Physical and Hydrologic Assessment of the Carmel River Watershed California

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Preface

The following report documents the present hydrologic and physical condition of the Carmel Watershed. The descriptions and interpretations are based upon digital, aerial, and land-based views, and a review of the regional literature. The report provides an overview of geology, climate, hydrology, and susceptibility to landslides and erosion. Following those broad descriptions, each subwatershed of the Carmel River is analyzed in more detail. Lastly, recommendations for future watershed management strategies are provided.

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A companion set of posters (Appendix A) can be cited as:
Newman, W.B., Smith, D.P. and Watson, F.G.R., 2004, The Carmel River Watershed – Map Set. The Watershed Institute, California State University Monterey Bay, Publication No. WI-2004-04. 5 maps.

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1 Executive Summary

The Carmel Watershed is a terrestrial jewel in the California landscape. Its forested headwaters harvest rain from the Pacific storms each winter, providing a natural cascade of resources enjoyed by human residents and the broader ecosystem. Although the Carmel River is not currently listed as "impaired" by the State of California, there have been significant human impacts that could lead to impaired waters. These impacts are now recognized and defined in this report so that remediation and future management policies can be developed.

This report is one facet of the Carmel Watershed Assessment orchestrated by the Carmel River Watershed Conservancy. We assess the physical and hydrologic components of the watershed, chiefly focusing on two major classes of problems, water quantity and excess sediment. Both of these issues are important when considering human needs and the needs of the broader ecosystem, including endangered aquatic and riparian species.

The Carmel Watershed has finite annual rainfall as its only water resource. That resource is currently stretched too thin, leaving new urban, suburban, rural, and industrial development in and around the watershed at odds with pre-existing water appropriation and environmental requirements (e.g., SWRCB, 1995a; 1995b). Certain kinds of common land-uses and road designs supply excess sediment above natural background rates. Some of the major problems in the watershed are summarized below, in no particular order.

- Demand for water far exceeds water supply, leading to many related subordinate problems, including diminished surface water for endangered steelhead trout.
- Extensive urbanization exists within the regulatory 100-year floodplain and in the dam-failure inundation zone.
- Excess sediment is generated from a very large number of dirt roads, some of which are abandoned, some of which out of compliance with grading ordinances, but most of which are clearly within regulations.
- Nearly all sub-road drainage culverts are undersized, leading to downstream erosion, whether related to dirt roads, paved roads, or highways.
- Excess sediment is generated by a great number of bare road cuts on dirt roads, paved roads, and highways.
- Excess sediment is generated in the Los Chupines and Sycamore Creek drainages by soil slip, gullies, unstable stream banks, and roads. Many of those issues are related to cattle impacts.
- Excess sediment is generated in a great number of incised streams that have tall, exposed banks.
- San Clemente Dam is unsafe owing to sediment burden and proximity to active faults.
- Decommissioning the San Clemente Dam will likely lead to a significant shift in river morphology and flood response, owing to the restoration of historic bedload transport rates.
- Los Padres Dam is rapidly infilling with sediment and is also close to active faults.
- Watershed impairment is the result of incremental, permitted, changes that have a large cumulative impact on the watershed.

Closer adherence to the Carmel Valley Master Plan (CVMP, 1996; Appendix C) and County ordinances will foster resource sustainability and aesthetic living conditions. Among the salient points in that document are the following guidelines for development (CVMP, 1996).
1. Preserve the rural character of the Carmel Valley
2. Protect all natural resources with emphasis on biological communities, agricultural lands, the Carmel River and its Riparian corridor, air quality and scenic resources.

