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Technical Memorandum 2B- Availability of Water Sources for Phase 1 Conjunctive Use and Enhanced Aquifer Recharge Project:

November 2010

Prepared for

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Technical Memorandum 2B

Streamflow and Stormwater Assessment

Availability of Water Sources for a Conjunctive-Use Framework Approach for Water Resources in the San Lorenzo River Watershed, Santa Cruz County, California

Prepared for:

Santa Cruz County Conjunctive Use and Enhanced Aquifer Recharge Project

Kennedy/Jenks Consultants and Santa Cruz County Health Services Agency

By:

Balance Hydrologics, Inc.

November 2010

Availability of Water Sources for a Conjunctive-use Framework Approach to Water Resource in the San Lorenzo Creek Watershed, Santa Cruz County, California

Report prepared for:

Santa Cruz County Health Services Agency

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Availability of water sources for a conjunctive-use framework approach to water resource in the San Lorenzo Creek Watershed, Santa Cruz County, California

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF FIGURES CONTINUED

APPENDICES

EXECUTIVE SUMMARY

Balance Hydrologics (Balance) is pleased to provide the Santa Cruz County Health Services Agency (County) with this report in support of the Conjunctive Use and Enhanced Aquifer Recharge Project (Conjunctive Use Project). The Conjunctive Use Project is one of sixteen projects funded by a Proposition 50 Water Bond grant from the State Water Resources Control Board to the Regional Water Management Foundation, a subsidiary of the Community Foundation of Santa Cruz County. The Conjunctive Use Project is Project #3 of the grant and is being administered by the County.

The objective of the Conjunctive Use Project is to conduct a planning-level assessment of the most appropriate approaches for coordinating water projects and increasing groundwater storage to provide reliable drinking water to the lower San Lorenzo River watershed, mitigate declines in groundwater levels, and increase stream baseflow. The Project will investigate the opportunities to use water exchanges, winter streamflow diversion, and/or reclaimed wastewater to replenish groundwater storage in the Santa Margarita Groundwater Basin.

Technical Memorandum 2B (TM2B) summarizes the work performed as part of Task 2 Surface Water Availability Assessment of the Conjunctive Use Project Scope of Work. It provides an evaluation of the following items:

- **Surface Water Availability -** Define the potential quantities of surface water that may be available during various times of the year and over various climatic conditions.
- **Surface Water Quality** - Evaluate the water quality factors that may impact use of surface water for groundwater recharge
- **Storm-water Assessment -** Evaluate the quantity and quality of storm-water that occurs in the project area.

We investigated potential sources of water for a conjunctive use water-supply framework for the San Lorenzo Valley. Diversions from Bean Creek, Carbonera Creek, and Zayante Creek were analyzed for flow impairment and overall water quality. Feasibility of stormwater capture and effects of hydromodification on Carbonera Creek were analyzed for a potential water source for ground-water recharge. Current operations of the City of Santa Cruz's Felton Diversion were also adapted from prior summaries (RAMLIT, 2002).

The following conclusions were made:

- An average annual diversion of 500 acre-feet on Bean or Zayante is mostly within the acceptable impairment guidelines of the critical flow impairment index (CFII) calculated for the periods of streamflow record available. Further feasibility analysis will require biologic assessment and flow impairment calculations for all points of diversion below the proposed diversions.

- An average annual diversion of 500 acre-feet on Carbonera Creek causes significant flow impairment per the CFII and may require additional efforts to make it feasible. Downstream of the Carbonera Creek gage, the drainage more than doubles at a fish barrier (waterfall). Baseflows there may be different than evaluated in this report and could possibly be evaluated in a later phase of the project.
- Preliminary estimates suggest that diverted streamflow would require some level of treatment for suspended sediments prior to direct use or percolation, such settling basins or pond partitions. Although sediment yields vary from year to year and within the channel depending on the means of diversion, an estimated average of 650 tons of suspended sediment would be diverted from a proposed Zayante Creek diversion.
- Increased volumes of stormwater off impermeable surfaces such as roadways and rooftops have caused hydromodification to Carbonera Creek. In general, the average annual streamflow has increased about 1,000 acre-feet per year and baseflow has decreased to dry-season isolated pools when previously had maintained 1 cfs during an average year.
- Loss of baseflow in Carbonera Creek is an indicator of lost recharge to the Santa Margarita Aquifer, which was previously estimated by other investigators on the order of 1,000 acre-feet per year on average.
- Aquifer-wide reductions in ground-water levels and baseflows in Carbonera Creek are generally not connected which provides an opportunity to reclaim baseflows in the creek with focused aquifer recharge near the creek.

Further data collection and analysis are necessary to proceed with the feasibility analysis for supplemental water availability. Recommendations for the next phase of feasibility analysis are:

- Water quality sampling in Bean and Zayante Creeks for suspended sediment, general mineral, general physical, and Title 22 inorganics during early season and late season high-flow events to document quality of potentially diverted water. If funding is available, the constituents sampled can be expanded to selected priority pollutants and to personal care and pharmaceutical compounds in stormwater.
- More accurate estimates of suspended sediment loads of diverted water based on sediment transport rating curves.
- Conduct flow impairment analysis for fisheries at downstream points of diversion for Bean and Zayante Creeks.

- We note that the Carbonera Creek data are anomalous in several respects, particularly for water year 2001, and suggest that the County verify the data it commissioned from USGS for that year.
- Identify potential locations for stormwater harvest in the storm drain network and proximity to potential percolation sites. Establish a monitoring network to measure flow volumes and water quality.
- Complete an estimation of increased recharge to the Santa Margarita resulting from permeable pavement retrofit and establish a monitoring network to measure water quality of stormwater potentially percolated at these locations.
- Model chemical interactions of the percolated waters and receiving aquifer.

1. INTRODUCTION

The Santa Cruz County Department of Environmental Health is currently investigating potential conjunctive use alternatives to promote long term-water supplies for Scotts Valley/Pasatiempo Groundwater Subareas by providing active or in-lieu recharge to the Santa Margarita and/or Lompico Sandstone aquifers. The Santa Margarita Aquifer has experienced long-term overdraft which has caused water levels to decline to the point where the aquifer has been essentially de-watered (ETIC, 2006). This has forced the Scotts Valley Water District to shift pumping into the Lompico Sandstone Aquifer. Long-term overdraft was the result of increases in ground-water extractions linked to population growth, and has been exacerbated by changes in land use limiting recharge to the Santa Margarita Aquifer.

A conjunctive use approach may reasonably include diversions of water from streams and rivers or stormwater capture for direct use or percolation into the Santa Margarita Aquifer. Recharge ponds could potentially be located one of several inactive or closed sand quarries, such as the Hanson Quarry, and operated to recharge the Santa Margarita and the Lompico Sandstones. Stormwater capture from the City of Scotts Valley storm drain system may potentially be recharged in percolation basins or retrofits to current rooftops and/or parking lots and implementation of recharge promoting stormwater best management practices (BMP's) may potentially induce enough recharge to allow significant recharge to begin offsetting the local overdraft.

Potential water sources for augmentation of ground-water supplies, at minimum, could offset overdraft in the Santa Margarita and Lompico Aquifers, but also possibly further replenish the aquifers. Potential sources of water include:

A. New surface-water diversions from Bean Creek, Carbonera Creek, and/or Zayante Creek;

B. A possible conjunctive use approach to operations of the City of Santa Cruz Felton Diversion on the San Lorenzo River; and,

C. A stormwater capture and recharge program implemented in the City of Scotts Valley.

Limitations on the availability of supplemental water for conjunctive uses are the availability, sediment load and water quality of streamflow and the feasibility of stormwater capture, treatment and recharge.

Study objectives for Balance Hydrologics (Balance) were to evaluate the effects of stream diversions on fish habitat from a hydrologic perspective, and to assess the contribution of stormwater to streamflow in Carbonera Creek to provide a context for evaluating the feasibility of stormwater capture and percolation. Where data were available, water quality of flows within a potential diversion availability envelope are presented. TM2B summarizes our work completed to date and covers the following topics:

A. A review of prior documents and available data;

B. A discussion of the hydrologic setting, describing the watersheds of Bean Creek, Carbonera Creek, Zayante Creek, and San Lorenzo River, and available rainfall and streamflow data.

C. A preliminary evaluation of potential diversions for volume, habitat, and water quality for Bean, Carbonera, and Zayante Creeks and San Lorenzo River.

D. Effects of stormwater on Carbonera Creek and how this may affect the feasibility of stormwater capture and recharge.

E. Conclusions and recommendations.

2. REVIEW OF PRIOR DOCUMENTS AND AVAILABLE DATA

Our document and data review identified available records of rainfall and streamflow at key locations, land-use history, geologic and soil type maps and reports, records of water-diversion operations, and water-quality and sediment-transport data. Reviewed data and reports include:

- Fifteen-minute USGS stream gaging data, field observations, rating tables, and associated technical forms for Bean, Carbonera, Zayante Creeks and the San Lorenzo River.
- Fifteen-minute Balance Hydrologics stream-gaging data, field observations, sediment rating tables, cross-sections, and sediment source data for Zayante and Bean Creeks and the San Lorenzo River.
- Hourly rainfall data from De Laveaga CIMIS station.
- Technical documents from the Balance Hydrologics library related to the San Lorenzo watershed. Many of these investigations were conducted by Balance staff and were not compiled into official reports. For these investigations, primary sources included original field notes and maps from the 1970s, 1980s and 1990s.
- City of Santa Cruz Water Department operational data and observer logs for Felton Diversion.
- County Environmental Health files, notes, and staff recollections.
- San Lorenzo River fisheries and aquatic-habitat studies conducted by Don Alley and Jerry Smith (1981, 1982, and 1983) and by Don Alley (1994, 1995, 1997, and 2009).
- Planning documents for Santa Cruz City Water Department and Soquel Creek Water District outlining potential cooperative operation of a desalination plant to manage water resources for the two entities.
- City of Scotts Valley Planning Department construction records.
- City of Scotts Valley storm drain drawings.

3. HYDROLOGIC SETTING

The San Lorenzo River rises in the Santa Cruz Mountains and drains its 138 square-mile watershed that southward to its mouth at the north end of Monterey Bay. Zayante Creek, Bean Creek and Carbonera Creek are all tributaries to the San Lorenzo River (Figure 1). Bean Creek parallels Zayante Creek to the south and east, flowing into Zayante Creek only about 3,000 feet upstream of the San Lorenzo River. The U.S. Geological Survey (USGS) gaging station on San Lorenzo River at Big Trees State Park (No. 11160500) is about 2,000 feet downstream from the mouth of Zayante Creek. The contributing area above the gage is 106 square miles. Carbonera Creek is south of Bean Creek and is a tributary to Branciforte Creek, which flows into the San Lorenzo River well downstream of the USGS Big Trees gage, in the City of Santa Cruz about 6,000 feet upstream of the river's mouth.

3.1 Geology

The San Lorenzo Watershed has been broadly divided into 3 distinct geologic terrains (DWR, 1958; Brown, 1973; Ricker, 1979; Akers and Jackson, 1980; Hecht and Enkeboll, 1980; Johnson, 1988; Swanson, 1996; Hecht and Kittleson, 1998), defined by the juxtaposition of differing rock types associated with the northwest-southeast trending Zayante fault (paralleling the San Andreas fault zone) and the north-south trending Ben Lomond Fault. The differing rock types and fault related movement of these regions is the primary cause for the rugged topography, varied slopes, and differing soil properties, erosion rates, and ground-water recharge properties. Distinctly different upland vegetation types have established, as well as varying stream low flow and habitat characteristics, and water quality conditions (Ricker, 2001, 1979).

In the uppermost portion of the watershed, north of the Zayante fault (and south of the Summit fault), interbedded sandstones, shales, and mudstones outcrop in steeply inclined and folded strata. Bedrock outcrops, shallow but complex mosaics of soils, and sparse to dense vegetation dominate this region. Slopes tend to be steep, have slow to moderate infiltration rates, hold little water, and are prone to moderate to severe erosion. Dry-season flows are generally lowest in this geologic terrain, with streams often drying down to isolated pools. Principal watersheds are the upper San Lorenzo River (above Boulder Creek), Kings, Two Bar, and Bear Creeks, plus the northern portions of the Boulder Creek and upper Zayante Creek.

South of the Zayante fault and west of the Ben Lomond fault, the tectonically uplifted eastern side of Ben Lomond Mountain forms the southwestern edge of the San Lorenzo watershed. Principal watersheds are Fall, Alba, Clear, Sweetwater, Malosky, Peavine and Jamison Creeks, and the southern portion of the Boulder Creek basin. Crystalline granitics, schists, and marbles have developed medium to relatively thick soils which support small, steep, forested watersheds. The soils have low to moderate infiltration rates, moderate water holding capacities, and low to moderate background erosion rates. The lower portions of these watersheds have developed in downslope-dipping sandstones and mudstones, locally prone to landsliding, especially where disturbed. Summer flows are generally sufficient to support perennial stream threads and diverse aquatic habitat (Hecht and Kittleson, 1998)

The third terrain is found south of the Zayante fault, and east of the Ben Lomond fault and the San Lorenzo River. It includes the Love Creek, Quail Hollow, Graham Hill Road, Mount Hermon and Scotts Valley areas, as well most of the Bean, Branciforte, Carbonera, and Newell Creek basins. Figure 2 shows the surface geology of the sub-watersheds analyzed in this study which are found in this region. By far the largest continuous units of sandy soils are found in this area, and these tend to be sandier than other sandstone-derived soils elsewhere in the watershed. Consequently, infiltration rates, water-holding capacities, and erosion rates are often high to extreme in this terrain, especially where sandy soils occur in headwater areas or near channels. These sandy soils, which were capable of absorbing nearly all rainfall under natural conditions, now form steep-walled gullies and gulches where runoff from paved or covered surfaces is concentrated. Residential, commercial, and industrial uses (including quarries) are the densest throughout this region of the San Lorenzo watershed. The Santa Margarita and Lompico aquifers are recharged through the sandy soils where geologic connections allow deep percolation. These two aquifers not only provide the municipal and industrial water supply for much of the watershed's population, but also sustain summer flows in the San Lorenzo River and lower Zayante Creek (Ricker, 1979; Ricker and others, 1994). Water quality in these aquifers is controlled by recharge, and to the extent that land-use changes results in increased runoff (and less low-salinity, low-nitrate recharge), water quality is also diminished. (Hecht and Kittleson, 1998)

3.2 Soils

Soils in the Zayante, Bean, and Carbonera watersheds are diverse, reflecting the complex bedrock geology of mudstone/shales and sandstones, fractured granitic rocks, schists, and metamorphosed limestones from which they were derived. Soils vary, sometimes markedly, from location to location, depending on the underlying parent materials, and other factors such as climate, aspect, vegetation cover, and local relief (Lindsey and Beutler, 1968).

Figure 3 illustrates the variety of soils that have developed in these watersheds. In the most general terms, it can be stated that soils underlain by permeable sandstones, as well as igneous and metamorphic rocks, are classified as deep and well drained to excessively well drained. These sandy and sandy loam soils are dispersed throughout this region of the San Lorenzo Valley, most notable in areas underlain by the Santa Margarita formation. Soils formed from mudstones and shales also tend to be deep, and less well drained. Overall depth is often limited by steep slopes and the gradual loss of topsoil to erosional forces. In alluvial areas of San Lorenzo, soils are also considered to be deep and well drained, although soil depth may be locally limited by clay-rich subsoils. (Hecht and Woyshner, 1984)

Infiltration and water-holding capacities of the soils control flow generated from watersheds in response to rainfall. When rainfall rates exceed infiltration soil infiltration capacities, runoff occurs. The total amount of water a soil column can hold is limited by total connected pores and is described with total water-holding capacity. Following the first rains of the season, the soil columns become saturated and subsequent rainfalls can not infiltrate unless the soil has drained, and hence immediately become runoff. In this capacity, infiltration and water holding capacities of soils act as a buffer between rainfall and runoff. Characterizing these properties can help to understand variability in flow response to storm events and can help to shape operational protocols of potential diversions.

Balance compiled NRCS datasets for the study watersheds into summary tables which are included as Appendix A. Water holding capacities for the study watersheds are shown in Figure 4. Balance divided the water holding capacities for each soil type by the corresponding area covered by each soil type to obtain the average antecedent rainfall required before flows are generated from each watershed. Absent effects of land use, Bean, Zayante and Carbonera watersheds require catchment-wide averages of 5.9, 6.5, and 7.8 inches of antecedent rainfall respectively before winter flows should be expected. However, winter flows in Carbonera Creek currently occur before the watershed has received 7.8 inches of rain due to effects of urbanization, as is further discussed later in this report.

3.3 Rainfall and storm intensity

Water available for potential diversions is linked to rainfall patterns and is thus subject to climatic variability. Average rainfall over the San Lorenzo Watershed varies from 28 inches per year at the coast to more 60 inches per year on Ben Lomond Mountain (Figure 1). Annual rainfall totals for Zayante Creek, Bean Creek, and Carbonera Creek watersheds average about 45, 42, and 34 inches per year, respectively, and vary considerably from year to year. The year-to-year variability of rainfall going back to 1905 is shown in the record for the National Weather Service City of Santa Cruz station (Figure 5). For comparison, the periods of record for streamflow at the Zayante Creek, Bean Creek, and Carbonera Creek gages are identified on Figure 5. Recurrence intervals of annual rainfall totals for the Santa Cruz station are displayed in Figure 6.

Rainfall depth-duration-frequency relationships were calculated using the method outlined in Rantz, 1973 to classify storm intensities expected for each watershed. The relationship for the Bean Creek Watershed is shown in Figure 7, for the Carbonera Creek Watershed in Figure 8, and for Zayante Creek in Figure 9.

These data characterize storm intensities, potentially for and correlation to corresponding flow records. Correlations between predicted storm intensities and predicted streamflow may be incorporated into operation protocols for potential surface water diversions.

3.4 Streamflow records

Fifteen-minute interval average and maximum streamflow data were obtained from the USGS for each of the following gages for their period of record:

- San Lorenzo River at Big Trees;
- Bean Creek at Zayante Road;
- Carbonera Creek at Scotts Valley; and,
- Zayante Creek near Zayante Road.

For the purposes of this study, the 15-minute data were reduced to daily means, and if more detailed analyses are required for future phases of work, the data are available.

3.4.1 USGS Gage No. 11160500: San Lorenzo River at Big Trees

The USGS station on the San Lorenzo River at the Big Trees gage is the primary stream gage in the San Lorenzo Valley, with the longest period of record (from October 1936 to present). Prior to 1972, the gage was located, immediately downstream of the confluence of Eagle Creek and the San Lorenzo River. This former location was just above a large boulder riffle that controls the water surface elevation in the pool and provided the cross-section where streamflow was usually measured. The current gage is located about a mile and a half upstream from the former location, 12 feet upstream from the bridge on Henry Cowell State Park Road, 200 feet upstream from Shingle Mill Creek and 0.3 miles downstream from Zayante Creek. The gage responds to flow from the Zayante and Bean Creek systems, which constitute 18 percent of the contributing watershed to the gage. It is also affected by the operations of Loch Lomond Reservoir on Newell Creek, including seasonal diversions from San Lorenzo River, which supplies water to the reservoir from the inflatable diversion dam at the Felton Diversion, as well as the inflation and deflation of this dam.

Daily mean streamflow values are plotted in Figure 10, showing annual variability.[1] Of the period of record, there are 42 out of the 72 years where flows exceeded 2,000 cfs and 53 out of 72 years where flows exceeded 3,000 cfs. Figure 11 shows the recurrence for annual total streamflow at the Big Trees gage. Calculated average annual streamflow total through the Big Trees Gage was 96,100 acre-feet per year, with a statistical recurrence interval of 2.6 years. In addition, flows in excess of 10,000 acre-feet per year occur with a statistical recurrence interval of slightly over 1 year.

3.4.2 USGS Gage No. 11160430: Bean Creek at Zayante Road

The USGS streamflow gage on Bean Creek is located approximately 1.2 miles upstream of the confluence of Bean and Zayante Creeks, 100 ft upstream of Mount Hermon Road. The drainage area above the gage is 8.81 square miles, which is 90 percent of the total watershed (above its Zayante Creek confluence).[2] All major tributaries to Bean Creek are upstream of the gage and captured in the gaging record. Downstream of the gage, Bean Creek flows over the Monterey Formation which is largely impermeable mudstones and shales. Summer baseflows in Bean Creek are supported by ground water seeping into the channel from the Santa Margarita and Purisima Formations pinching out against the Monterey Shale. Baseflow is maintained throughout all of the years of record, but is clearly lowest during below average to critically dry rainfall years.

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1 Extremes for period of record: Maximum discharge, 30,400 ft^3/s, Dec. 23, 1955, gage height, 22.55 ft, site and datum then in use, from rating curve extended above 11,000 ft^3/s, on basis of slope-area measurement of peak flow, maximum gage height, 28.85 ft, Jan. 5, 1982; minimum daily discharge, 5.6 ft^3/s, July 27, 28, 1977.

2 Balance and County staff have intermittently operated stream gages of varying types at or near the mouth of Bean Creek, where the drainage area is 9.9 square miles. A USGS water-quality station was also operated at this location (see Sylvester and Covay,, 1978)

The average daily streamflow record is plotted in Figure 12.[3] The period of record for the gage is from January 1989 through water year 2007, when the gage was discontinued. Annual streamflow totals and recurrence intervals for the Bean Creek gage are plotted in Figure 13. Average annual total streamflow through the Bean Creek gage was 8,000 acre-feet, which represents 8.3 percent of the annual average streamflow at the San Lorenzo at Big Trees station.

3.4.3 USGS Gage No. 11161300: Carbonera Creek at Scotts Valley

Carbonera Creek gage is located 4.1 miles upstream of its confluence with Branciforte Creek and 1.1 miles upstream of Glen Canyon Road. The drainage area to the gage is 3.60 square miles, which is 50 percent of the total watershed above the confluence with Branciforte Creek, which flows into the San Lorenzo River about a half mile further downstream. The period of record is from February 1985 through water year 2007, when the gage was discontinued.

The gage was located in a losing reach of Carbonera Creek where the stream transitions from flowing over Santa Cruz Mudstone to Santa Margarita and alluvial stream terrace deposits. Below the former gage, the creek bed transitions from alluvial and sandstone to crystalline granite bedrock. On October 24, 2008, Balance staff and Scotts Valley Water District staff performed a creek walk, mapped creek bed geology, and observed the losing section of the creek. The gage did not measure flows from Camp Evers Creek or the unnamed creek that joins Carbonera Creek below Camp Evers. Both of these creeks are characterized as perennial by Santa Cruz County Environmental Health.

Average daily streamflow is plotted in Figure 14.[4] Average annual streamflow totals measured by the gage were 4,000 acre-feet. We note that the Carbonera Creek data are anomalous in several respects, particularly for water year 2001, and suggest that the County verify the data it commissioned from USGS for that year. Based on daily flows derived from the 15-minute data (kindly provided by USGS staff), our analysis shows that WY2001 has the highest recurrence for annual flow totals during the period of record, higher than the El Nino year of 1998, which predominates this period of record at other nearby gages.

Annual streamflow totals and recurrence intervals for the Carbonera Creek gage are plotted in Figure 15. These computations assume that the flow regime of Carbonera Creek has remained constant over the years; we later show that this may not be the case.

3.4.4 USGS Gage No. 1160300: Zayante Creek at Zayante

[3] Extremes for period of record: Maximum discharge, 1,710 ft^3/s, Feb. 3, 1998, gage height, 10.85 ft, from rating curve extended above 310 ft^3/s on basis of slope-area measurement at gage height 9.29 ft; minimum daily, 0.94 ft^3/s, Jan. 31, 1992.

[4] Extremes for period of record: Maximum discharge, 1,090 ft3/s, Feb. 14, 1992, gage height, 10.05 ft, from rating curve extended above 330 ft3/s on basis of slope-area measurement at gage height 9.48 ft; no flow for many days in each year.

The Zayante Creek gage operated during water years 1958 to 1992. It was located 3.5 miles upstream from the confluence of Zayante Creek with San Lorenzo River, at the bridge near the Zayante Store, with a drainage area of 11.1 square miles, 60 percent of the total Zayante Creek Watershed. The Zayante gage measured flow above the confluence with Lompico Creek, which has a drainage area of 3.4 square mile. The Lompico Creek supplies a substantial portion of the streamflow in Zayante Creek (RAMLIT, 2002). A major purpose for the gage was to collect background data for a proposed surface-water impoundment in the upper Zayante Watershed. The gage was abandoned after construction of the reservoir became infeasible.

Downstream from the Zayante gage, the channel flows through the sandy soils of the southeastern block, underlain by the hard shales and mudstones of the Monterey formation. Summer baseflows near the confluence with Bean Creek are fed by ground water by the same mechanism that supplies baseflow to Bean Creek (see above discussion).

Average daily flow for Zayante Creek for the period of record is plotted in Figure 16. Average annual streamflow for the period of record is 8,000 acre-feet, which represents 8.3 percent of the annual average streamflow at the San Lorenzo at Big Trees station. Annual streamflow totals and recurrence intervals for the Zayante Creek gage are plotted in Figure 17.

4. EVALUATION OF POTENTIAL DIVERSIONS FOR VOLUME, HABITAT, AND WATER QUALITY FOR BEAN, CARBONERA, AND ZAYANTE CREEKS AND SAN LORENZO RIVER.

As outlined in multiple studies completed on the Scotts Valley/Pasatiempo Groundwater Subareas, a long-term overdraft of approximately 500 acre-feet per year has been occurring for the past 15 years (RAMLIT, 2002, Johnson, 1991, ETIC, 2004). Average pumping by the Scotts Valley Water District has been on the order of 2,000 acre-feet per year for the last 5 years.

The volume of surface water available for diversion and recharge potential will be defined in protocols adopted by the California Department of Fish and Game (CDFG), NOAA Fisheries, and State Water Resources Control Board, including its Division of Water Quality and its Division of Water Rights (SWRCB). Potential effects of the diversions to natural hydrographs and water quality in the streams during times of diversion are the focus of the protocols. Diversion times are limited to high flows, which are generally associated with low concentrations of dissolved solids and high turbidity (high concentrations of suspended sediment). These water-quality parameters will be important for the feasibility analysis of potential percolation basins.[5]

Guidelines for permitting a new surface-water diversion define two categories of diversions: (1) those proposing to remove less than 200 acre-feet per year and to maintain a maximum water diversion rate of less that 3 cfs, and (2) those proposing to withdraw more than 200 acre-feet per year and have instantaneous diversion rates larger than 3 cfs. Project yield numbers under consideration for potential conjunctive alternatives are larger than 200 acre-feet per year, so the second category of diversions was investigated.

The proposed new diversion will require the following components (Alley, 2008):

- A habitat-based stream needs assessment that incorporates habitat, species and life history criteria specific to each diverted stream or stream reach;
- An evaluation of the existing level of impairment (diversion) and limiting factors for salmonid restoration based upon habitat, species and life history-specific criteria for each diverted stream or stream reach;
- A specific proposal to provide periodic channel maintenance and flushing flows that are representative of the natural hydrograph; and

[5] Other stormwater contaminants will be considered in reports from others assessing these aspects of conjunctive use.

- A plan to monitor the effectiveness of stipulated flows and procedures for making subsequent modifications, if necessary.

Initial work to establish bypass flows for the San Lorenzo River was performed in 1976 by the State Water Resources Control Board (SWRCB) and revised in the late 1980's as part the water rights process.and established a bypass flow requirement of up to 25 cfs as discussed in Technical Memorandum 2A. Under present practice of the resource agencies and the SWRCB Division of Water Rights, bypass flows that evaluate the level of flow impairment associated with a proposed diversion is accomplished by calculating the Cumulative Flow Impairment Index (CFII) for the proposed diversion using a methodology developed for use on the Russian River which as been extended to other waterways.. (DFG, 2002) The CFII is a measure of the potential flow impairment to streamflow caused by all diversions on the creek or river. CFII is calculated by taking the ratio between the volumes of water naturally available in the stream (unimpaired flows) and the total volumes of water legally diverted from the watershed through existing water rights. The volume of water diverted for the Cumulative Diverted Volume (CDV) is for the period October 1 to March 31 season (including riparian rights, small domestic and stock pond registrations, pre-1914 rights and other appropriative rights). The runoff period for the Estimated Unimpaired Runoff (EUR) is from December 15 to March 31. If the other diversions are not likely to occur during the CDV season, then they may be discounted (Alley, 2008).

$$CFII = \frac{\textit{Cumulative Diverted Volume}}{\textit{Estimated Unimpared Runoff}}$$

The level of impairment indicated by the CFII determines subsequent study effort needed to address significant cumulative impacts associated with the new water diversions. Thresholds for CFII values are:

- If the CFII is greater than 0.10 then there are likely significant cumulative impacts. When the CFII is greater than 0.10, site-specific studies will be required to assess cumulative impacts, and the applicant must consult with NMFS and DFG to scope out the site specific studies needed to assess these impacts.

- When the CFII is between 0.05 and 0.10, the applicant must provide additional hydrologic analysis to document the estimated effects of cumulative diversions on the stream hydrograph at Points of Interest (POI's: determined by DFG and NMFS staff) during three representative normal (near-average) years and two representative dry years. If the natural hydrograph is appreciably impaired (diminishes the frequency and magnitude of unimpaired high flows (1.5 or 2-year recurrent interval) and unimpaired moderate and high flows (higher than February median flow) by more than 5%) during the migratory and spawning period of anadromous salmonid species, then additional site-specific study may be warranted. Additionally, the resource agencies ask the proponent to demonstrate that the cumulative maximum rate of instantaneous withdrawal at the point of diversion should not exceed a flow rate equivalent to 15% of the estimated “winter 20% exceedance flow.”

- If the CFII is less than 0.05, it is assumed that significant cumulative impacts due to diversion are unlikely, and no additional studies are required to assess these impacts.

For this study, potential volumes of diverted water were used to test the effects of proposed diversions on flow impairment. CFII is typically calculated for average (normal) water years having a recurrence interval of 2 to 3 years (Alley, 2008). CFII values for proposed diversions on Bean Creek, Carbonera Creek, and Zayante Creek were calculated for all years of record to show the variability of CFII values with recurrence interval of annual streamflow. These tributaries to the San Lorenzo are potential diversions under consideration. This analysis for these specific tributaries supplements the bypass flow analysis conducted by the SWRCB on the San Lorenzo River.

