t+sPrecip.t1+sWater_Year)
lm6 <-lm(sDry.Flow~sPrecip.t+sPrecip.t1+sPrecip.t2+sWater_Year)

# returns summary of fitted models- includes coefficient estimates and standard errors
summary(lm0)
summary(lm1)
summary(lm2)
summary(lm3)
summary(lm4)
summary(lm5)
summary(lm6)

# AIC function returns AIC score for each fitted model
AIC(lm0, lm1,lm2,lm3,lm4,lm5,lm6)

# small sample size version of AIC used in research; K is number of model parameters
AICc <- aic$AIC + 2 * K * (K+1) / ( n - K - 1 )

# Delta AIC
deltaAIC<- AICc - min( AICc )

#Akaike weight
```

```
AICwi <- exp(-0.5*deltaAIC) / sum( exp(-0.5*deltaAIC))

#Evidence Ratio of best model to second best and evaluated according to the criteria of Jeffreys 1961 (as cited in Stauffer 2008)
ER<-AICw1/AICw2

#Coefficient estimates and standard errors obtained with model averaging; coefficient estimates returned for each model with the summary function were copied and pasted into a spreadsheet; Model-averaged coefficient estimates and standard errors for each model were then calculated with the following equations:
```

Model-averaged coefficient estimate (for *N* candidate models):

$$\bar{\theta} = \sum_{i=1}^{N} w_i \ \theta_i$$

Model-averaged coefficient standard error:

$$SE_i = \sum_{i=1}^{N} w_i \sqrt{\theta_i^2 + (\theta_i - \bar{\theta}_i)^2}$$

Method 2

```
#covariates standardized with std function, same as Method 1 previously described

#candidate a priori models; ssDry.Flow is Study Stream dry season baseflow, rsDry.Flow is Reference Stream baseflow; lm0b is Null, lm1b is No-Trend, lm2b is Trend model

lm0b<-lm(ssDry.Flow~1)
lm1b<- lm(ssDry.Flow~rsDry.Flow)
lm2b<- lm(ssDry.Flow~rsDry.Flow+sWater_Year)

