Central
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Garrapata Watershed Assessment: Hydrology and Sedimentology (2001 to 2004)

Report No. WI-2005-03
23 February 2005

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Preface

Dr. Douglas Smith, Watershed Institute staff, and students in the Division of Science and Environmental Policy at CSU-Monterey Bay have monitored the flow of sediment and water from the Garrapata Watershed since August 20, 2001. This report summarizes their findings through September 31, 2004. The monitoring was chiefly done on Garrapata Creek above the mouth of Joshua Creek and on Joshua Creek near its mouth. A small amount of data also exist for Wildcat Creek. To assess sediment sources, an inventory of near-channel sediment sources was made, and both video and digital still photos of the general watershed were obtained during a fixed-wing flight. This report is written for the Garrapata Watershed Council as part of their watershed assessment funded by California Department of Fish and Game.

This report may be cited as:
Smith, D.P, Casagrande, J., Vincent, M., McDermott, J., Martin, A., Price, A., and Carlson, Z., 2004, Garrapata Watershed Assessment: Hydrology and Sedimentology (2001 to 2004): The Watershed Institute, California State University Monterey Bay, Publication No. WI-2005-3, 49 pp.

Acknowledgements

This work was funded by a grant from California Department of Fish and Game (GRANT NUMBER) to The Garrapata Watershed Council. The Watershed Council subcontracted the Watershed Institute through the Foundation at CSU-Monterey Bay to perform part of the scope of their grant. We would like to acknowledge the tireless support of Ken Ekelund (Garrapata Watershed Council) for downloading gauge data, arranging access to private property, and for being a driving force in improving conditions in the Garrapata Watershed. We also acknowledge the following individuals for allowing access to private property, providing technical support, and aiding our work in other ways.

- Greg James (MPWMD)
- Nikki Nedeff
- Tad Masek (Pilot)
- Leslie Turrini-Smith
- Landowners of the Garrapata Watershed
- Watershed council
- Technical Advisory Committee

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1 Executive Summary

The Garrapata Watershed lies on the Pacific slope of the Santa Lucia Mountains in Central California. The 27.5 km^2 (10.7 mi^2) drainage basin includes two main tributaries to the trunk river: Wildcat Creek (7.5 km^2 (2.9 mi^2))and Joshua Creek (5.3 km^2 (2.1 mi^2)). We assessed the Garrapata Watershed in terms of geology, hydrology, sediment transport, and sediment sources. The data include:

1) Three years of continuously recorded water elevation on Garrapata Creek,
2) Several instantaneous measures of sediment and water flow on Garrapata Creek, Joshua Creek, and fewer in Wildcat Creek,
3) Twenty two years of monthly rainfall data in the Garrapata watershed
4) Foot reconnaissance in the watershed where access was permitted
5) A proxy long-term rainfall record at San Clemente Dam
6) A proxy long-term peak flood record from the Big Sur River.
7) Oblique and orthorectified aerial photographs,
8) U.S.Geological Survey digital elevation models,
9) U.S. Geological Survey digital topographic quadrangles, and
10) Assorted GIS data layers produced by Monterey County.

Average rainfall is 74 cm/yr (30 in/yr) at the Garrapata rain gauge. Using that value to adjust an isohyetal analysis of total rainfall in the watershed, the total average rain is 17,800 acre-feet/yr. A robust synthetic 82-year record of rainfall suggests that the long-term average rainfall at the rain gauge may be somewhat lower 71 cm (28 in) than the average calculated from 22 years of rainfall record. After the annual rain is partitioned into evaporation, transpiration, and recharge of deep aquifers, there is enough shallow groundwater storage to keep all the main streams perennial through springs and seeps that bleed water throughout the year. During the three years of gauging, the average annual flow of water from the watershed was 3 million m^3 (2421acre -feet), giving a yield of 108,000 $m^3/km^2/yr$ (141 acre-feet/mi^2/yr). Seventeen percent of that flow originated in Joshua Creek. We estimate that 73% of the annual rainfall either evaporates or is used to support the vegetative ecosystem.

The average annual flow of sediment from the watershed was 507 tonnes, giving a yield of 18 tonnes/km^2/yr. Joshua Creek subwatershed produces 78% of the bedload sediment, but accounts for only 19% of the Garrapata Watershed area. Sediment sources include minor natural erosion of the hillslopes, small landslides, and impacts associated with dirt road construction, maintenance, and decay. Aerial reconnaissance of the watershed indicates that the relatively higher sediment yield in Joshua Creek is produced by dirt road construction or maintenance along steep, easily eroded slopes.

The chief environmental problem we recognize in terms of water and sediment is the excess sand and silt in the channels that would otherwise be relatively sand free if there were no severe land disturbance. Excess sand and silt has been called a biologically limiting factor in anadromous fisheries. Although both Garrapata and Wildcat have what we consider excess sand locally, they are in much better condition than Joshua Creek, which has lost much of its pool habitat as the pools fill with sand. We estimated that there was approximately 584 metric tonnes of excess sand and silt present in the channel of Joshua Creek in early November 2004. This value excludes the sediment temporarily trapped behind debris jams and other barriers reported by Casagrande and Smith (2004)). Based upon that estimate of highly mobile bedload sediment and our understanding of the sediment transport capacity of Joshua Creek, the channel would be clear of the pool-filling sand and silt within approximately two years if all sediment sources in Joshua Creek were suddenly stopped. Given that a small amount of natural sediment supply must be transported as well, our estimate of channel cleaning may be a slight underestimate.

The Watershed Council has a goal of improving watershed conditions so that anadromous fisheries can be optimized. Their management plan will consider the implications of such variables as invasive plant species, migration barriers, sediment from roads and near-channel sources, and water quantity. Given the scope of the present report, there is one major restoration opportunity that stands out above all others we have investigated: reducing the excess sediment shed from dirt roads, especially in the Joshua Creek Watershed. In general the sediment would be reduced if culverts were properly sized and maintained, the sediment shed from side-casting is stabilized by vegetation or appropriate geotextiles, the roadcuts are stabilized, and future maintenance involves end-hauling the excavated material to a region that will not deliver the sediment to the valley floor.

2 Introduction

Garrapata Watershed drains 27.5 km^2 (10.7 mi^2) of the northern part of the Santa Lucia Range (Fig. 1). It lies southwest of the adjacent Carmel watershed, north of the Palo Colorado and Rocky Creek watersheds, and south of the Doud and San Jose watersheds.

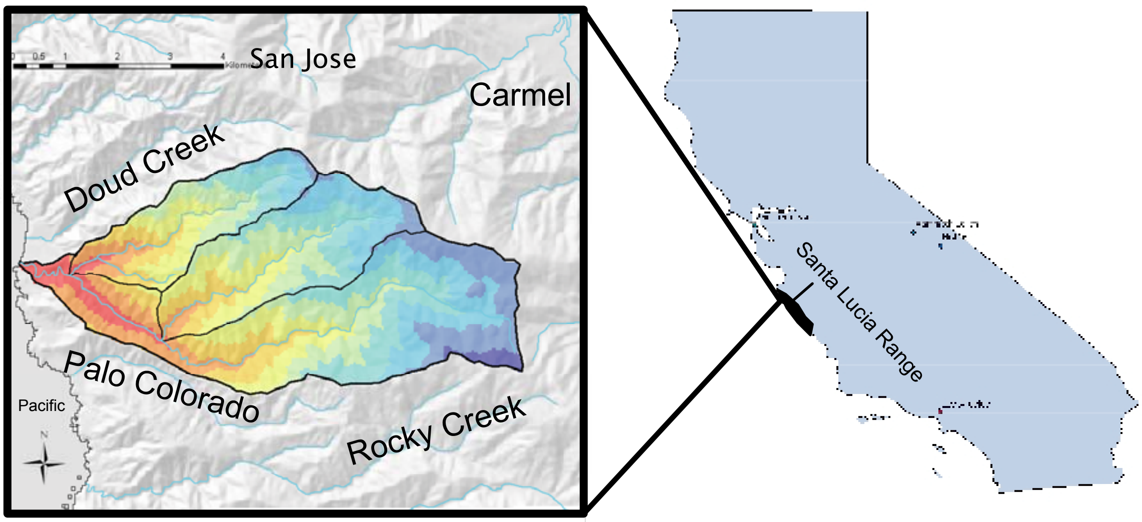

Figure 1: Location of Garrapata Watershed (colored by elevation) within the northern Santa Lucia Range.

The Garrapata Watershed Council is completing a watershed resource assessment so that restoration opportunities can be identified, and to inform the development of a long-range watershed management plan. The Watershed Institute of California State University, Monterey Bay was subcontracted to monitor and evaluate water quantity and to evaluate the sediment transport and near-channel sediment sources as part of the assessment process.

We provide a detailed look at the watershed hydrology based upon historic rainfall records and three years of stream gauge records. We provide frequency analysis of rainfall, drought, and flood based upon log-Pearson type-III frequency analysis and correlation with the long-term records of rain in Carmel Valley and long term records of river flows in the Big Sur River. New sediment transport measurements allow us to estimate the volume and mass of sediment produced by the watershed. Digital oblique aerial photography obtained during a reconnaissance flight on October 31, 2004 allows us to evaluate the general physical condition of the watershed and helps us locate specific sediment sources affecting the river.

3 Description of the Garrapata Watershed and Tributaries

Garrapata Creek is a perennial stream draining the western slope of the Santa Lucia Mountains in the Coast Ranges geomorphic province (Fig. 1). The watershed divide rises to approximately 915 m (3000 ft) along the Carmel Watershed divide, where Twin Peak has the maximum elevation of 1100 m (3610 ft). The watershed drains 27.5 km^2 (10.7 mi^2) of land, following both overland and subterranean routes leading to the Garrapata lagoon and federally protected waters of the Monterey Bay National Marine Sanctuary. There are two major tributaries (subwatersheds) contributing flow to Garrapata Creek (Fig. 1). Several attributes of the watershed are presented in Table 1.

There is one continuously recording stream gauge located on Garrapata Creek, approximately 10 m upstream from the mouth of Joshua Creek (Fig. 2). The gauge was installed in summer of 2001, and has been maintained by the Watershed Institute (CSU-Monterey Bay).

Table 1: Physical attributes of Garrapata Watershed

Drainage area	27.5 km^2 (10.7 mi^2)
Axial trend	270°
Length	7.7 km (4.8 mi)
Highest peak (Twin Peak)	1100 m (3610 ft)
General divide elevation	915 m (3000 ft)
Mouth elevation	Sea level at mouth of Garrapata Lagoon
Relief	915 m (3000 ft)
Average slope	12%
Approximate Strahler stream order	5th
Network geometry	Dendritic, but controlled by active faulting
Dominant stream types	Headwaters dominated by A, B Mid-slope dominated by B with sporadic waterfalls Lowland dominated by B with minor C (classification of Rosgen, 1994)
Land-use	Wilderness, sparse residential, and light agriculture.
Vegetative Ecosystems	Dominated by chaparral, scrub, and oak/bay woodland. Local redwood forests near valley bottoms. Eucalyptus groves locally present. Cape Ivy is greatest non-native threat

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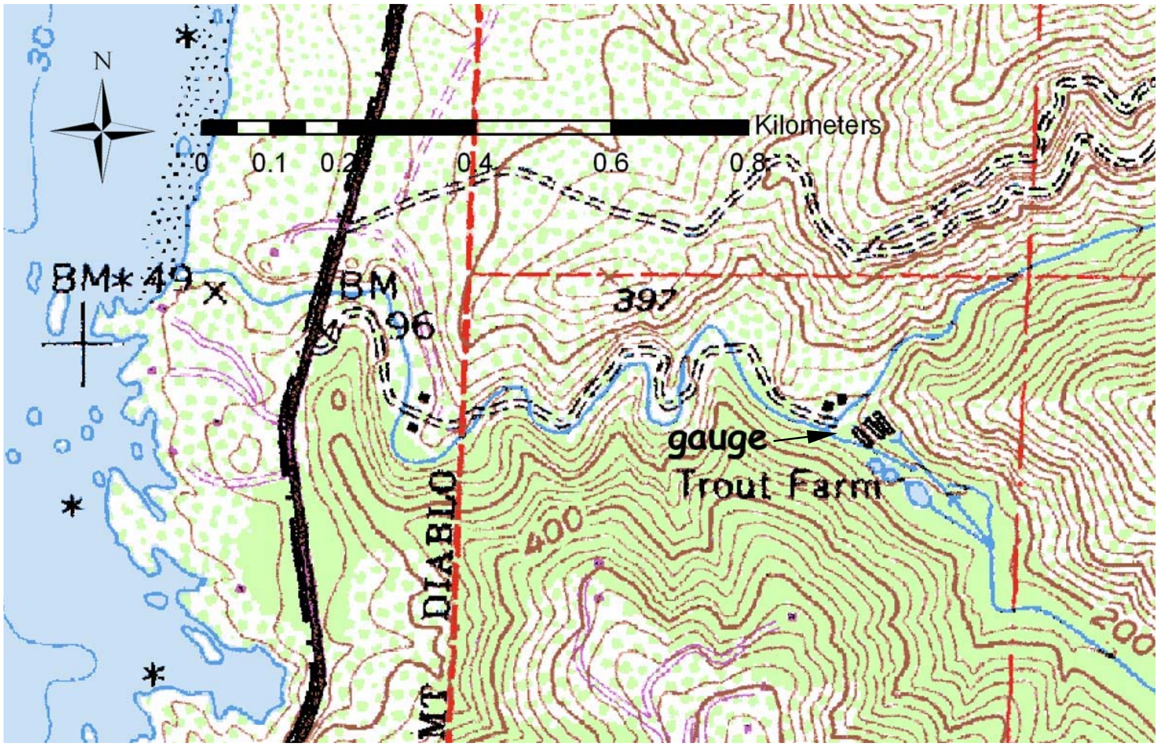

Figure 2: Lower reach of Garrapata Creek. Gauge is located at E598130 N4030570 UTM zone 10N WGS84.

4 Geologic Setting

Geology is one of the fundamental variables controlling the physical condition of a watershed. Rock type controls the soils, groundwater resources, erodibility, landslide potential, ecosystem potential and both the land-use opportunities and liabilities. The substrate in the Garrapata Watershed is chiefly faulted and fractured granitic rocks with generally steep slopes. Because the geology is so simple, and the climate and ecosystems are relatively uniform, a single set of environmental management strategies might hold for the entire watershed.

4.1 Regional Geologic History

The following geologic history is based upon personal interpretation of the regional geology (Fig. 3), and is, in part, paraphrased from Rosenberg (2001).

California is cut by innumerable faults that sliver the state into a quilt-work of rocks. The rocks lying between major faults sometimes share a mutual geologic past, distinct from the rocks on the other side of the major faults. The region between these major faults are termed structural blocks. The Garrapata Watershed dissects the Santa Lucia Mountains, which compose part of the much larger Salinian structural block. Based upon the rocks in the Salinian block, the following general history occurred. In Paleozoic time (400 million years ago) the Salinian block was located just south of the Sierra Nevada, where the Mojave Desert is today (Mattinson and James, 1985).