We reduced the USGS 15-minute record to daily mean flows to calculate the CFII for each year. We used the total flow from December 15 through March 31 as the EUR. Then for each day from October 1 through March 31, we calculated a daily diverted volume based the rate needed to average a long-term 500 acre-feet annual yield. As described in the next section, this long-term yield was selected to offset the estimated average annual overdraft (ETIC, 2005). For each year, the daily diverted volumes were totaled to estimate the CDV, and then divided by the corresponding EUR to calculate the CFII.

CFII calculations for each existing point of diversion below the proposed diversion will be required for the next component of the feasibility analysis. Because proposed diversions for Bean Creek and Zayante Creek are above the Felton Diversion operated by the City of Santa Cruz, the effects of proposed diversions on the Felton diversion will need to be investigated as a next level of feasibility. Evaluation of intake velocities for the diversions parallel and perpendicular to streamflow will also need to be evaluated if one or more potential diversions are selected for further analysis.

4.1 Proposed diversion simulations

To evaluate average annual diversion yields and flow impacts for each proposed diversion, Balance performed simulations of the diversions using a daily time step at the gage location. Time envelope for diversions was held between October 1st and March 31st and the low flow bypass threshold was set at 10 cfs. The 10 cfs minimum bypass rate was set to achieve an estimated average annual diversion volume of 500 acre-feet and is consistent with the diversion threshold of 10 cfs for Bean and Zayante Creeks used by RAMLIT in their 2002 study (p. 7 and 8). Multiple diversion simulations for Bean Creek, Carbonera

Creek, and Zayante Creek were completed measuring the effects on average annual yield and flow impairment to varying instantaneous maximum diversion rates. Average annual diversion yields of 500 acre-feet per year are presented for all evaluated diversions because it represents the annual yield required to offset annual overdraft identified for the Scotts Valley/Pasatiempo Groundwater Subareas. Annual yields of greater than 500 acre-feet per year generally create impaired flow conditions in the creeks and seemed to be difficult to implement.

All diversions are assumed to be located at the USGS gage site on each stream. Adoption of a diversion program that optimizes recharge and effective protection of biological functions will likely require diversions from more than one stream, perhaps in different proportions during each season/life stage or in different types of years. At present, we are proceeding separately with the analysis for each diversion or stream. The analysis, hence, is conservative, in that a balanced set of diversions from more than one stream would have substantially less effect than if the entire 500 acre feet per year, on average, are sought from an individual diversion.

We note that daily diversion rates and totals are not presented in this report but are available for sizing of percolation basins or storage facilities and evaluating the effects of sediment entrained in the diversions on those facilities, part of the next phase of analysis. We also assume that all flows diverted are in fact recharged or used directly to offset the existing overdraft; 'loss' of diverted water to evaporation or to 'short circuiting' back to the stream system without recharging the aquifers is neglected at this phase of analysis.

Finally, diversions of high flows from these three streams can reduce the adverse effects of high flows further downstream on salmonids and on other aquatic biota. Lower peak flows downstream can lead to improved bed and bank stability and to less loss of key organisms and habitat elements during floods. Diversions would have to be made during most peak flows for beneficial effects to be realized, a potential consideration in selecting the size of facility or the rate of diversion. However, the downstream benefits of peak flow diversions would have to be balanced against the higher turbidity and sediment loads associated with peak flows. The comparative analysis between peak flow diversion benefits and challenges could be evaluated during a subsequent phase of this study.

4.1.1 Bean Creek diversion

Figure 18 represents the relationship between maximum instantaneous diversion rate and average annual yield from the diversion over the 1992 to 2007 period of record for a proposed Bean Creek diversion. At an instantaneous diversion rate up to 5 cfs, the average annual yield for the diversion would be 520 acre-feet per year. Figure 19 shows the annual flow in Bean Creek for each water year and the volume of water that would have been diverted with a 5 cfs maximum diversion rate between October 1st and March

31st and a minimum bypass flow of 10 cfs. The annual average streamflow is 8,000 acre-feet, approximately a 2.6-year seasonal recurrence (Figure 13).

CFII for the proposed diversion was calculated for each water year of record and is displayed in Figure 20 with the recurrence interval of the streamflow. The average CFII is 0.085, which is within the acceptable ranges that are thought to not cause significant cumulative impacts to anadromous fish through flow impairment. The ranges of yearly CFII are mostly within the acceptable ranges, but several years are above the threshold indicating likely significant cumulative impacts. All points of diversion downstream of the gage will need to be evaluated for flow impairment as detailed in the 2002 NOAA/CDFG memorandum during the next stage of feasibility analysis.

If the CFII values are between 0.05 and 0.1, threshold parameters must be demonstrated to occur during a 2-year annual streamflow recurrence interval. These threshold parameters are a) not reducing February stormflows by greater than 5 percent, and b) the allowance of winter storm events to pass through the diversion with exceedance flows greater than 20% of average winter flow. Streamflow data from water year 1996 was used to test these threshold parameters. Figure 21 illustrates the natural hydrograph and hydrograph altered by the diversion, and shows that the flow requirements are satisfied over this water year. The location and geologic formation where the diverted water is recharged will determine the level and location of baseflow benefit to Bean Creek.

4.1.2 Carbonera Creek diversion

Figure 22 represents the relationship between maximum instantaneous diversion rate and average annual yield from the diversion over the 1988 to 2007 period of record for a proposed diversion on Carbonera Creek. At an instantaneous diversion rate up to 10 cfs, the average annual yield over the period of record of the diversion would be 480 acre-feet per year. Figure 23 shows the annual flow in Carbonera Creek per water year and the volume of water that would have been diverted with a 10 cfs diversion rate between October 1st and March 31st and a minimum bypass flow of 10 cfs. The annual average streamflow is 4,000 acre-feet, approximately a 2.6-year seasonal recurrence (Figure 15).

CFII for the proposed diversion was calculated for each water year of record and is displayed with recurrence interval of water year in Figure 24. The ranges of CFII exceed the threshold indicating likely significant cumulative impacts to anadromous fish through flow impairment. The average CFII is 0.16. Because the CFII values are above 0.1, flow impacts of the proposed diversion will be initially deemed to be severe and any must be considered infeasible. However, because of the ongoing changes in the hydrology of Carbonera Creek which have prevailed during the past decade, described below, it may be appropriate to consider other approaches to making diversions most compatible with a healthy aquatic environment. It may be useful, for example, to consider greater diversions for use in sustaining summer baseflows downstream from a Carbonera Creek diversion to help offset their continuing loss, or to compute the CFII based on post-1995 hydrology.

Carbonera Creek is a special case when computing the CFII values, as a waterfall blocks steelhead passage about 2 miles downstream of the former USGS gage (Alley, 2002; see also the regional discussion in CEMAR, 2004). The upstream limit of anadromy (adult migration) on Carbonera is at river mile 3.39 (Don Alley, pers. comm.), adjacent to the Moose Lodge. At this location, the drainage area is approximately 5.41 square miles, relative to 3.60 square miles at the USGS gage site. Accordingly, CFII computations for purposes of steelhead management at this point of interest should be reduced by a drainage area factor of 0.67. Hence, when comparing possible sources of diversions, the CFII computed for below the Moose Lodge falls should appropriately be used when assessing potential effect on steelhead.[6] For comparison, we show the CFII in Figure 24 for the Moose Lodge waterfall location. The ranges of CFII are mostly are above the threshold of likely significant cumulative impacts but some years are within the acceptable ranges that are thought to not cause significant cumulative impacts to anadromous fish through flow impairment. The average CFII at Moose Lodge Falls is 0.104.

Carbonera Creek anadromy (CEMAR, 2004):

- Carbonera Creek consists of about 9.9 stream miles and is tributary to Branciforte Creek. It flows south, entering Branciforte Creek at about stream mile 1.2. In 1956, DFG described a "forty-foot natural rock falls at [stream mile 3.5 that] forms the upstream limit for salmon and steelhead" (DFG 1956c). A 2001 enhancement plan refers to this feature as Moose Lodge Falls.

- The stream survey report from 1956 calls Carbonera Creek "an important spawning tributary [to the San Lorenzo River]" while noting that "approximately 1/2 mile of spawning area has been destroyed by logging operations" resulting in siltation and debris loading (DFG 1956c). The surveyor found *O. mykiss* fingerlings to be "quite common throughout" the creek.

- In a 1966 survey report, DFG states that Carbonera Creek "has some of the best spawning areas in the county" for steelhead and resident trout (DFG 1966a). By 1974, DFG said that most Carbonera Creek spawning areas were degraded by silt derived largely from logging

[6] While it is premature to consider locations for diversion, effects on steelhead (and other aquatic habitat considerations) are likely to be primary factors. To the extent that CFII is used to estimate effects on flows, it might be noted that values computed for Zayante Creek above Bean Creek are likely to be perhaps 10 to 15 lower than the values given for the Zayante Creek at Zayante gage site, as the diversion most reasonably might be further downstream. CFII values computed for Bean Creek may be used as given, since future diversions may be from the reach near the USGS gage site. CFII values for Zayante Creek downstream of the Bean Creek confluence have not been computed. CFII computations are a basic assessment required by NOAA Fisheries and the California Department of Fish and Game; local considerations, plus year-round effects on sediment, temperature, and water quality, will also influence the relative impacts of diversion from the three streams.

operations (DFG 1974c). Based on observations in August 1980, DFG found *O. mykiss* present throughout Carbonera Creek, "though in small numbers" (DFG 1980b).

- As part of a larger study of Santa Cruz County streams, consultants sampled Carbonera Creek in 1981. The resulting report indicated that *O. mykiss* was observed at two of three sites. The report notes "poor" rearing habitat, with substrate, lack of cover, and low flows presenting primary limiting factors to production (HSA 1982).

- In a 1996 memo concerning habitat limitations in central coast streams, DFG staff note the impact of groundwater pumping, encroachment, and runoff on Carbonera Creek (DFG 1996c). A 1996 survey report recommended allowing recruitment of woody debris and controlling sediment sources into the creek (DFG 1996a).

- An enhancement plan deemed Carbonera Creek one of seven "important producers of YOY's and yearlings" (Alley 2004a). According to the plan, the creek is one of three particularly important sources of summer baseflow for the San Lorenzo River (Alley 2004a). It also is said to produce high sediment loads related to urbanization.

4.1.3 Zayante Creek diversion

Figure 25 represents the relationship between maximum instantaneous diversion rate and average annual yield from the diversion over the 1958 to 1992 period of record for a proposed diversion on Zayante Creek. At an instantaneous diversion rate of 5.5 cfs, the average annual yield over the period of record of the diversion would be 500 acre-feet per year. Figure 26 shows the annual flow in Zayante Creek per water year and the volume of water that would have been diverted with a 5.5 cfs diversion rate between October 1st and May 31st and a minimum bypass flow of 10 cfs. The annual average streamflow of 8,000 acre-feet corresponds to approximately a 2.6-year seasonal recurrence (Figure 17).

CFII for the proposed diversion was calculated for each water year of record and is displayed with recurrence interval of water year in Figure 27. The average CFII is 0.067 at this gaging site and is within the acceptable ranges that are thought to not cause significant cumulative impacts to anadromous fish through flow impairment. 7 The ranges of yearly CFII are mostly within the acceptable ranges that are thought to not cause significant cumulative impacts to anadromous fish through flow impairment, but some years are above the threshold indicating likely significant cumulative impacts. All points of diversion downstream of the gage will need to be evaluated for flow impairment as detailed in the 2002 NOAA/CDFG memorandum during the next stage of feasibility analysis.

[7] The drainage area of Zayante Creek increases from 11.2 at the gage to about 16 square miles at the confluence of Bean Creek. Approximately 3.4 of the 4.8 square-mile difference is attributable to Lompico Creek. Flows just upstream of the mouth of Bean Creek might be perhaps 40 percent higher than at the gage, with a concomitant decrease in computed CFII, assuming no winter diversions.

If the CFII values are between 0.05 and 0.1, threshold parameters must be demonstrated to occur during a 2-year annual streamflow recurrence interval. These threshold parameters are a) not reducing February stormflows by greater than 5 percent, and b) the allowance of winter storm events to pass through the diversion with exceedance flows greater than 20% of average winter flow. Streamflow data from water year 1962 was used to test these threshold parameters during a normal, non-drought streamflow year. Figure 28 illustrates the natural hydrograph and hydrograph altered by the diversion, and shows that the flow requirements are satisfied over this water year.

4.2 Felton Diversion – a potential conjunctive use approach

The City of Santa Cruz maintains an inflatable dam and a surface water diversion just upstream of the Big Trees Gage on the San Lorenzo River. Water diverted from this facility is used to supplement Loch Lomond Reservoir storage. Re-operation of the Felton Diversion was identified as a source of water in the 2002 Conceptual Framework for Conjunctive Use of Water Resources for the Lower San Lorenzo Valley report produced by RAMLIT Associates. RAMLIT cited the maximum amount of water diverted by this facility was 1,643 acre-feet during water year 1989, leaving 1,357 acre-feet remaining from the 3,000 acre-feet available for diversion to a conjunctive use. As discussed in Section 3.4.1., the water flows and volume at the San Lorenzo River at the Big Trees gauge indicate that high flows over 200 cfs, as suggested in Section 7.2 of the RAMLIT report, and relatively high diversion rates (e.g. 30 cfs maximum diversion rate) will be available. A review of the Big Trees gauge daily flow data indicates that during approximately 30% of the wetter months, flows in excess of 200 cfs are recorded.

In recent communications with City of Santa Cruz Resource Management Staff and review of conceptual cooperative operations of a desalination plant with Soquel Creek Water District, water that has not historically been diverted may not be available to the conjunctive use framework. The City is currently undergoing an internal re-evaluation of operations and may be changing the average annual volume of water diverted from the Felton Diversion to Loch Lomond Reservoir. Using past operational datasets to evaluate potential available water may produce inaccurate estimates of water that will not be diverted during future operations. This evaluation will need to be conducted following formalizing or implementing the City's new operational procedures.

A co-located diversion may be an option, but operation of this option will be closely tied to City operations and should be consistent with future operations of Loch Lomond and the Felton Diversion. Evaluation of CFII for a new diversion co-located with the Felton Diversion after the City has re-evaluated their diversion operations should be conducted in the second phase of this feasibility analysis because the assumptions for a CFII study were not clear at the time of this study and is beyond the scope of this conjunctive use study. The Tait Street diversion will also need to be included in the subsequent evaluations as it is a downstream diversion for the proposed Big Trees site. Any proposed operations of a new diversion at this site will need to be compatible with the cooperative plans between City of Santa Cruz and Soquel Creek Water District.

4.3 Water quality of diverted water

Quality of diverted water will have an effect on the usability of the water in the conjunctive use framework. Dissolved solids are highest during baseflow and diluted during winter flows. However, turbidity and suspended sediment concentration are higher during elevated winter flows. Balance has collected datasets from past reports to provide a preliminary estimate of expected water quality. Dissolved chemistry will play an important role in recharge applications to assess reactions between percolated water and the receiving aquifer. Suspended sediments transported by the streams and river will be diverted along with the water, and will require filtration or settling ponds to clarify the water, as to optimize recharge at the percolation basin. Without treatment for suspended sediments, the sediments will settle on the base of the percolation ponds and significantly reduce infiltration rates, possibly even 'seal' the base of the pond. Data are available for the San Lorenzo River and Zayante Creek for sediment transport and dissolved chemistry data are available for all or the creeks and river. Balance (Hecht and Enkeboll, 1980) and DWR (1958) staffs gathered pertinent data, and Balance is currently collecting suspended sediment data on Bean Creek as part of other work the County's Department of Environmental Health.

There have been many past efforts relating to salmonid habitat to identify sources of sediment within the San Lorenzo Watershed. Some of the sources are chronic and some are episodic leading to varying levels of suspended sediment transport during winter flows. Chronic sources will supply a constant suspended sediment load to water available for diversion and will establish a baseline concentration for suspended sediment. Sources of chronic sediments are erosion from rock outcrops and roads. Episodic sources will raise suspended sediment concentrations above baseline levels. Episodic sources include effects of major storms (such as 1982), landslides, gullying or incision associated with hydromodification, construction activities and post-wildfires sediment pulses. The San Lorenzo watershed contains substantial areas of fire-adapted vegetation, reported to burn at historical intervals of typically 40 to 80 years (Thomas, 1961; Langenheim and others, 1983). In subsequent years, sedimentation diminishes, as vegetation becomes re-established. Available data suggest that the process of recovery in Santa Cruz Mountain streams may generally be expected to take perhaps 3 to 5 years (Hecht, 1981; Hecht, 1983; Iwatsubo and others, 1988). Reduced water-supply yields to diversions may be experienced following fires due to increased suspended sediment transport loads.

Chemistry data from the Santa Cruz County Environmental Health have been collected intermittently for the past 30 years. Balance sorted the data by instantaneous streamflow associated with the sample collection to provide a proxy for the potential chemistry of diverted water. Unfortunately, most of the samples were collected during low flows or when flow records were not available. To assess the quality of water potentially available for diversion, water quality monitoring during high flows will be necessary.

4.3.1 Potential water quality of water diverted from San Lorenzo River.

In the San Lorenzo Watershed, steep slopes, unsurfaced roads, and road cuts are notable sources of persistent suspended sediments, particularly where year-round road use is necessary for residential access. Sources of suspended sediments at the Felton Diversion have been identified as Mudstones in Kings Creek, Logan Creek, and the upper San Lorenzo River. Where exposed, vegetation is often naturally sparse, soils are thin or non-existent, and weathering continuously exposes erosive surfaces. (Hecht and Kittleson, 1998)

Figure 29 is comprehensive plot of all suspended-sediment measurements made by USGS at the Big Trees gage from 1976 to 1993. Average winter streamflow (October to March) is 500 cfs. This range has been highlighted on the plot to show the associated ranges of sediment expected to be present during diversions. During acceptable diversion flows, the San Lorenzo River will likely be transporting between 70 and 1700 tons of sediment per day. Prior to direct use or percolation, the diverted water would need treatment for suspended sediment.

4.3.2 Potential water quality of water diverted from Bean and Zayante Creeks.

There is a sharp decrease in relative bed material sizes on Bean Creek below Lockhart Gulch. Development-related disturbance and road-related(?) landslides in Lockhart Gulch are likely sources. Slides and associated gullies on Bean Creek Road, particularly a set of slides 0.5 miles north of Camp Evers, also are significant sources of fines to this reach. Zayante Creek at Zayante is subject to significant aggradation following sediment-producing events (Swanson, 1996). In 1980, the bed material present in Zayante and Bean Creeks appeared to be generated now north of the Zayante fault (Brown, 1973; Hecht and Enkeboll, 1980). Quartzites and volcanics originate almost exclusively north of the fault. Proportionately more sediment is originating from areas downstream of the Zayante fault, most of which are sandy. Proportionally, more sediment is generated in middle and lower Bean Creek subwatershed (Hecht and Kittleson, 1998). In these areas, fine may be easier to control through erosion control measures.

A regression of annual total suspended sediment transported against annual total streamflow was completed in 1996 as a component of a sediment sourcing study by Swanson Hydrology and

Geomorphology Figure 30 shows the average annual streamflow in Zayante creek of 8,000 acre-feet should transport 8,000 tons of sediment. For this value of average annual streamflow, Balance simulated an average diversion of 650 acre-feet. The average amount of diverted water represents 8 percent of the total flow (a CFII value of 0.08). As a rough estimate, 650 acre-feet of diverted water would contain approximately 650 tons of suspended sediment that would be delivered to potential recharge ponds. The diverted water would need settlement and treatment for suspended sediment prior discharging to recharge ponds or injection wells.

4.3.3 Potential water quality of water diverted from Carbonera Creek.

Several geologic formations are consistent contributors of sediment loads to local Carbonera Creek, despite stabilization efforts. The Santa Margarita Sandstone along Carbonera Creek is susceptible to erosion and to channel incision and widening associated with urbanization-induced hydromodification. Disturbance of the Zayante soils and a weathered mantle results in severe gullying and long-term instability in the upper portions of the watershed. High permeability and low available water capacity and fertility in exposed Santa Margarita sandstone severely limits revegetation efforts, particularly on south-facing slopes. Sandier members of the Purisima and Lompico formations, particularly where residential development, roads, agricultural practices and livestock (primarily horses) concentrate flows or reduce capacity of the soils to hold moisture and attenuate runoff are also sources of landslides and winter debris. (Hecht and Kittleson, 1998)

The lower Carbonera Creek watershed is densely urbanized and therefore stormwater runoff has a large influence on the dissolved chemistry of potential diversion water. Stormwater carries contaminants that are washed off the surfaces of streets and into the stormdrain system. Typically, the “first flush” or flow associated with the first winter rains have the highest concentrations of contaminants. First flush data for the Scotts Valley Stormwater System is presented and discussed later in this report.

5. EFFECTS OF URBANIZATION AND POTENTIAL STORMWATER CAPTURE IN CARBONERA CREEK WATERSHED.

As part of our investigation, we completed a number of analyses to quantify the flow in Carbonera Creek generated from stormwater runoff, and then created an estimate for lost recharge to the Santa Margarita aquifer. Conjunctive use interests specifically for the Carbonera Creek watershed arise from the identified prime recharge potential for the Santa Margarita Ground Water Basin due to sandy soils and underlying Santa Margarita aquifer across the region. In addition, Scotts Valley Drive runs parallel to Carbonera Creek for approximately 4 miles, and Santa Cruz County Environmental Health and SVWD staff have suggested that recent development projects in this area of Scotts Valley have led to less recharge and consequently a loss of baseflow in Carbonera Creek. Therefore, stormwater capture and recharge may prove to be a feasible element of a conjunctive use framework if loss of recharge can be offset.

Balance obtained maps of the City of Scotts Valley storm drain system and used them to delineate sub-watersheds created by the drain network within the Carbonera Creek Watershed along Scotts Valley Drive (Figure 31). Balance and SVWD staff completed a creek walk on October 24, 2008 to identify and map a) major outfalls from the storm drain network into Carbonera Creek, b) creek bed geology, and c) wetted segments of the creek bed.

Balance then performed a rainfall response analysis using the rational runoff method. Daily rainfall records were obtained from the De Laveaga CIMIS weather station (Figure 32), about 5 miles to the south. Rainfall data were sorted by all storm events with rainfall totals greater than 1 inch in 24 hours. Each storm total was multiplied by the catchment area above the USGS gage to obtain a total rainfall volume per storm event. Associated storm runoff hydrographs were identified from the fifteen-minute streamflow data. Total volume of water recorded in the hydrographs was calculated, the baseflow subtracted, and the total runoff generated by the storm events obtained. Total volume of rainfall was divided by total volume of streamflow to attain a runoff coefficient for each storm event. Figure 33 is a time-series plot of the runoff coefficients associated with storm events greater than 1 inch in 24 hours. Several patterns emerge from this graph:

- Over the course of each water year, the runoff coefficient increases as the watershed becomes saturated and the soils reach their water holding capacity. Average water holding capacity for Carbonera Watershed was calculated as 7.8 inches. As soils drain, the runoff coefficient returns to the baseline value and late season storms generate less unit runoff. This is a typical cycle expected for a watershed with sandy soils in a Mediterranean Climate.

- The dashed blue line represents the average runoff coefficient over a water year. The average annual winter runoff coefficient has increased from 0.42 in 1990 to 0.60 in 2006. This increase is caused by urbanization of the watershed. Runoff from impervious surfaces is conveyed rapidly by the storm drain system and routed to Carbonera Creek, resulting in higher instantaneous peak flows during each storm. The soils covered by impervious surfaces can no longer infiltrate a portion of the rainfall which increases the early and late season runoff coefficients and raises the yearly average runoff coefficient.

- The orange dashed line identifies the early-season "first storms" runoff coefficient base level. This baseline has increased with time and degree of urbanization. This trend is caused by rainfall falling directly on impervious surfaces and immediately being routed into the storm drain system and into Carbonera Creek.

Balance completed an aerial photograph investigation to identify recent construction along the Scotts Valley Drive Corridor. There is a marked change in baseline runoff coefficient starting in the 1997 water year. Figure 34 shows the construction since 1991, surface and streambed geology, and storm drain catchments and outfalls to Carbonera Creek. The Scotts Valley Planning Department staff informed us that the Scotts Valley Drive Improvement Project was constructed over the summers of 1997 and 1998. The capital improvement project widened Scotts Valley Drive and added infrastructure to the existing storm drain system along this portion of Carbonera Creek. Following the project, many of the businesses along Scotts Valley Drive extended their parking lots to meet the recently widened road. The timing of this construction corresponds to increased runoff coefficient identified in Figure 33.

Balance completed two analyses to quantify the increase in annual average streamflow in Carbonera Creek due to stormwater:

- Because there is such a marked shift in the runoff coefficient around 1997, Balance separated the streamflow record into two records, pre and post 1997, and ranked logarithmic distribution for each record.[8] Figure 35 illustrates a shift in annual flow volume between pre 1997 and post 1997 streamflow datasets. For both the pre and post 1997 analyses, a 4-year annual streamflow recurrence interval represented the average streamflow in Carbonera Creek, and the average annual increase due to stormwater was 1,100 acre-feet.

- Average rainfall over the pre and post 1997 streamflow records was 27.9 and 34.2 inches respectively. To remove the climate signal, annual streamflow totals (in acre-feet) were normalized by annual rainfall totals (in inches) for each water year to obtain annual unit runoff values (acre-feet/inch). Figure 36 illustrates unit runoff over the streamflow and rainfall period of record from 1989 to 1996. On average, unit runoff increased 29 acre-feet

[8] The ranking method (or Gumble Distribution method) is a graphical distribution that is commonly used for 'fitting' observed flow data. When the population of events is very positively skewed, the data are usually log-transformed.

per inch at or around 1997. Multiplying this value by the average annual rainfall of 34 inches, estimates on the order of 980 acre-feet increase in average annual streamflow due to stormwater over the period of record since 1997. We believe that much or most of this represents a loss of recharge, with diminished baseflow and decreases in evapotranspiration making up the remainder.

Hydromodification[9] of Carbonera Creek has resulted in the increased timing and volume stormwater runoff. Higher volume wet-season flows have caused downcutting and lateral erosion in many locations (Figure 37). In addition, reduced infiltration and recharge to the Santa Margarita along this corridor has resulted in a noticeable reduction of baseflow in the last 10 years (Figure 33).

Balance analyzed Carbonera Creek streamflow records to identify the effects of increased stormwater runoff on baseflow and completed an estimate of potential lost recharge to the Santa Margarita Aquifer. Average daily flows for the months of August and September were averaged over each water year as an estimate of baseflow. Figure 38 illustrates a decline in dry-season baseflow from near 1 cfs during 1989 to 1996 to about 0.1 cfs after 1998 (or about 90 percent). Annual rainfall totals are included in the plot to show that the decline in baseflow is not related to rainfall. Prior to increased runoff to Carbonera Creek, corresponding rainfall could have infiltrated into the soil, recharge the aquifer, and re-entered Carbonera Creek as baseflow (or percolated deeper in the aquifer).

A hydrograph comparison between water years 1989 and 2004 was used to quantify the component of baseflow present at the USGS gage prior to 1997. Water Years 1989 and 2004 were chosen because they have similar rainfall totals, 24.2 inches and 24.4 inches respectively at the De Laveaga rain gage. In 1989, total streamflow was 2,496 acre-feet and in 2004 streamflow was 3,031 acre-feet. Figure 39 is the comparison of the two hydrographs. The hydrograph for 1989 shows a 1 cfs baseflow maintained year round, compared to 2004 when Carbonera Creek dried down in June and winter baseflow averaged 0.5 cfs. A daily baseflow of 1 cfs maintained for an entire water year is slightly more than 700 acre-feet annually. Table 1 is an estimated water balance for pre and post 1997 flows for an average streamflow year in Carbonera Creek.

In summary, the baseflow component to streamflow is now drastically different following the urbanization along this reach of Carbonera Creek. Annual streamflow has increased on average by 980 to 1,100 acre-feet per year. Prior to urbanization, a significant portion of this additional runoff would have percolated as recharge to the Santa Margarita aquifer. This runoff estimate is consistent with recharge estimates completed by Santa Cruz Environmental Health and Scotts Valley Water District (SVWD). Environmental Health staff has produced estimates of 500 acre-feet per year lost with a GIS analysis of

[9] Hydromodification is the alteration of the natural flow of water through a landscape, and often takes the form of channel modification.

soils properties, geologic structure, annual rainfall, and extent of urbanization (Cloud, 2004). SVWD used their regional MODFLOW model to obtain a 1,000 acre-foot estimate of loss to recharge due to urbanization (Kennedy/Jenks, 2008).

Depletion of the broader Santa Margarita Aquifer has occurred from the early 1980's to late 1990's. Figure 40 illustrates the water surface elevation measurements from SVWD Well No. 9 in comparison to baseflow in Carbonera Creek. The 10-year time lag between ground-water level decline in the Santa Margarita Aquifer and decreased baseflow in Carbonera Creek implies baseflow in Carbonera Creek was not directly fed by broader aquifer, but rather, more likely supported by recharge near the creek prior to development. This strongly suggests that baseflows may be restored in part by additional recharge to selected areas near the creek, and may not require aquifer-wide replenishment. To our knowledge, a geologic framework for understanding the separation between the shallow zones supporting baseflow and the developed aquifer has yet to be developed, and would logically precede further exploration of these ideas.

Stormwater capture and recharge could potentially be a component to a conjunctive use solution to overdraft in the Scotts Valley/Pasatiempo Groundwater Subareas or to supplement baseflows in Carbonera Creek. Feasibility of stormwater capture depends on the ability of harvest water from the storm-drain network, ability to percolate water, and the quality of stormwater. Volumes of stormwater available for capture are controlled by the individual watersheds associated with storm drain pipe inverts routing water to Carbonera Creek. The location in the storm drain network where water can be withdrawn will also control the available volume. Table 2 summarizes data collected from the Scotts Valley storm-drain network during 2005 by the Coastal Watershed Council. Locations in the storm-drain network where substantial volumes of water can be harvested and proximity to feasible percolation sites should be identified in the next phase of work. Flow volumes and water quality should be monitored to build a dataset to guide percolation basin sizing and identify necessary pretreatment measures.