# summary, AIC, AICc, deltaic, AICwi, ER, coefficient estimates and standard errors were obtained for these models, same as Method 1 above
```

Sensitivity Analysis

The sensitivity analysis used the same code and procedures as for Methods 1 and 2, as described above. The Method 1 and 2 procedure was repeated for each increment of baseflow reduction (from 0% to 80%, by 10% increments).

APPENDIX F

AIC tables for all streams using Method 1

Method 1 AIC tables are presented by length of record, with streams having the same record length presented together. Best models for each table are highlighted in bold italics. lm0 is the *Null* model, lm1 – 3 are *No-Trend* models, and lm4 – 6 are *Trend* models.

WY 1992 - 2007

Pine WY 92 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	27.68	0.00
lm1	3	-7.91	21.82	23.82	2.20	0.20
lm2	***4***	***-4.99***	***17.98***	***21.61***	***0.00***	***0.61***
lm3	5	-4.85	19.69	25.69	4.08	0.08
lm4	4	-7.86	23.71	27.35	5.74	0.03
lm5	5	-4.98	19.97	25.97	4.35	0.07
lm6	6	-4.85	21.69	31.02	9.41	0.01

Los Padres WY 92 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	28.99	0.00
lm1	3	-6.39	18.79	20.79	0.48	0.31
lm2	4	-5.68	19.35	22.99	2.68	0.10
lm3	5	-3.83	17.65	23.65	3.35	0.08
lm4	***4***	***-4.33***	***16.67***	***20.30***	***0.00***	***0.40***
lm5	5	-3.70	17.40	23.40	3.09	0.09
lm6	6	-2.43	16.85	26.19	5.88	0.02

Big Sur WY 92 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	28.49	0.00
lm1	3	-7.98	21.96	23.96	3.15	0.09
lm2	4	-5.10	18.19	21.83	1.02	0.25
lm3	5	-4.25	18.50	24.50	3.69	0.07
lm4	4	-5.65	19.29	22.93	2.12	0.14
lm5	***5***	***-2.40***	***14.81***	***20.81***	***0.00***	***0.41***
lm6	6	-2.05	16.09	25.43	4.62	0.04

Lower Garzas WY 92 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	19.91	0.00
lm1	3	-11.51	29.02	31.02	1.63	0.24
lm2	***4***	***-8.87***	***25.75***	***29.39***	***0.00***	***0.54***
lm3	5	-8.23	26.45	32.45	3.07	0.12
lm4	4	-11.51	31.02	34.66	5.27	0.04
lm5	5	-8.85	27.70	33.70	4.31	0.06
lm6	6	-8.05	28.11	37.44	8.06	0.01

San Clemente WY 92 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	30.22	0.00
lm1	3	-7.94	21.87	23.87	4.80	0.06
lm2	***4***	***-3.72***	***15.44***	***19.08***	***0.00***	***0.62***
lm3	5	-2.82	15.64	21.64	2.57	0.17
lm4	4	-7.38	22.76	26.39	7.32	0.02
lm5	5	-3.21	16.41	22.41	3.33	0.12
lm6	6	-2.57	17.14	26.47	7.40	0.02

WY 1999 – 2007

Pine Ck WY 99 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	5.08	0.04
lm1	3	-7.54	21.09	25.89	0.49	0.41
lm2	***4***	***-3.70***	***15.40***	***25.40***	***0.00***	***0.53***
lm3	5	-3.09	16.17	36.17	10.77	0.00
lm4	4	-7.09	22.19	32.19	6.79	0.02
lm5	5	-3.19	16.38	36.38	10.98	0.00
lm6	6	-2.73	17.46	59.46	34.07	0.00

Los Padres WY 99 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	13.46	0.00
lm1	***3***	***-3.11***	***12.22***	***17.02***	***0.00***	***0.94***
lm2	4	-3.03	14.06	24.06	7.04	0.03
lm3	5	-1.40	12.81	32.81	15.79	0.00
lm4	4	-2.83	13.65	23.65	6.63	0.03
lm5	5	-2.78	15.55	35.55	18.53	0.00
lm6	6	-1.31	14.62	56.62	39.60	0.00

Big Sur WY 99 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	9.11	0.01
lm1	***3***	***-5.29***	***16.57***	***21.37***	***0.00***	***0.84***
lm2	4	-3.61	15.21	25.21	3.84	0.12
lm3	5	-2.24	14.48	34.48	13.11	0.00
lm4	4	-5.27	18.54	28.54	7.16	0.02
lm5	5	-3.61	17.21	37.21	15.84	0.00
lm6	6	-2.15	16.31	58.31	36.93	0.00

San Jose WY 99 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	1.59	0.26
lm1	3	-11.40	28.80	33.60	4.71	0.05
lm2	***4***	***-5.45***	***18.89***	***28.89***	***0.00***	***0.57***
lm3	5	-1.58	13.16	33.16	4.27	0.07
lm4	4	-10.21	28.41	38.41	9.52	0.00
lm5	5	-2.00	14.00	34.00	5.11	0.04