The Paleozoic rocks were deposited in a marine setting that was similar in geometry to the present eastern seaboard of North America. During Mesozoic time, those marine sediments were highly metamorphosed by heat from an enormous volume of magma that was generated below ancient volcanoes that lay near the present Sierra Nevada. The metamorphic rocks are present today as schist, marble, and gneiss in the Santa Lucia Range. Pico Blanco in Big Sur is "blanco" (white) because it is made of pale marble. The magma chambers cooled to form what is popularly called "granite." There are many kinds of "granite," including the "hornblende-biotite-quartz diorite of Soberanes Point" which underlies approximately 99% of the Garrapata Watershed (Fig. 3). Uplift and erosion of those granitic rocks brought them to the surface of the earth. The granitic rocks then subsided to below sea level to become the sea floor where sandstone and shale were deposited in submarine canyons and submarine fans. This subsidence occurred in Late Cretaceous time, perhaps starting 70 million years ago. These deep marine sedimentary rocks include the conglomerates exposed at Point Lobos and the tilted sandstone beds exposed just north of the mouth of Garrapata Creek (Fig. 3)

Beginning perhaps 20 million years ago, these metamorphic, granitic and sedimentary rocks were transported westward away from the present position of the Mojave Desert on the Garlock Fault and then were transported northwestward on the west side of the San Andreas fault system. The Salinian block and Garrapata Watershed are still moving northwestward relative to stable North America (east of the San Andreas Fault). The presence of both dormant and seismically active faults within the Big Sur region and adjacent continental shelf are evidence that this area is still under constant stress from the movement (Fig. 4). The Salinian block lies west of the San Andreas Fault so it is part of the Pacific tectonic plate moving about 5 cm/yr northwestward.

During its continuous northwestward journey, the Salinian block has been slivered by innumerable small and a few large faults. Various parts of the Salinian block have risen, then fallen, as the stresses alternately produce compression, then extension. This “porpoising” action alternately produced mountains and marine basins during the last 20 million years. The most recent motion of the Santa Lucia Range is uplift, producing numerous well expressed marine terraces that were cut by wave action, but then uplifted away from sea level. A broad terrace exists north of the mouth of Garrapata Creek (Fig. 5). The terrace is covered by young alluvial fan deposits that were shed from steep canyons in the uplifted bedrock hills (Fig. 5). The edge of the marine terrace with overlying young sediments is visible in seacliff exposures and along roadcuts on Highway One. Although the rocks of the Santa Lucias are moving upward, the average elevation of the range is decreasing because erosion rates have exceeded uplift rates for the past 2 million years (Ducea et al., 2003).

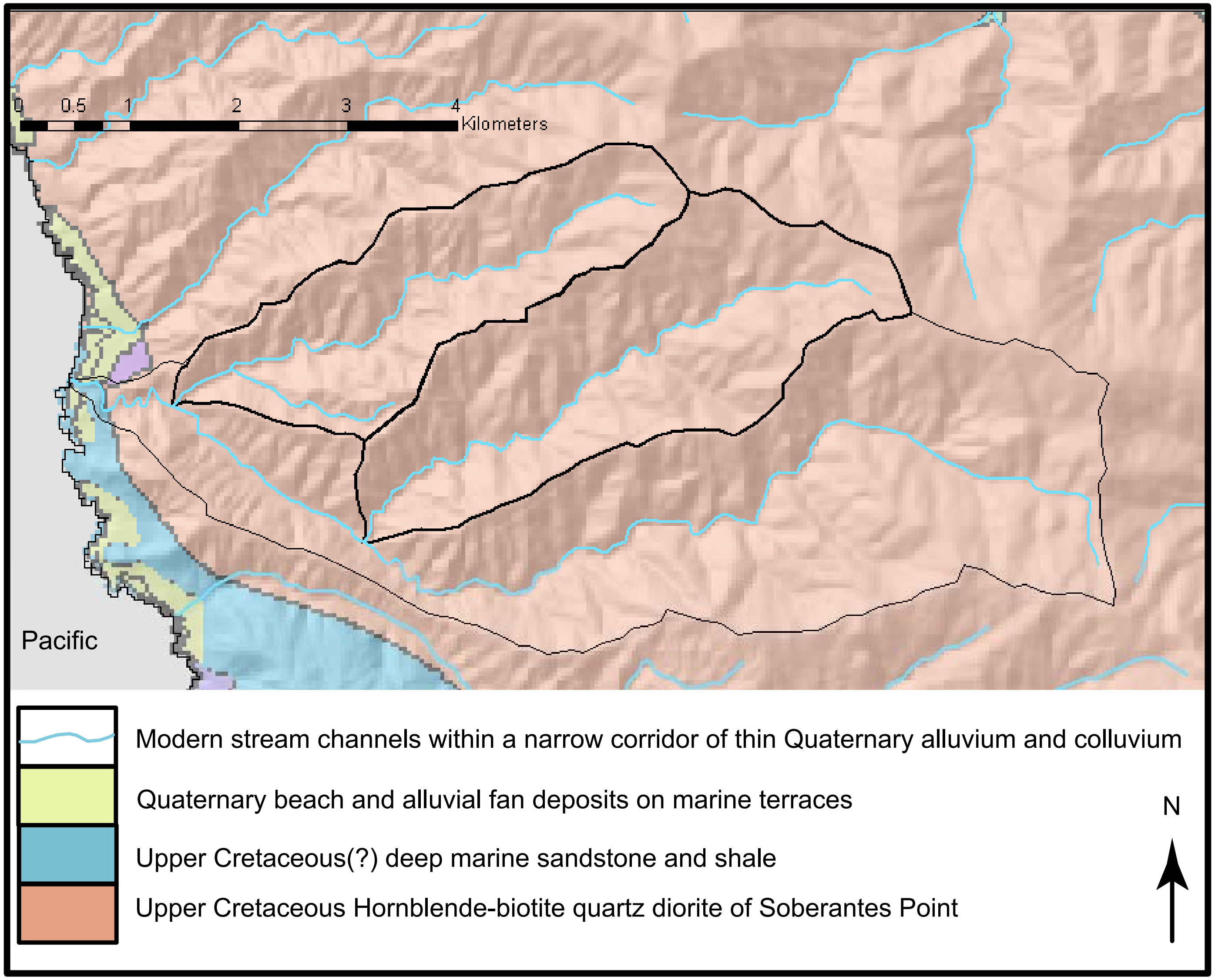

Figure 3: Regional Geology near Garrapata Watershed. Data modified from Rosenberg (2001)

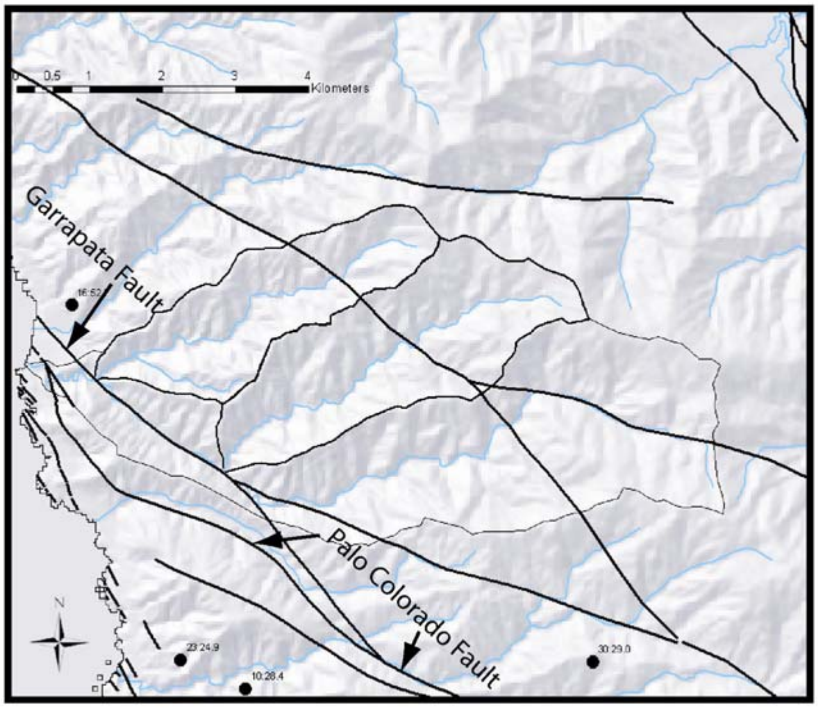

Figure 4: Fault network near Garrapata Watershed. Recent earthquake epicenters are shown as black dots.

Figure 5: Geology and geomorphology near the mouth of Garrapata Creek. 1986 color aerial photo provided by Lew Rosenberg.

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4.2 Faults

The granitic rocks underlying the Garrapata Watershed are pervasively fractured and faulted as a result of millions of years of strain, repeatedly being crushed, sheared, and extended by the relative motions of the Pacific and North American plates. The mappable through-going faults include, from south to north, Palo Colorado, Garrapata, and two un-named faults whose histories and level of activity have not been documented (Fig. 5). The Garrapata and Palo Colorado faults are active, having offset young marine terraces and a 1200 year old soil (Clark and Rosenberg, 1999). The total offset on the faults is unknown, but may be as much as 3.2 km (2 mi) on the Garrapata and "extensive" on the Palo Colorado (Rosenberg, 2001). Fracturing and faulting make the otherwise impermeable granitic rocks of this region an exploitable aquifer.

4.3 Landslides

Slope failure is a natural mechanism by which over-steepened mountain slopes reduce their slopes to achieve temporary stability. Landslides in the Big Sur region are the chief mechanism for bringing the gravel, cobbles, and boulders to the valley floor where flowing water can arrange the material into high-quality aquatic habitat suitable for anadromous fisheries. Excess fine sediment (sand, silt, and clay) brought down slope from disturbed lands can introduce sand and finer material to the creeks, leading to negative environmental impacts.

Willis et al. (2001) mapped over 1500 landslides along Highway 1 between San Capoforo Creek and Point Lobos, suggesting that slope-failure processes are a common occurrence along the western flanks of the Santa Lucia Range. Slope failure rates are especially high where naturally steep slopes have been further steepened and disturbed by road construction, as is true along much of the coastal Highway 1 corridor (Willis et al., 2001). Smith et al. (2003) recognized the presence of shallow landslides in upper Williams Canyon, which is part of the San Jose Watershed located directly north of the Joshua Creek divide (Fig. 1). Some of those slides were the result of logging impacts, and some were clearly triggered by severe rainstorms of the 1995 or 1998 El Nino season. Smith et al. (2004) concluded from new evidence and past work that landslides are a considerable source of excess sediment in the nearby Carmel watershed, especially where land use included cattle impacts or dirt roads cut along steep slopes.

Despite the relatively high number of landslides in the region, and the very steep slopes of the Garrapata Watershed, Garrapata has relatively few natural landslides. Garrapata Watershed owes its relative stability to the specific kind of "granitic rocks" into which it is cut. Smith et al. (2004) found that "geologic substrate" was a fundamental control on the presence of Quaternary landslides in the Carmel Valley. Their findings show that "hornblende-biotite-quartz diorite of Soberanes Point" (Fig. 3) is one of the least landslide prone kinds of rock in the region (Fig. 6). Rosenberg (2001) assessed Monterey County region for "landslide susceptibility" including the Garrapata Watershed (Fig. 7). With little exception the Garrapata watershed has a "low susceptibility" to landslides (Fig. 7).

There are three areas with natural shallow colluvial landslides. These slides are on the northern flank of Garrapata Creek (Fig. 8), where vertical motion along the Garrapata fault has over steepened the valley walls (Fig. 9), and a small slide on the northern wall of Wildcat Canyon.

There are also active shallow landslides associated with road cuts that have over-steepened the valley walls between Highway 1 and the Trout Farm and above Joshua Creek (Fig. 10).

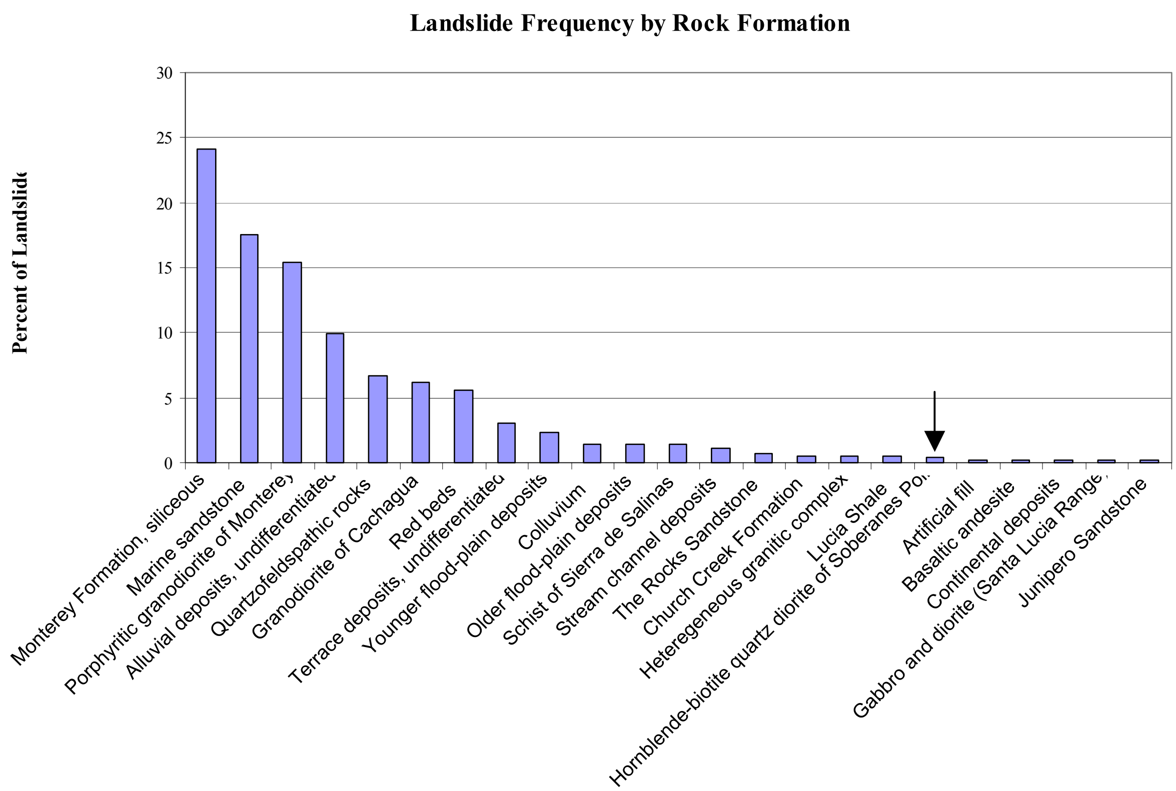

Figure 6: Relationship between mapped Quaternary landslides and rock Formations of the Carmel Valley (Smith et al., 2004).