Non site-specific measures to promote percolation of stormwater can be implemented. Best management practices to treat and percolate stormwater such as vegetated swales, percolation basins, and permeable pavement could be implemented as retrofits of existing development, and/or required for new construction. Basin scale water quality concerns associated with stormwater infiltration should be investigated through water quality monitoring and possible demonstration projects. Figure 41 is examples of stormwater percolation infrastructure implemented by the City of Portland, Oregon. Likely, many stormwater projects will need to be implemented in order to achieve offset of loss to recharge from urbanization.

7. LIMITATIONS

This report was prepared in general accordance with the accepted standard of practice in surface-water hydrology existing in Central California for projects of similar scale at the time the investigations were performed. No other warranties, expressed or implied, are made.

As is customary, we note that readers should recognize that interpretation and evaluation of factors affecting the hydrologic context of any site is a difficult and inexact art. Judgments leading to conclusions and recommendations are generally made with an incomplete knowledge of the conditions present. More extensive or extended studies, including additional hydrologic baseline monitoring, can reduce the inherent uncertainties associated with such studies. We note, in particular, that many factors affect local and regional issues related to the magnitude and frequency of high flows. If the client wishes to further reduce the uncertainty beyond the level associated with this study, Balance should be notified for additional consultation.

We have used standard environmental information -- such as rainfall, topographic mapping, and soil mapping -- in our analyses and approaches without verification or modification, in conformance with local custom. New information or changes in regulatory guidance could influence the plans or recommendations, perhaps fundamentally. As updated information becomes available, the interpretations and recommendations contained in this report may warrant change. To aid in revisions, we ask that readers or reviewers advise us of new plans, conditions, or data of which they are aware.

Concepts, findings and interpretations contained in this report are intended for the exclusive use of Santa Cruz County Department of Environmental Health, under the conditions presently prevailing except where noted otherwise. Their use beyond the data limits or assumptions discussed in the text could lead to environmental or structural damage, and/or to noncompliance with water-quality policies, regulations or permits. Data developed or used in this report were collected and interpreted solely for developing an understanding of the hydrologic context at the site as an aid to conceptual planning. They should not be used for other purposes without great care, updating, review of sampling and analytical methods used, and consultation with Balance staff familiar with the site. In particular, Balance Hydrologics, Inc. should be consulted prior to applying the contents of this report to geotechnical or facility design, sale or exchange of land, or for other purposes not specifically cited in this report.

Finally, we ask once again that readers who have additional pertinent information, who observed changed conditions, or who may note material errors should contact us with their findings at the earliest possible date, so that timely changes may be made.

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TABLES

Table 1. Average streamflow pre and post water year 1997 for Carbonera Creek, Santa Cruz County, California.

	Total Average Flow [1]	Baseflow [2]	Surface runoff [3]	Percent of baseflow [4]
Pre 1997 [5]	2,700	700	2,000	26%
Post 1997 [6]	3,800	100	3,700	3%
Difference [7]	1,100	-600	1,900	

Notes:

1) Average of total annual streamflow through USGS gage over period of record by water year.
2) Component of flow not associated with rainfall and runoff.
3) Component of flow associated with rainfall and runoff.
4) Baseflow total divided by total average flow.
5) Average of streamflow water years 1989 to 1997
6) Average of streamflow water years 1998 to 2007
7) Post 1997 - Pre 1997

Table 2. Stormwater quality for outfalls into Carbonera Creek, Santa Cruz County, California

Site	Total Nitrogen[1] (Mg-N/L)	Total[1] Mg-P/L	E. Coli[1] MPN/100 ml	Zinc[1] µg/L	Copper[1] µg/L	Lead[1] µg/L	TSS[1] mg/L	Cl[2] mg/L	Phenols[2] mg/L	Water Temp[2] °C	Conductivity[2] µS/cm	Average pH[2]	Oil Sheen[2] % present in samples
Glen Canyon[3]	0.6	0.4	5000	150	5	1	20	nd	nd	13 - 23.5	650	7.2	0
Disc Drive[4]	0.8	0.2	6000	100	5	1	30	nd	nd	13.5 - 19.5	825	6.8	11
Carbonero[5]	0.7	1	2000	120	40	5	20	nd	nd	14.5 - 20	625	6.0 - 8.0	0
Seagate[6]	1	0.2	3000	130	42	8	80	nd	nd	NA	NA	NA	18

Notes:

1) Data are from 2005 Dry Run & First Flush Monitoring Report - Monterey Bay Sanctuary Citizen Watershed Monitoring Network
2) Data are from 2005 Urban Watch-First Flush Storm Drain Monitoring Program in the City of Scotts Valley Santa Cruz County, California
3) Glen Canyon site was visited 40 times from 10/25/05 to 7/25/05. Flowing water was observed 98% of the field visits
4) Disk Drive site was visited 38 times from 10/25/05 to 7/25/05. Flowing water was observed 100% of the field visits.
5) Carbonero site was visited 38 times from 10/25/05 to 7/25/02. Flowing water was observed 37% of the visits.
6) Seagate site was visited 38 times from 10/25/05 to 7/25/05. Flowing water was observed 37% of the visits

FIGURES

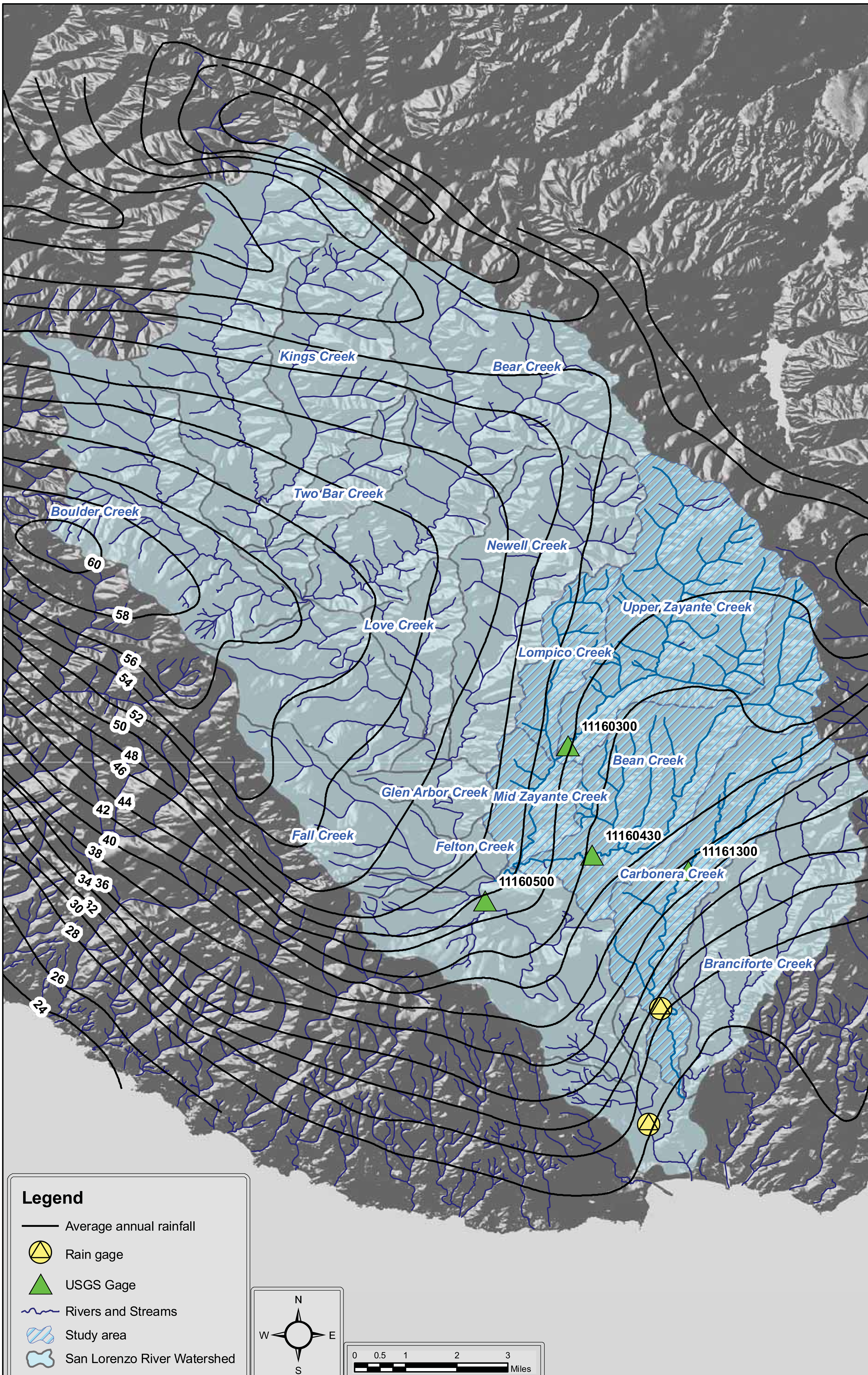

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Figure 1. Mean annual isohyets within the San Lorenzo River, Santa Cruz County, California.

Datasources: Santa Cruz County GIS: rainfall, watersheds, streams
USGS: DEM

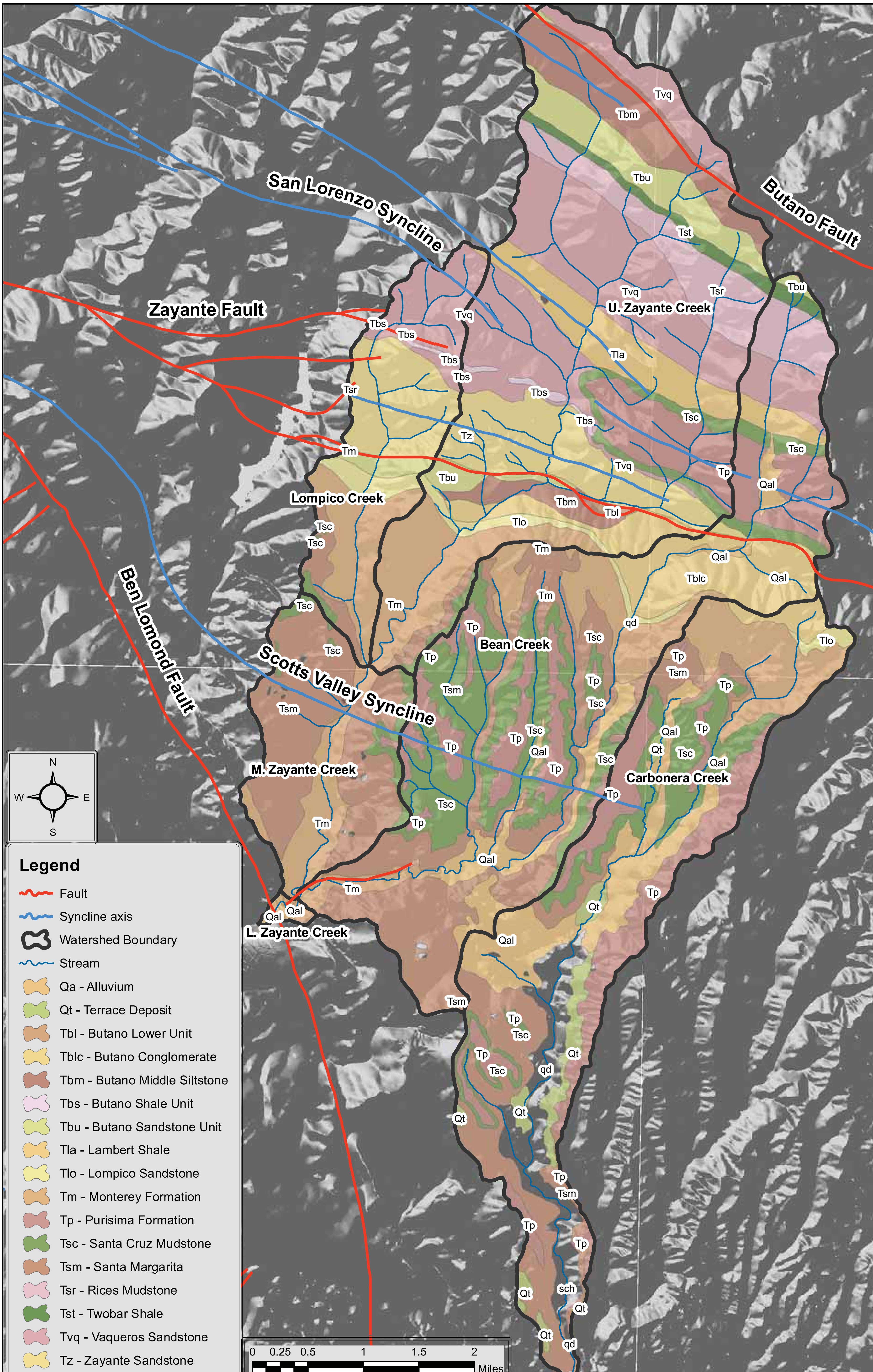

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Figure 2. Surface geology of Bean, Carbonera, and Zayante Creek watersheds, Santa Cruz County, California.

Datasources: DEM, USGS; Geology, Greene, 2002

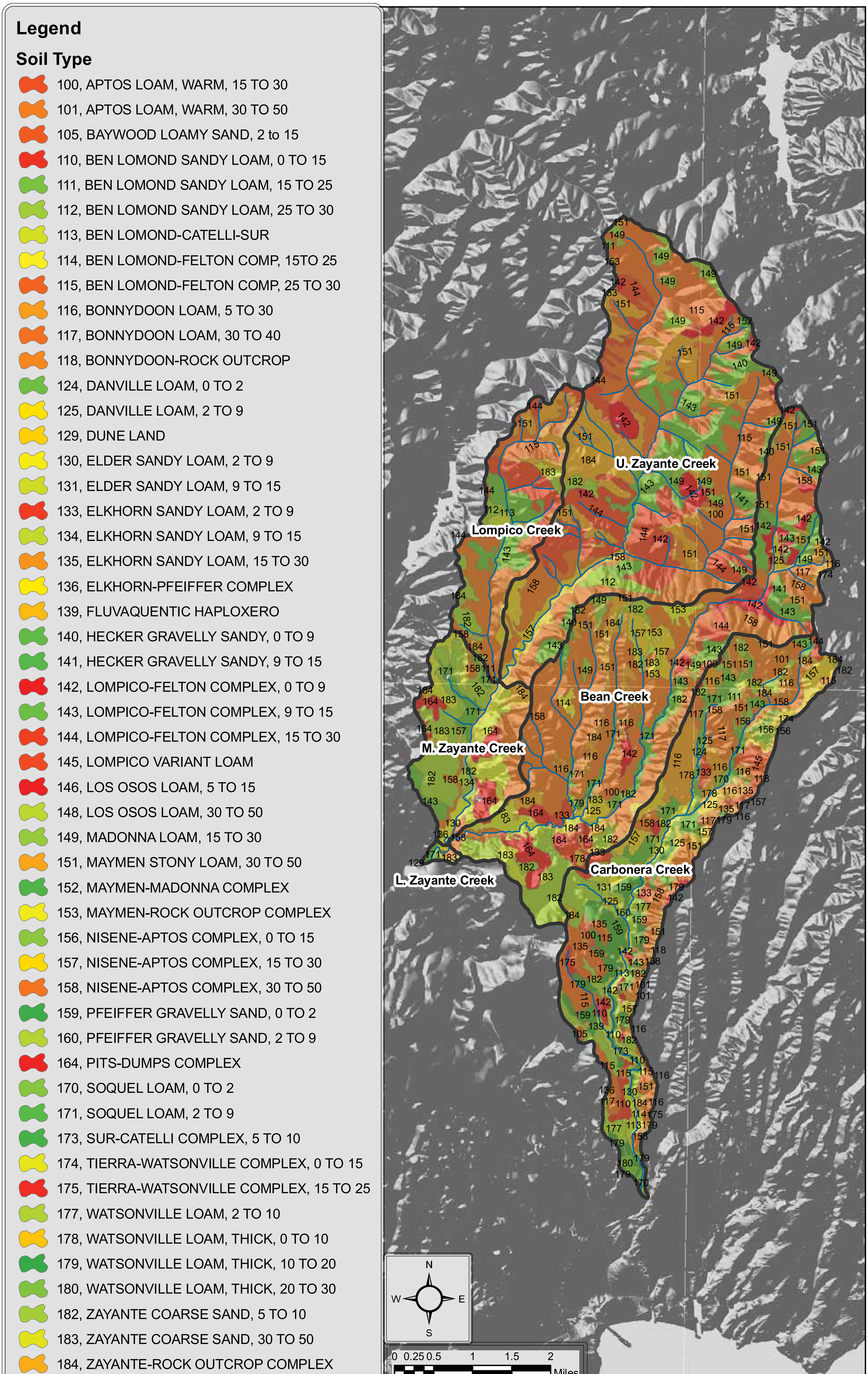

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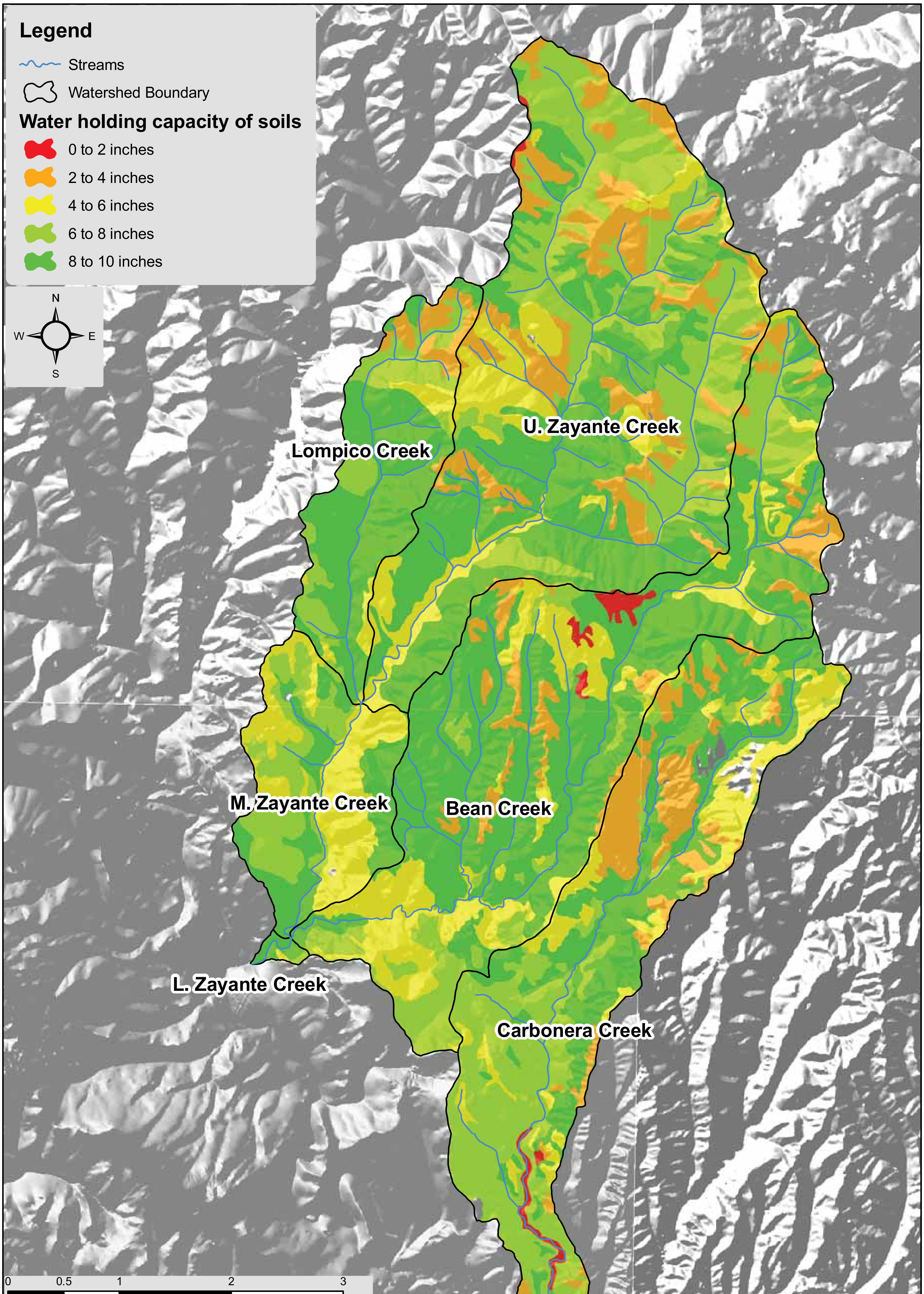
Figure 3. Soil types of Bean, Carbonera, and Zayante Creek watersheds, Santa Cruz County, California.

Datasources: DEM, USGS; Soil types, NRCS



Cumulative rainfall required to saturate soils and innate runoff

Watershed	(inches)
Zayante	6.5
Bean	5.9
Carbonera	7.8

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Figure 4. Soil water holding capacity of Bean, Carbonera, and Zayante Creek watersheds, Santa Cruz County, California.

Datasources: DEM, USGS; Soil Properties; NRCS

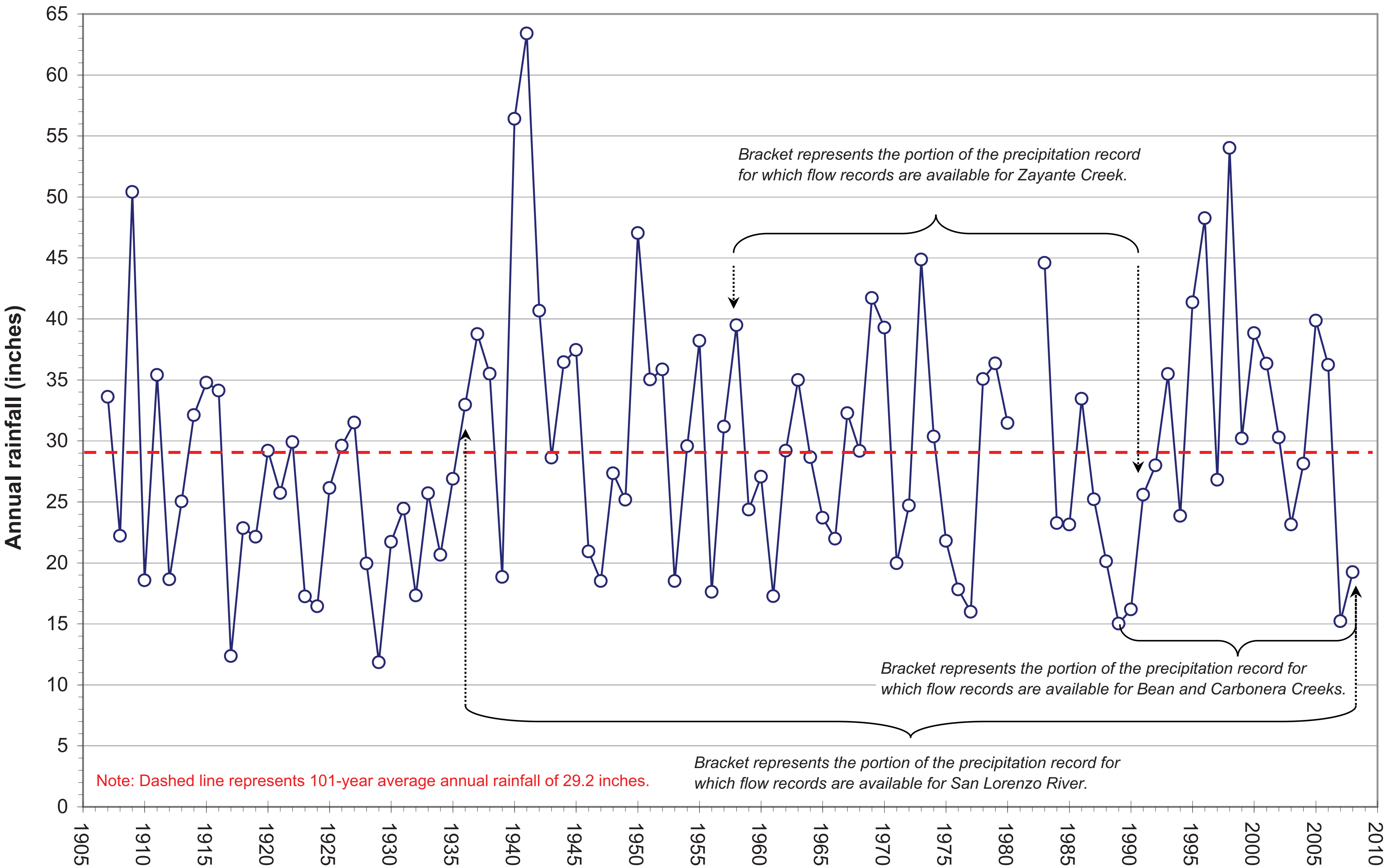

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Figure 5. Precipitation recorded by water year at National Weather Service SRZ station, Felton, Santa Cruz County, California. Source: National Weather Service SRZ precipitation station. Data are missing from 1-1-1982 through 9-1-1983, two years of extremely high rainfall.

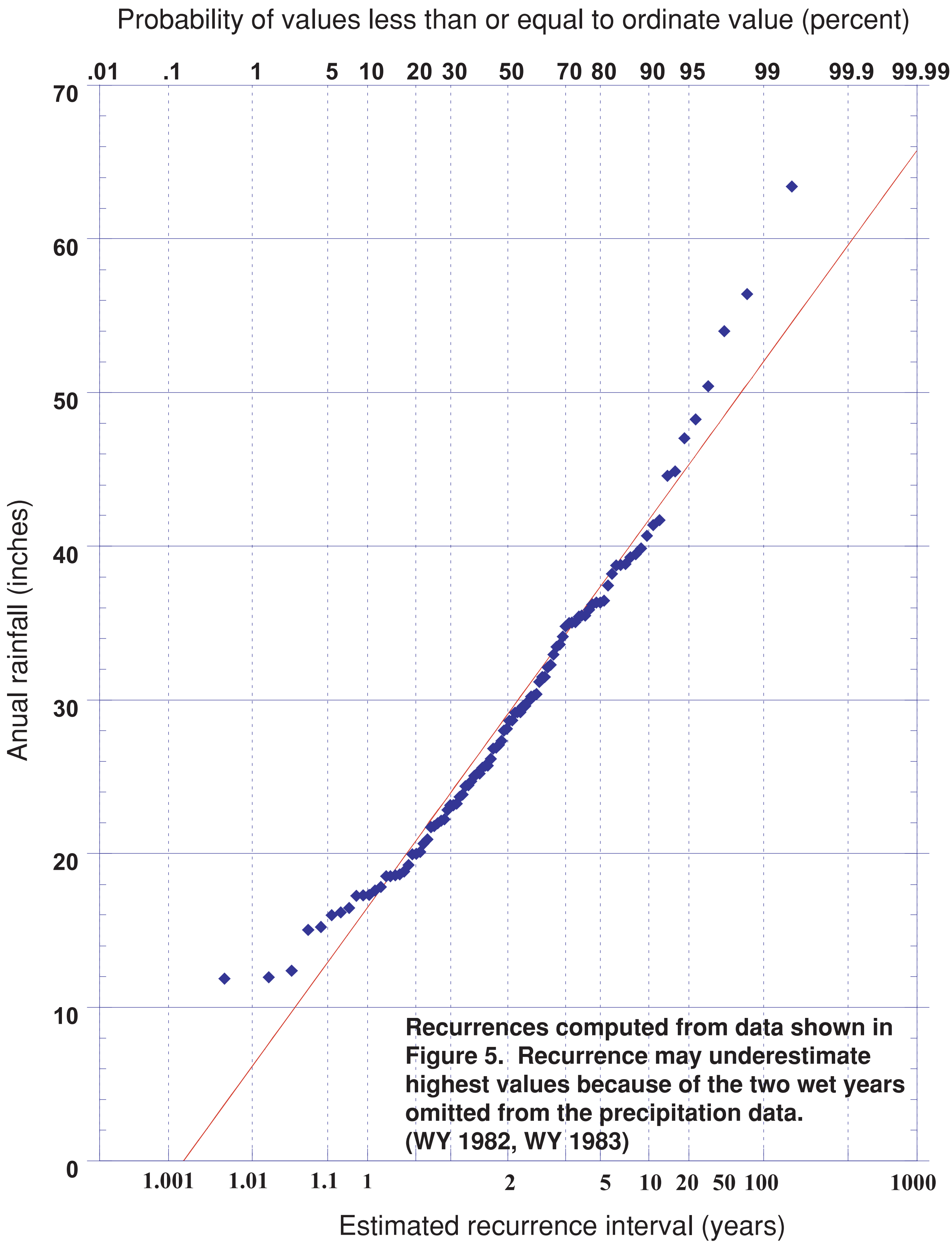

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Figure 6. Recurrence interval of annual precipitation for National Weather Service CRZ station, Santa Cruz County, California

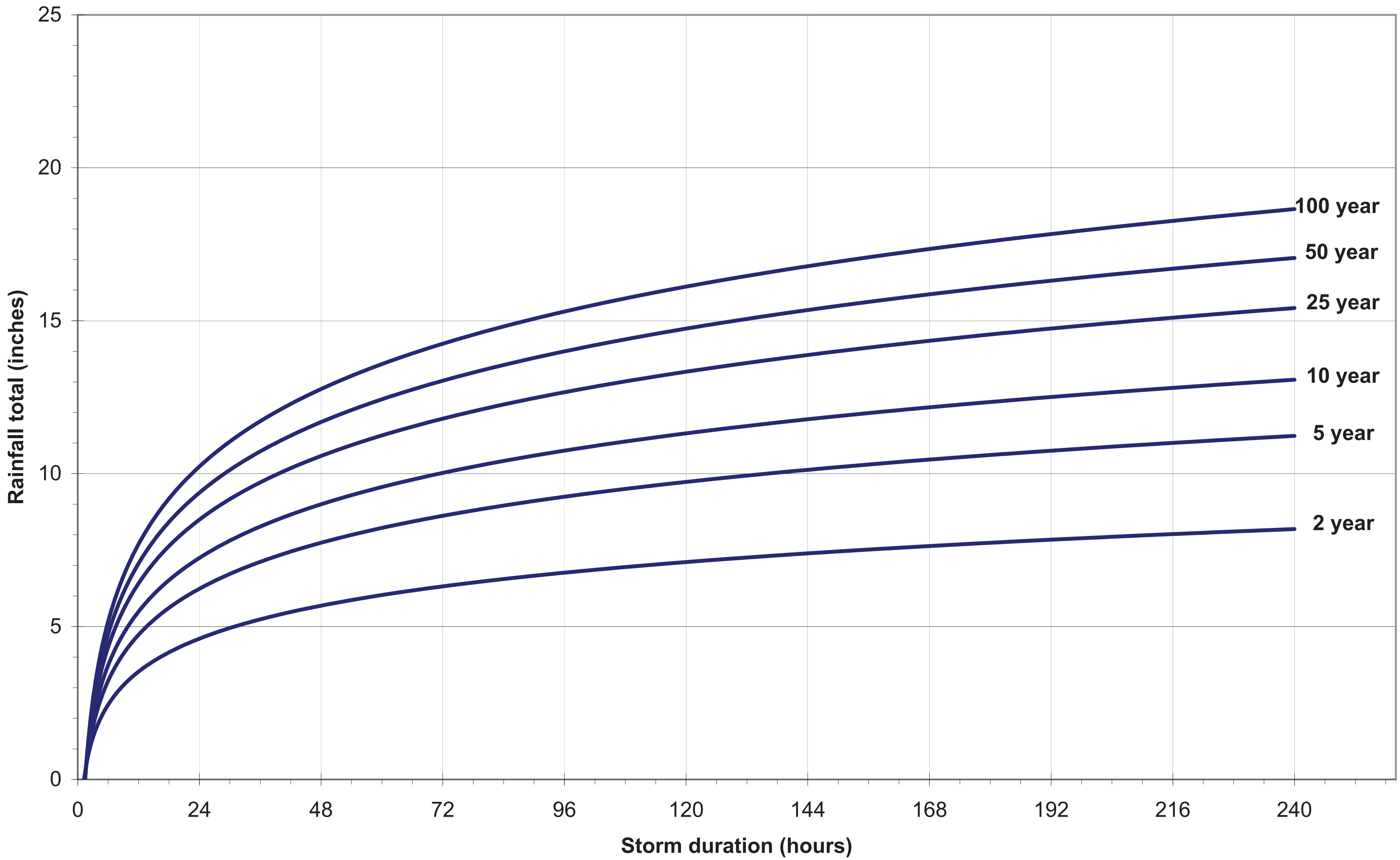

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Figure 7. Depth - duration - frequency relationships for Bean Creek Watershed, Santa Cruz County, California

Relationships to mean annual rainfall given in Rantz, 1973. The mean annual rainfall for Bean Creek is 37.5 inches (source: USGS and Santa Cruz County Water Resources).