lm6	6	5.67	0.66	42.66	13.77	0.00

WY 2001 – 2007

Pine Ck WY 01 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	6.58	0.04
lm1	***3***	***-2.60***	***11.20***	***19.20***	***0.00***	***0.96***
lm2	4	-2.22	12.44	32.44	13.24	0.00
lm3	5	-1.93	13.86	73.86	54.66	0.00
lm4	4	-2.22	12.43	32.43	13.23	0.00
lm5	5	-2.14	14.28	74.28	55.07	0.00

Los Padres WY 01 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	9.37	0.01
lm1	***3***	***-1.21***	***8.41***	***16.41***	***0.00***	***0.99***
lm2	4	-0.91	9.82	29.82	13.40	0.00
lm3	5	-0.87	11.74	71.74	55.33	0.00
lm4	4	-1.13	10.27	30.27	13.85	0.00
lm5	5	-0.89	11.78	71.78	55.37	0.00

Big Sur WY 01 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	5.64	0.06
lm1	***3***	***-3.07***	***12.15***	***20.15***	***0.00***	***0.93***
lm2	4	-0.87	9.74	29.74	9.60	0.01
lm3	5	-0.83	11.67	71.67	51.52	0.00
lm4	4	-2.19	12.37	32.37	12.23	0.00
lm5	5	-0.87	11.74	71.74	51.59	0.00

Upper Garzas WY 01 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	5.17	0.07
lm1	***3***	***-3.31***	***12.62***	***20.62***	***0.00***	***0.91***
lm2	4	-0.33	8.67	28.67	8.05	0.02
lm3	5	1.82	6.36	66.36	45.74	0.00
lm4	4	-1.42	10.84	30.84	10.22	0.01
lm5	5	-0.05	10.09	70.09	49.47	0.00

WY 2002 - 2007

Pine Ck WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	2.59	0.21
lm1	***3***	***-1.67***	***9.34***	***21.34***	***0.00***	***0.79***
lm2	4	-1.44	10.89	50.89	29.54	0.00
lm4	4	-1.64	11.29	51.29	29.95	0.00

Los Padres WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	4.37	0.10
lm1	***3***	***-0.78***	***7.57***	***19.57***	***0.00***	***0.90***
lm2	4	-0.59	9.18	49.18	29.61	0.00
lm4	4	-0.78	9.57	49.57	30.00	0.00

Big Sur WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	2.03	0.27
lm1	***3***	***-1.95***	***9.91***	***21.91***	***0.00***	***0.73***
lm2	4	-0.07	8.13	48.13	26.23	0.00
lm4	4	-1.73	11.45	51.45	29.55	0.00

Lower Garzas Canyon WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	***2***	***-7.97***	***19.93***	***23.93***	***0.00***	***0.66***
lm1	3	-3.62	13.23	25.23	1.30	0.34
lm2	4	-0.29	8.58	48.58	24.64	0.00
lm4	4	-2.36	12.73	52.73	28.79	0.00

San Clemente-SLP WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	0.86	0.39
lm1	***3***	***-2.54***	***11.07***	***23.07***	***0.00***	***0.61***
lm2	4	0.00	7.99	47.99	24.92	0.00
lm4	4	-0.93	9.86	49.86	26.79	0.00

Potrero WY 02 - 07

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	0.59	0.43
lm1	***3***	***-2.67***	***11.35***	***23.35***	***0.00***	***0.57***
lm2	4	-1.27	10.54	50.54	27.19	0.00
lm4	4	-0.50	9.00	49.00	25.65	0.00

APPENDIX G

AIC tables for all streams using Method 2

Method 2 AIC tables are presented by study stream and include a separate table for each of the reference streams (Pine, Los Padres, Big Sur). Best models for each table are highlighted in bold italics. lm0 is the *Null* model, lm1 is the *Trend* model, and lm2 is the *No-Trend* model.

Lower Garzas

Lower Garzas - *Pine* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	36.27	0.00
lm1	4	-2.46	12.91	16.55	3.53	0.15
lm2	***3***	***-2.51***	***11.02***	***13.02***	***0.00***	***0.85***

Lower Garzas – *Los Padres* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	20.66	0.00
lm1	4	-9.39	26.79	30.42	1.79	0.29
lm2	***3***	***-10.32***	***26.63***	***28.63***	***0.00***	***0.71***

Lower Garzas – *Big Sur* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	19.84	0.00
lm1	4	-9.48	26.96	30.60	1.15	0.36
lm2	***3***	***-10.73***	***27.45***	***29.45***	***0.00***	***0.64***

San Clemente

San Clemente - *Pine* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	64.58	0.00