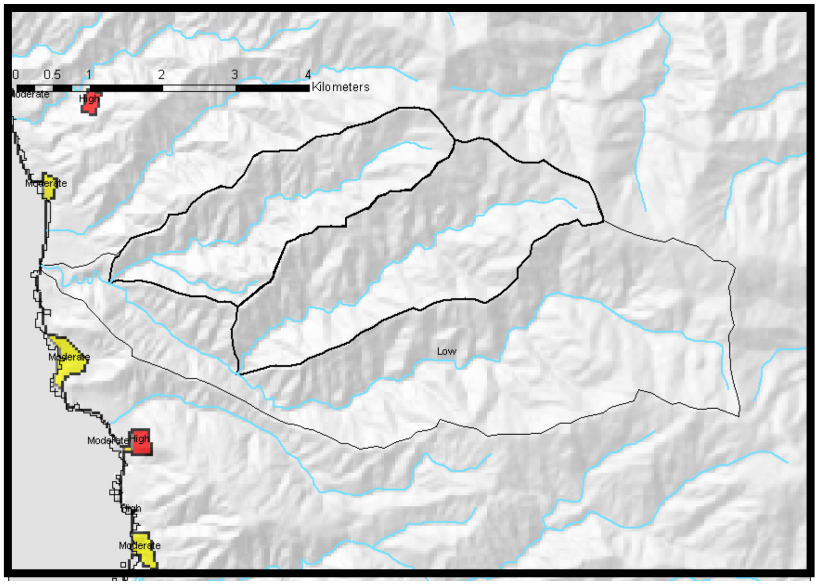

Figure 7: Landslide susceptibility in the Garrapata Watershed (Rosenberg, 2001). Red regions are highly susceptible to landslides, yellow regions are moderately susceptible, and uncolored regions have a low landslide susceptibility.

Figure 8: Two natural landslides along northern flank of Garrapata Creek (Oct. 31, 2004). Right photo also shows abandoned roads leading from Garrapata Creek to Wildcat Creek. Cut slopes along those roads appear to be continuing sediment sources.

Figure 9: Slightly increased abundance of soil slips along the trend of the Garrapata Fault zone (Oct. 31, 2004).

Fig. 10: Shallow soil slip in slope above Joshua Watershed road cut (Oct. 31, 2004).

4.4 Erosion

Rocks of the Santa Lucia Mountains have been continuously rising for the last 6 million years (Ducea et al., 2003). Erosion has been continuous as well, so the Santa Lucias have never had extremely tall peaks. In fact, erosion over the past 2 million years has outpaced uplift resulting in a net reduction in average elevation of the range (Ducea et al., 2003). This continuous battle between uplift and erosion results in rugged, deeply incised "V"-shaped valleys with steep walls and steep river gradients (Fig. 11; Table 1). Note that erosion is the particle-by-particle movement of loose sediment eroded from a region, whereas landslides are larger regions of soil or bedrock that move down slope at the same time.

In naturally steep, tectonically rising terrain like the Santa Lucia Range, equilibrium slope angles are maintained through erosion and slope failure. In general, slopes in such regions are almost always near the threshold of failure. Grading for roads and building sites on steep slopes will locally increase the slope angle at the road cut and side cast material below the road. (Fig. 12). Slopes that have been increased beyond the equilibrium angle will commonly be sites of chronic erosion and excess sediment in creeks until erosion and slope failure have reduced the slope angle to its equilibrium profile. For this reason, the Garrapata Watershed is highly susceptible to erosion according to Rosenberg (2001; Fig. 13).

There are three locations in the Garrapata Watershed where chronic road-related sediment sources can be seen from the air; many more sites lie beneath forest canopy (Pacific Watershed Associates, 2003). One of these erosion sites is the abandoned road in the right-hand photo of Figure 8. The second site is an access road for the PG&E power lines (Fig. 14).

Figure11: View down Garrapata Creek from above Rocky Creek Watershed. Garrapata Fault extends up canyon from offshore. The fault lies in the valley bottom and crosses into Palo Colorado Watershed at the low saddle (arrow).

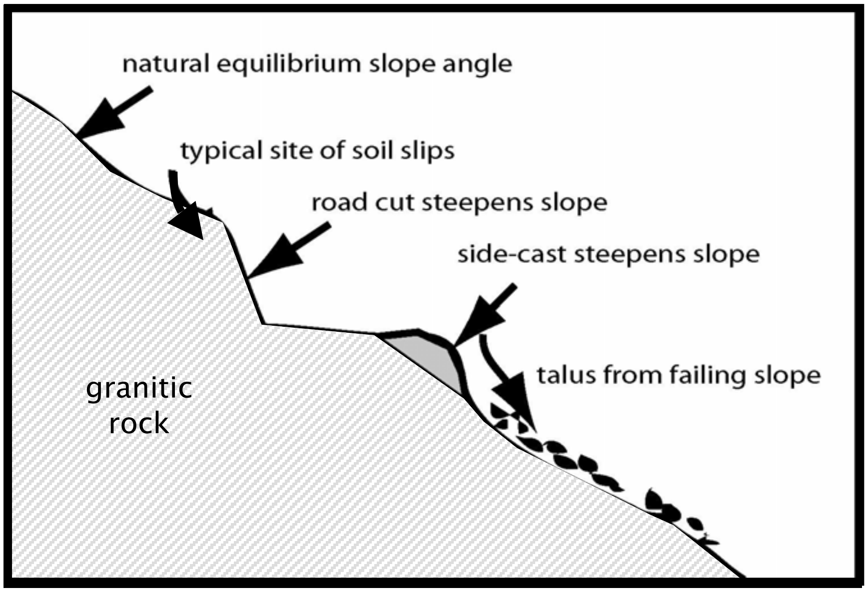

Figure 12: Profile illustrating the typical anatomy of a dirt road cut through steep slopes.

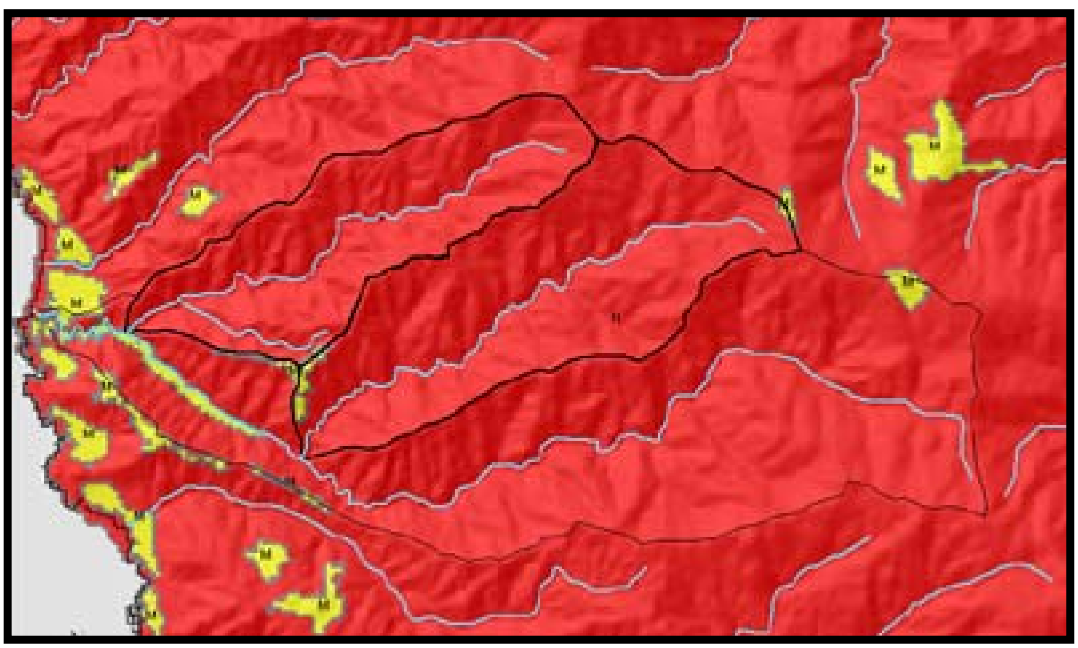

Figure 13: Erosion susceptibility in Garrapata Watershed. Red is high susceptibility, yellow is moderate susceptibility.

Figure 14: PG&E power line access road aimed steeply down slope in the headwaters of Garrapata Creek is potentially a chronic source of erosion and sediment delivery to Garrapata Creek (Oct. 31, 2004).

The third erosion site is approximately 4.4 km (2.8 mi) of roadway cut into the steep slopes above Joshua Creek (Figs. 15 and 10).

Figure 15: Detail of road in Joshua Creek subwatershed with erosion problems (Oct. 31, 2004).

The roads in Joshua Creek subwatershed exhibit the classic erosion associated with road construction across steep slopes (c.f. Fig. 12). Bare, un-vegetated substrate exposed in scalloped road-cut scarp suggest that erosion is still a chronic problem, years after road construction. The light colored aprons beneath the roads are talus slopes shed from side-cast material and eroded from cut side of road. The talus aprons below the road show the path of sediment from the road system to the creek below. During heavy rainfall, the narrow, steep gullies or debris chutes visible below the roads in Figure 15 route the loose sediment directly to the Joshua Creek channel.

In general, periodic maintenance (grading) of dirt roads and the adjacent road cuts keeps the road-cuts slopes over-steepened and unstable and contributes more unstable loose material on side-cast slopes below the road.

5 Climate

Coastal central California has a "Mediterranean" climate with mild dry summers and rainy winters. The annual rainfall measured at San Clemente Dam in the nearby Carmel Valley provides a decadal record showing periods of high magnitude storms and multi-year drought (Fig. 16). Although the Garrapata Watershed receives more rainfall each year than the gauge at San Clemente Dam, the patterns of heavy rainfall and drought should be similar.

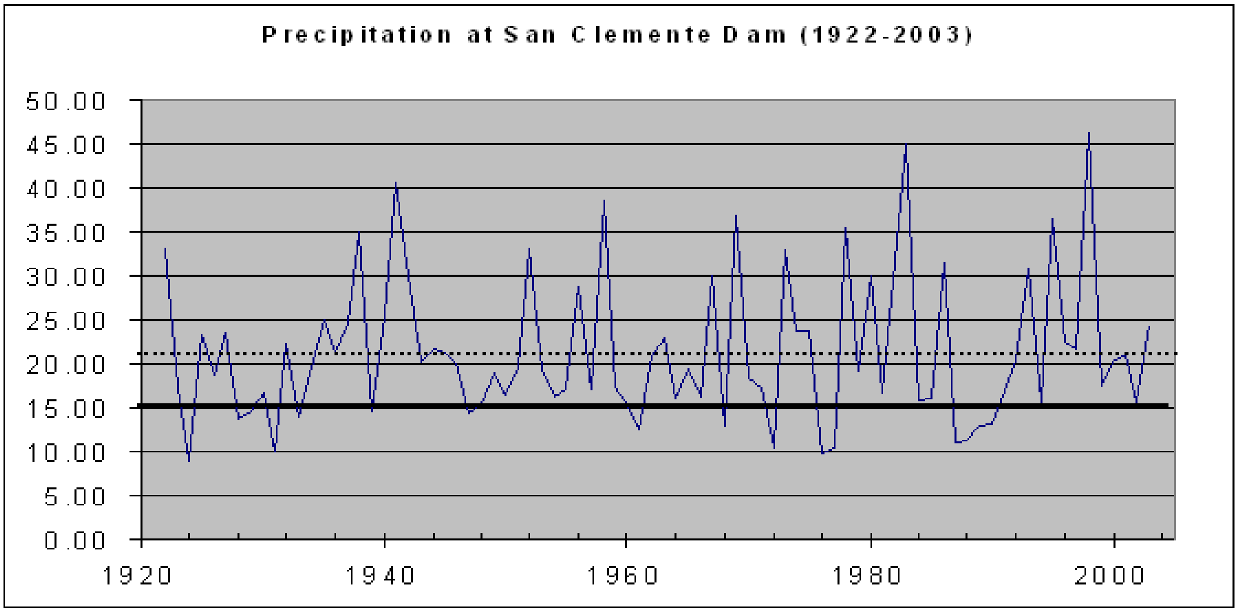

Figure 16: Rainfall at San Clemente Dam since 1922. Dotted line is average (21.37 inches). Bold line approximates the level of rainfall giving rise to hydrologically "dry years" reported in James (2004). Rainfall values below that line approximately correspond to hydrologically "critically dry years." Cal-Am data from James (2004).

Pacific storms advancing against the coast encounter the steep western flank of the Santa Lucia Range. The rising air masses cool and condense so that rain is literally squeezed from the clouds. Thus the Garrapata Watershed is poised to harvest a considerable amount of rain from the typical winter season. According to regional weather data, the annual average rainfall in Garrapata Watershed ranges from a high of 107 cm (42 in) in the headwaters to a low of approximately 83 cm (33 in) near the mouth (Fig. 17). Using the ishoyetal pattern in Figure 17, the average annual rainfall in the Garrapata Watershed is 93 cm (36.6 in). That value indicates that the water resource entering the watershed is 2.55×10^7 m^3/yr (20,700 acre-ft/yr). We modify this estimate in the next section, incorporating a 22-year precipitation record in the Garrapata Watershed.

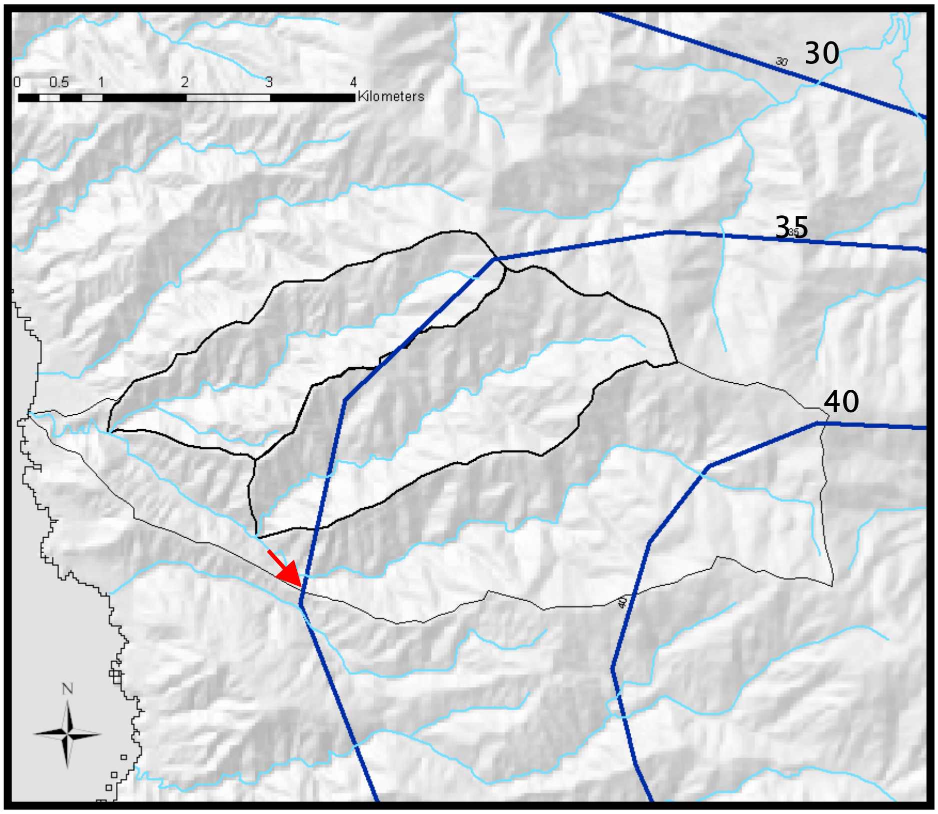

Figure 17: Inches of annual rainfall across the Garrapata Watershed based upon regional data (Rosenberg, 2001). Arrow shows location of the Garrapata rain gauge. See also arrow in Figure 11.