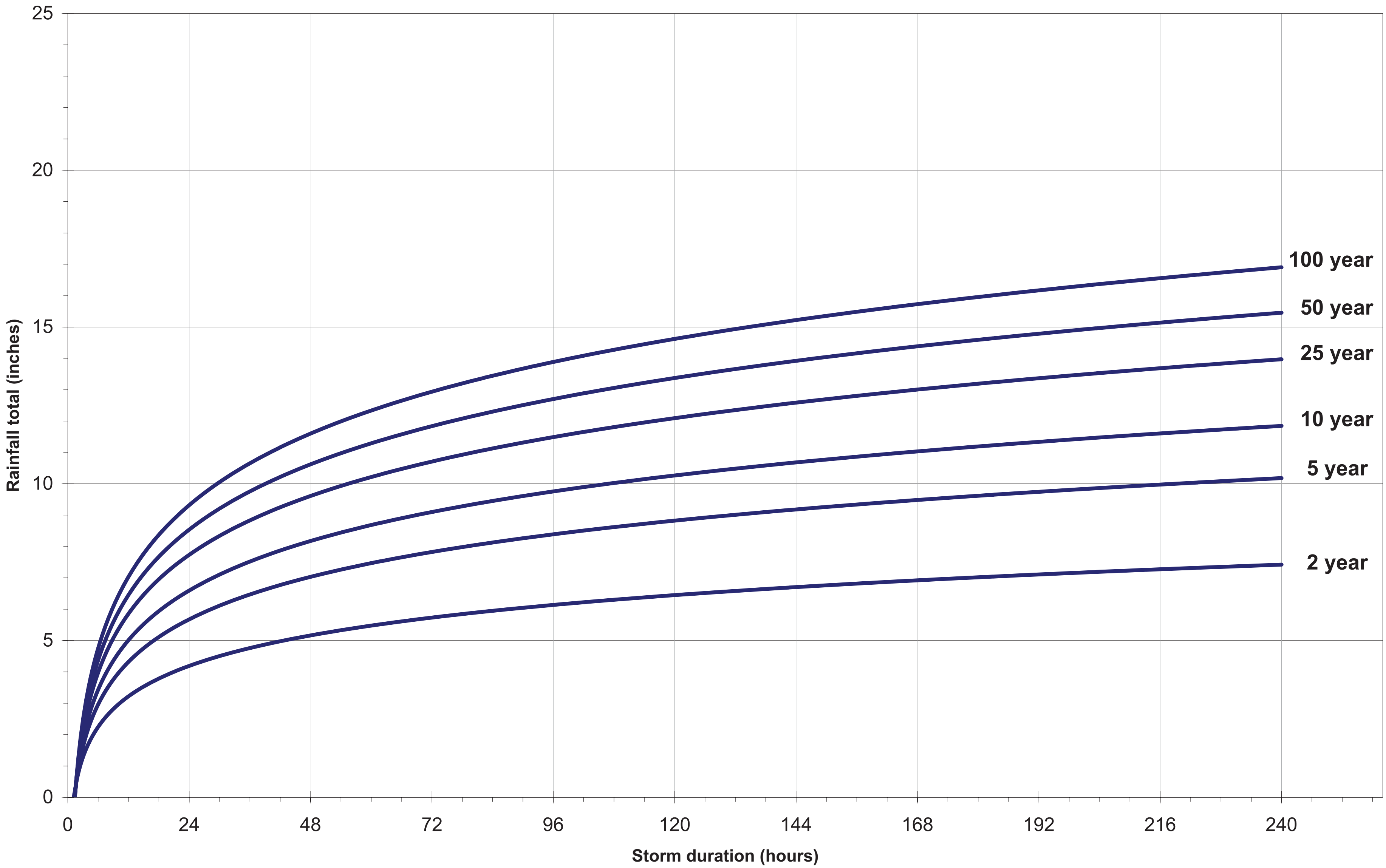

Figure 8. Depth - duration - frequency relationships for Carbonera Creek Watershed, Santa Cruz County, California

Relationships to mean annual rainfall given in Rantz, 1973. The mean annual rainfall for Carbonera Creek is 34 inches (source: USGS and Santa Cruz County Water Resources).

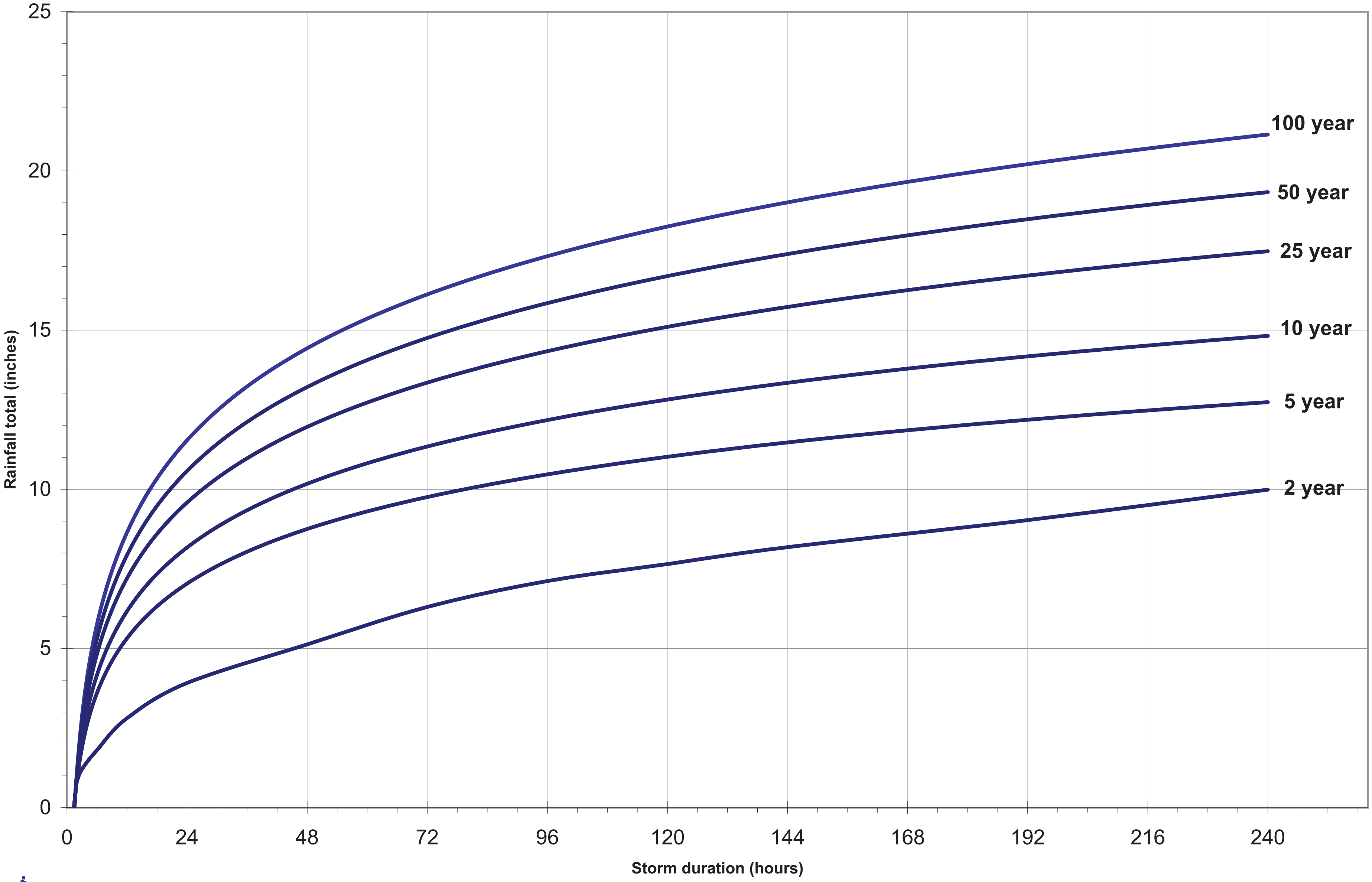

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Figure 9. Depth - duration - frequency relationships for Zayante Creek Watershed, Santa Cruz County, California

Relationships to mean annual rainfall given in Rantz, 1973. The mean annual rainfall for Zayante Creek is 45 inches (source: USGS and Santa Cruz County Water Resources).

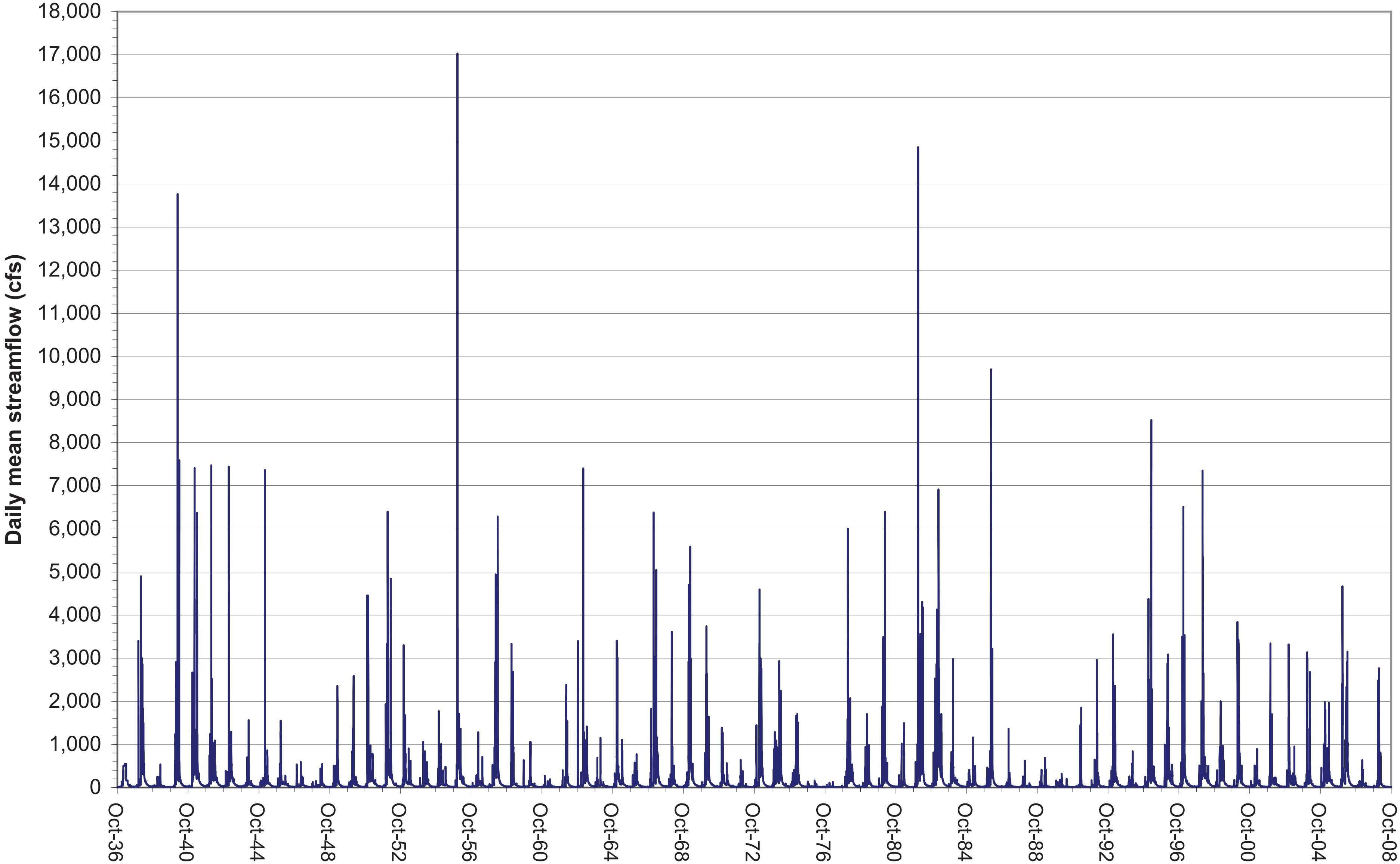

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Figure 10. Daily mean streamflow in San Lorenzo River at Big Trees State Park for water years 1940 through 2007, Santa Cruz County, California.

Data source: USGS Gage No. 11160500

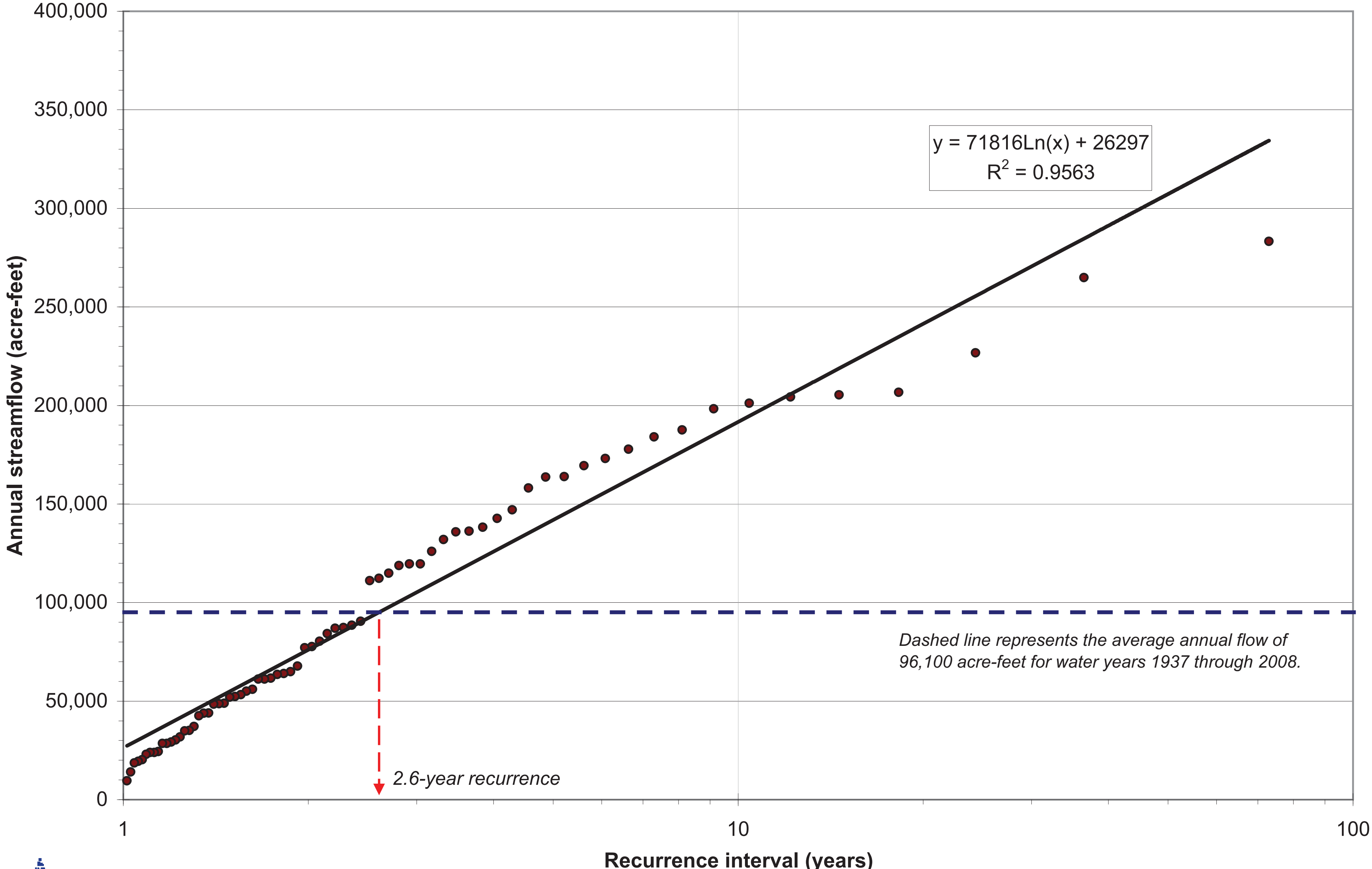

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Figure 11. Annual yield and recurrence interval for San Lorenzo River at Big Trees State Park, Santa Cruz County, California. Data source: USGS gage no. 11160500. Gumbel Type III method used to rank data.

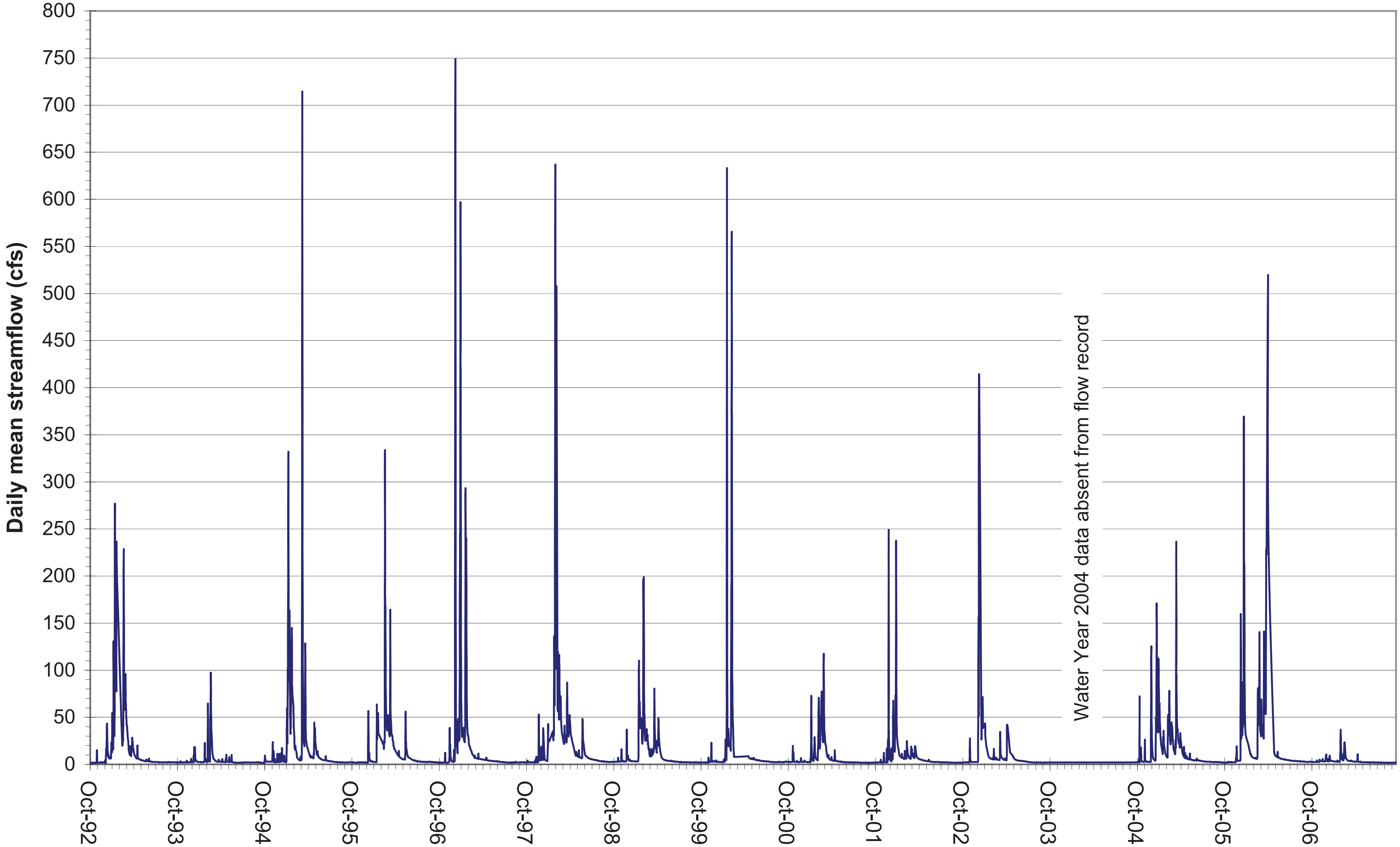

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Figure 12. Daily mean streamflow in Bean Creek near Scotts Valley for water years 1993 through 2007, Santa Cruz County, California. Data source: USGS Gage No. 11160430.

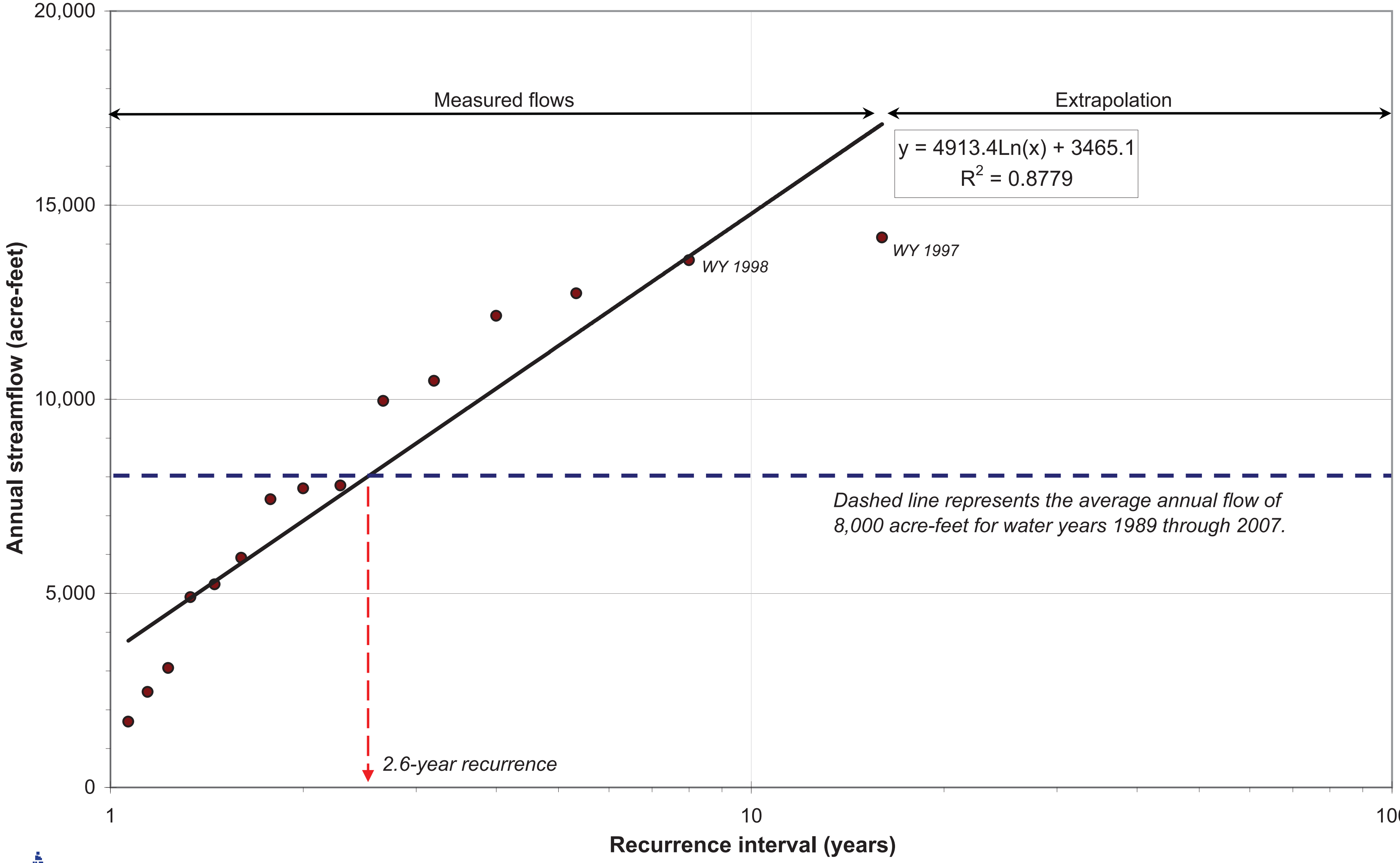

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Figure 13. Annual yield and recurrence interval for Bean Creek near Scotts Valley, Santa Cruz County, California. Data source: USGS Gage No. 11160430. Gumbel Type III method used to rank data.

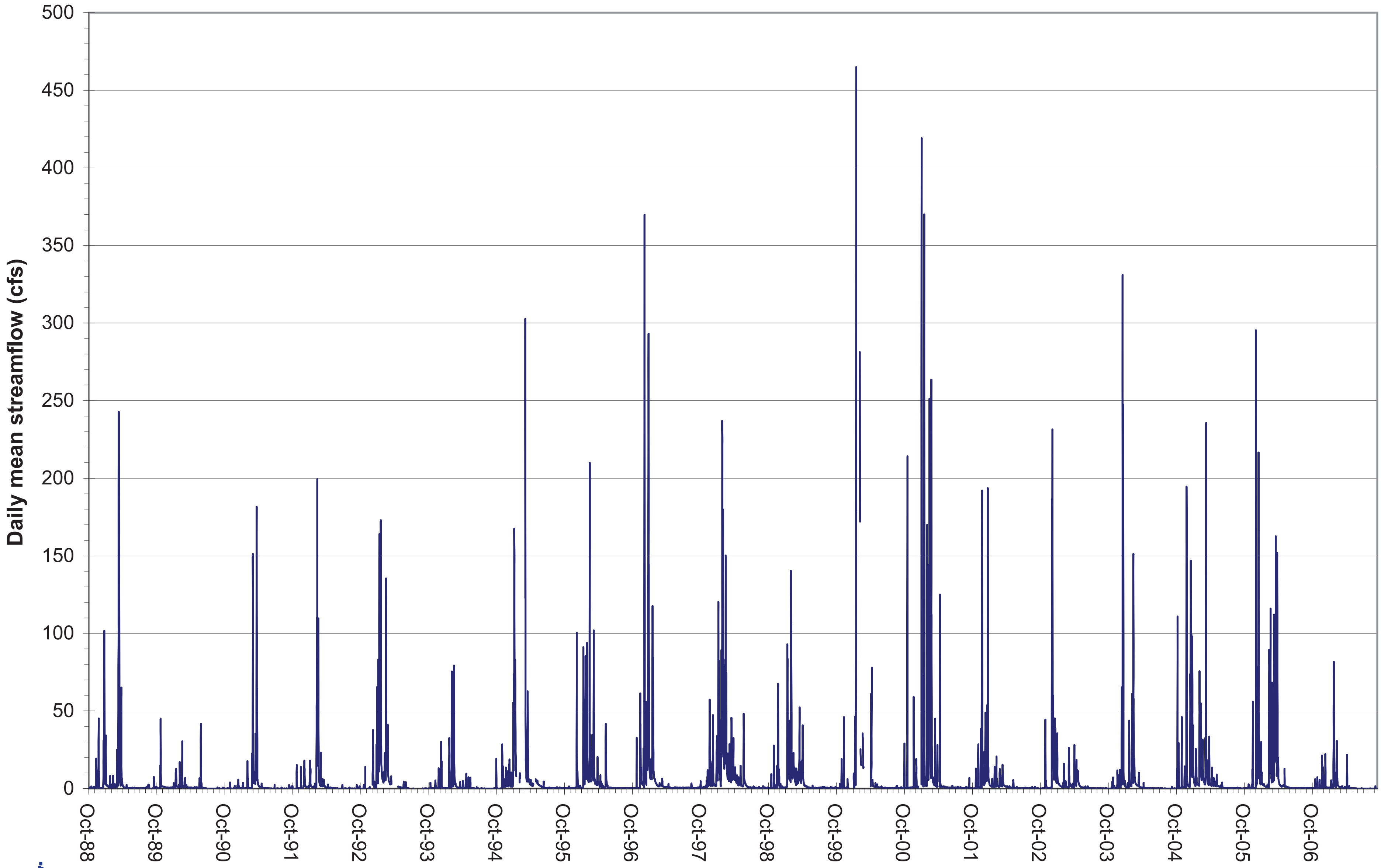

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Figure 14. Daily mean streamflow in Carbonera Creek at Scotts Valley for water years 1989 through 2007, Santa Cruz County, California. Data source: USGS Gage No. 11161300.