We note that the large-scale negative impacts we describe in the Carmel Watershed mainly resulted from the cumulative effects of small, insignificant, permitted landscape or hydrologic alterations (e.g., Dunne et al., 2001). With that in mind, guidelines for sustainable resource use could begin with an agreed upon ultimate level of resource use, depletion, or degradation, beyond which, no further landscape or hydrologic alterations will be permitted. Using water supply as an example, the best strategy for sustainability is to determine the total cumulative resource usage, and then stop permitting further requests for resource use when the agreed upon cumulative impact is met—the concept of water rights appropriation. This same "cumulative impact" management strategy could be applied to other cumulative watershed impacts, such as total miles of dirt road per square mile of watershed area, or total area of impervious cover per square mile of watershed area. These strategies can be applied once a cumulative impact target has been established upon sound science, and codified by stakeholder agreement. Considering that the cumulative negative impacts in the watershed are the net result of innumerable, insignificant modifications, we can predict that innumerable, small positive restorative efforts in the watershed would eventually produce large positive impacts on watershed health including water quality and quantity.

1.1 Data Needs
We have used available data to present a snapshot of the condition of the Carmel Watershed. We list below some of the key pieces of data that would be beneficial in a continuing effort to monitor watershed conditions, identify and quantify specific problems, and to assign specific water quality/quantity goals for the Carmel River and its tributaries. Of critical importance are regularly scheduled direct measurements of sediment transport from a few select sub-watersheds, so that when stakeholders agree on target conditions, there will be some indication of the magnitude of watershed restoration that is required. Such a program could establish reference conditions for which stakeholders strive. We recognize several classes of sediment sources in this report, but we do not have enough data to prioritize them in terms of their relative impacts on watershed conditions. In the absence of more data, such prioritization will have to come from best professional judgment and broad stakeholder input. We identify the following data gaps.
- An institutionalized program of bedload and suspended load sediment measurements in major tributaries and main-stem river to improve baseline conditions and determine the effects (if any) of urbanization and various land-uses.

- Road inventory and restoration prioritization in most rural watersheds, with emphasis on improved stream crossings on active roads, and decommissioning rarely-used, or abandoned, roads.
- Comprehensive inventory and prioritization of culvert problems on paved and dirt roads.
- Monitoring data showing seasonal and long-term trends in upland groundwater resources throughout the watershed.
- Improved understanding of the relationship between upland bedrock aquifers and the Carmel River water resources.
- Bedrock aquifer recharge area delineation.
- Public access to water use data.
- Recovery/restoration potential of various landscape settings. These data would come from establishing and monitoring demonstration restoration sites on various riparian and upland landscapes. Data on ecosystem/soil recovery rates following cattle exclusion would help develop grazing management strategies if cattle must be part of the watershed.
- Studies of the impact of cattle as a function of the number of head per season per acre.
- Improved understanding of climate averages, trends, and expected extremes.
- Improved measurements and modeling of water balance components, especially evapotranspiration.

2   Introduction

This watershed assessment is a venue for summarizing the resources, physical conditions, problems, restoration opportunities, and management strategies of the Carmel Watershed, California (Figure 1; Appendix A-1). The assessment is a snapshot of watershed conditions, as they were known at the time of the assessment. It utilizes the extant environmental data sets and points out data gaps that could be filled in future studies. Ultimately, the assessment is one step on a pathway toward resource sustainability while honoring the varied needs and rights of all stakeholders, including those of the broader ecosystem (e.g., Jones and Stokes, 2003).

The Carmel River is part of the south central steelhead trout evolutionary significant unit (ESU), and has historically supported a run of now federally listed steelhead trout. The number of watersheds in California that support anadromous fisheries is greatly diminished because of watershed alteration (McEwan and Jackson, 1996); therefore, identifying and preserving high-quality watersheds is now the key to the fostering the survival of these fish. The Carmel River Watershed Conservancy (CRWC) spearheaded the current assessment in hopes of identifying opportunities for watershed improvement and to ensure resource sustainability. The CRWC is especially interested in improving conditions for the endangered steelhead trout population that spawn in the Carmel Watershed if winter flows are sufficient to breach the beach berm at the mouth of the river (see references in Casagrande and Watson, 2003).