5.1 Local Rainfall Records

Monthly precipitation records have been kept by Barbara Cox, a resident of the divide between Garrapata and Palo Colorado Creeks (arrow in Fig. 17). The annual total rainfall is shown in Figure 18 and Table 2. The annual Garrapata rainfall values are compared to the partial record at San Clemente Dam (Fig. 18). The typical distribution of rainfall throughout the year is shown in Figure 19. The average annual precipitation for the 22 years of record spanning 1982 to 2003 is 30.19 inches, about 14% lower than the 35 inches predicted by regional isohyets for the gauge location (Fig. 17). The isohyets (Fig. 17) are not closely controlled by long term gauges in this part of the Santa Lucia Range, so we heavily weight the local record in our analyses. Considering this discrepancy, we reduce by 14% our estimate of the total water resource calculated using regional isohyets. With this adjustment, the total average input of water to the Garrapata drainage is estimated to be 2.20×10^{7} m^{3} /yr (17,800 acre-ft/yr).

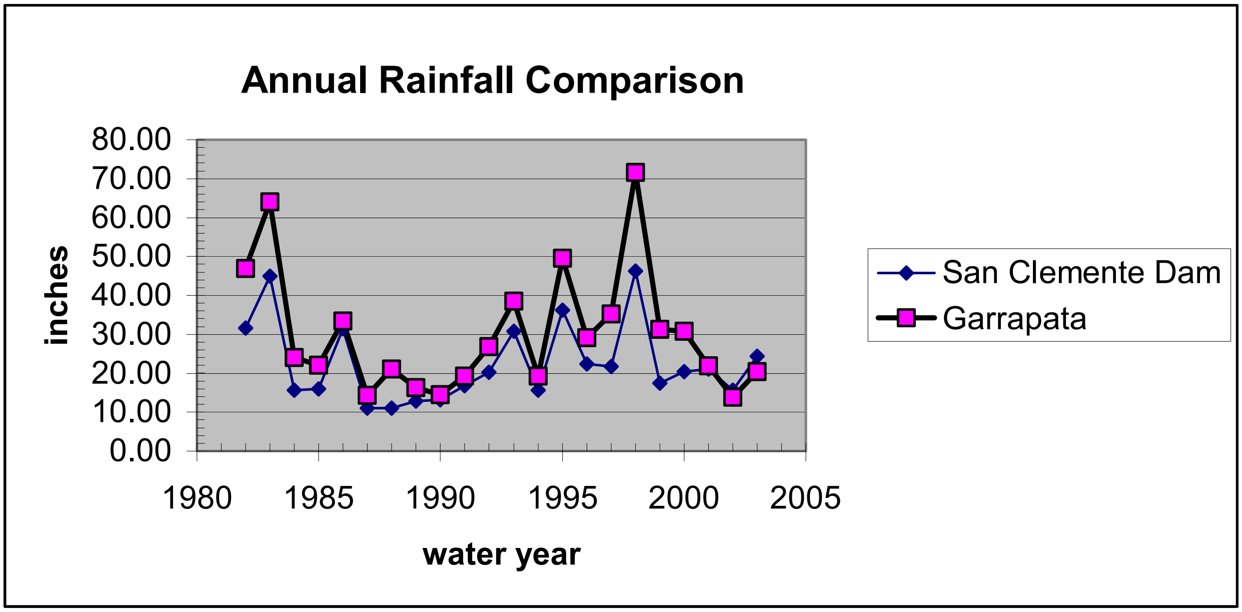

Figure 18: Total annual rainfall at the Garrapata rain gauge compared to the partial record from San Clemente Dam in the Carmel Watershed. Carmel data from James (2004).

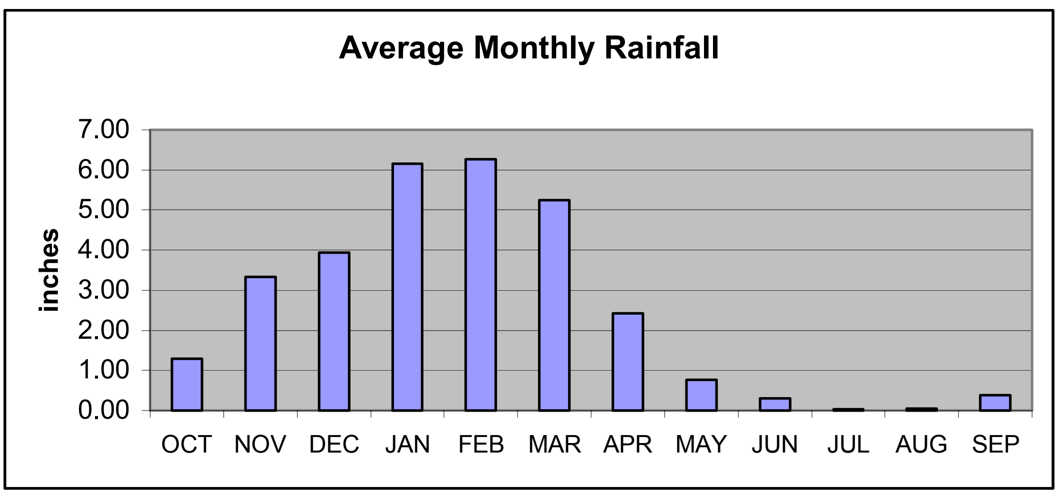

Figure 19: Distribution of rainfall through the year at the Garrapata rain Gauge, based upon monthly data from water years 1982 to 2003.

Table 2: Monthly rainfall data from the Garrapata Watershed Gauge. Figure 18 is a graph of the annual totals.

Water Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Total[1]
1982	4.16	8.43	3.51	9.05	3.73	10.22	5.10	0.00	0.75	0.00	0.00	1.92	46.87
1983	2.55	6.68	3.97	10.70	8.55	21.40	8.03	0.65	0.00	0.00	0.10	1.45	64.08
1984	0.85	9.30	7.75	0.95	3.35	1.40	0.35	0.00	0.00	0.00	0.00	0.10	24.05
1985	2.55	5.89	2.42	0.35	2.20	7.40	0.65	0.00	0.00	0.15	0.00	0.41	22.02
1986	1.70	5.46	2.10	3.15	10.77	7.70	0.66	0.58	0.00	0.00	0.00	1.29	33.41
1987	0.00	0.48	1.37	2.95	4.80	3.07	1.37	0.35	0.00	0.00	0.01	0.00	14.40
1988	1.52	2.97	6.05	3.22	1.79	0.52	3.69	0.95	0.35	0.00	0.00	0.00	21.06
1989	0.00	1.28	4.61	1.88	3.19	3.12	0.84	0.22	0.00	0.00	0.00	1.23	16.37
1990	2.52	1.67	0.15	4.30	2.99	1.25	1.55	0.00	0.00	0.00	0.00	0.12	14.55
1991	0.27	0.55	1.63	0.12	3.65	11.81	0.75	0.35	0.15	0.00	0.00	0.00	19.28
1992	1.76	0.10	4.20	2.35	12.10	5.45	0.38	0.00	0.25	0.25	0.06	0.00	26.90
1993	1.40	0.05	7.30	12.02	9.08	3.96	0.90	2.00	1.35	0.00	0.00	0.50	38.56
1994	0.40	0.80	2.20	3.59	5.50	1.20	3.75	1.35	0.10	0.00	0.00	0.35	19.24
1995	0.50	3.11	3.15	20.31	1.75	12.50	4.30	1.67	2.15	0.10	0.00	0.00	49.54
1996	0.10	0.00	4.75	7.30	9.62	3.50	1.60	2.05	0.00	0.00	0.00	0.22	29.14
1997	1.85	4.50	13.20	13.30	0.55	0.25	0.40	0.10	0.10	0.00	0.90	0.00	35.15
1998	0.85	10.10	3.60	15.55	24.10	5.80	6.15	4.70	0.50	0.20	0.00	0.00	71.55
1999	0.60	4.40	1.35	5.45	6.80	7.65	4.60	0.00	0.00	0.00	0.10	0.25	31.20
2000	0.00	0.50	0.75	10.85	13.45	0.95	2.30	0.70	0.75	0.00	0.00	0.50	30.75
2001	4.55	0.47	0.50	5.53	5.19	2.70	2.79	0.00	0.01	0.00	0.00	0.08	21.82
2002	0.28	3.69	4.08	0.83	1.72	2.25	0.43	0.42	0.04	0.00	0.05	0.04	13.83
2003	0.00	2.82	7.88	1.81	3.00	1.29	2.89	0.73	0.00	0.02	0.00	0.02	20.46
Monthly Avg	1.29	3.33	3.93	6.16	6.27	5.25	2.43	0.76	0.30	0.03	0.06	0.39	

[1] Annual total

5.2 Evapotranspiration

The approximately 2.20×10^7 m^3 (17,800 acre-ft) of rain reaching the ground is divided into runoff, groundwater storage, evaporation, and transpiration (supporting the ecosystem). Hydrologists commonly lump evaporation and transpiration together as evapo-transpiration (ET). Although ET is very important for the watershed, hydrologists call ET a "loss" to the water budget, because it is water that is no longer in the useful phase for runoff or groundwater recharge. If we assume that groundwater is in balance on an annual basis (no net long-term change in storage) then we can write a simple watershed budget equation.

Rain-runoff-ET =0

In other words, the "0" value on the right of the equation requires the assumption that the fraction of rainfall entering the ground is balanced by an equal amount of water leaving the ground (springs, wells, etc.) when averaged over a typical year. There is currently no evidence of groundwater overdraft at this time, so the assumption of balanced groundwater is warranted.

Garzas Creek borders the Garrapata Watershed across the Carmel divide (Fig. 1). RSC-EIR (1994) estimates that 64% of the annual rainfall is lost in evapotranspiration in the Garzas subwatershed. If that value is regionally significant, we would expect ET to be approximately 1.41×10^7 m^3 (11,400 acre-ft), leaving only 7.91×10^6 m3 (6,410 acre-ft) for runoff during the year. We calculate runoff later in this report using the Garrapata stream gauge; we make a local estimate of ET at that time.

5.3 Rain Frequency Analysis: Correlation with San Clemente Dam

Hydrologic statistics of annual rainfall are more robust with more years of record. Based upon the close match between the pattern of rainfall in Garrapata and the San Clemente Dam record (Fig. 18), we mathematically synthesize a longer Garrapata record through regression with the San Clemente record (Fig 16). We then apply log-Pearson type-III frequency analysis to the resulting 82-year record. Regressing the two rainfall records shows a close agreement (Fig. 20). We are confident enough ($p=9 \times 10^{-11}$) to synthesize the 82-year record of Garrapata rainfall (Fig. 21).

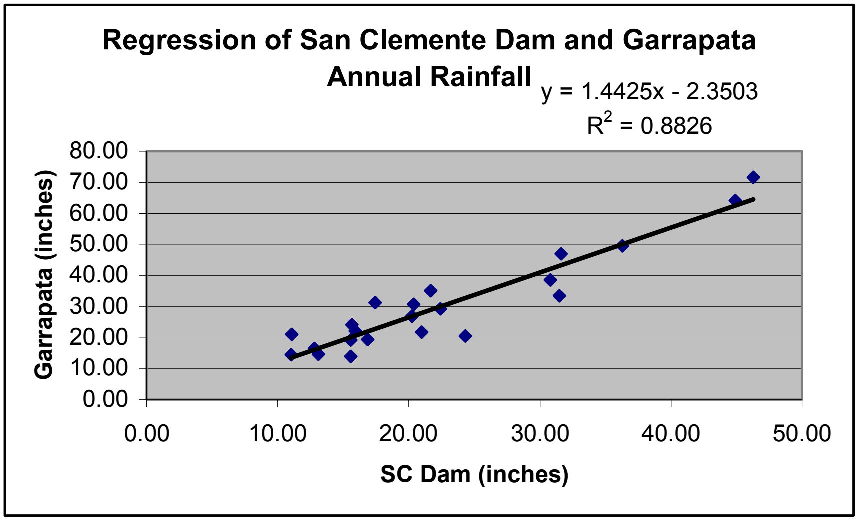

Figure 20: Comparison of annual rainfall at San Clemente Dam and the Garrapata rain gauge from 1982 to 2003.

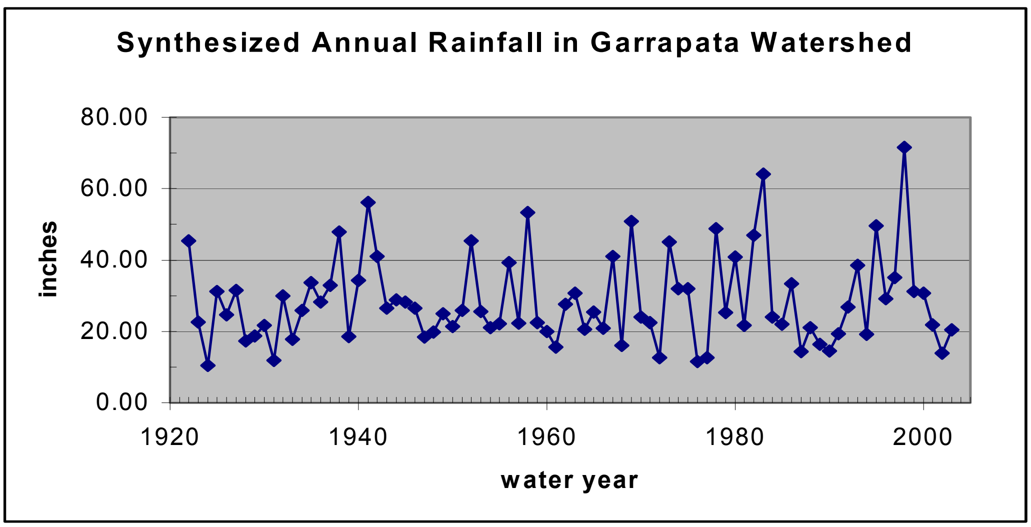

Figure 21: Synthesized 82-year record of rainfall in at the Garrapata gauge based upon the regression in Figure 20. Values from 1982 to 2003 are the actual values recorded in Garrapata.