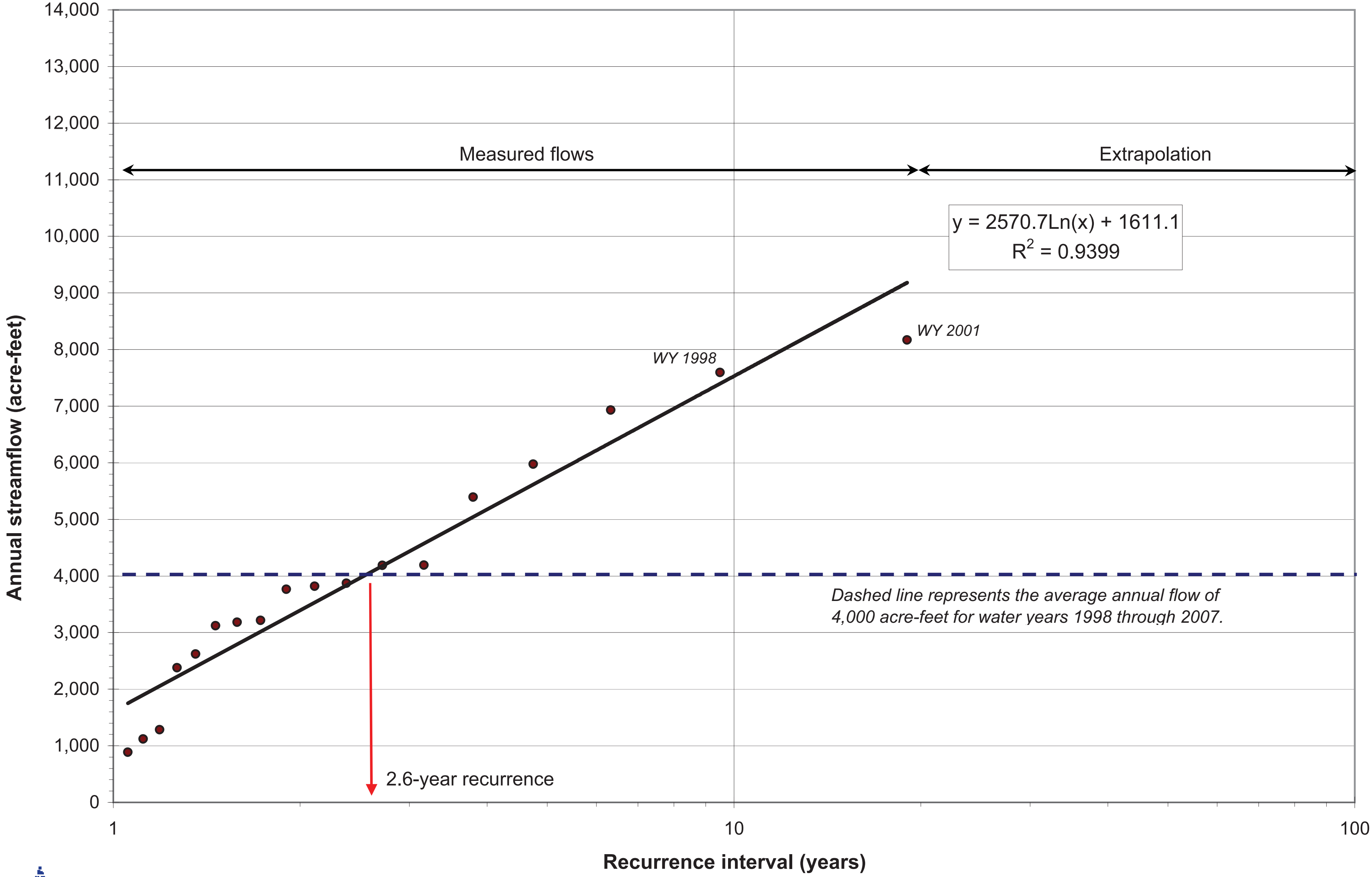

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Figure 15. Annual yield and recurrence interval for Carbonera Creek at Scotts Valley, Santa Cruz County, California. Data source: USGS Gage No. 11161300. Gumbel Type III method used to rank data.

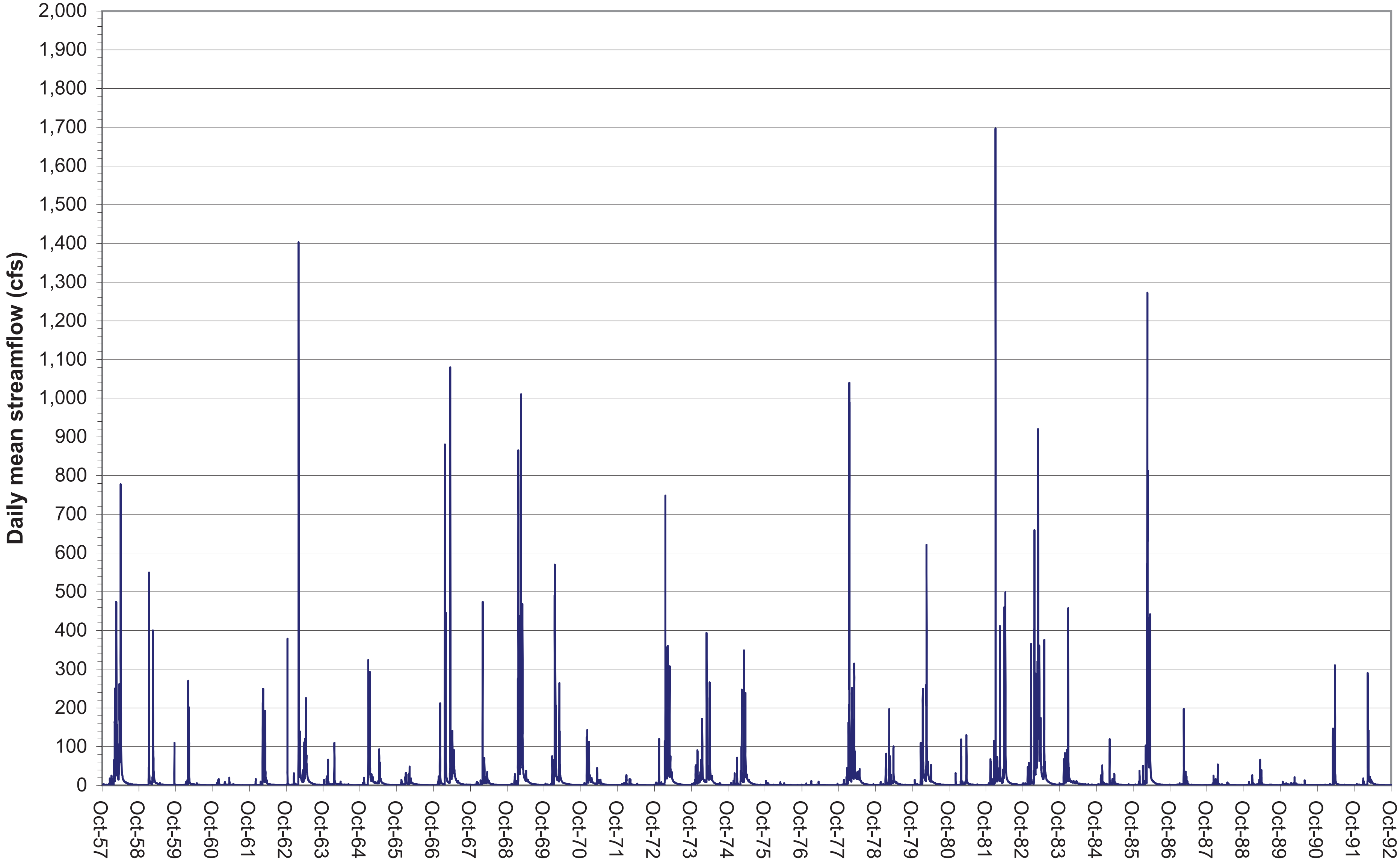

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Figure 16. Daily mean streamflow in Zayante Creek at Zayante for water years 1959 through 1992, Santa Cruz County, California. Data source: USGS Gage No. 11160300.

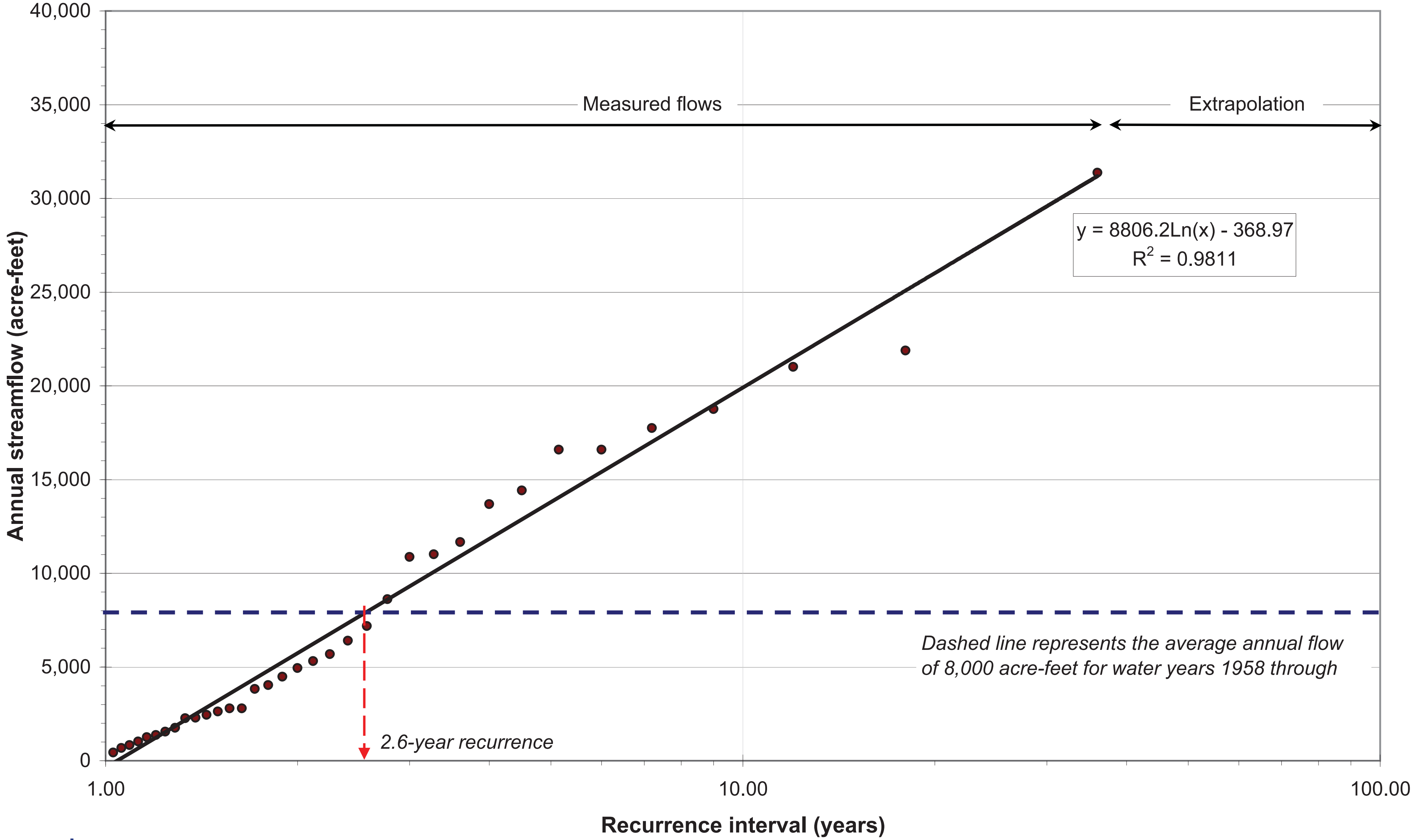

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Figure 17. Annual yield and recurrence interval for Zayante Creek at Zayante, Santa Cruz County, California. Data source: USGS Gage No. 11160300. Gumbel Type III method used to rank data.

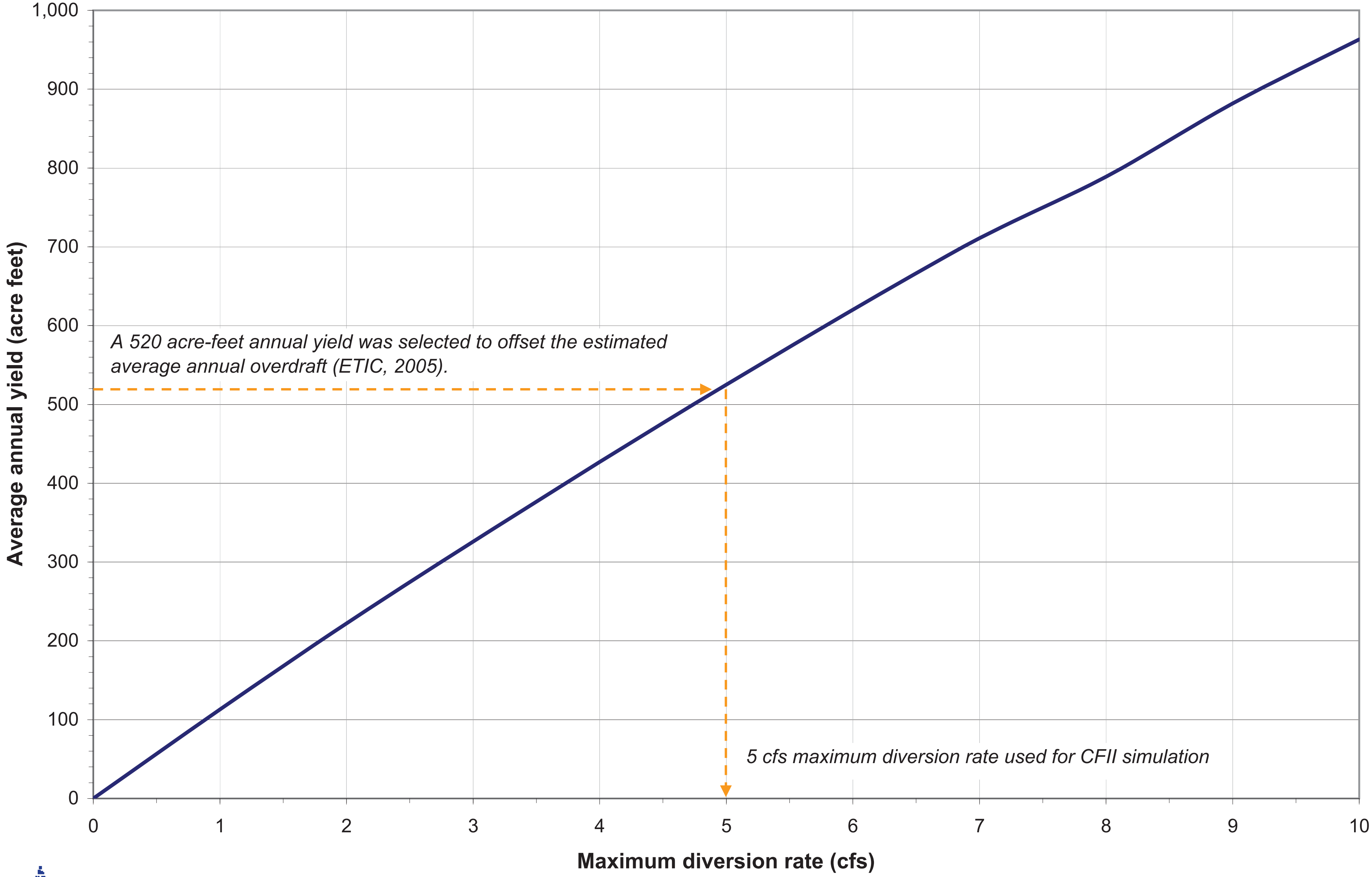

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Figure 18. Maximum diversion rate versus annual yield, Bean Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs; Diversions October 1 through March 31.

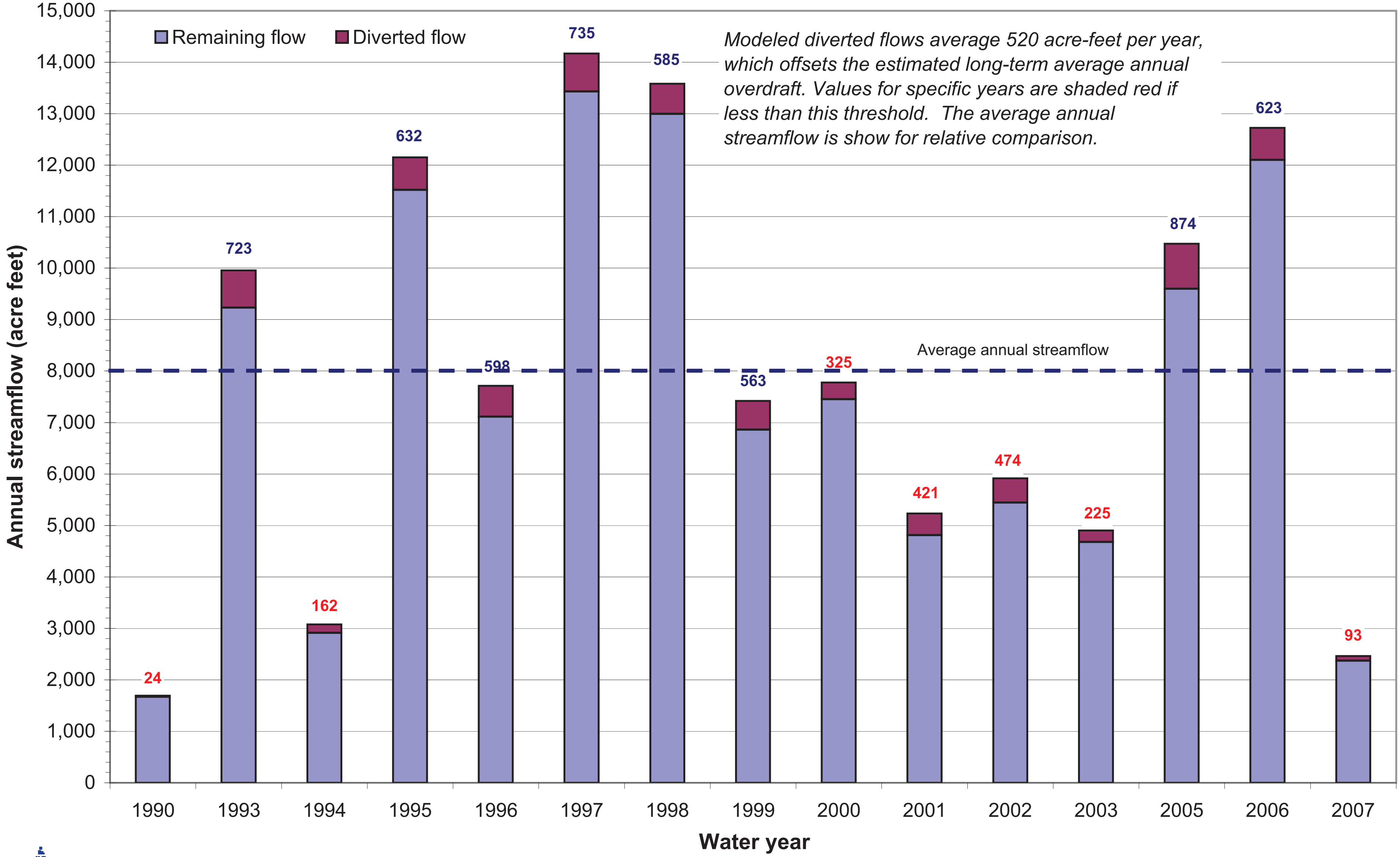

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Figure 19. Annual volume of water available by water year for diversion from Bean Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs, the maximum diversion rate of 5 cfs, and a diversion period from October 1 through March 31.

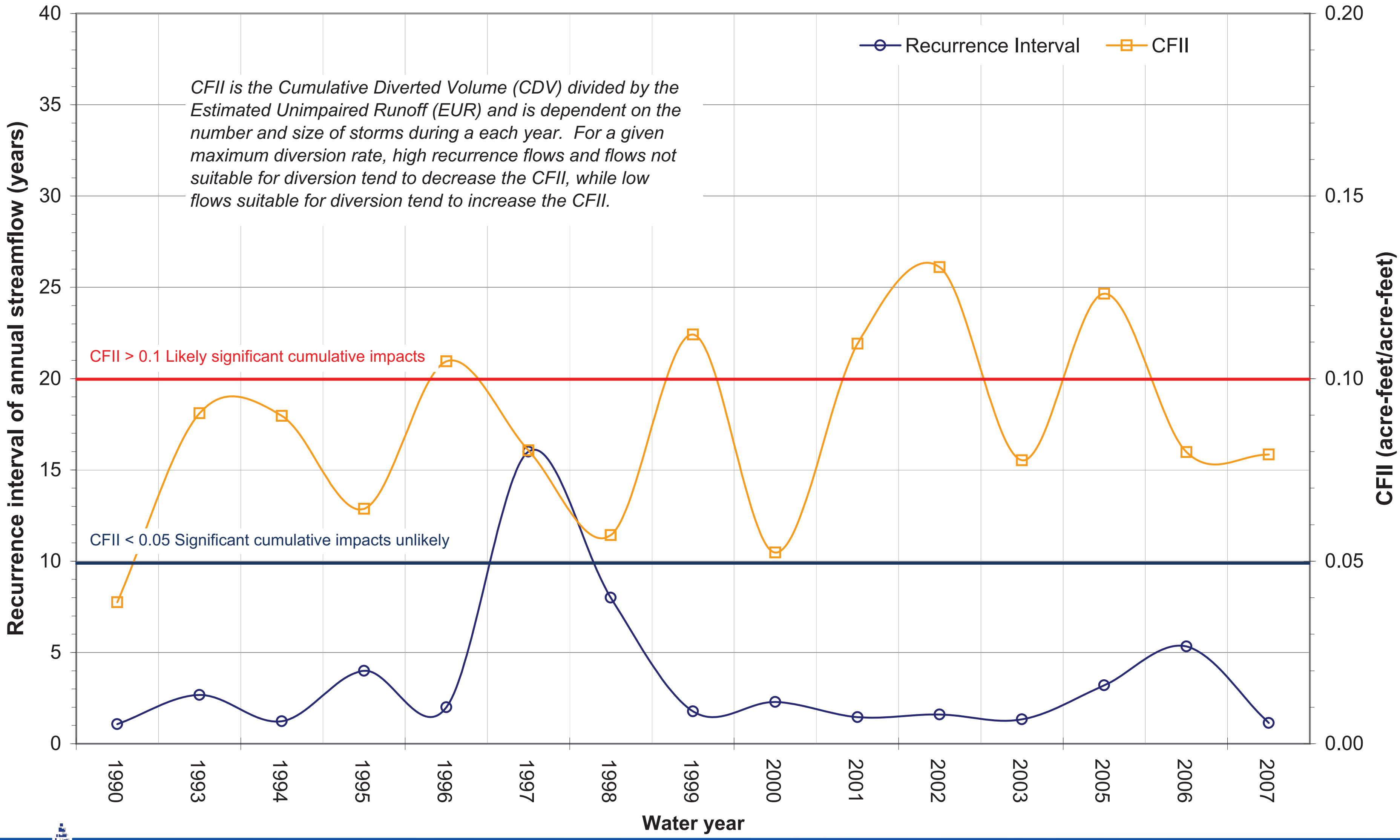

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Figure 20. Recurrence interval of annual yield and simulated Cumulative Flow Impairment Index (CFII) by year for proposed diversion operations, Bean Creek, Santa Cruz County, California. Proposed maximum diversion rate of 5 cfs from October 1 to March 31.

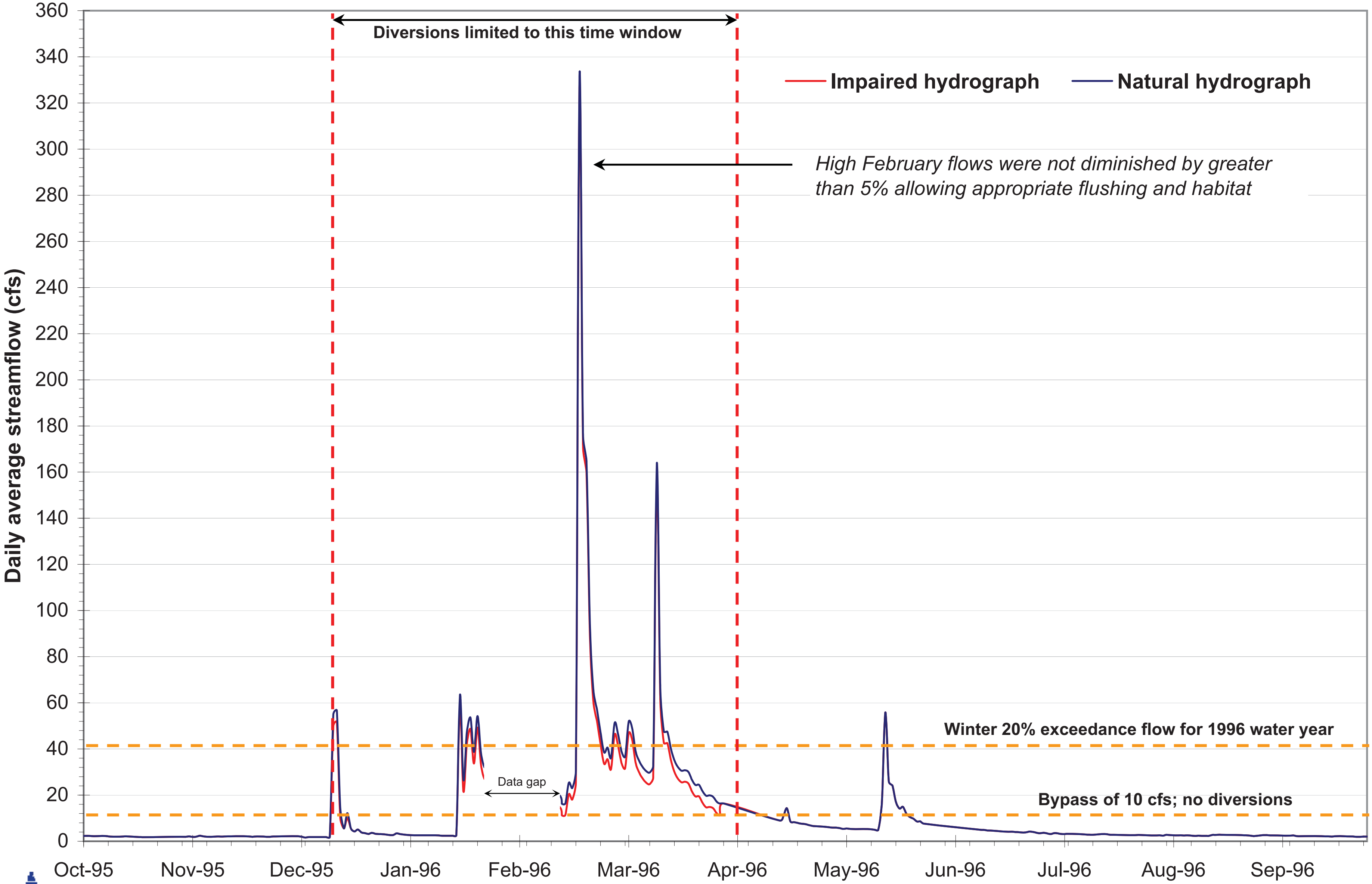

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Figure 21. Recorded hydrograph for water year 1996 and simulated hydrograph with proposed diversion operations of 5 cfs maximum rate, Bean Creek, Santa Cruz County, California. Water year 1996 was chosen because it represents a 2-year annual flow return interval of 7,100 acre-feet for Bean Creek. Total simuated diversion is 598 acre-feet.

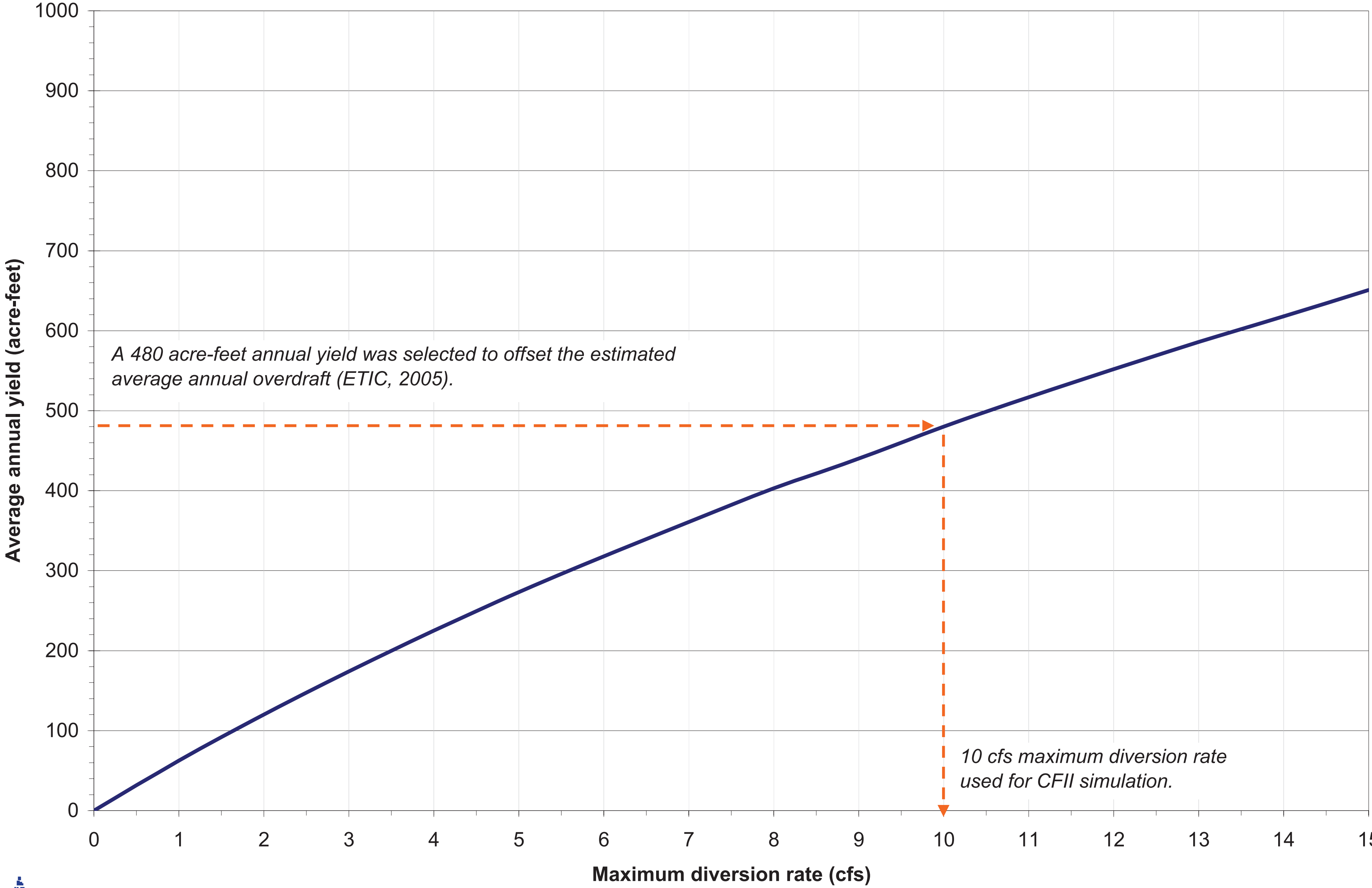

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Figure 22. Maximum diversion rate versus annual yield, Carbonera Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs; Diversions October 1 through March 31.