The Carmel Watershed is not listed among the 304 impacted California Rivers that were deemed impaired in the 1998 EPA Clean Water Act (Section 303(d)) listings. On the other hand, there are significant human impacts in the basin, and the impacts are increasing as more of the landscape is utilized for water extraction, housing, roads, grazing and agriculture. Although not all human impacts carry associated significant water resource impairments, it has been repeatedly shown that incremental, permitted, watershed alterations eventually add up to very significant cumulative negative effects for the environment. It is in this framework that we have been assigned to assess the current physical and hydrologic resources of the Carmel Watershed, and to make recommendations regarding opportunities for restoration and future management strategies.

Excess sediment is currently the worst non-point source water pollutant in North America. Although much of the excess sediment eroded in Monterey County has been thought to erode from agricultural lands, there is also a growing recognition of the major contribution from unstable river banks (e.g., Watson et al., 2003) and poorly designed road systems (e.g., Smith et al., 2002; 2003). A central theme of this report is to broadly document sources of excess sediment in the Carmel Watershed so that remediation can be discussed and planned.
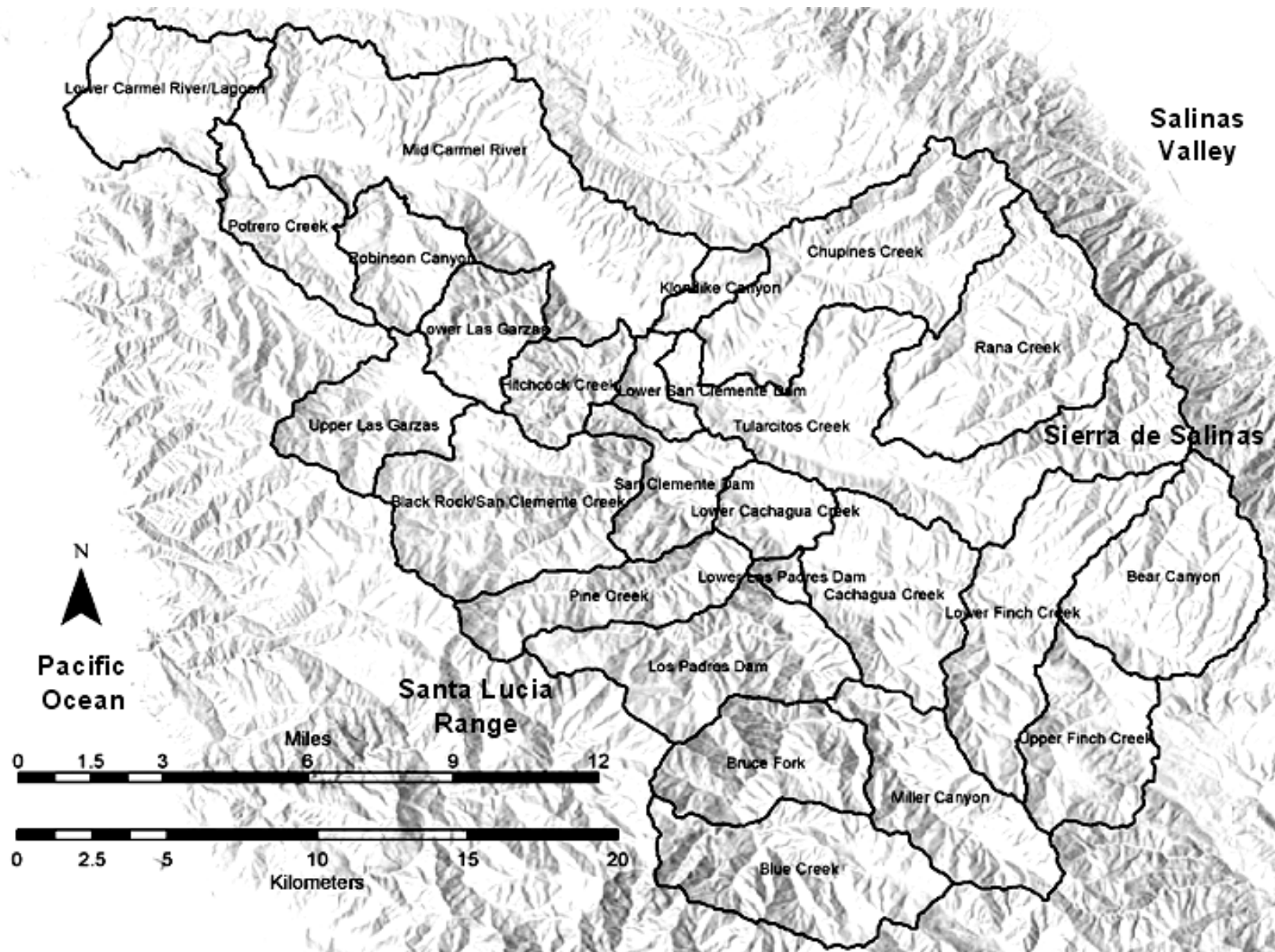
Figure 1: Subwatersheds of the Carmel River basin, Coast Ranges province of California