As a further check on the accuracy of the synthetic data, we synthesized the last 22 years of record to compare that average with the real Garrapata gauge average. The average of the synthesized data is 30.19, exactly the same as the real data set. We use the synthetic Garrapata rainfall to calculate the longer-term hydrologic statistics for the Garrapata Watershed at the location of the rainfall gauge. The synthesized long-term average rainfall at the gauge is 28.48 in, 1.7 in lower than the 22-year average, suggesting that the average annual rainfall volume is actually lower than the 17,800 acre-feet/yr calculated in the previous section of the report. Figure 22 displays the results of frequency analysis. Table 3 summarizes the estimates of the return periods of various annual rainfall values. Although there are large uncertainties with high magnitude rainfall frequency, the 1998 rainfall of 71 inches (Table 2) was approximately the 100 yr rainfall (Table 3). The true 100 yr rainfall lies between 57 inches and 89 inches with 95% confidence (Fig. 22).

Table 3: Calculated rainfall recurrence and annual exceedance probability (LP-III)

Exceedance Return Period (yrs)	Annual Exceedance (%)	Annual Rainfall at Gauge (in)
2	50%	25
5	20%	37
10	10%	45
25	4%	55
50	2%	63
100	1%	71
200	0.5%	80

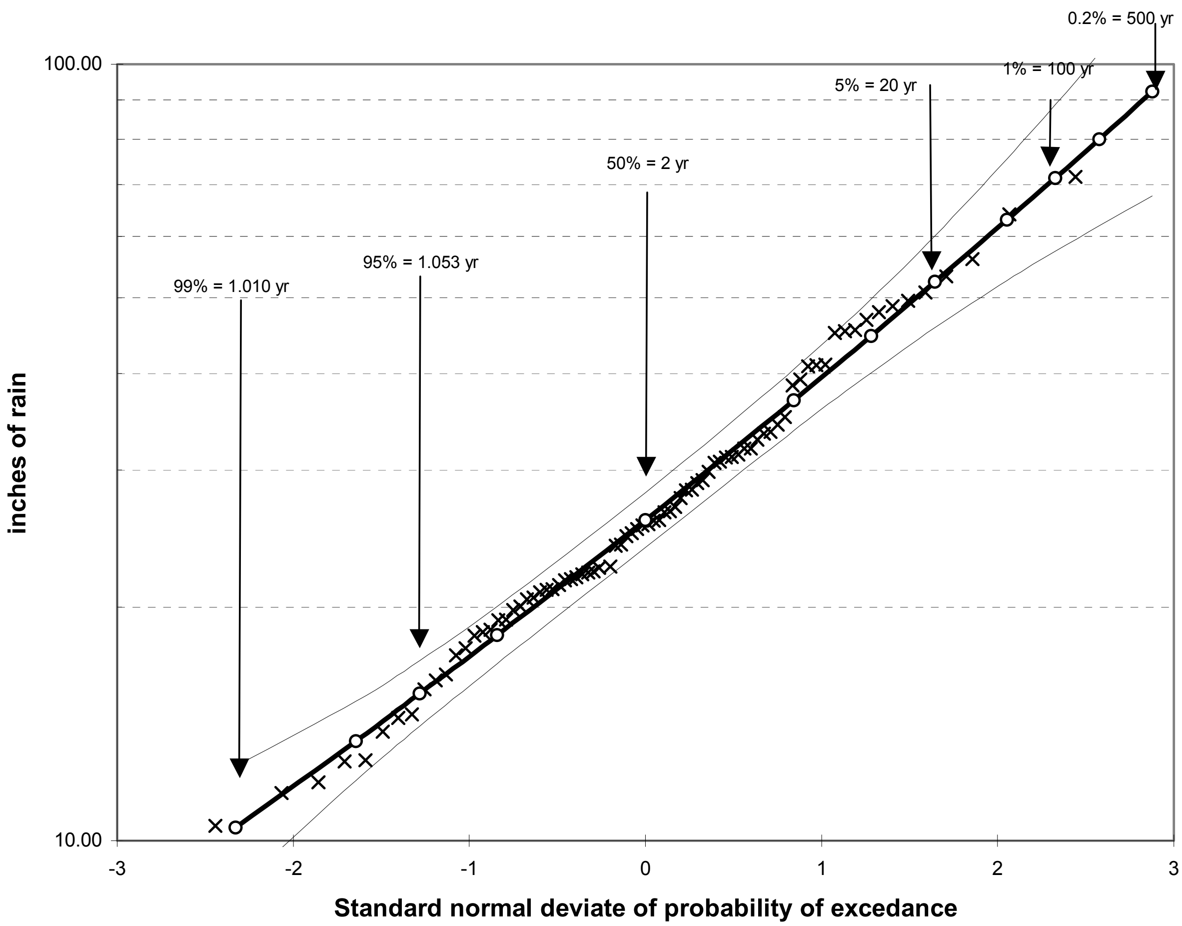

Figure 22: Exceedance probability and 95% confidence limits on synthesized 82 years of rainfall at the Garrapata gauge. "x" shows data. "o" shows model points for various return periods. Thick line is log-Pearson type III model. Thinner lines are the 95% confidence limits on the model. Dashed horizontal lines represent changes of 10 inches of annual rainfall.

6 Stream Flow Data

In summer of 2001, the Watershed Institute installed and began maintaining, a continuously-recording pressure gauge on Garrapata Creek approximately 10 m upstream from the mouth of Joshua Creek (Fig. 2). The pressure gauge is a Telog 2109e-5 series with one channel and 0-10 psi pressure range. The instrument has a stated accuracy of ±0.075% of the reading. The data logger is set to sense water pressure every 500 ms, and record an average pressure every 15 minutes. The data are downloaded and analyzed several times a year. The gauge is situated approximately 1.5 m upstream from an historic concrete weir structure that was used as part of an earlier "Trout Farm" operation. The weir provides excellent grade control for the pressure sensor. There has been no significant "shift" in the gauge rating during the life of the gauge.

6.1 Hydrology of Garrapata above Joshua Creek

The gauge on Garrapata Creek is rated by taking flow measurements with a calibrated Gurley brand pygmy flow meter at a straight section of channel near a wooden foot bridge located 25 m upstream from the weir. Discharge measurements are made using standard procedures for a small stream (Harrelson et al., 1994). At least 20 velocity readings are made during times of high flow, but the channel is wide enough to accommodate only 10 velocity measurements at lower flow conditions. The history of measurements is presented in Table 4. The relationship between staff plate and pressure gauge readings indicates that the stream geometry has remained stable over the life of the project (Fig. 23). An R^2 value of 0.96 indicates a very robust equation relating gauge depth to discharge (Fig. 24). We use that equation to convert from continuous gauge depth to continuous discharge (Figs 25, 26, 27).

Table 4: Discharge and stage measurements on Garrapata Creek

Date	Staff plate (ft)	gauge (ft)	Discharge (cfs)
10/27/01	0.647	0.946	0.96
11/03/01	0.659	1.018	1.30
2/09/02	0.800	1.342	5.22
3/10/02	0.840	1.254	5.21
4/29/02	0.800	1.238	3.74
9/09/02	0.570	0.902	1.57
2/15/04	0.815	1.283	3.14
2/19/04	1.005	1.617	8.17
2/26/04	1.310	2.310	25.61
3/12/04	0.915	1.452	6.96
3/23/04	0.850	1.330	4.39
3/24/04	0.840	1.340	4.86
4/25/04	0.720	1.122	--
7/27/04	0.510	0.692	0.46
10/7/04	0.420	0.557	0.34

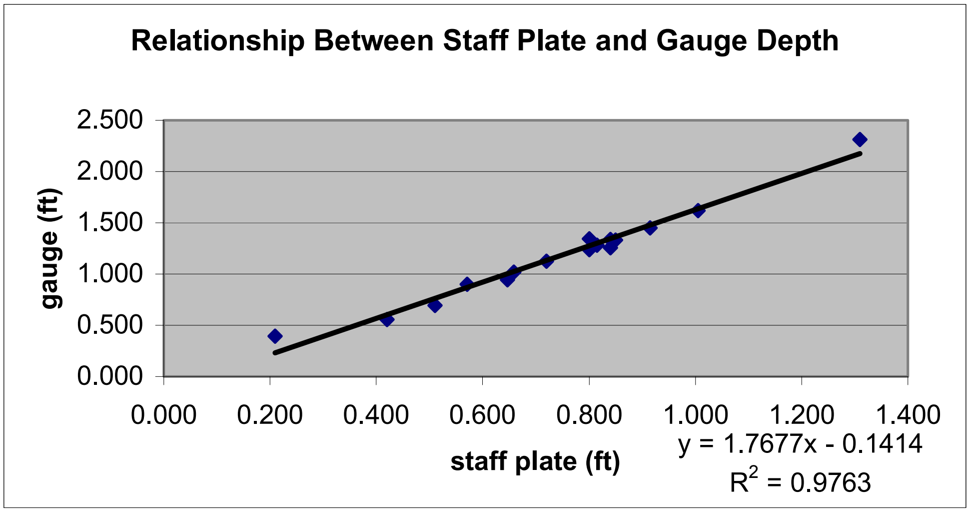

Figure 23: Scatterplot of Garrapata gauge depth and staff plate depth.

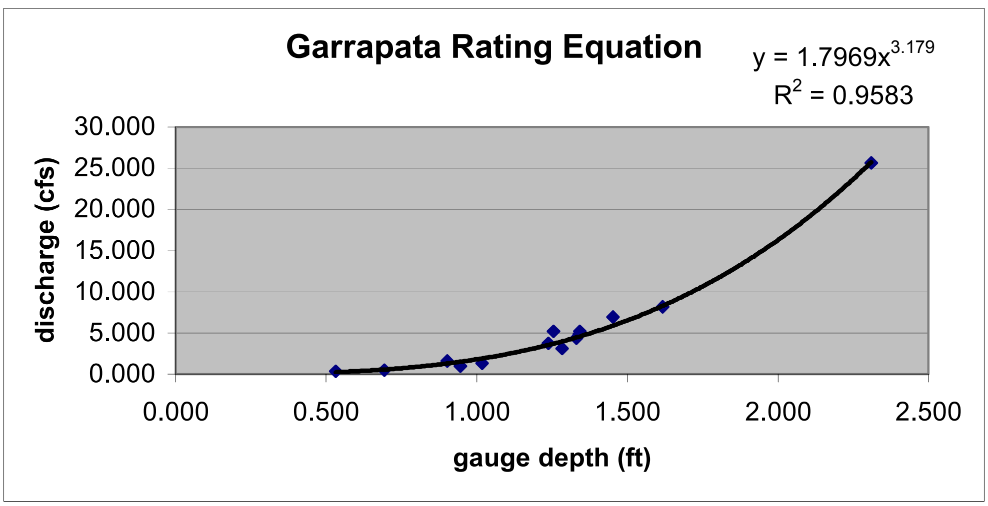

Figure 24: Scatterplot of Garrapata gauge depth and stream discharge.

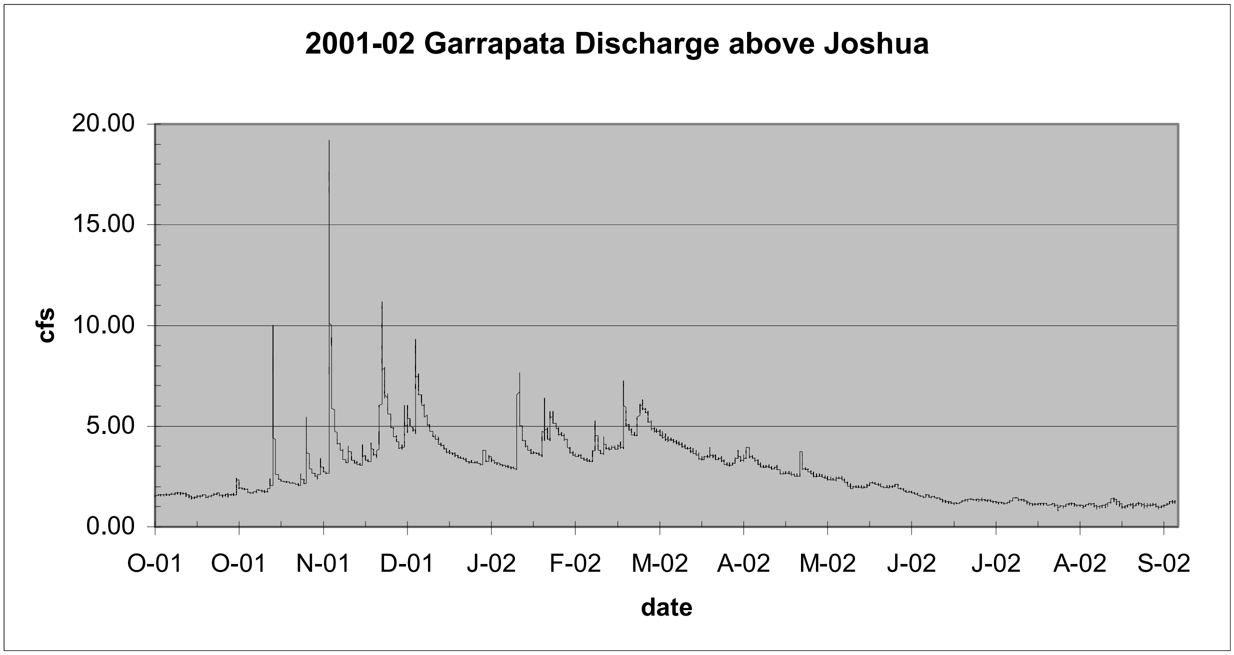

Figure 25: Garrapata discharge between October 1, 2001 and September 30, 2002.