lm1	***4***	***13.46***	***-18.92***	***-15.28***	***0.00***	***0.75***
lm2	3	10.54	-15.08	-13.08	2.20	0.25

San Clemente – *Los Padres* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	41.60	0.00
lm1	4	0.75	6.49	10.13	2.43	0.23
lm2	***3***	***0.15***	***5.70***	***7.70***	***0.00***	***0.77***

San Clemente – *Big Sur* (WY 92 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-22.19	48.37	49.30	45.51	0.00
lm1	4	3.90	0.20	3.84	0.06	0.49
lm2	***3***	***2.11***	***1.78***	***3.78***	***0.00***	***0.51***

San Jose

San Jose - *Pine* (WY 99 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	4.02	0.11
lm1	4	-6.32	20.64	30.64	4.18	0.10
lm2	***3***	***-7.83***	***21.66***	***26.46***	***0.00***	***0.80***

San Jose – *Los Padres* (WY 99 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	***2***	***-12.24***	***28.48***	***30.48***	***0.00***	***0.70***
lm1	4	-9.63	27.25	37.25	6.77	0.02
lm2	3	-10.76	27.52	32.32	1.84	0.28

San Jose – *Big Sur* (WY 99 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-12.24	28.48	30.48	0.01	0.46
lm1	4	-8.00	24.00	34.00	3.53	0.08
lm2	***3***	***-9.83***	***25.67***	***30.47***	***0.00***	***0.46***

Upper Garzas

Upper Garzas - *Pine* (WY 01 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	8.15	0.02
lm1	4	-0.95	9.91	29.91	12.27	0.00
lm2	***3***	***-1.82***	***9.64***	***17.64***	***0.00***	***0.98***

Upper Garzas – *Los Padres* (WY 01 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	7.74	0.02
lm1	4	-0.02	8.04	28.04	10.00	0.01
lm2	***3***	***-2.02***	***10.04***	***18.04***	***0.00***	***0.97***

Upper Garzas – *Big Sur* (WY 01 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-9.39	22.79	25.79	11.75	0.00
lm1	4	0.41	7.19	27.19	13.15	0.00
lm2	***3***	***-0.02***	***6.04***	***14.04***	***0.00***	***1.00***

Lower Garzas Canyon

Lower Garzas Canyon - *Pine* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	2.36	0.23
lm1	4	0.29	7.42	47.42	25.85	0.00
lm2	***3***	***-1.79***	***9.57***	***21.57***	***0.00***	***0.77***

Lower Garzas Canyon – *Los Padres* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	1.83	0.29
lm1	4	0.63	6.74	46.74	24.64	0.00
lm2	***3***	***-2.05***	***10.10***	***22.10***	***0.00***	***0.71***

Lower Garzas Canyon – *Big Sur* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	7.44	0.02
lm1	4	3.84	0.32	40.32	23.83	0.00
lm2	***3***	***0.75***	***4.49***	***16.49***	***0.00***	***0.98***

San Clemente-SLP

San Clemente-SLP - *Pine* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	3.46	0.15
lm1	4	0.83	6.34	46.34	25.87	0.00
lm2	***3***	***-1.23***	***8.47***	***20.47***	***0.00***	***0.85***

San Clemente-SLP – *Los Padres* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	3.06	0.18
lm1	4	1.45	5.10	45.10	24.23	0.00
lm2	***3***	***-1.44***	***8.87***	***20.87***	***0.00***	***0.82***

San Clemente-SLP – *Big Sur* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	6.89	0.03
lm1	4	2.32	3.36	43.36	26.32	0.00
lm2	***3***	***0.48***	***5.04***	***17.04***	***0.00***	***0.97***

Potrero

Potrero - *Pine* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	2.77	0.20
lm1	4	1.15	5.70	45.70	24.54	0.00
lm2	***3***	***-1.58***	***9.16***	***21.16***	***0.00***	***0.80***

Potrero – *Los Padres* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	2.07	0.26
lm1	4	1.48	5.03	45.03	23.17	0.00
lm2	***3***	***-1.93***	***9.86***	***21.86***	***0.00***	***0.74***

Potrero – *Big Sur* (WY 02 - 07)

Model	**Parameters (k)**	**Log-likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
lm0	2	-7.97	19.93	23.93	3.48	0.15
lm1	4	0.30	7.41	47.41	26.95	0.00
lm2	***3***	***-1.23***	***8.45***	***20.45***	***0.00***	***0.85***