3 Methods and Data Sources

Data for this report were collected during a 15-month period beginning January 2003. Fixed wing flights on January 15, 2003 and June 30, 2003 produced dozens of oblique digital aerial photographs and two hours of analog videotape. Two-foot resolution orthorectified and georeferenced digital aerial photographic coverage of 90% of the watershed became available for analysis very late in our work, but was used for referencing our own aerial imagery and gaining perspective on regional problems. Rosenberg (2001) GIS layers were used in both the geologic and hydrologic analyses.

Notes and digital photographs were taken from public roads, and various sites were revisited to note environmental changes. Hastings Natural History Preserve provided a high vantage point for photographing and visually assessing the upper watershed and Tularcitos Ridge. Consulting reports were accessed from the extensive research library at the Ryan Ranch office of the Monterey Peninsula Water Management District (MPWMD). MPWMD staff also provided recent data and interpretations. U.S. Geological Survey water data were used in flow analysis.

Analyses included visual inspection of the watershed at a wide range of scales and perspectives, discovering sources of excess sediment, impaired watershed function, and poor land-use leading to diminished resources. These perspectives included both digital and real vistas. Tributary and main-stem flow data were analyzed to gain an understanding of the seasonality of flow and the interconnectedness of upland groundwater and other parts of the hydrologic system.

The digital maps in this report and its appendices were created from the digital elevation model, and basins edited according to watershed characteristics such as land cover, land use, or river channel similarities. Data used in these maps were: USGS DEM (Seamless.usgs.gov/viewer.htm). EPA RF3 hydrologic data and Monterey County Roads layers compiled by the California Coastal Commission (WATER dataset) (centralcoast.org). Watershed basins were processed and edited by W. Newman and D. Smith. All layers were processed using Microimages TNTMips software. May of the images in the body of the report were projected in ArcMap 8.2 software before exporting to an image file for manipulation in Photoshop software.

Location coordinates used in this report, such as xxxxxxxE; yyyyyyyyN, are eastings and northings in feet. The coordinates refer to NAD 83,California State Plane IV projections.

Photos 11,32,33,34,37, and 61 are courtesy of the MPWMD aerial imagery project. All remaining photographs were shot by Doug Smith, unless credited otherwise in the caption.

4 Physical Description of the Carmel Watershed and subwatersheds

The Carmel watershed is the northernmost of a series of northwest–southeast trending valleys dissecting the rugged Santa Lucia mountains of the California Coast Ranges (Figure 1). The Sierra de Salinas forms the northeastern divide of the watershed and the northern terminus of the Santa Lucia Mountains forms the southwestern divide. Like the neighboring Salinas River and most other watersheds near the California Coast Ranges, the Carmel watershed owes its overall geometry and physical orientation to its bedrock framework, myriad faults, and climate and river erosion.