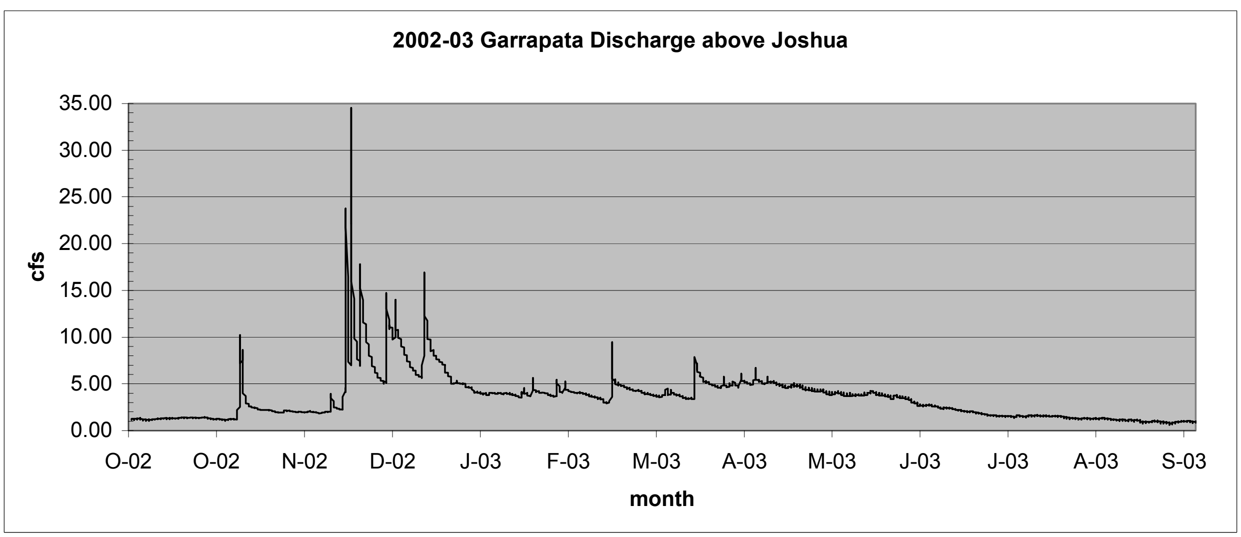

Figure 26: Garrapata discharge between October 1, 2002 and September 30, 2003.

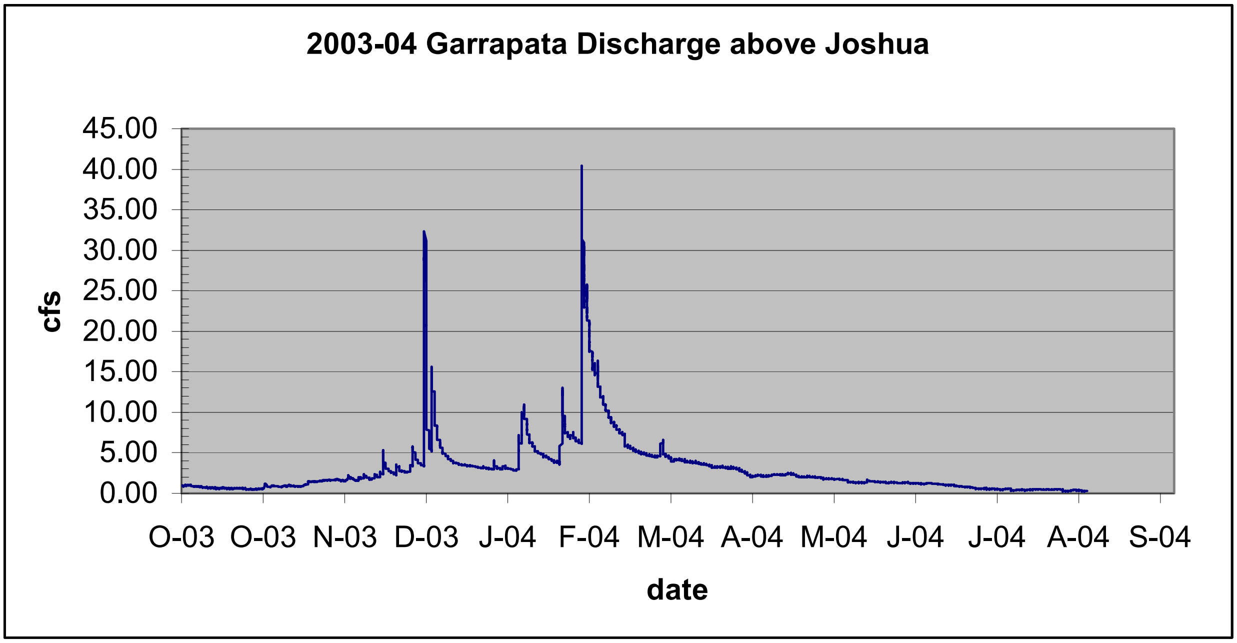

Figure 27: Garrapata discharge between October 1, 2003 and September 30, 2004.

6.2 Hydrology of Joshua Creek Near Confluence with Garrapata

The Garrapata gauge is located upstream from the mouth of Joshua Creek, so hydrologic measurements of Joshua Creek are required to develop an estimate of the total runoff in the watershed. There are no significant tributaries located downstream from the mouth of Joshua Creek, so adding the discharge of Joshua Creek to the discharge calculated at the Garrapata gauge will account for nearly all the surface water flowing from the Garrapata Watershed.

Estimates of flow velocity were taken on Joshua Creek at an abandoned foot bridge that includes a broad flat floored cement box culvert. The rectangular culvert simplified flow cross section measurements. Table 5 provides the history of measurements. An R^2 value of 0.96 indicates a very robust equation relating Garrapata Creek gauge depth to Joshua Creek discharge (Fig. 28). We use that equation to convert from continuous gauge depth to continuous discharge (e.g. Fig. 29). Because the best fit equation is a second-order polynomial, there is a rise in the model values at low values of gauge depth (Fig. 28). To correct this error, we apply a best fit power function to calculate the discharge when values of gauge depth are below 1.5 feet.

Table 5: Discharge on Joshua and gauge depth on Garrapata Creek

date	gage (ft)	Joshua (cfs)
10/27/01	0.946	0.862
11/03/01	1.018	0.181
2/19/02	1.342	1.480
3/10/02	1.254	0.862
4/29/02	1.238	0.396
9/9/02	0.902	0.104
2/15/04	1.283	0.950
2/19/04	1.617	1.797
2/26/04	2.310	8.076
3/12/04	1.452	1.222
3/23/04	1.330	0.658
3/24/04	1.340	0.511
4/25/04	1.122	0.727
7/27/04	0.692	0.063
10/7/04	0.557	0.074
7/27/04	0.392	0.001

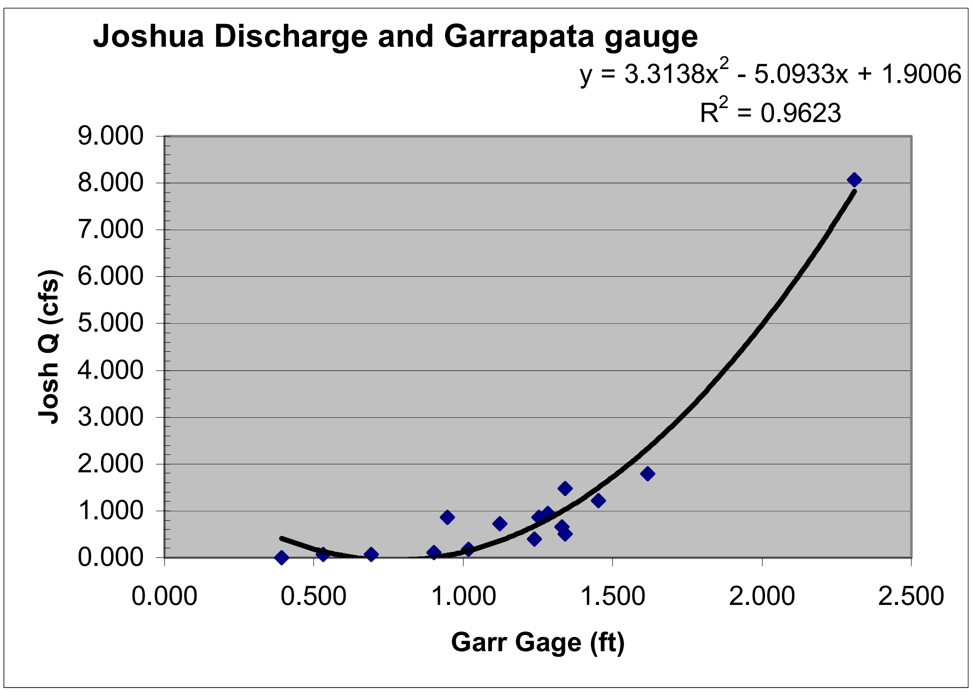

Figure 28: Scatter plot of Garrapata gauge depth and discharge on Joshua Creek

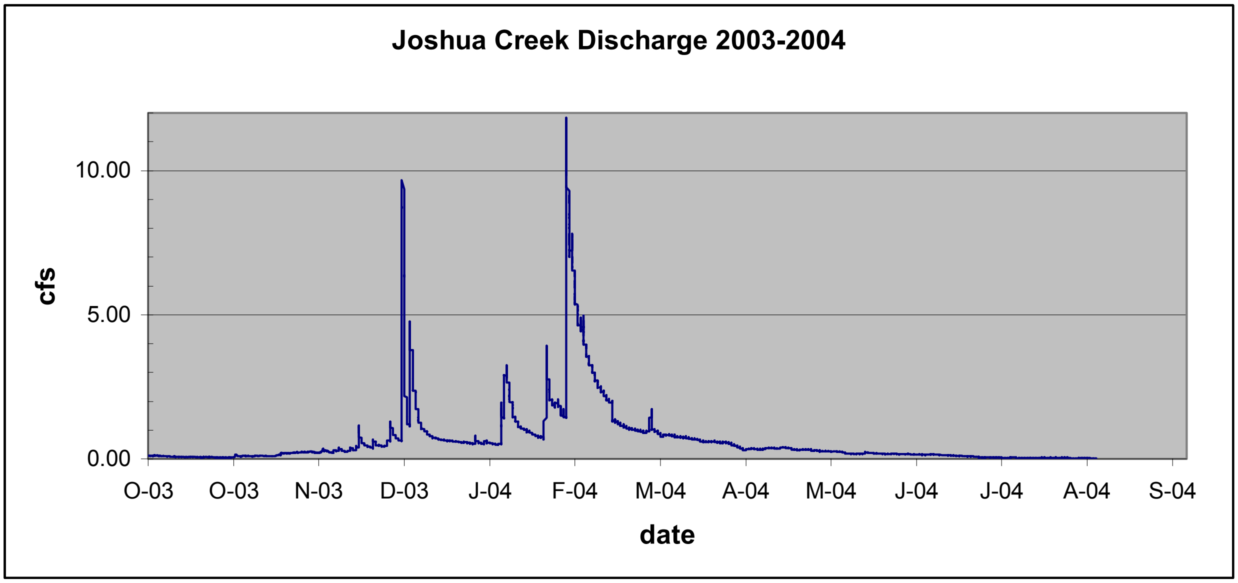

Figure 29: Joshua Creek discharge between October 1, 2003 and September 30, 2004.

6.3 Hydrology Summary for Garrapata Watershed

For most of the gauge record, the depth data were averaged and recorded every 15 minutes. For each data interval, flow volumes were calculated. The sum of those incremental volumes provide the best estimate of the volume of water flowing in the creeks. The average values calculated for flow volume and watershed yield (Table 6) are lower than they would be in the long run, because they are based upon three years of below normal rainfall. Normal years see almost twice as much rainfall as was present during our study. Keeping that in mind, the average resource values in Table 6 are low, perhaps only 50% of what they will be as record keeping continues. Table 6 shows that on average the entire watershed contributes 141 acre-ft per square mile of watershed. For water years 2001-02 and 2002-03, the watershed yields were very similar to Garzas Creek across the divide in the Carmel Watershed (James, 2004).

Table 6: Volume of stream flow (acre-ft). Average yield (acre-ft/ mi^2) is the annual average flow per unit area of watershed

Water year	Garrapata	Joshua	Watershed	Rain (in)
2001-02	1516	281	1797	13.83
2002-03	2534	534	3068	20.46
2003-04	1974	425	2399	
Annual average	2008	413	2421	
Average yield	145	125	141	

Recall that we earlier calculated that 17,800 acre-ft of precipitation falls on the watershed. We stated that if the groundwater is balanced and ET is 64%, as was reported for the neighboring

Garzas watershed, then there should be approximately 6410 acre-ft left for runoff. The large discrepancy between the expected value (6410 acre-ft) and the measured value (2421 acre-ft) may have any of several causes. Most likely it is a combination of 1) 50% less rainfall input during the years of record, and 2) higher ET values in Garrapata Watershed because there is a greater proportion of south-facing slopes than in Garzas Watershed. Using that approach we calculate that ET in the Garrapata Watershed is approximately

Fifty percent of the average rainfall is 8900 acre-ft, so the watershed budget for the period of record is,

(8900 acre-ft) - (2421 acre-ft) - ET = 0.

So ET is approximately 6479 acre-ft, or 73% of the total rainfall, assuming balanced groundwater.

6.4 Flow Frequency Analysis: Correlation with Big Sur River

Three years of flow data are insufficient for estimating the magnitudes of various flows of interest such as the 50 year flood. We extend the Garrapata flow record using the long-term U.S. Geological Survey record of the nearby Big Sur River as a proxy. We can correlate the two data sets by comparing the peak flows recorded on both rivers where we are confident that the flows were produced by the same storm system (e.g., Fig. 30).

We selected a variety of discharge values to obtain a broad range of representative data for correlation (Table 7). The regression equation is shown with the scatterplot of the discharge data (Fig. 31). A 52-year record of peak annual discharge in the Big Sur River was converted a synthetic record for Garrapata (Table 8). The synthetic Garrapata record was analyzed using Log-Pearson type-III analysis (Fig. 32). Select flows are shown in Table 9. The data used in the correlation were neither randomly chosen nor plentiful. Although the results are an interesting approximation of the historic record, we do not hold a high level of confidence in these results. The analysis used the discharge measured at the stream gauge above Joshua Creek. The discharge values listed in Table 9 would be approximately 20% higher for Garrapata Creek below the confluence with Joshua Creek.

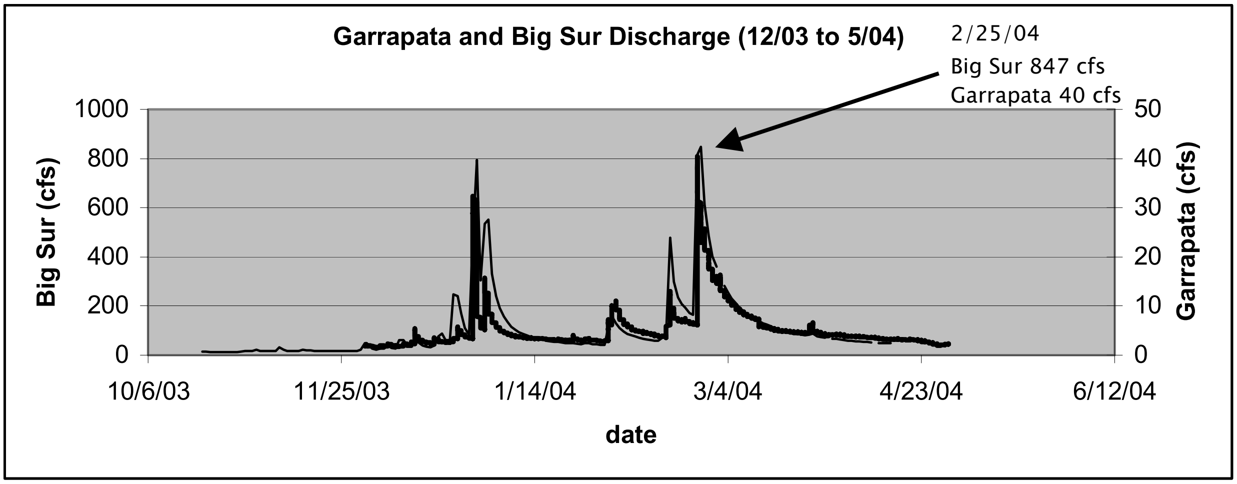

Figure 30: Example of graph used to pick peak flows for comparison. Thin line is Big Sur and thick line is Garrapata.