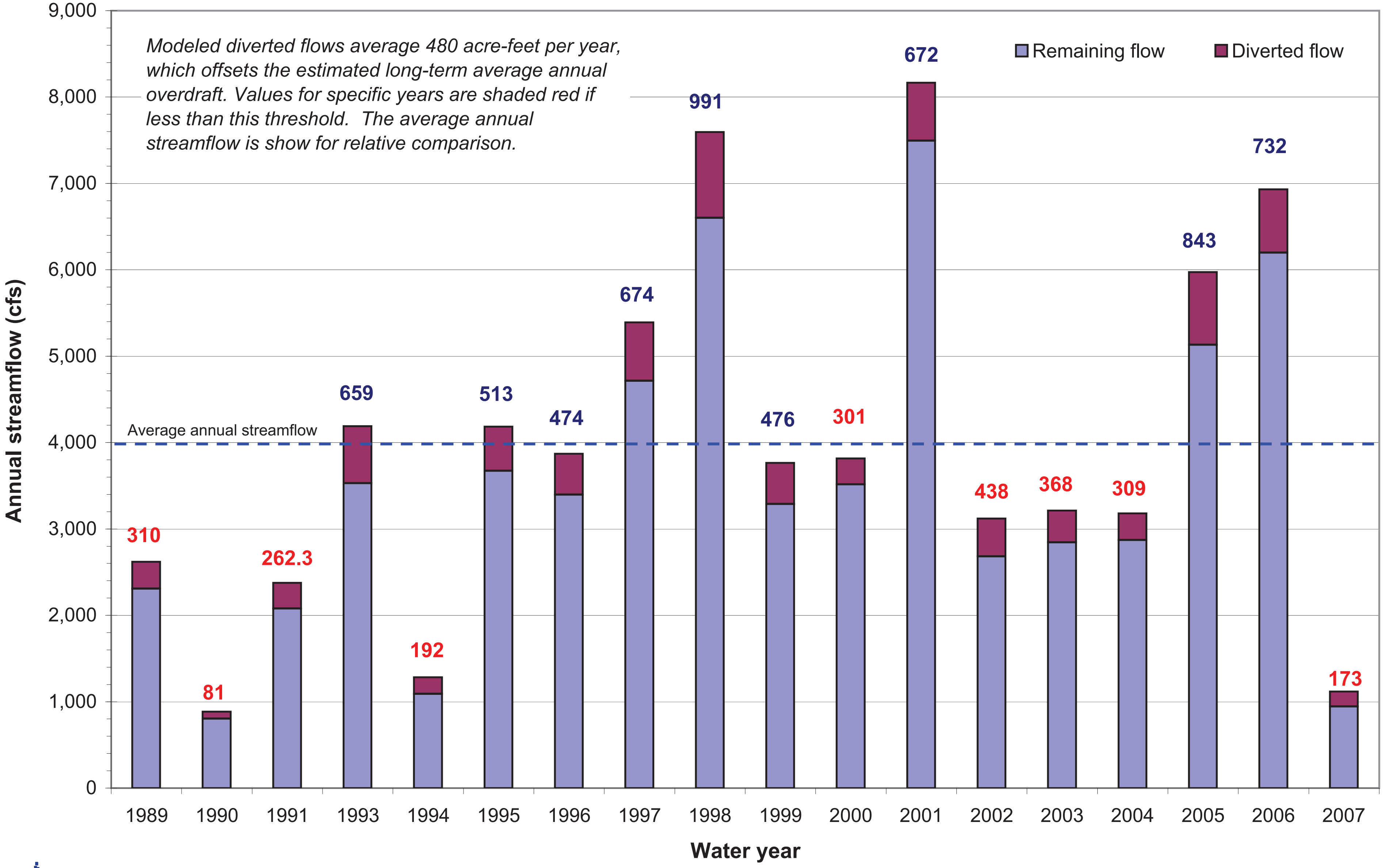

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Figure 23. Annual volume of water available by water year for diversion from Carbonera Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs, the maximum diversion rate of 10 cfs, and a diversion period from October 1 through March 31.

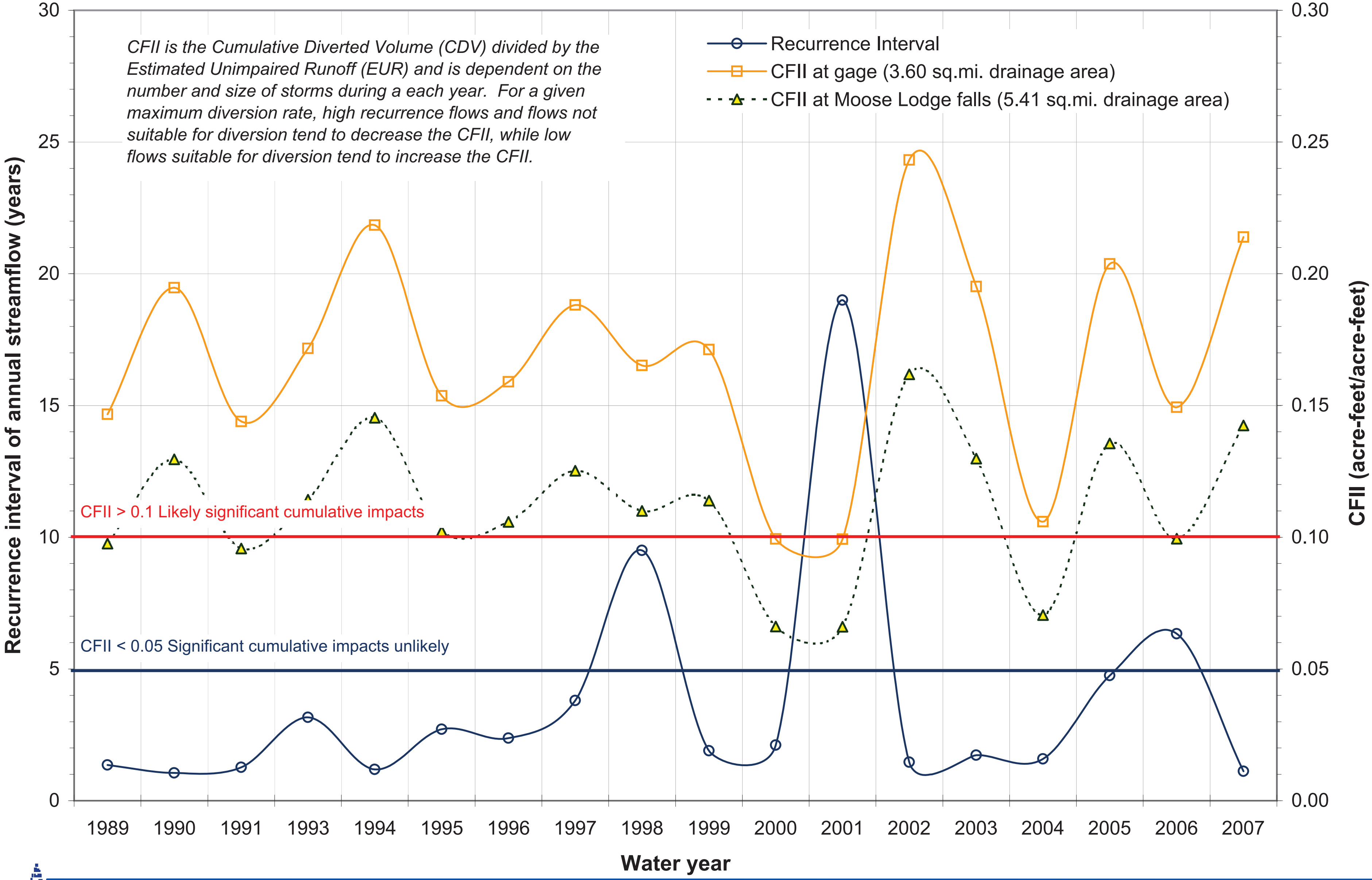

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Figure 24. Recurrence interval of annual yield and simulated Cumulative Flow Impairment Index (CFII) by year for proposed diversion operations, Carbonera Creek, Santa Cruz County, California. Proposed maximum diversion rate of 12 cfs from October 1 to March 31.

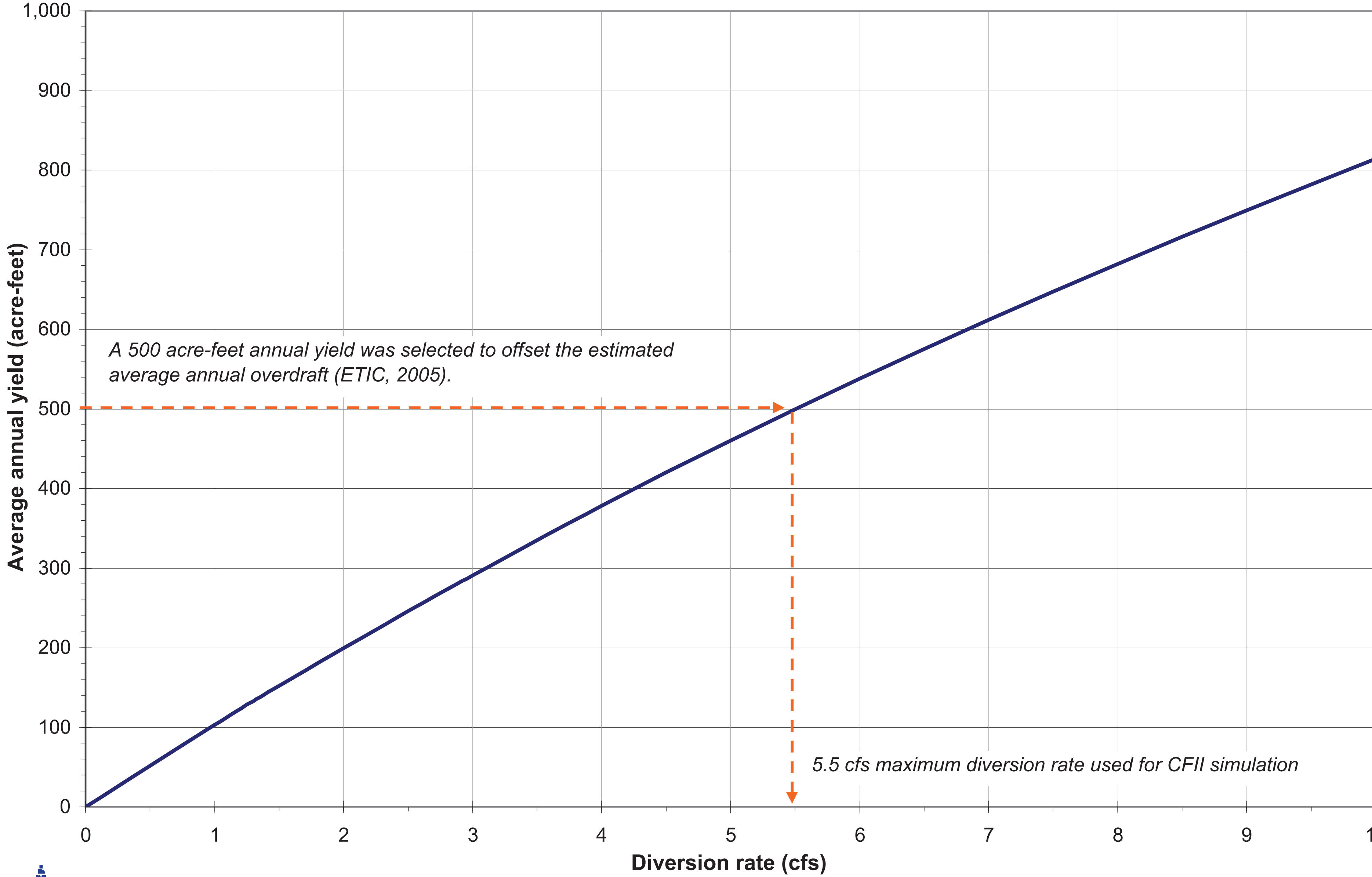

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Figure 25. Maximum diversion rate versus annual yield, Zayante Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs; Diversions October 1 through March 31.

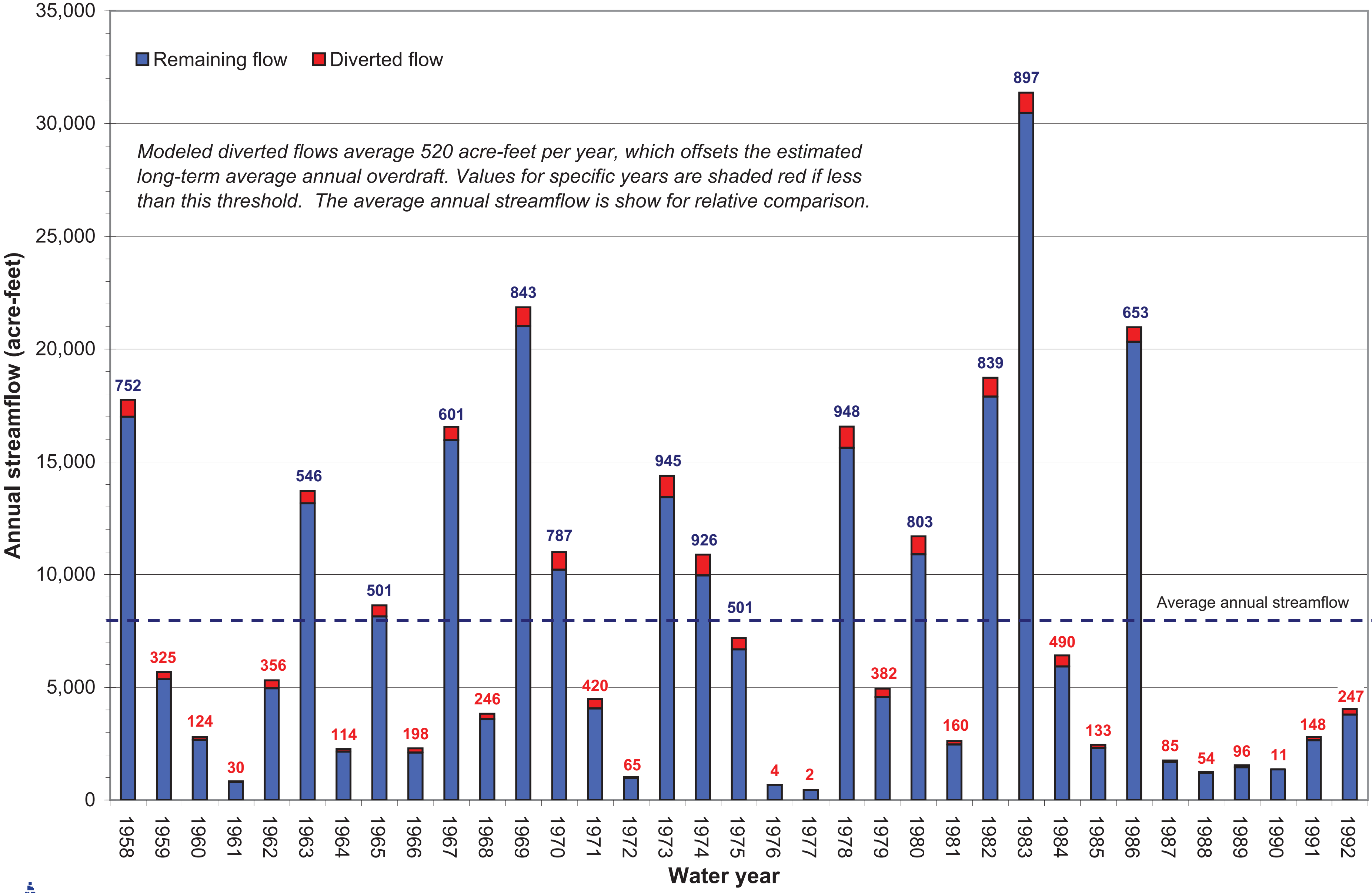

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Figure 26. Annual volume of water available by water year for diversion from Zayante Creek, Santa Cruz County, California. Assumptions: Bypass flow of 10 cfs, the maximum diversion rate of 5.5 cfs, and a diversion period from October 1 through March 31.

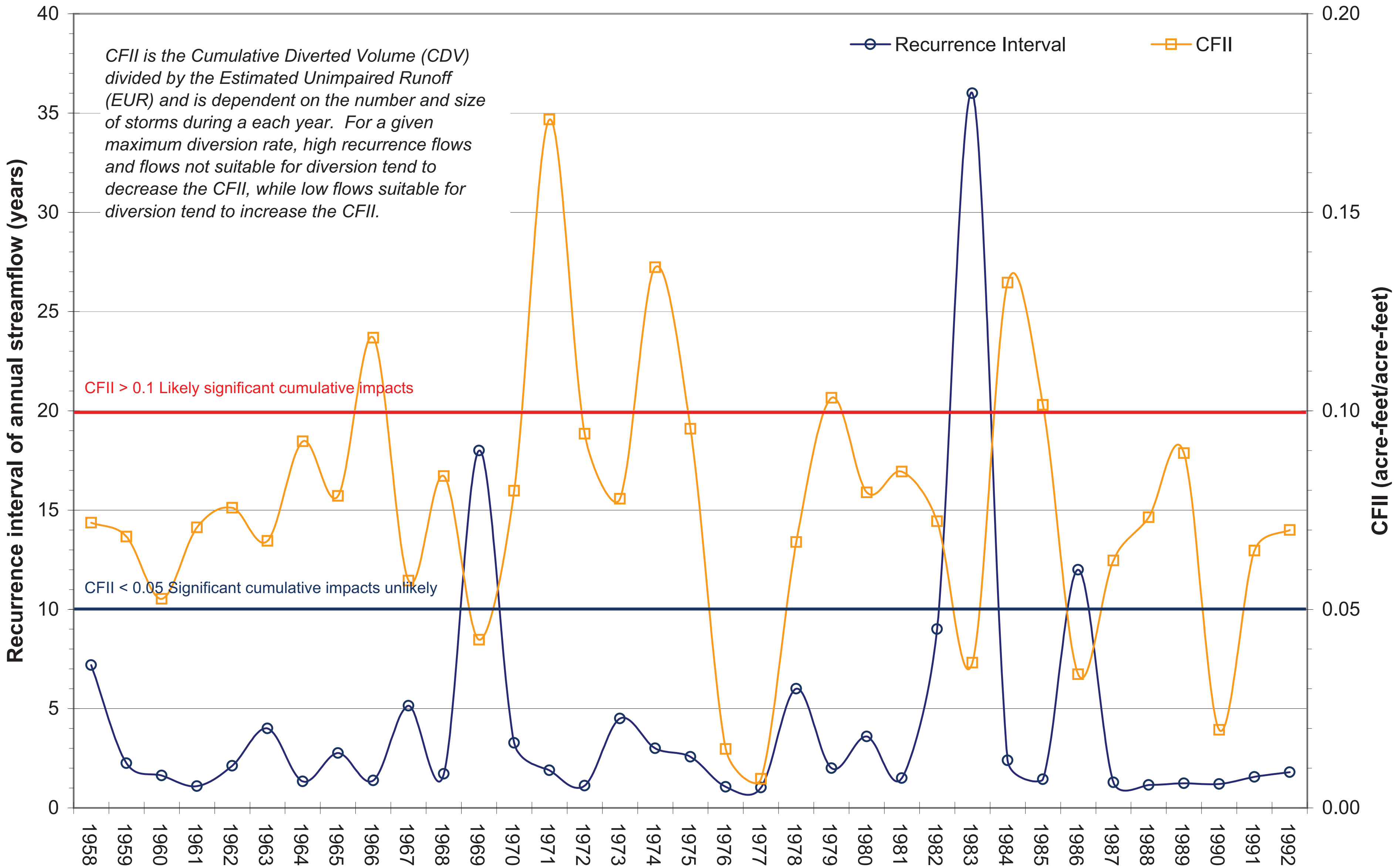

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Figure 27. Recurrence interval of annual yield and simulated Cumulative Flow Impairment Index (CFII) by year for proposed diversion operations, Zayante Creek, Santa Cruz County, California. Proposed maximum diversion rate of 5.5 cfs from October 1 to March 31.

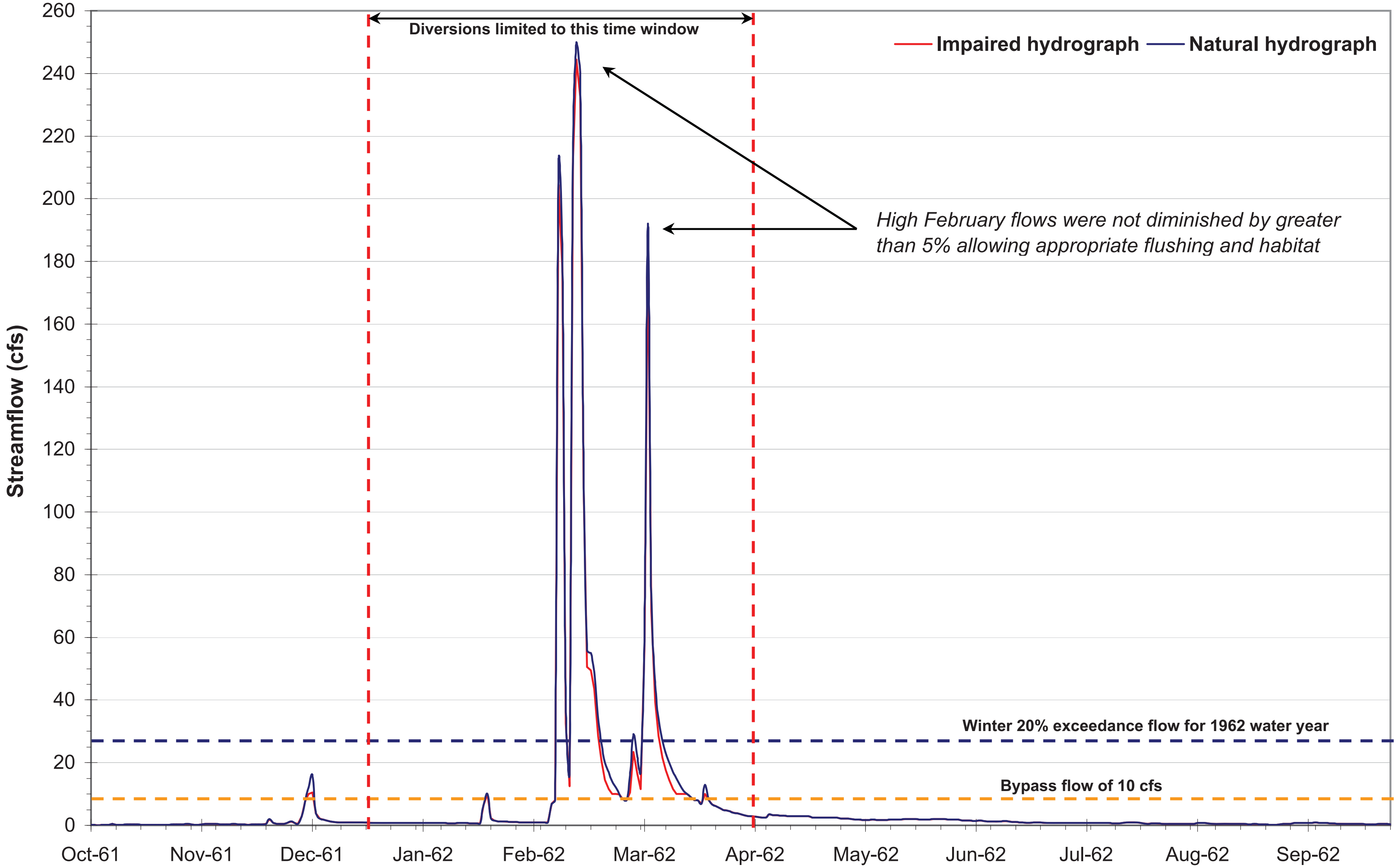

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Figure 28. Recorded hydrograph for water year 1962 and simulated hydrograph with proposed diversion operations of 5.5 cfs maximum rate, Zayante Creek, Santa Cruz County, California. Water year 1962 was chosen because it represents a 2-year annual flow return interval of 6,700 acre-feet for Zayante Creek. Total simuated diversion is 356 acre-feet.

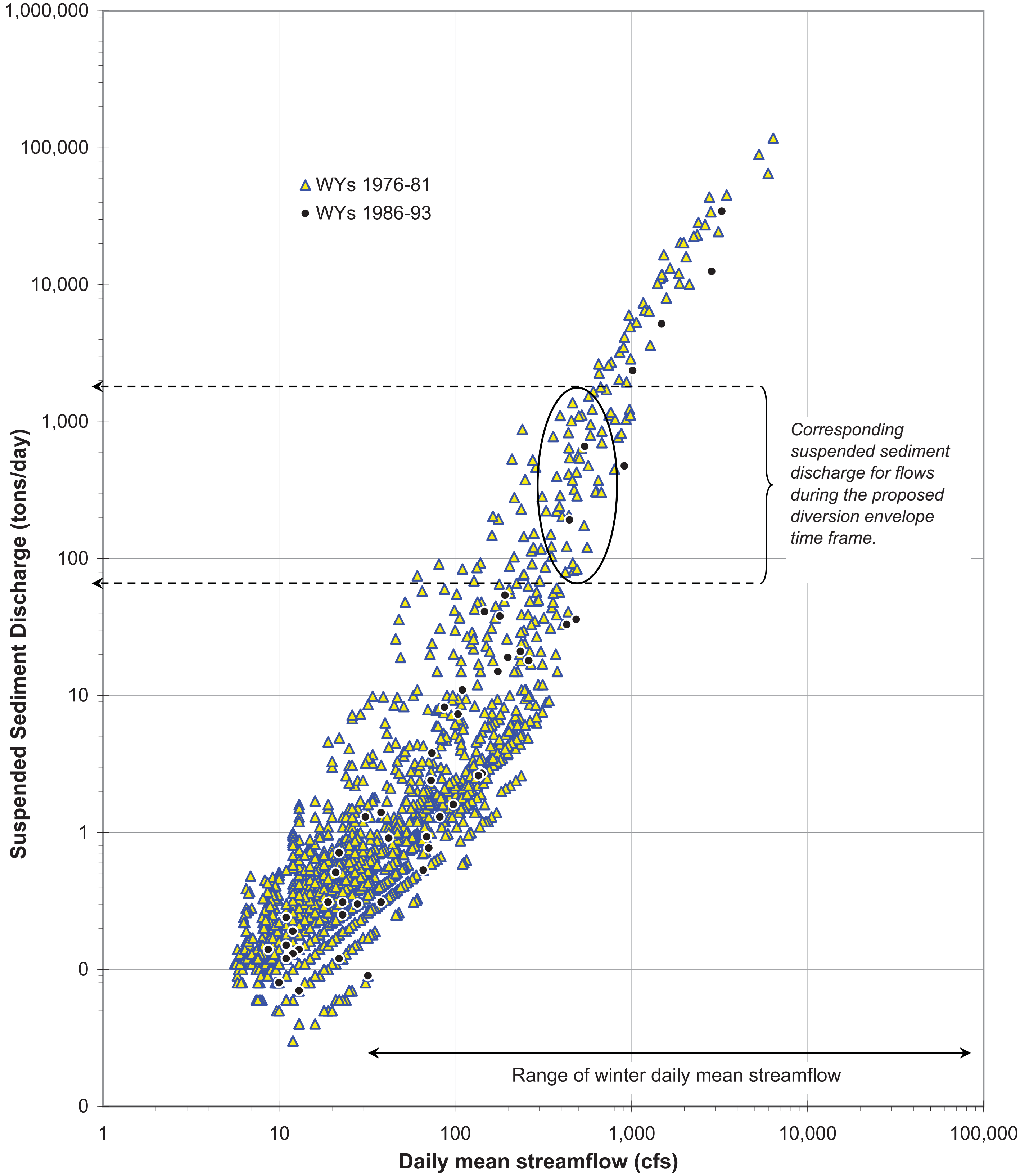

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Figure 29. Suspended-sediment transport in San Lorenzo River at Big Trees State Park, Santa Cruz County, California. Source: USGS via Hydrosphere CD-ROM

204141 sanlor_s 7-21-09.xls, 7/21/2009

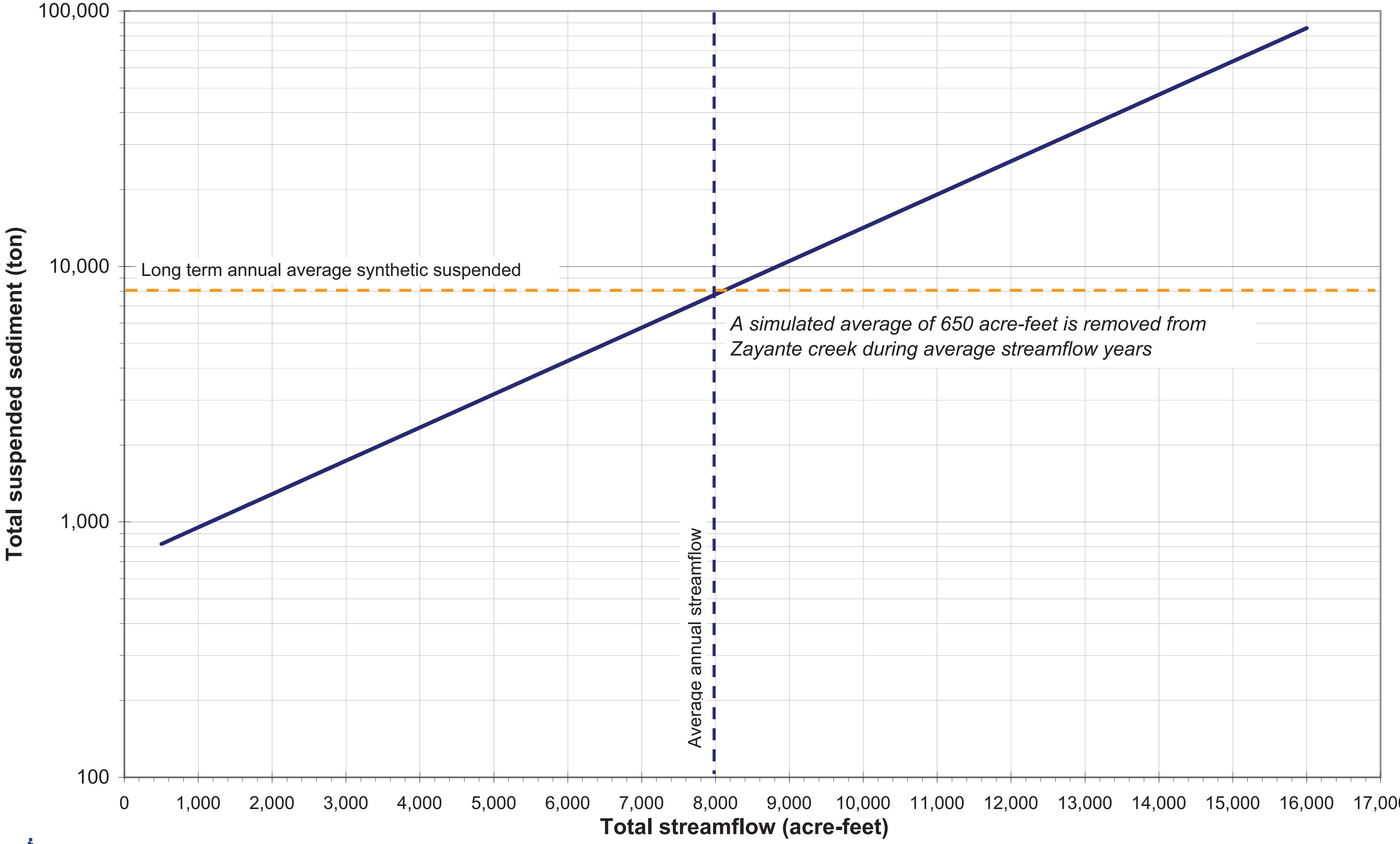

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Figure 30. Sediment yield rating curve for Zayante Creek at USGS Gage No. 1160300, Santa Cruz County, California. Figure transcribed from: Swanson Hydrology and Geomorphology, 1996.