The watershed divides rise to approximately 1400 m (4500 ft) along the Sierra de Salinas and soar to 1500 m (4800 ft) along the Santa Lucia Range with Ventana Double Cone providing the maximum elevation of 1480 m (4853 ft). Water drains 656 km^2 (256 mi^2) of land, following both overland and subterranean routes to reach the coastal Carmel lagoon and eventually the Pacific Ocean. There are countless small tributaries to the Carmel River (Fig. 1). We have subdivided the region into 25 subwatersheds based upon natural divides and geographic names. The boundaries and several attributes of the watershed are presented here, and in more detail on posters presented as Appendix A (Newman et al., 2004), plotted upon a 30-meter resolution digital elevation model (DEM) assembled from 7.5 minute DEMs (Newman et al., 2003). There are 14 continuously recording stream gauging stations—two maintained by the US Geological Survey, and 12 maintained by the MPWMD (Appendix A-1).

Table 1: Physical attributes of the Carmel Watershed

Drainage area	656 km^2 (256 mi^2)
Axial trend	315°
Length	43 km (25.8 mi)
Highest peak (South Cone)	1514 m (4965 ft)
General divide elevation	1200 m (4000 ft)
Mouth elevation	Sea level at mouth of Carmel submarine canyon
Relief	1200 m (4000 ft)
Average slope	3%
Approximate Strahler stream order	7th
Network geometry	Dendritic
Dominant stream types (Rosgen, 1994)	Headwaters dominated by A, B, G Midslopes dominated by B, C, G, F Lowlands dominated by C, F Minor reaches of D (classification of Rosgen, 1994)
Land-use	Wilderness, grazing, viticulture, golf-courses, sparse residential, suburban, urban, and light industrial.
Vegetative Ecosystems	Dominated by chaparral, grasslands, and oak woodland. Local conifer and redwood forests present.
Soil Series	Wide range

5 Geologic Framework and History

A complete geologic history, with reference to early and modern data, is provided by Rosenberg (2001). The geology is a complex quilt of igneous, metamorphic and sedimentary rocks in part stitched together by faults of varying ages and other kinds of contacts (Appendix A-2). The Carmel Watershed is carved into the Salinian Block, a piece of crust that began its existence near the Mojave desert and moved northward, dragged by the Pacific plate for the past 20 million years. If we undue this tectonic slip, the rocks of the Salinian Block would bridge the current geological gap between the southern terminus of the Sierra Nevada range and the northern end of the Peninsular Ranges of southern California and Baja California (Mattinson and James, 1985).

Geology plays a first order role in determining the physical condition of the watershed. The physical strength of the rocks and soils determine the erodibility, landslide potential, and ecosystem and land-use potential. The rocks hold a significant water resource in upland aquifers. Their varied colors and textures provide scenic aesthetic qualities to the watershed as well (CVMP, 1996; Appendix C). The combination of a large range of annual precipitation in the watershed and complex geology gives rise to a complex distribution of soil types, erosion rates, landslide potential, aquifers, recharge areas, ecosystems and human land use. For this reason, proper resource management practices may be very specific to certain watersheds rather than globally relevant.

The Santa Lucia and Sierra de Salinas Ranges have experienced substantial uplift rates for the past two million years (Ducea et al., 2003). The uplift of the mountains keeps the rivers in a state of general downward incision. Many of the headwater streams and larger tributaries of the Carmel watershed occupy geologically youthful "V"-shaped canyons with sharp dividing ridges, this geometry leads to a naturally high sediment rate and a state of episodic down-cutting of the river channels. This kind of tectonically active, youthful terrain is commonly in balance with slope failure; many of these slopes are at their failure threshold. Therefore, they are very susceptible to slope failure and extremely high sediment yield when disturbed and over steepened during road or subdivision grading. Examples of highly accelerated erosion and soil-slip rates associated with simple road construction are pervasive on the steep slopes around the entire watershed, despite the grading limits imposed by County and local ordinance (CVMP, 1996; Appendix C).