Table 7: Discharge data used to correlate Big Sur and Garrapata Discharge Records

Approx. date	Big Sur (cfs)	Garrapata (cfs)
12/16/02	1250	34
12/30/03	793	32
2/5/04	160	11
2/18/04	477	13
2/25/04	847	40
11/5/04	27	3.6
11/10/04	65	1.7
10/25/04	119	3.3

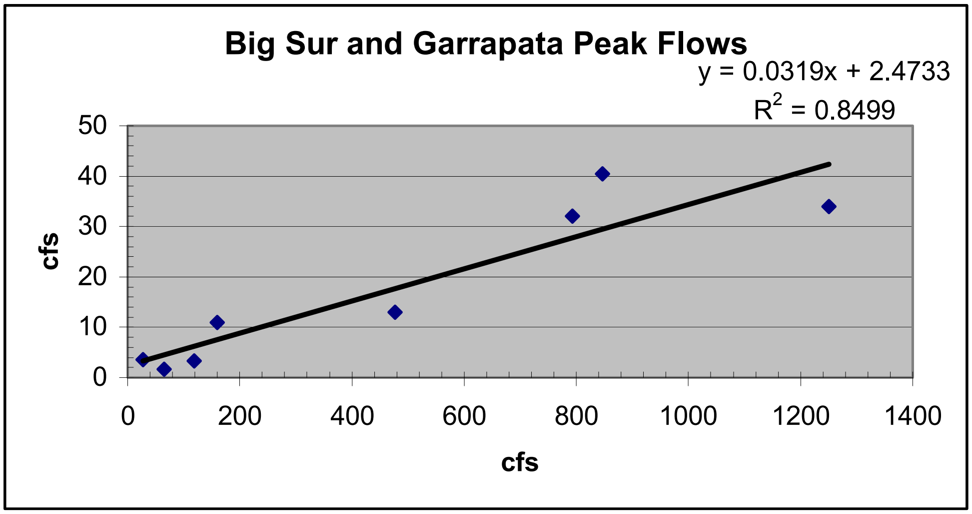

Figure 31: Scatterplot of peak discharges of Big Sur and Garrapata Creeks for select storms.

Table 8: Synthesized discharge record for Garrapata Creek

Month-year	Garrapata (cfs)	Big Sur (cfs)	Month-year	Garrapata (cfs)	Big Sur (cfs)
Nov-50	136	4200	Jan-77	16	415
Jan-52	135	4150	Jan-78	344	10700
Dec-52	96	2920	Nov-78	51	1510
Jan-54	36	1050	Jan-80	120	3670
Dec-54	23	630	Jan-81	77	2330
Dec-55	169	5220	Jan-82	131	4030
Feb-57	67	2010	Dec-82	120	3670
Apr-58	184	5680	Dec-83	58	1730
Sep-59	40	1170	Feb-85	81	2460
Feb-60	75	2280	Feb-86	139	4280
Dec-60	27	760	Feb-87	97	2960
Feb-62	103	3160	Dec-87	17	451
Feb-63	175	5400	Dec-88	52	1560
Jan-64	49	1470	Feb-90	46	1360
Jan-65	69	2100	Mar-91	78	2370
Nov-65	32	918	Feb-92	69	2090
Dec-66	146	4510	Jan-93	111	3400
Jan-68	42	1230	Feb-94	38	1100
Jan-69	124	3820	Mar-95	216	6690
Jan-70	123	3790	Feb-96	98	3000
Nov-70	54	1600	Jan-97	162	5000
Dec-71	41	1220	Feb-98	213	6590
Feb-73	91	2790	Feb-99	72	2180
Mar-74	69	2100	Feb-00	144	4440
Feb-75	91	2780	Mar-01	50	1500
Feb-76	18	496	Dec-01	71	2140
			Dec-02	114	3500

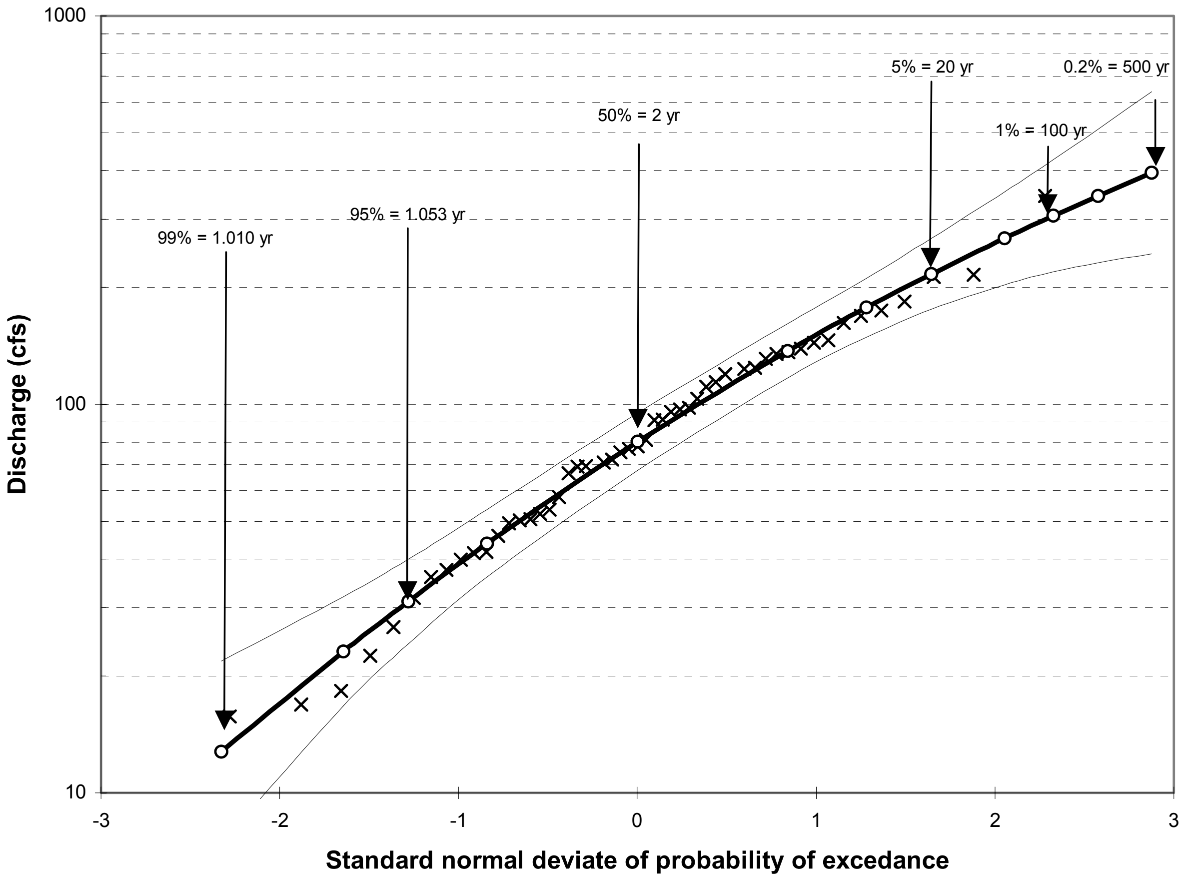

Figure 32: Exceedance probability and 95% confidence limits on synthesized 53 years of synthetic discharge at the Garrapata stream gauge. "x" shows data. "o" shows model points for various return periods. Thick line is log-Pearson type III model. Thinner lines are the 95% confidence limits on the model.

Table 9: Calculated discharge recurrence and annual exceedance probability (LP-III)

Exceedance Return Period (yrs)	Annual Exceedance (%)	Annual Peak Discharge at Gauge (cfs)
1.5	67%	60
2	50%	80
5	20%	140
10	10%	180
25	4%	230
50	2%	270
100	1%	310
200	0.5%	340

6.5 Groundwater Resources

During a rainstorm water either runs off as overland flow or penetrates the soil to become part of the stored groundwater resources. Between storms, some of the groundwater evaporates, some is used to support the watershed ecosystem, and the remainder is available for future use. Some of the stored groundwater surfaces as seeps and springs to maintain perennial surface flow, and the rest replenishes deeper bedrock aquifers.

Although shallow aquifers and water perched at the colluvium-bedrock interface provide much of the perennial flow between storms in the winter, the summer flows likely depend upon springs from larger bedrock aquifers that gradually bleed out water through various subterranean fractures and faults in crushed granitic bedrock leading to surface springs and seeps. Evidence for the link between upland bedrock aquifers and annual surface water yield is presented by Smith et al. (2004). Their study included streams immediately across the Garrapata divide in the Carmel Watershed.

An inventory of groundwater resources in the Garrapata Watershed has not been done. Considering that the physical and climatic conditions in the Garrapata watershed are approximately the same as in the adjacent Garzas Creek Watershed of the Carmel Valley (Fig. 1), the assessment of that watershed may be applicable in Garrapata as well (RSC-EIR, 1994). In that report it was determined that the shape of the water table closely approximated the muted general shape of the topography. There are water table "ridges" under the topographic ridges, etcetera. This geometry indicates that groundwater recharge is important everywhere across the landscape, rather than in specific low lying areas. Considering that a robust groundwater resource is required to sustain perennial flow, land-use management in the watershed should minimize impervious cover that blocks infiltration.

Valley floor alluvial aquifers are also present in the Garrapata drainage. Alluvial aquifers occur in parts of the valley where the valley gradient is slightly lower and where the valley walls are farther apart. These aquifers are constructed of river deposits that lie atop the bedrock framework of the valley, somewhat like a thick layer of sand in a bathtub (Fig. 33).

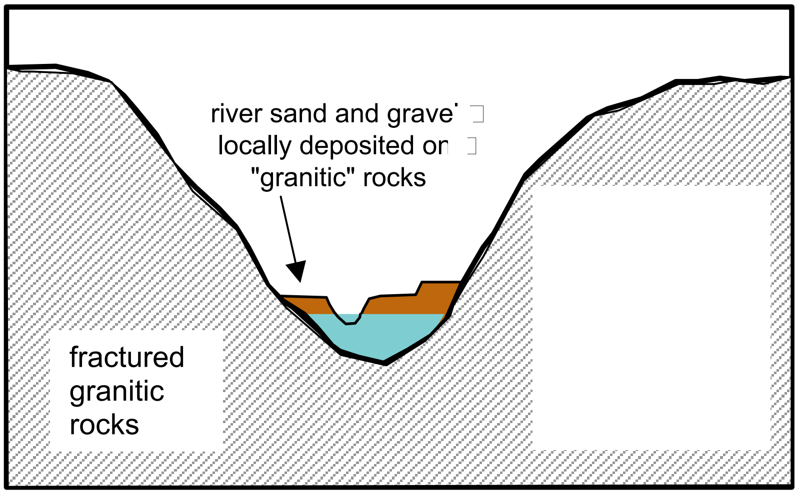

Figure 33: Valley architecture where alluvium rests upon bedrock

The water flowing down valley is partly flowing underground and partly above ground. The surface water and alluvial groundwater are the same resource because there is good fluid connectivity through coarse sediment. This property of flow in alluvial valleys has been long understood by scientists (Kondolf and Curry, 1982; Maloney, 1984), but only recently has been recognized in water law courts (SWRCB, 1995a). It is now recognized that during multi-year droughts, or during times of increased extraction from wells in valley-floor alluvium, surface flow may be impaired. An example of that situation is present in the Carmel Valley where the alluvial aquifer is overused to the point that the river runs dry and riparian vegetation is dependent upon irrigation in summer months. The extraction well located in the alluvial aquifer of lower Garrapata Creek has not impacted the riparian corridor. There is no evidence that withdrawals at that site have influenced surface water flow; however the potential for impacts exists in the context of growing demand or sustained drought conditions.

Sustainability of an alluvial aquifer is achieved by management practices that ensure abundant surface flows from upstream and extractions that do not exceed recharge, especially in low flow conditions of the late summer and early fall.

7 Sediment Discharge

Sediment flows down creeks as bedload that bounces along the bottom, and as suspended load supported by water turbulence. We have made several spot measurements of both bedload and suspended load in order to develop equations relating sediment transport to water discharge. The equations can be used to estimate total annual sediment yield from the watershed. Our measurements were taken in Garrapata Creek upstream from the mouth of Joshua Creek and in Joshua Creek, not far from its mouth. Theses sites are the same sites used to measure water flow described in the previous section.

7.1 Field Methods

Bedload was collected using a 3" Helley Smith bedload sampler, adhering to published U.S. Geological Survey methods. Normally we sampled each cross section twice using 10 verticals on each pass, for a total of 20 verticals. Each single vertical was sampled for 60 seconds, except for high flow conditions in Joshua Creek where 30 second samples were taken to avoid overfilling the sample bag. Fewer verticals were taken in Joshua Creek because it has a small channel. Samples were rinsed into a labeled canvas bag and brought to CSU-Monterey Bay for analysis.

Suspended load was collected in labeled Nalgene one-liter bottles using a DH-48 depth-integrated sampler. The sampler was dipped using constant velocity down and up. Approximately four verticals were sampled for each stream, with the spacing designed to integrate lateral variability. Each bottle was capped in the field and brought to CSU- Monterey Bay for processing

7.2 Lab Methods

Bedload samples were oven dried for at least 24 hours and weighed. The sample mass, proportion of the channel sampled by the Helley-smith sampler and total sampling time were used to calculate the sediment discharge in g/s.

Suspended load samples were analyzed using standard procedures for "Suspended Solids Concentration" (Watson et al., 2003). The resulting concentrations (g/l) were converted to sediment discharge (g/s) by multiplying the concentration by the stream discharge measured measured immediately after sediment sampling (l/s).

7.3 Data

The results of the sediment transport monitoring are in Tables 10 and 11. Figures and 34 and 35 show the relationships between flow and sediment transport in Garrapata Creek. Figures 36 and 37 show the relationships between flow and sediment transport in Joshua Creek.