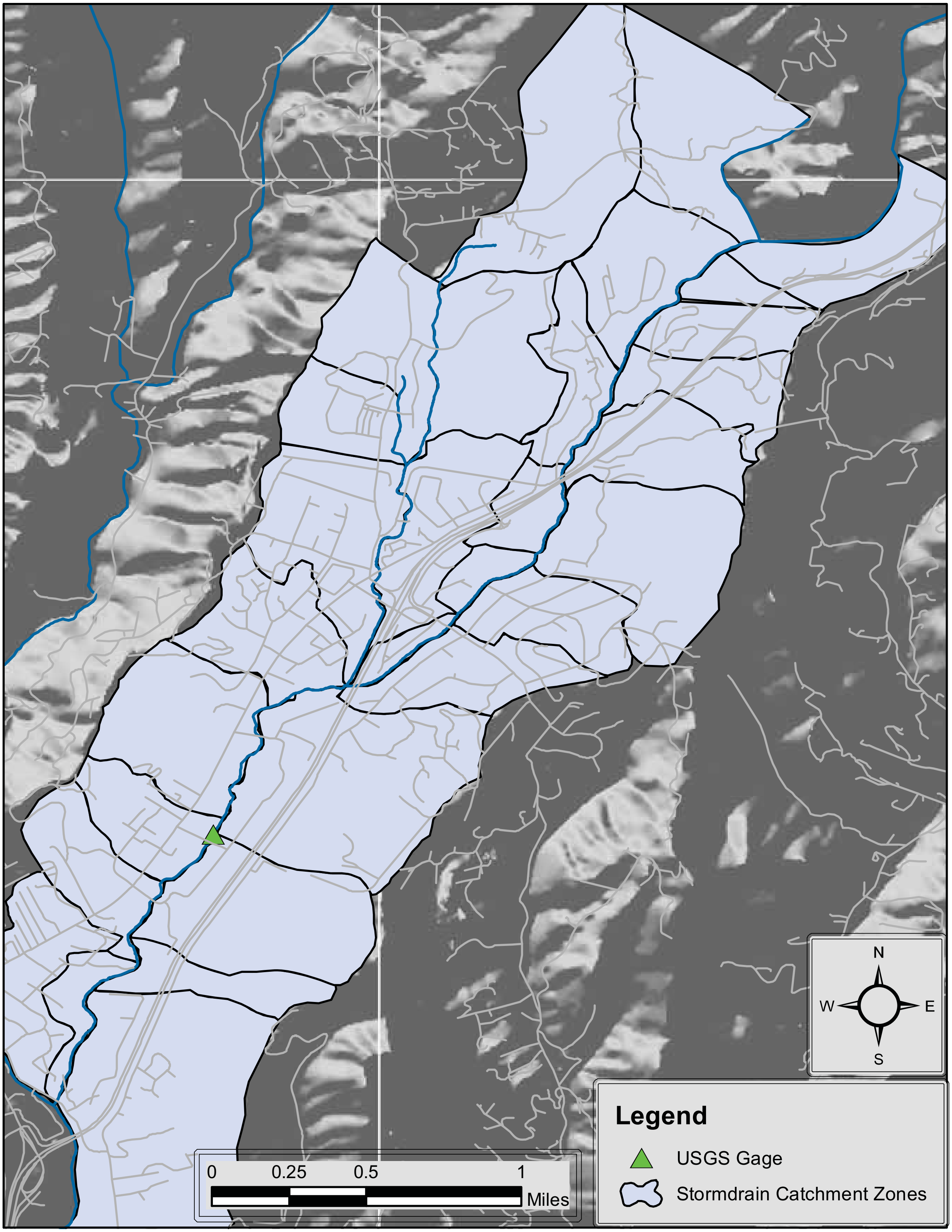

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Figure 31. Stormdrain catchments in Carbonera Creek Watershed, Scotts Valley, Santa Cruz County, California.

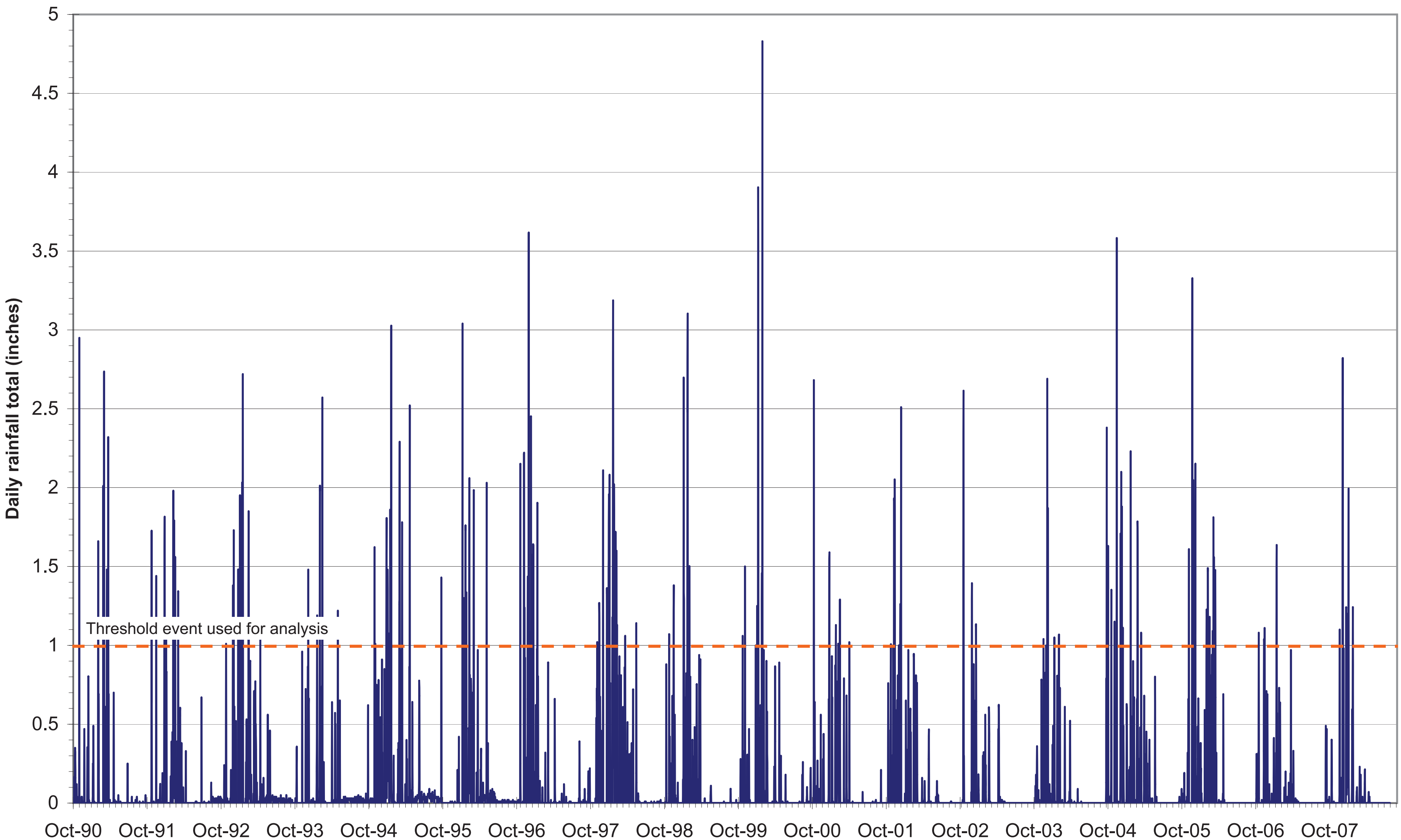

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Figure 32. Daily rainfall recorded at CIMIS Station No. 104 De Laveaga, Santa Cruz County, California

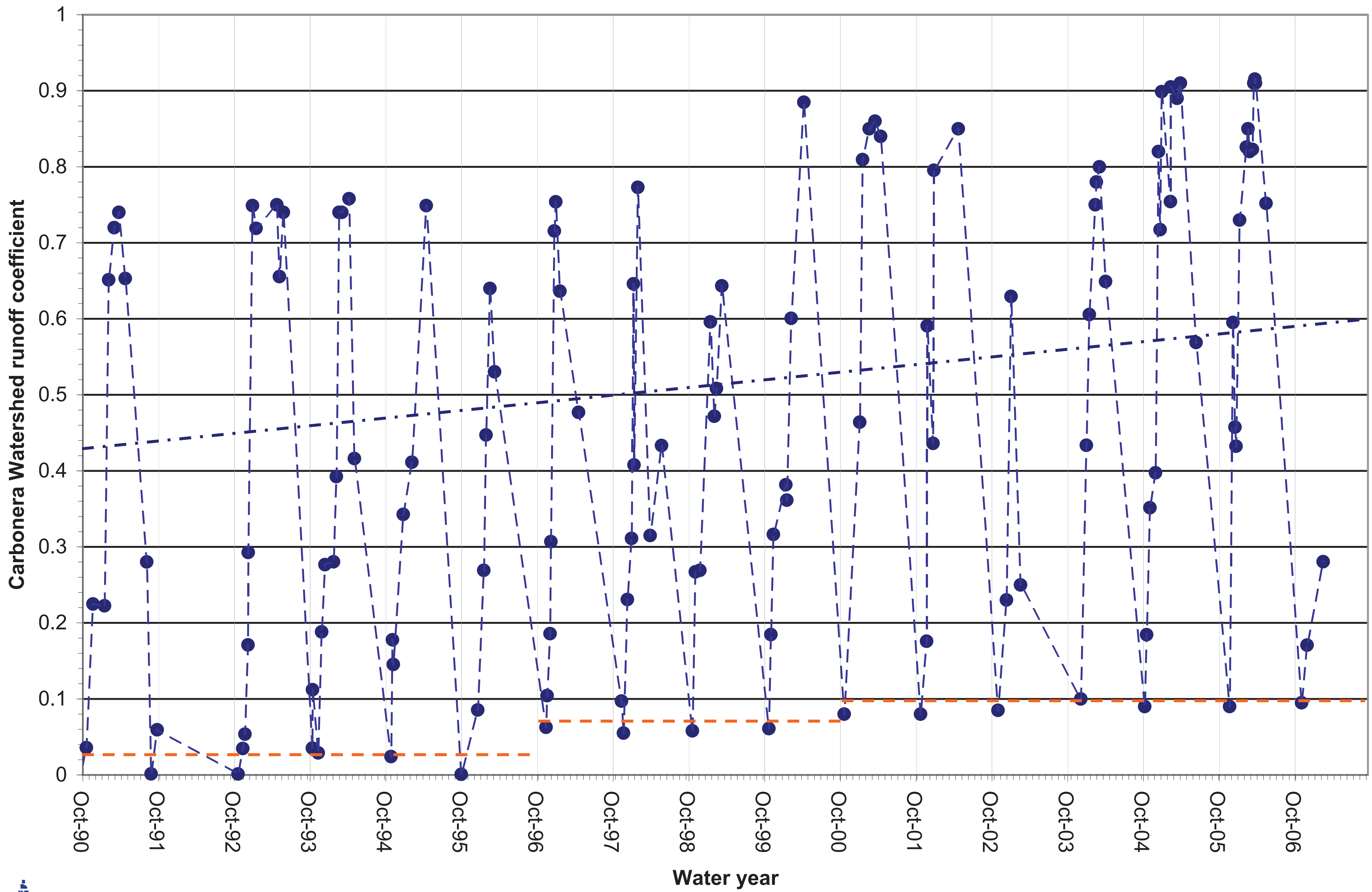

Figure 33. Average runoff coefficient by water year for Carbonera Creek, Santa Cruz County, California

Note: Rational method used for calculation. Dashed range line represents runoff coeffieient for the first storm in a water year. Dashed blue line represents average runoff coefficient for entire water year.

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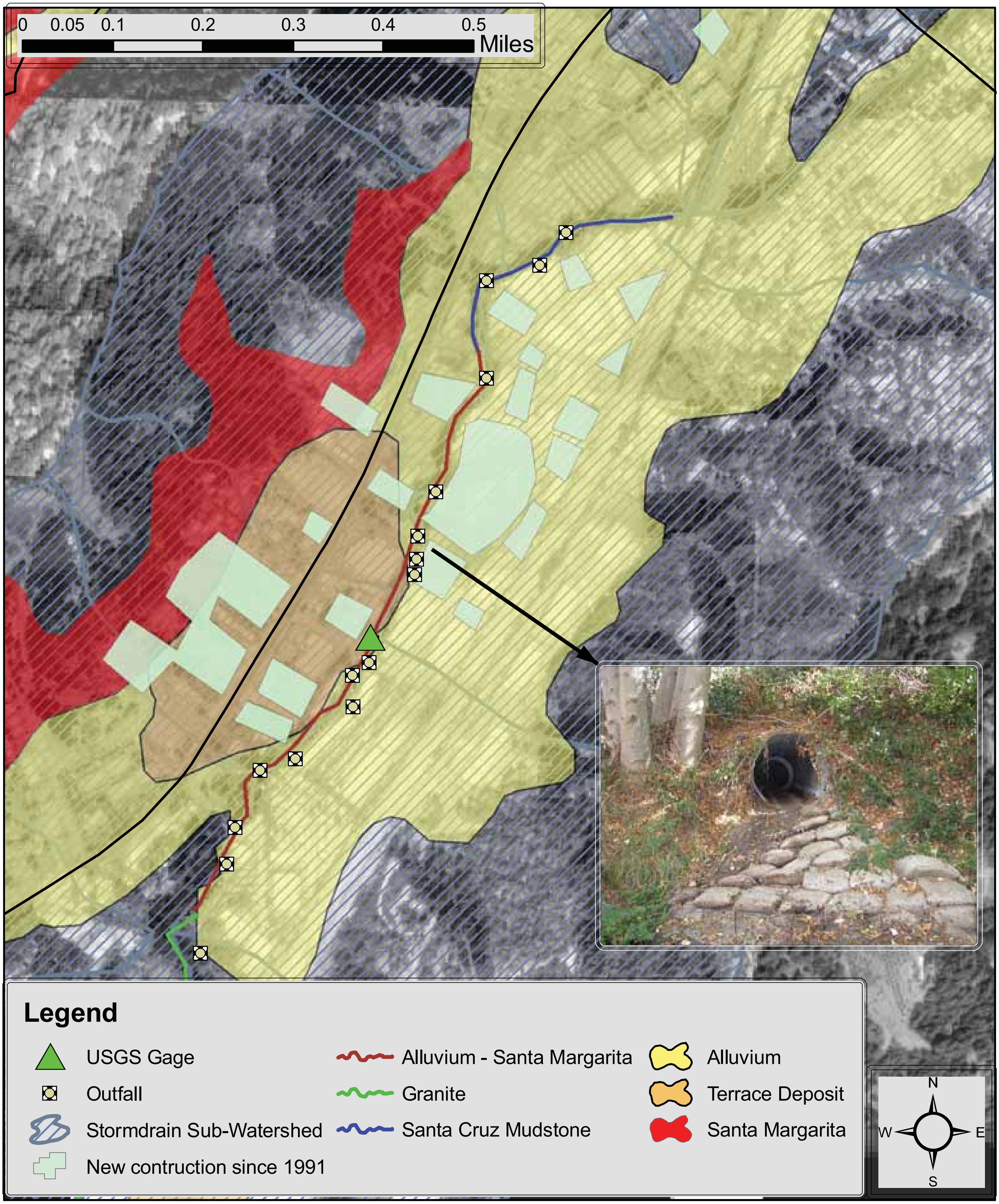

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Figure 34. Recent urbanization of Carbonera Creek corridor relative to watershed area and surface geology, Scotts Valley, Santa Cruz County, California.

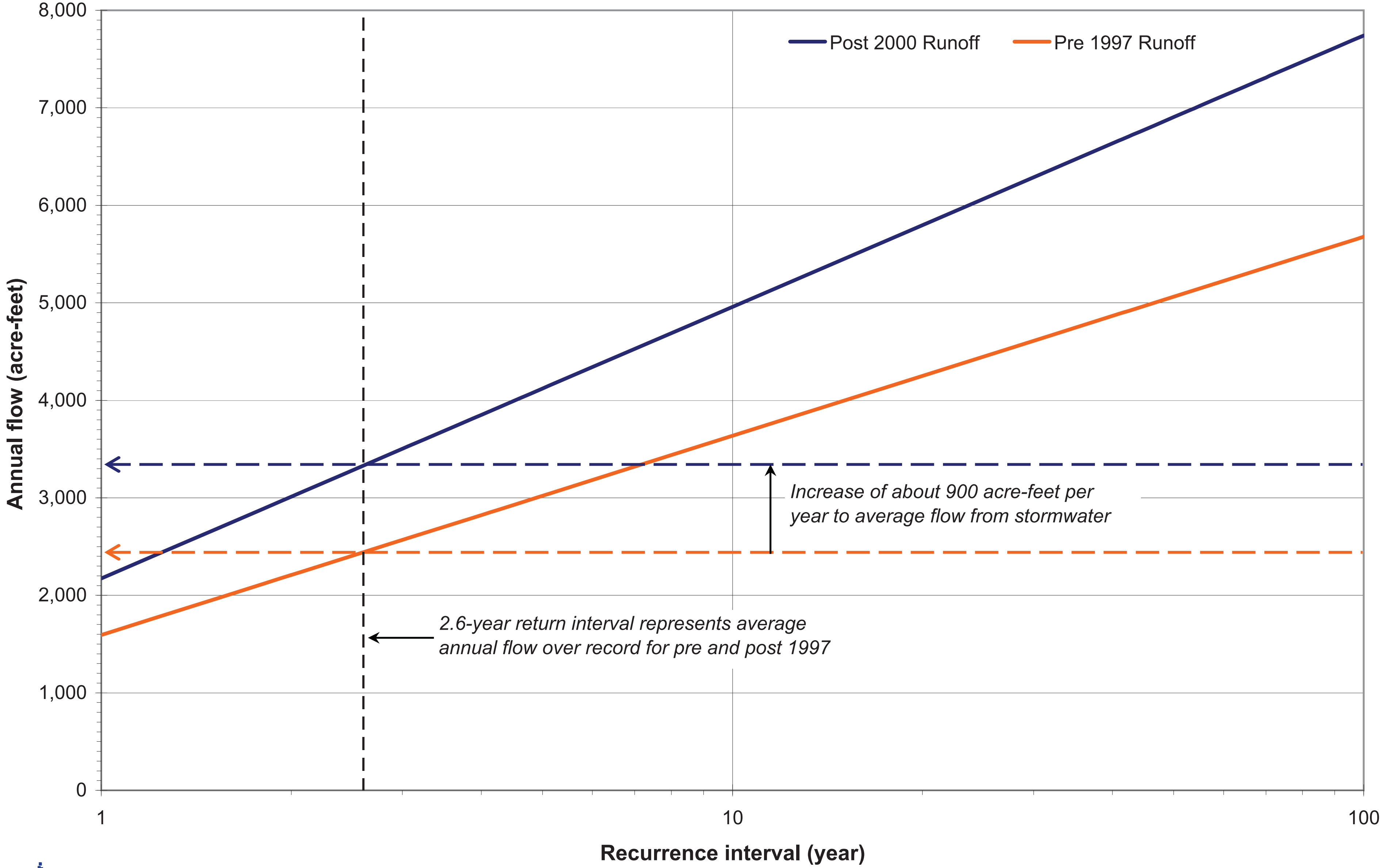

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Figure 35. Recurrence interval and related flows in Carbonera Creek, Santa Cruz County, California. Note: Log Gumble Type III method used to calculate recurrence interval. Streamflow values for Carbonera Creek for water years 1989 through 2007 were used for the calculation. Data source: USGS gage No. 11161300.

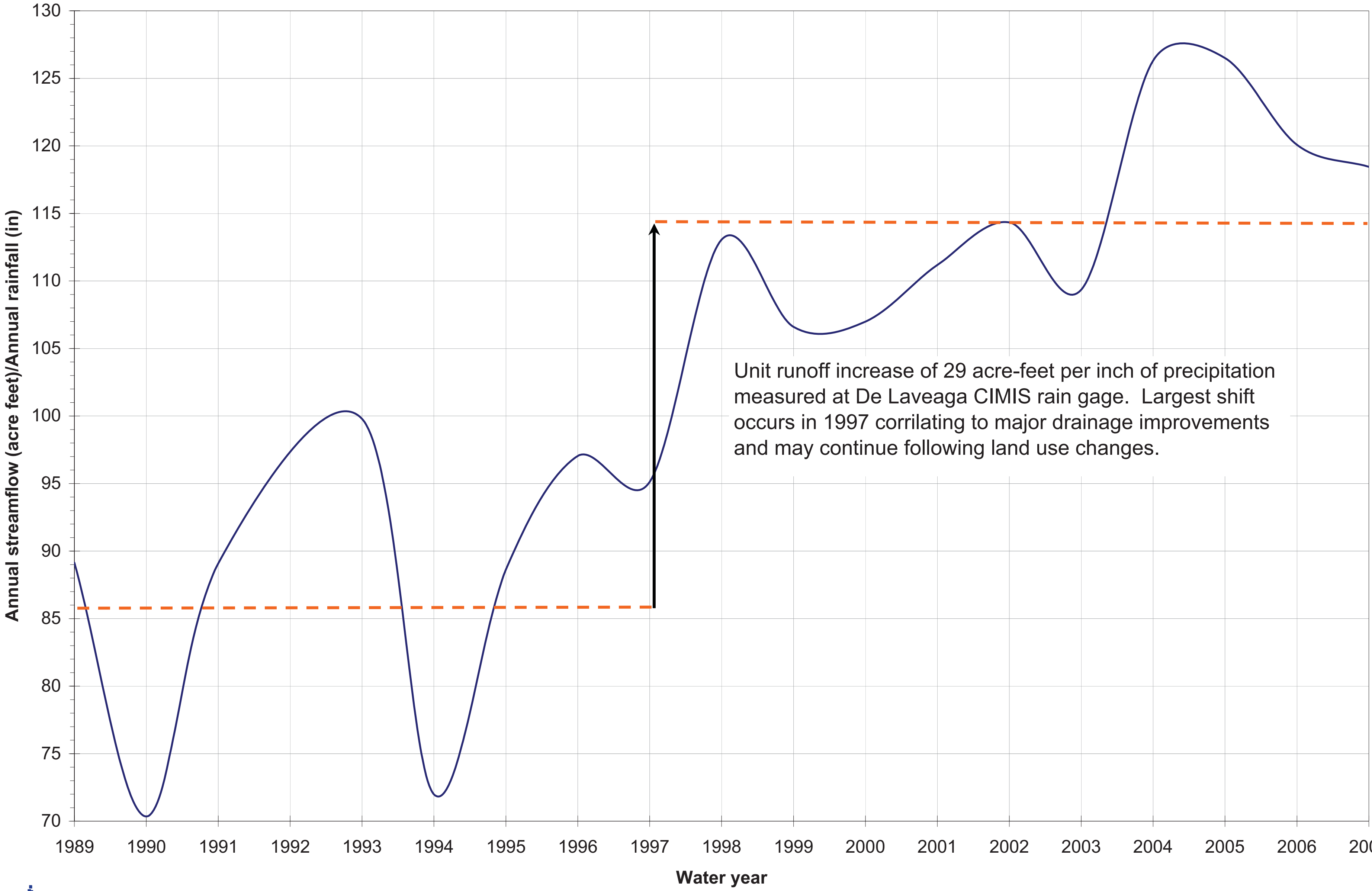

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Figure 36. Annual streamflow in Carbonera Creek by annual rainfall normalized by Annual rainfall, Santa Cruz County, California

Data sources: Stramflow data from USGS Gage No. 11161300. Rainfall CIMIS Station No. 116

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Figure 37. Geomorphic evidence of hydromodification in Carbonera Creek, Santa Cruz County, California. Photos taken 300 feet upstream of USGS gage.