Every terrestrial landscape is the net result of climatic forces that are tearing apart the watershed, moving material gradually to the sea and the resistant bedrock framework that, to varying degrees, resists that erosive force. Lowlands and valleys are typically created where less resistant material is preferentially eroded over a long time, leaving more resistant material as uplands and watershed divides. Complicating that process in significant ways are the slow, but inexorable, vertical and lateral crustal motions that occur along faults. The Carmel Watershed has physical landscape diversity because it is underlain by a wide range of soils and

bedrock types, and because the landscape is cut by myriad active faults (Appendix A-2; Rosenberg, 2001). The Carmel Valley owes its character and location to ongoing erosion that has taken advantage of weak rock, crushed in splays of the still active Tularcitos fault zone (Appendix A-2). This fault zone symmetrically splits the watershed into the Santa Lucia Range and the Sierra de Salinas.

5.1 Faults

Incremental motion between the Pacific and North American tectonic plates has periodically broken the crust in the Carmel Watershed. Various studies have determined that several of these faults show evidence of motion in Quaternary time ($<$ 2 million years) and some have moved much more recently (Curry, 1984; Norman Janke Associates, 1989). Because there are two large dams on the river (Fig. 2; Appendix A-1), and one reservoir is virtually filled with sediment (Fig. 4; Entrix, 2000), the risk to human culture and ecosystems of the valley is considerable. The trace of the Cachagua fault is covered by the sediment stored in San Clemente Dam and it is estimated that a severe earthquake with a magnitude of up to 7.1 could hit the basin on the Tularcitos fault system, which is not far away (Fig. 3, Appendix A-2; Rosenberg, 2001). This hazard went unrecognized for decades, so now significant urban development is present in harm's way in the event of dam failure. Therefore, San Clemente Dam is among the least safe in California (DWR, 2003).
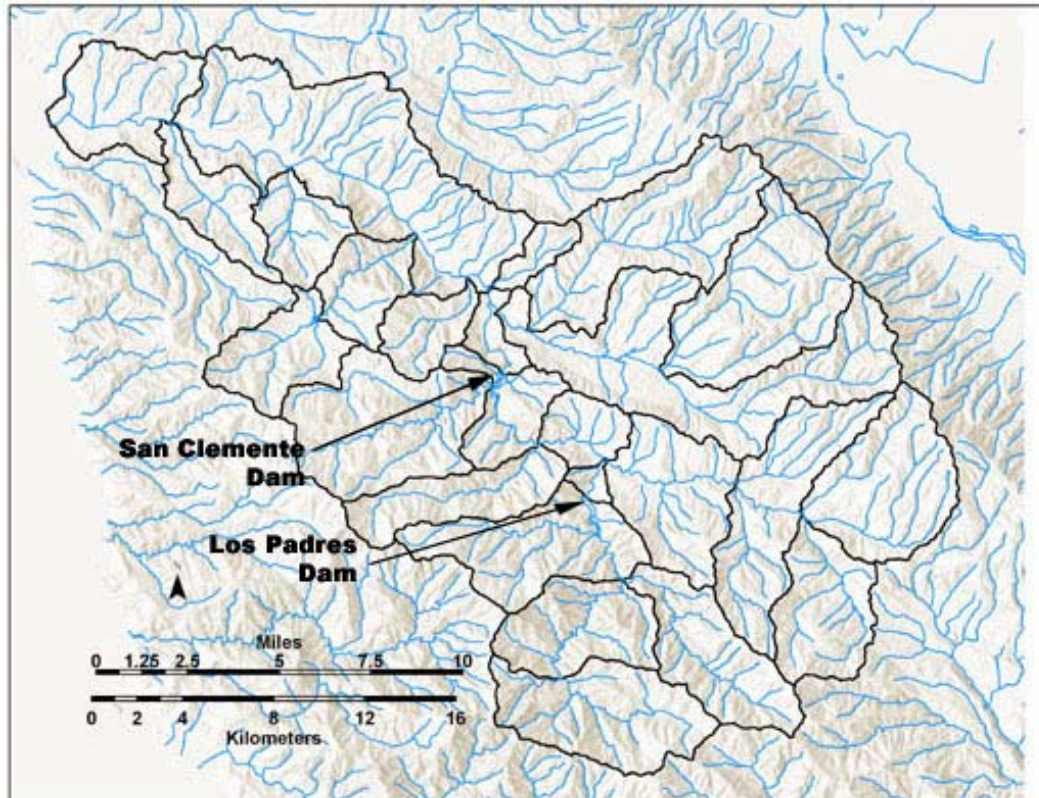
Figure 2: Drainage network of the Carmel Watershed
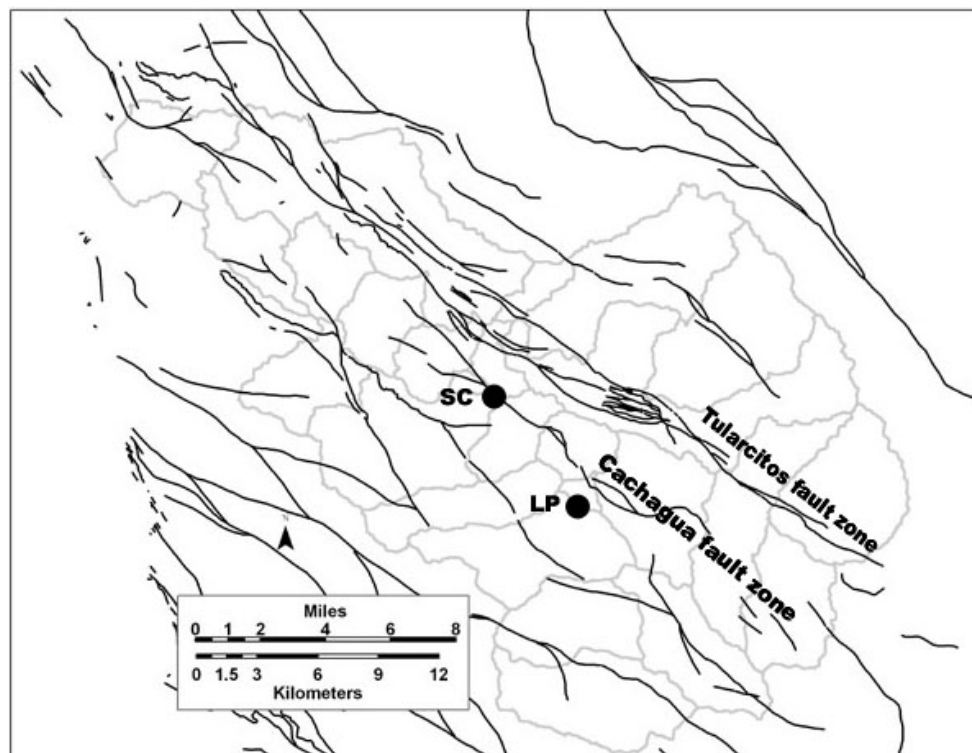
Figure 3: Major faults of the Carmel Watershed. SC is San Clemente Dam. LP is Los Padres Dam.

5.2 Landslides

Willis et al. (2001) mapped over 1500 landslides along Highway 1 between San Capoforo Creek and Point Lobos, just near the mouth of the Carmel Valley, suggesting that slope-failure processes are a common occurrence in the region. Rosenberg (2001) assessed Monterey County region for landslide susceptibility including Carmel Watershed (Fig 5).