Table 10: Bedload and suspended load measurements for Joshua Creek

Date	gauge (ft)	Discharge (cfs)	Bedload (g/s)	Suspended (g/s)
10/27/01	0.946	0.96	0.836	0.325
2/09/02	1.342	5.22	3.320	1.629
3/10/02	1.254	5.21	2.242	3.871
4/29/02	1.238	3.74	2.521	
9/09/02	0.902	1.57		0.906
2/15/04	1.283	3.14	3.629	0.560
2/19/04	1.617	8.17	11.840	4.163
2/26/04	2.310	25.61	40.903	39.067
3/23/04	1.330	4.39	3.423	1.408
3/24/04	0.840	1.340		1.050
4/25/04	1.122		2.920	
7/27/04	0.692	0.46	0.00	

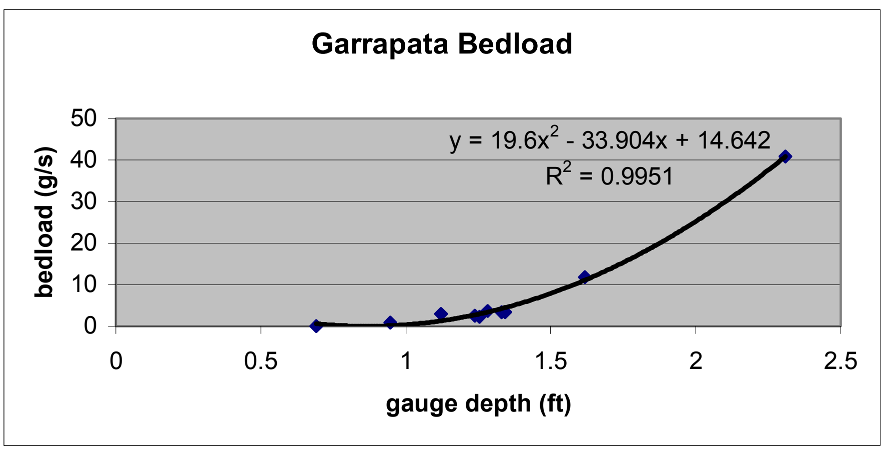

Figure 34: Scatterplot of Garrapata bedload and Garrapata gauge depth.

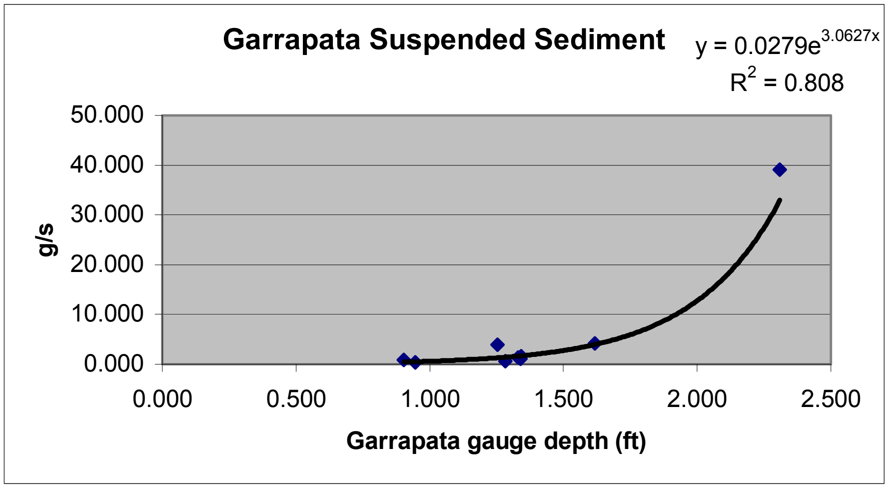

Figure 35: Scatterplot of Garrapata suspended load and Garrapata gauge depth.

Table 11: Bedload and suspended load measurements for Joshua Creek

date	gage (ft)	Joshua (cfs)	Bedload (g/s)	Suspended (g/s)
10/27/01	0.946	0.862		0.466
2/9/02	1.342	1.480		7.625
3/10/02	1.254	0.862	14.494	2.350
4/29/02	1.238	0.396	3.888	
9/9/02	0.902	0.104	2.991	0.009
2/15/04	1.283	0.950	87.703	0.147
2/19/02	1.617	1.797		9.687
2/26/04	2.310	8.076	228.199	111.987
3/23/04	1.330	0.658	2.717	0.177
3/24/04	1.340	0.511	6.051	0.068
4/25/04	1.122	0.727	0.043	0.039

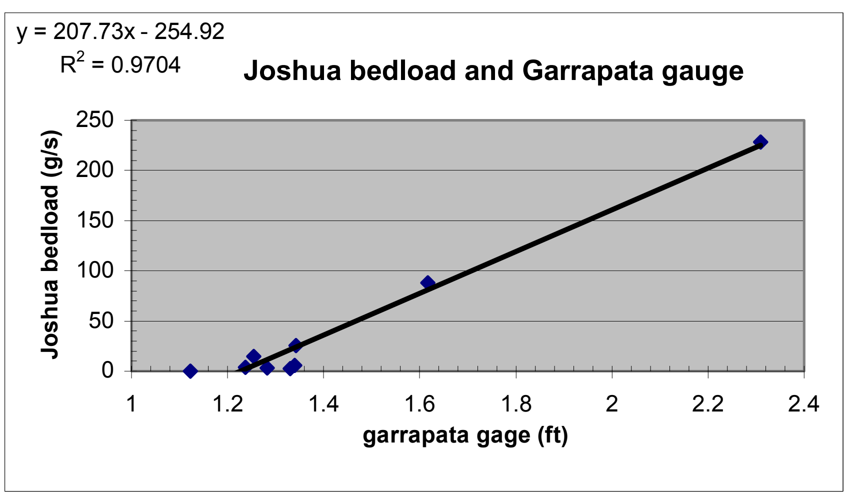

Figure 36: Scatterplot of Joshua bedload and Garrapata gauge depth

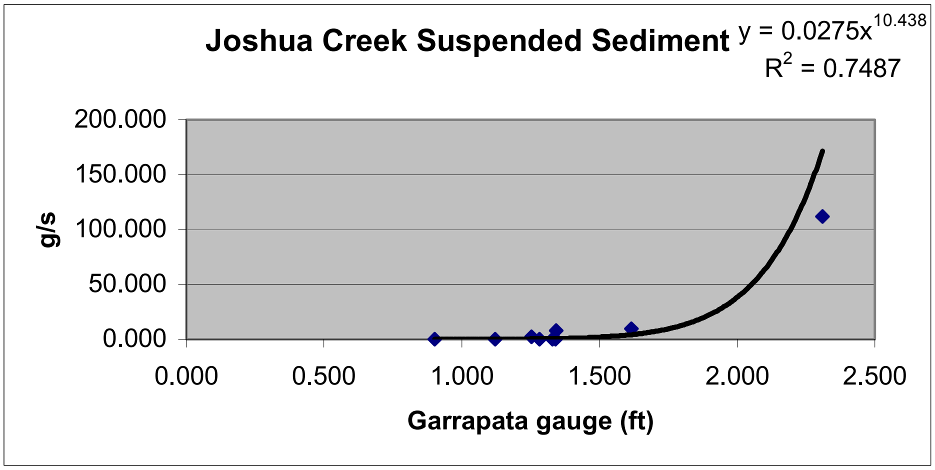

Figure 37: Scatterplot of Joshua suspended sediment and Garrapata gauge depth

7.4 Summary of Sediment Data from Garrapata Watershed

Of note is the contrast between the sediment transport rates of Garrapata and Joshua Creeks (Fig. comp). As discharge increases in Garrapata Creek, there is only a slight rise in the amount of bedload carried by the flow. In contrast, as discharge increases in Joshua Creek, bedload increases dramatically. The interpretation is that there is a plentiful supply of bedload material in Joshua Creek that is ready to move, given an increase in flow. We would expect the two watersheds to have the same line slope on the bedload transport graphs (Fig. 38) because the two watersheds do not have any natural differences in variables that control sediment delivery to the creek bottom such as geology, slope, aspect, climate, or vegetative cover. Figure 39 illustrates the differences in the sediment transport rates of the two creeks during a moderate flow. This disparity strongly indicates that there are significant human induced slope instabilities in the Joshua Creek watershed relative to Garrapata Creek.

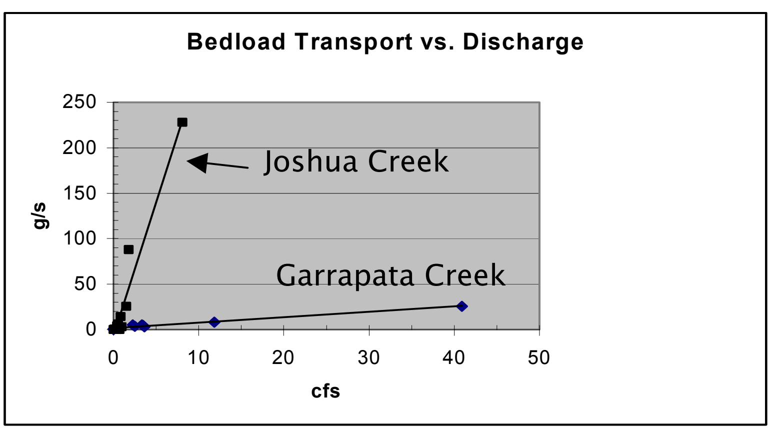

Figure 38: Bedload transport rate as a function of water discharge on Garrapata and Joshua Creeks.

The equations relating sediment transport rate to gauge depth are used to generate sediment mass transport throughout the year based upon the continuous gauge record. Table 12 summarizes those estimates. For the period of record, the average mass of sediment leaving Joshua Creek is 398 tonnes while the entire watershed generated 507 tonnes. Joshua Creek composes 19% of the Garrapata Watershed area, provides 17% of the water, but disproportionately contributes 78% of the bedload sediment.

Fig 39: Bedload material collected on Feburary 19, 2004. Left pile is 5260 g collected from Joshua Creek. Right pile is 710 grams collected from Garrapata Creek. Sampling time for both creeks was 20 minutes. Ruler numbers are decimeters.

Table 12: Summary of sediment flow from Garrapata Watershed. Values are metric tonnes/yr. Yield is metric tonnes/yr/km^2. Column labeled "Garrapata" is Garrapata Watershed without Joshua Creek. Column labeled "Watershed" is the whole Garrapata Watershed.

Water year	Garrapata	Joshua	Watershed
2001-02	68	163	231
2002-03	142	547	688
2003-04	119	483	602
average	110	398	507
average yield	5	75	18

In Wildcat Canyon, too few samples were taken to provide much information about sediment transport rates. Site visits during low flow conditions provided some insights. The turbidity was exceptionally low, but there was excess fine bedload (sand and fine gravel) partially filling pools. The impacts are far less than seen in Joshua Creek, but there are clearly some chronic sediment sources in the watershed, Aerial reconnaissance indicates that a poorly maintained road present in the upper watershed that could be a continuing source of sediment.

There is an historic homestead ruin located low in the Wildcat basin that is now partially buried in sediment (Fig. 40) It is clear that Wildcat Creek watershed has periodically been a source of sediment in the past, and continues to transport considerable sand from the upper watershed.

Figure 40: Fireplace of homestead ruins in Wildcat Creek. Sediment has buried the hearth and nearly all of the firebox. Photo by Nikki Nedeff (October 2004).

8 Discussion

Our assessment of watershed conditions finds three issues of concern.

8.1 Water Quantity

With the goal of optimizing conditions for anadromous fish, the highest priority is maintaining perennial flow. At present the main tributaries and main stem have perennial flow. To maintain perennial flow it is critical to control the use of impermeable building materials as the watershed continues to be developed. Likewise, an inventory of stream and alluvial aquifer withdrawals in the watershed would help determine what the present impact is on water flow. The stream will be most sensitive to excess withdrawals during the late part of the dry season when flow is already naturally low.

As management decisions arise that might influence water allocation in the watershed, a hard look at historic drought is warranted. Since 1976, the Monterey Peninsula has endured two extended periods of mandatory rationing; 18 months in 1976 to 1977 and 28 months in 1989 to 1991 (SWRCB, 1995b). Fritts and Gordon (1980) report that we should view the historic Garrapata rainfall record (Fig. 21) as a relatively wet period, considering the severity and number of droughts California as witnessed in the past 360 years. They cite six decade-long, severe droughts in the state during the following time periods: 1560-1580, 1600-1625, 1665-1670, 1720-1730, 1760-1780, 1865-1885 (Fritts and Gordon, 1980). The period from 1890 to the present has been one with a surplus of rain, as compared to the 360-year proxy record. Clearly, a conservative approach to allocating water resources is warranted in coastal California watersheds like Garrapata.

8.2 Excess Sediment

Because water quantity is presently abundant enough to support fisheries, the highest priority project for improving fisheries in Garrapata Watershed should be the reduction of excess sediment eroding from the upland roads, especially in Joshua Creek (e.g. Fig, 15). There are techniques available for reducing the flow of sediment (e.g., Weaver and Hagans, 1994). Many other improvements in upland roads should be considered as well (Pacific Watershed Associates, 2003). Future road development should be permitted only if the design includes state of the art considerations for minimizing erosion and landscape disturbance. No matter what care is taken, roads cut into steep slopes of the fractured granitic material underlying the region will be periodic sources of sediment to the creeks; therefore, future road construction should be permitted only on low slopes.

Sediment reduction goals normally carry a timeline management plans, such as reducing sediment by 20% in 5 years. Such goals can be made more realistic, given a knowledge of how long it takes rivers to naturally clean out an existing inventory of excess sediment. For example, if all sources of excess sediment were suddenly repaired, how long would it take Joshua Creek to clean out its pools under natural flow conditions?

By direct measurement we estimate that 103 m^3 (135 yd^3) of mobile sediment is present in Joshua Creek between the mouth and the large waterfall forming the limit to anadromous fish (location shown in Casagrande and Smith, 2004). The stream length containing that sediment volume is 1.05 km (0.65 mi). We extend the estimate beyond the waterfall by assuming the same rate of sand volume per stream length in the creek above the waterfall (98 m^3/km or 205 yd^3/mi). We extrapolate that rate upstream to a point where it appears that roads are not significantly adding sediment to the creek (via aerial reconnaissance of road conditions). The resulting total mobile sediment in Joshua Creek is approximately 220 m^3 (290 yd^3). Using the approximation that most of the sediment has a density close to the density of quartz (2.65 g/cm^3), the mass of the excess sediment is 584 metric tonnes. Given that Joshua moves an average of 398 tonnes/yr (Table 12), 584 tonnes of excess sediment would be cleaned out of the Creek in less than two years. This time frame assumes that all sources of excess sediment were suddenly absent. We note that this estimated cleanout time is an underestimate because Joshua Creek would also have to move its natural background sand at the same time.

8.3 Migration Barriers

Another priority is the removal of key migration barriers as detailed in a companion report (Casagrande and Smith, 2004).

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