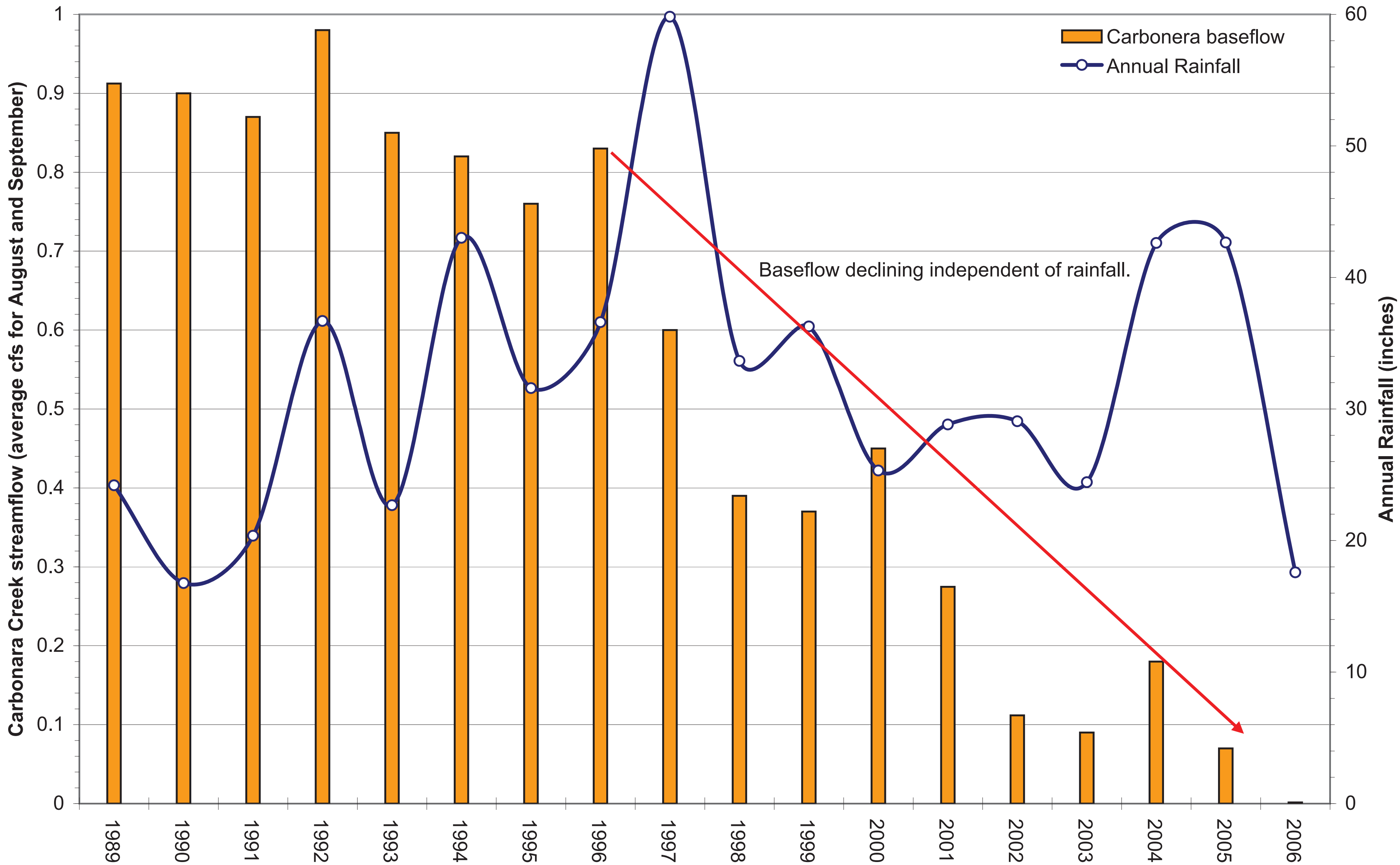

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Figure 38. Average streamflow for August and September by water year for Carbonera Creek, Santa Cruz, California

Carb Daily Flow 2 (version 2).xls, 5/1/2009

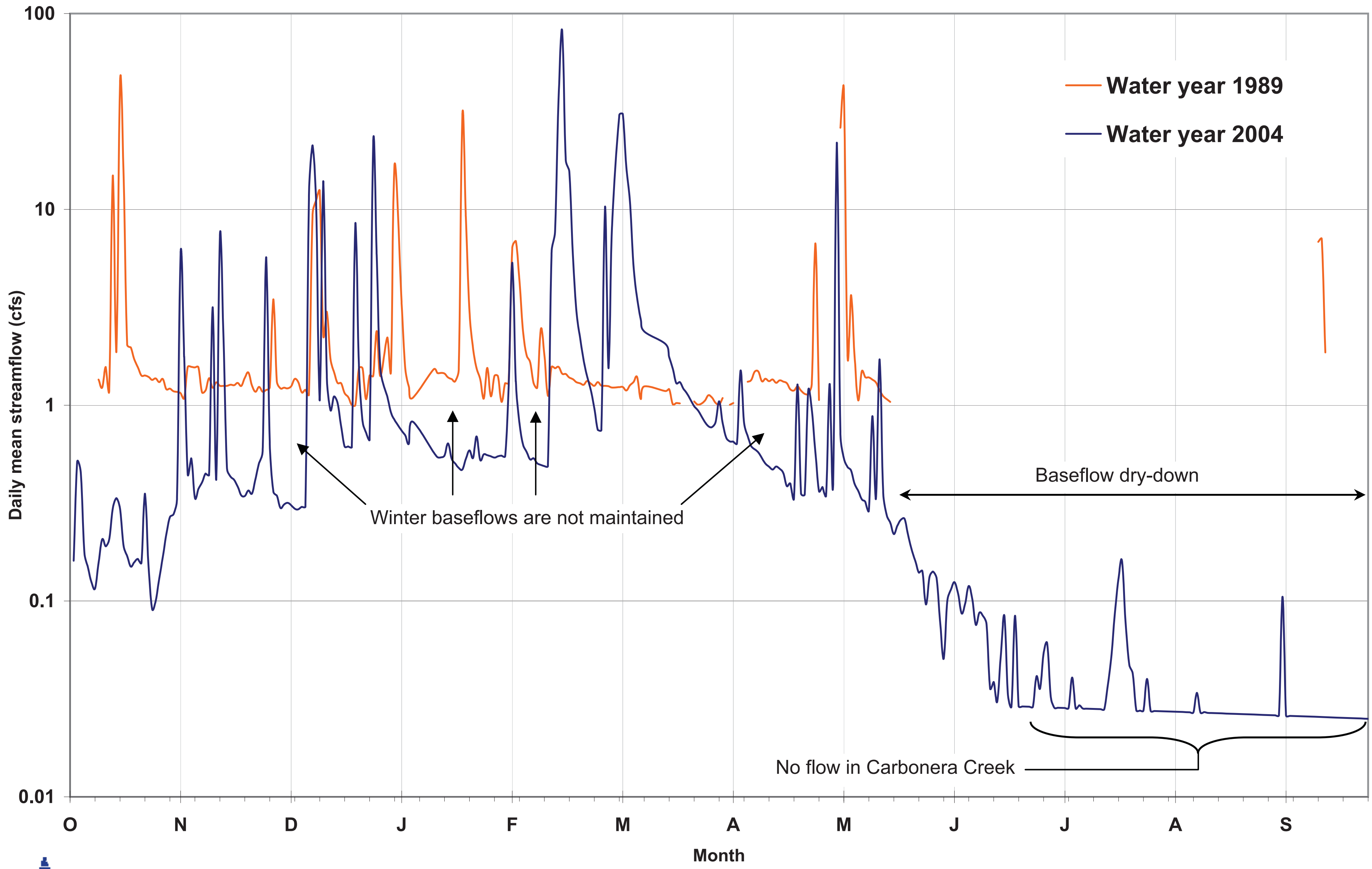

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Figure 39. Streamflow comparison for water years 1989 and 2004 in Carbonera Creek, Santa Cruz County, California

Datasource: USGS gage No. 11161300

Carb Daily Flow 2 (version 2).xls, 5/1/2009

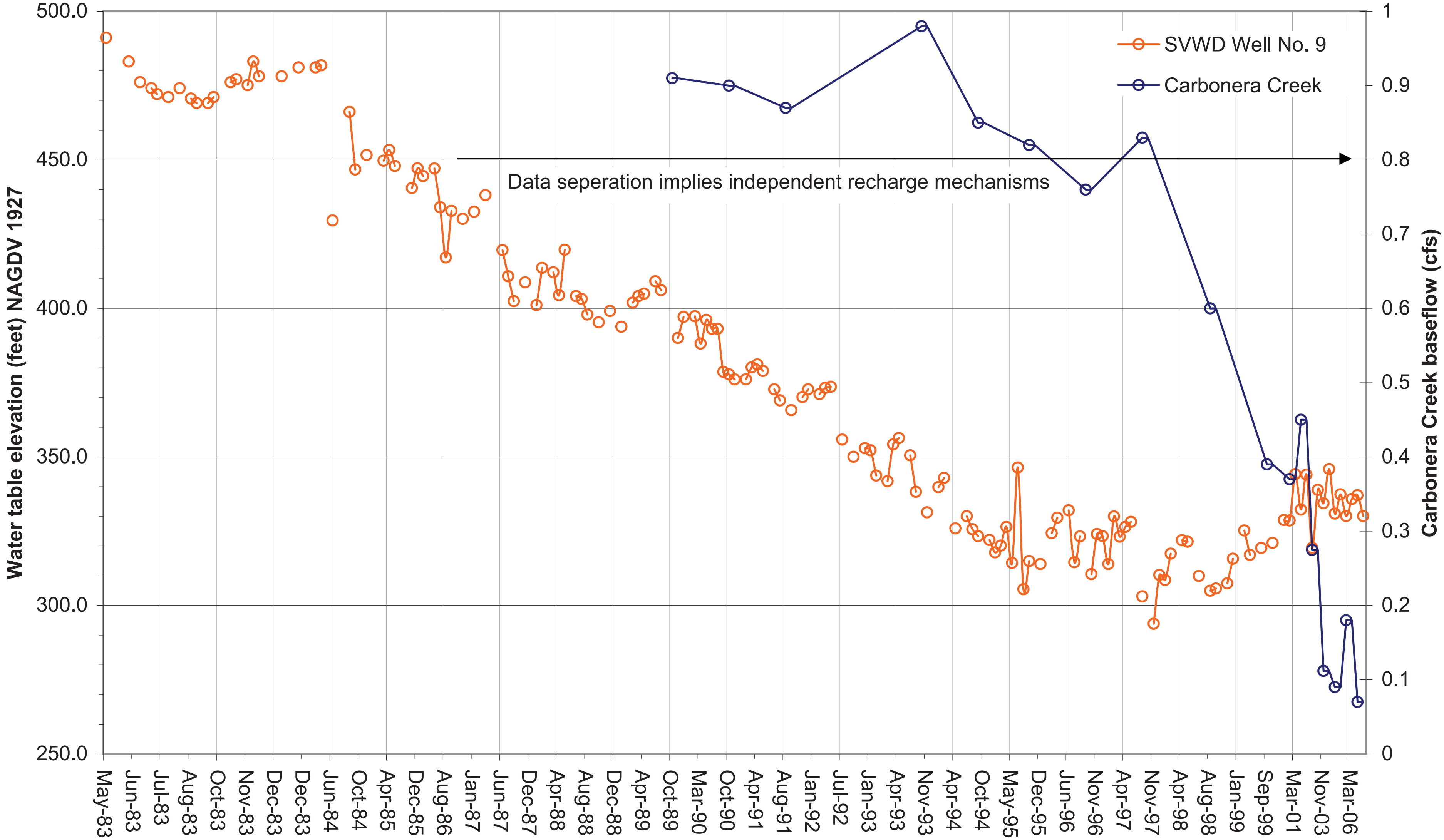

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Figure 40. Water level hydrograph for Scotts Valley Water District well No. 9 and baseflow in Carbonera Creek, Santa Cruz County, California.

Datasource: SVWD database

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Figure 41. Photographs of bioretention BMPs utilized in an urban setting.

Source: City of Portland Stormwater Management Manual and a powerpoint presentation prepared by Larry Coffman.

APPENDICES

APPENDIX A

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits		Permeability	Available Water Capacity[3]		Reaction	Remarks
						Liquid	Plastic	(inches/hour)	Per Inch *(in./in. of soil)*	Profile *(total, in)*	(pH) *(pH)*	
100	Aptos loam, 15 to 30 percent slopes.	Santa Cruz Mudstone (Tsc) and Purisima (Tp)	C (slow infiltration, high runoff potential)	0 to 18 18 to 35 35	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	2.9 2.7 *5.6*	5.1 to 6.5 5.1 to 6.5	Steap Hillslopes and ridge tops above drainages.
101	Aptos loam, 30 to 50 percent slopes.	Santa Cruz Mudstone (Tsc) and Purisima (Tp)	C (slow infiltration, high runoff potential)	0 to 18 18 to 24 24	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	2.9 1.0 *3.8*	5.1 to 6.5 5.1 to 6.5	Steap Hillslopes and ridge tops above drainages.
105	Baywood Loamy Sand, 2 to 15 percent slopes.	Purisima (Tp), Santa Margarita (Tsm)	A (fast infiltration, low runoff potential)	0 to 17 17 to 61 61	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.19 to 0.21 *Total*	3.2 8.4 *11.6*	5.1 to 6.0 5.1 to 6.0	Low lying regions of Carbonera Watershed at low slopes.
110	Ben Lomond Sandy Loam, 5 to 15 percent slopes.	Purisima (Tp), Santa Margarita (Tsm)	B (moderate infiltration and runoff potential)	0 to 11 11 to 46 46	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.18 to 0.21 *Total*	1.8 6.3 *8.1*	5.1 to 5.5 5.6 to 6.0	Found mostly in Carbonera Watershed weathered from sandier portions of purisima near ridge tops
111	Ben Lomond Sandy Loam, 15 to 50 percent slopes.	Purisima (Tp), Santa Margarita (Tsm)	B (moderate infiltration and runoff potential)	0 to 11 11 to 46 46	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.18 to 0.21 *Total*	1.8 6.3 *8.1*	5.1 to 5.5 5.6 to 6.0	Found mostly in Carbonera Watershed weathered from sandier portions of purisima near ridge tops
112	Ben Lomond Sandy Loam, 15 to 50 percent slopes.	Purisima (Tp), Santa Margarita (Tsm)	B (moderate infiltration and runoff potential)	0 to 11 11 to 46 46	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.18 to 0.21 *Total*	1.8 6.3 *8.1*	5.1 to 5.5 5.6 to 6.0	Found mostly in Carbonera Watershed weathered from sandier portions of purisima near ridge tops

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits		Permeability (inches/hour)	Available Water Capacity[3]		Reaction (pH)	Remarks
						Liquid	Plastic		Per Inch *(in./in. of soil)*	Profile *(total, in)*	*(pH)*	
113	Ben Lomond-Catelli-Sur complex, 30 to 75 per cent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 16 16 to 45	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.18 0.16 to 0.18	2.5 4.1	5.1 to 6.5 5.1 to 6.5	This complex is on mountains. Most areas, extend from ridgetops to drainageways, but a few areas occupy only small parts of mountainsides.
				45					*Total*	*6.6*		
114	Ben Lomond-Felton complex, 30 to 50 percent slopes.	Purisima (Tp, Santa Margarita (Tsm)	B (moderate infiltration and runoff potential)	0 to 19 19 to 46	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.19 to 0.18	2.9 4.1	5.1 to 6.0 5.1 to 6.0	This complex consists mainly of soils in concave areas near drainageways.
				46					*Total*	*6.9*		
115	Ben Lomond-Felton complex, 50 to 75 percent slopes.	Purisima (Tp, Santa Margarita (Tsm)	B (moderate infiltration and runoff potential)	0 to 19 19 to 46	SM SC	NA NA	NA NA	0.63 to 2.0 0.63 to 2.0	0.16 to 0.18 0.19 to 0.18	2.9 4.1	5.1 to 6.0 5.1 to 6.0	This complex consists mainly of soils in concave areas near drainageways.
				46					*Total*	*6.9*		
116	Bonnydoon loam, 5 to 30 percent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	D (High infiltration and runoff potential)	0 to 11	SM	NA	NA	0.63 to 2.0	0.16 to 0.14	2.6	5.1 to 5.5 5.6 to 6.0	This shallow, somewhat excessively drained soil is mainly on south-facing side slopes of bills and mountains.
									Total	*2.6*		
117	Bonnydoon loam, 30 to 50 percent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	D (High infiltration and runoff potential)	0 to 11	SM	NA	NA	0.63 to 2.0	0.16 to 0.14	2.6	5.1 to 5.5 5.6 to 6.0	This shallow, somewhat excessively drained soil is mainly on south-facing side slopes of bills and mountains.
									Total	*2.6*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits Liquid	Attenberg Limits Plastic	Permeability (inches/hour)	Available Water Capacity[3] Per Inch *(in./in. of soil)*	Available Water Capacity[3] Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
118	Bonnydoon-Rock outcrop complex, 50 to 85 per cent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	D (High infiltration and runoff potential)	0 to 11	SM	NA	NA	0.63 to 2.0	0.16 to 0.14	2.6	5.1 to 5.5 5.6 to 6.0	This complex is on hills and mountains.
									Total	*2.6*		
124	Danville loam, 0 to 2 percent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	C (slow infiltration, high runoff potential)	0 to 17 17 to 65	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.7 6.7	5.1 to 6.5 5.1 to 6.5	This very deep, well-drained soil is on alluvial fans and in narrow valleys. It formed in alluvium.
									Total	*9.4*		
125	Danville loam, 2 to 9 percent slopes.	Santa Margarita Sandstone (Tsm), Purisima (Tp), and Santa Cruz Mudstone (Tsm)	C (slow infiltration, high runoff potential)	0 to 17 17 to 65	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.7 6.7	5.1 to 6.5 5.1 to 6.5	This very deep, well-drained soil is on alluvial fans and terraces. Areas are small.
									Total	*9.4*		
129	Elder sandy loam, 0 to 2 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) in Zayante Watershed.	B (moderate infiltration and runoff potential)	0 to 20 20 to 60	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	3.2 6.4	5.1 to 5.5 5.6 to 6.0	This very deep, well-drained soil is on alluvial fans and plains and in narrow valleys. It formed in mixed alluvium.
									Total	*9.6*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits: Liquid	Attenberg Limits: Plastic	Permeability (inches/hour)	Available Water Capacity[3]: Per Inch *(in./in. of soil)*	Available Water Capacity[3]: Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
130	Elder sandy loam, 2 to 9 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) in Zayante Watershed.	B (moderate infiltration and runoff potential)	0 to 20 20 to 60	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	3.2 6.4	5.1 to 5.5 5.6 to 6.0	This very deep, well-drained soil is on alluvial fans and plains and in narrow valleys. It formed in mixed alluvium.
									Total	*9.6*		
131	Elder sandy loam, 9 to 15 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) in Zayante Watershed.	B (moderate infiltration and runoff potential)	0 to 20 20 to 40	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	3.2 3.2	5.1 to 5.5 5.6 to 6.0	This very deep, well-drained soil is on alluvial fans, in wide swales on alluvial and marine terraces, and in narrow valleys. It formed in mixed alluvium. Areas are elongated.
									Total	*6.4*		
133	Elkhorn sandy loam, 2 to 9 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 12 12 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	1.9 7.8	5.1 to 6.5 5.1 to 6.5	This very deep, well-drained soil is on old alluvial fans and marine terraces.
									Total	*9.8*		
134	Elkhorn sandy loam, 9 to 15 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 12 12 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	1.9 7.8	5.1 to 6.5 5.1 to 6.5	This very deep, well-drained soil is on old alluvial fans and marine terraces.
									Total	*9.8*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits: Liquid	Attenberg Limits: Plastic	Permeability (inches/hour)	Available Water Capacity[3]: Per Inch *(in./in. of soil)*	Available Water Capacity[3]: Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
135	Elkhorn sandy loam, 15 to 30 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 12 12 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	1.9 7.8	5.1 to 6.5 5.1 to 6.5	This very deep, well-drained soil is on old alluvial fans and marine terraces.
									Total	*9.8*		
136	Elkhorn-Pfeiffer complex, 30 to 50 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 21 21 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.8 5.6	5.1 to 5.5 5.6 to 6.0	This complex is on dissected marine terraces and hills.
									Total	*8.4*		
139	Fluvaquentic Haploxerolls-Aquic Xerofluvents complex, 0 to 15 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) and Purisima (Tp) in Carbonera Watershed	B (moderate infiltration and runoff potential)	0 to 24 24 to 60	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.9 5.0	5.1 to 5.5 5.6 to 6.0	These deep, moderately well-drained soils formed in alluvium. Included with this complex in mapping are areas of Danville loam, Elder sandy loam, and Soquel loam.
									Total	*7.9*		
140	Hecker gravelly sandy loam, 30 to 50 percent slopes.	Monterey formation (Tm), Purisima Formation (Tp), Lambert Shale (Tla), and Santa Cruz Mudstone (Tsc)	B (moderate infiltration and runoff potential)	0 to 12 12 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	1.9 7.8	5.1 to 6.5 5.1 to 6.5	This deep, well drained soil is on mountains. It formed in material weathered from sandstone, mudstone, or shale. It is on south- and north-facing slopes, mainly at or near fault zones.
									Total	*9.8*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits		Permeability (inches/hour)	Available Water Capacity[3]		Reaction (pH) (pH)	Remarks
						Liquid	Plastic		Per Inch (in./in. of soil)	Profile (total, in)		
141	Hecker gravelly sandy loam, 50 to 75 percent slopes.	Monterey formation (Tm), Purisima Formation (Tp), Lambert Shale (Tla), and Santa Cruz Mudstone (Tsc)	B (moderate infiltration and runoff potential)	0 to 12 12 to 61	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	1.9 7.8 *9.8*	5.1 to 6.5 5.1 to 6.5	This deep, well-drained soil is on mountains, mainly at or near fault zones. It is mainly on south- and west-facing slopes. It formed in material weathered from sandstone, mudstone, or shale.
142	Lompico-Felton complex, 5 to 30 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 5 5 to 37	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	0.8 5.1 *5.9*	5.1 to 6.5 5.1 to 6.5	This complex consists of soils on foot slopes and wide ridges. Slopes are dominantly complex. his complex is about 30 percent Lompico loam and 25 percent Felton sandy loam.
143	Lompico - Felton Complex, 30 to 50 percent slopes	Lompico Sandstone (Tlo)	B (moderate infiltration and runoff potential)	0 to 20 20 to 72	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16 *Total*	2.4 6.0 *8.4*	5.1 to 6.5 5.1 to 7.3	Upper Zayante Watershed, near the confluence of Lompico and Zayante Creeks.
144	Lompico-Felton complex, 50 to 75 percent slopes.	Lompico Sandstone (Tlo)	B (moderate infiltration and runoff potential)	0 to 20 20 to 72	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16 *Total*	2.4 6.0 *8.4*	5.1 to 6.5 5.1 to 7.3	This complex consists of soils that are dominantly on footslopes but are also in areas near ridgetops. This complex is about 35 percent Lompico loam and 30 percent Felton sandy loam. Included with this complex in mapping are areas of Aptos fine sandy loam, Nisene loam, and Maymen stony loam.

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Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits: Liquid	Attenberg Limits: Plastic	Permeability (inches/hour)	Available Water Capacity[3]: Per Inch *(in./in. of soil)*	Available Water Capacity[3]: Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
145	Lompico Variant loam, 5 to 30 percent slopes.	Butano Sandstone (Tbu), Monterey Shale (Tm), Puririma (Tp), and Lompinco Sandstone (Tlo)	C (slow infiltration, high runoff potential)	0 to 14 14 to 28	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	2.2 2.2 *4.5*	5.1 to 6.5 5.1 to 6.5	This moderately deep, well-drained soil is on terraces and mountains. It is mainly on ridges and in small, bench-like areas. It formed in residuum derived from sandstone, shale, or mudstone. Slopes are slightly convex.
149	Madonna loam, 15 to 30 percent slopes.	Monterey formation (Tm), Purisima Formation (Tp), Lambert Shale (Tla), and Santa Cruz Mudstone (Tsc)	C (slow infiltration, high runoff potential)	0 to 16 16 to 24	CL CH	20-40 30-60	15-30 20-40	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	1.9 1.3 *3.2*	5.1 to 6.5 5.1 to 6.5	This moderately deep, well-drained soil is on or near the crest of mountains. It formed in material weathered from mudstone or shale.
151	Maymen stony loam, 30 to 75 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	D (High infiltration and runoff potential)	0 to 8 8 to 14	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21 *Total*	1.3 1.0 *2.2*	5.1 to 6.5 5.1 to 6.5	This shallow, somewhat excessively-drained soil is on mountains. It is mainly on the upper part of south-facing slopes. It formed in material derived from shale, sandstone, or granitic rock. Areas are dominantly convex.

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits: Liquid	Attenberg Limits: Plastic	Permeability (inches/hour)	Available Water Capacity[3]: Per Inch *(in./in. of soil)*	Available Water Capacity[3]: Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
152	Maymen-Madonna complex, 30 to 50 percent slopes.	Butano Sandstone (Tbu), Monterey Shale (Tm), Puririma (Tp), Lompinco Sandstone (Tlo), Vaqueros Sandstone (Tvq), and Granite Outcrops	D (High infiltration and runoff potential)	0 to 20 20 to 72	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.4 6.0	5.1 to 6.5 5.1 to 7.3	Upper Zayante Watershed, near the confluence of Lompico and Zayante Creeks.
									Total	*8.4*		
153	Maymen-Rock outcrop complex, 50 to 75 per cent slopes.	Butano Sandstone (Tbu), Monterey Shale (Tm), Puririma (Tp), Lompinco Sandstone (Tlo), Vaqueros Sandstone (Tvq), and Granite Outcrops	D (High infiltration and runoff potential)	0 to 10 10 to 14	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	1.2 0.4	5.1 to 6.5 5.1 to 7.3	This complex is on ridges and the upper part of very steep slopes on mountains. This complex is about 45 percent Maymen stony loam and 25 percent Rock outcrop.
									Total	*1.6*		
156	Nisene-Aptos complex, 15 to 30 percent slopes.	Butano Sandstone (Tbu), Monterey Shale (Tm), Puririma (Tp), and Lompinco Sandstone (Tlo)	C (slow infiltration, high runoff potential)	0 to 48 14 to 58	SM GC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	8.6 1.8	5.1 to 6.5 5.1 to 6.5	This complex is mainly on foot slopes and wide ridges in the Santa Cruz Mountains. Slopes are complex. This complex is 35 percent Aptos fine sandy loam and 30 percent Nisene loam.
									Total	*10.4*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits		Permeability (inches/hour)	Available Water Capacity[3]		Reaction (pH)	Remarks
						Liquid	Plastic		Per Inch *(in./in. of soil)*	Profile *(total, in)*	*(pH)*	
157	Nisene-Aptos complex, 30 to 50 percent slopes.	Butano Sandstone (Tbu), Monterey Shale (Tm), Puririma (Tp), and Lompinco Sandstone (Tlo)	C (slow infiltration, high runoff potential)	0 to 16 16 to 29	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.6 2.3	5.1 to 6.5 5.1 to 6.5	This complex is mainly on foot slopes and wide ridges in the Santa Cruz Mountains. Slopes are complex. This complex is 35 percent Aptos fine sandy loam and 30 percent Nisene loam.
									Total	*4.9*		
158	Nisene-Aptos complex, 50 to 75 percent slopes.	Santa Margarita Sandstone (Tsm) and Santa Cruz Mudstone (Tsm)	C (slow infiltration, high runoff potential)	0 to 23 23 to 48	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	4.1 4.5	5.1 to 6.5 5.1 to 6.5	This complex is in the Santa Cruz Mountains. ncluded with these soils in mapping are areas of Felton sandy loam, Ben Lomond sandy loam, and Lompico loam.
									Total	*8.6*		
159	Pfeiffer gravelly sandy loam, 15 to 30 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 24 24 to 66	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.4 4.2	5.1 to 6.5 5.1 to 7.3	This deep, well-drained soil is on hills and dissected terraces. It formed in material weathered from granitic rock or sandstone or in marine sediment.
									Total	*6.6*		
160	Pfeiffer gravelly sandy loam, 30 to 50 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	B (moderate infiltration and runoff potential)	0 to 24 24 to 66	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.4 4.2	5.1 to 6.5 5.1 to 7.3	This deep, well-drained soil is on hills and dissected terraces. It formed in material weathered from granitic rock or sandstone or in marine sediment.
									Total	*6.6*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits Liquid	Attenberg Limits Plastic	Permeability (inches/hour)	Available Water Capacity[3] Per Inch *(in./in. of soil)*	Available Water Capacity[3] Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
164	Pits-Dumps complex.	Quarry Related	C (slow infiltration, high runoff potential)	0 to 14 14 to 28	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	2.2 2.2	5.1 to 6.5 5.1 to 6.5	Pits are open excavations from which soil material has been removed. Dumps are uneven areas of accumulated waste material.
									Total	*4.5*		
170	Soquel loam, 0 to 2 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) and Purisima (Tp) in Carbonera Watershed	B (moderate infiltration and runoff potential)	0 to 21 21 to 62	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	3.4 6.6	5.1 to 6.5 5.1 to 6.5	This very deep, moderately well-drained soil is on plains and in narrow valleys. It formed in alluvium.
									Total	*9.9*		
171	Soquel loam, 2 to 9 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) and Purisima (Tp) in Carbonera Watershed	B (moderate infiltration and runoff potential)	0 to 21 21 to 62	SM SC	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.21 0.16 to 0.21	3.4 6.6	5.1 to 6.5 5.1 to 6.5	This complex is in the Santa Cruz Mountains. ncluded with these soils in mapping are areas of Felton sandy loam, Ben Lomond sandy loam, and Lompico loam.This very deep, moderately well-drained soil is on plains. It formed in alluvium.
									Total	*9.9*		
174	Tierra-Watsonville complex, 15 to 30 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	D (High infiltration and runoff potential)	0 to 24 24 to 66	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.2 3.8	5.1 to 6.5 5.1 to 7.3	This complex consists of soils on alluvial and marine terraces. This complex is about 55 percent Tierra sandy loam and 30 percent Watsonville loam.
									Total	*5.9*		

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Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits: Liquid	Attenberg Limits: Plastic	Permeability (inches/hour)	Available Water Capacity[3]: Per Inch *(in./in. of soil)*	Available Water Capacity[3]: Profile *(total, in)*	Reaction (pH) *(pH)*	Remarks
175	Tierra-Watsonville complex, 30 to 50 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	D (High infiltration and runoff potential)	0 to 24 24 to 54	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.2 2.7	5.1 to 6.5 5.1 to 7.3	This complex consists of soils on alluvial and marine terraces. This complex is about 55 percent Tierra sandy loam and 30 percent Watsonville loam.
									Total	*4.9*		
179	Watsonville loam, thick surface, 2 to 15 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) and Purisima (Tp) in Carbonera Watershed	D (High infiltration and runoff potential)	0 to 24 24 to 66	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.2 4.2	5.1 to 6.5 5.1 to 7.3	This deep, somewhat poorly drained soil is on coastal terraces. It formed in alluvium.
									Total	*6.4*		
180	Watsonville loam, thick surface, 15 to 30 percent slopes.	Alluvial materials weathered from Santa Margarita (Tsm) and Purisima (Tp) in Carbonera Watershed	D (High infiltration and runoff potential)	0 to 24 24 to 66	SM SM	NA NA	NA NA	0.63 to 0.2 0.63 to 0.2	0.16 to 0.19 0.12 to 0.16	2.2 4.2	5.1 to 6.5 5.1 to 7.3	This deep, somewhat poorly drained soil is on coastal terraces. It formed in alluvium.
									Total	*6.4*		
182	Zayante coarse sand, 5 to 30 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	A (fast infiltration, low runoff potential)	0 to 30	SW	NA	NA	0.63 to 0.2	0.20 to 0.25	6.6	5.1 to 6.5	This very deep, somewhat excessively drained soil is on hills and mountains. It formed in residuum weathered from consolidated marine sediment or sandstone.
									Total	*6.6*		

Appendix A. Recharge and water-holding properties of surficial soils for Bean, Carbonera, and Zayante Watersheds
Santa Cruz County, California

Map Symbol	Soil Series[1]	Parent Material	Hydrologic Soil Group	Depth Zone (inches)	USCS[2]	Attenberg Limits		Permeability	Available Water Capacity[3]		Reaction	Remarks
						Liquid	Plastic	(inches/hour)	Per Inch *(in./in. of soil)*	Profile *(total, in)*	(pH) *(pH)*	
183	Zayante coarse sand, 30 to 50 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	A (fast infiltration, low runoff potential)	0 to 20	SW	NA	NA	0.63 to 0.2	0.20 to 0.25	4.4	5.1 to 6.5	This very deep, somewhat excessively drained soil is on hills and mountains. It formed in residuum weathered from consolidated marine sediment or sandstone.
									Total	*4.4*		
184	Zayante-Rock outcrop complex, 15 to 75 percent slopes.	Lompico Sandstone (Tlo) and Santa Margarita Sandstone (Tsm)	A (fast infiltration, low runoff potential)	0 to 20	SW	NA	NA	0.63 to 0.2	0.20 to 0.25	4.4	5.1 to 6.5	This complex is on hills and mountains. This complex is 45 percent Zayante coarse sand and 30 percent Rock outcrop.
									Total	*4.4*		

Notes:

1) Information taken from the most-recent USDA soil survey for the area (1972/1990).

2) USCS = Unified Soils Classification System, commonly used in geotechnical or soil-foundation investigations, and in routine engineering geologic logging.

3) Avaiable Water Capacity = Held water available for use by most plants, usually defined as the difference between the amount of soil water at field capacity (one day of drainage after a rain or recharge event) and the amount at the wilting point.