Our reconnaissance work indicates generally good agreement between the susceptibility map (Fig. 5) and the present distribution of large landslides. However, we further note that there is apparently a high risk of creating landslides on any steep slopes of the watershed if roads are poorly constructed.   Landslides presently are a significant source of both natural and anthropogenic sediment in the basin (Fig. 6). We used the digital geologic map of Rosenberg (2001) to further assess the conditions for landslide potential in the watershed. By cutting the geologic layer using the mapped Quaternary landslides as the cutting shape, we were able to determine both the rock formations (Fig. 7) and slope angles (Fig. 8) that are most conducive to producing large, mappable landslides.

Figure 5: San Clemente Dam in early 2003 showing the reservoir nearly filled with sediment. The "floodplain" and river channel upstream (left) from the dam was open water when the reservoir first filled in the 1920's. In early 2004, the sediment was nearly touching the face of the dam. The Cachagua and Tularcitos Fault zones are located close to the dam.
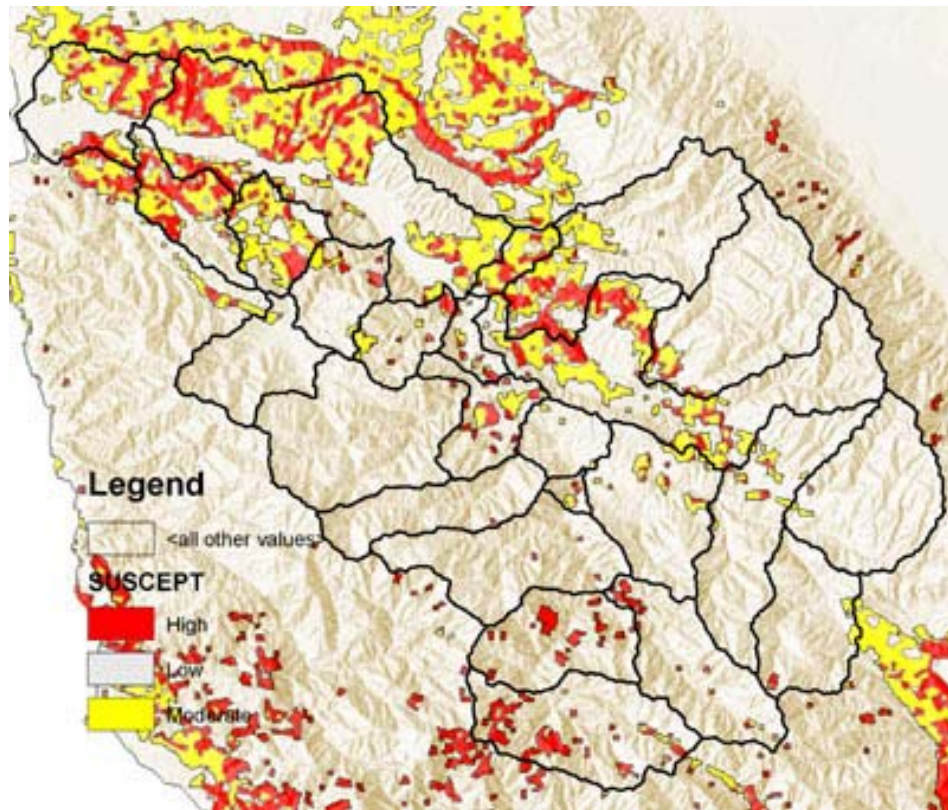
Figure 5: Landslide susceptibility in the Carmel Watershed (Rosenberg, 2001)

Figure 6: Active landslide located above San Clemente Reservoir. This landslide is long-lived, and perennially reactivated because it is located along outside bend of Carmel River, where erosion undercuts the steep slope (Robert Johnson and Associates, 1986).

Landslide Frequency by Rock Formation
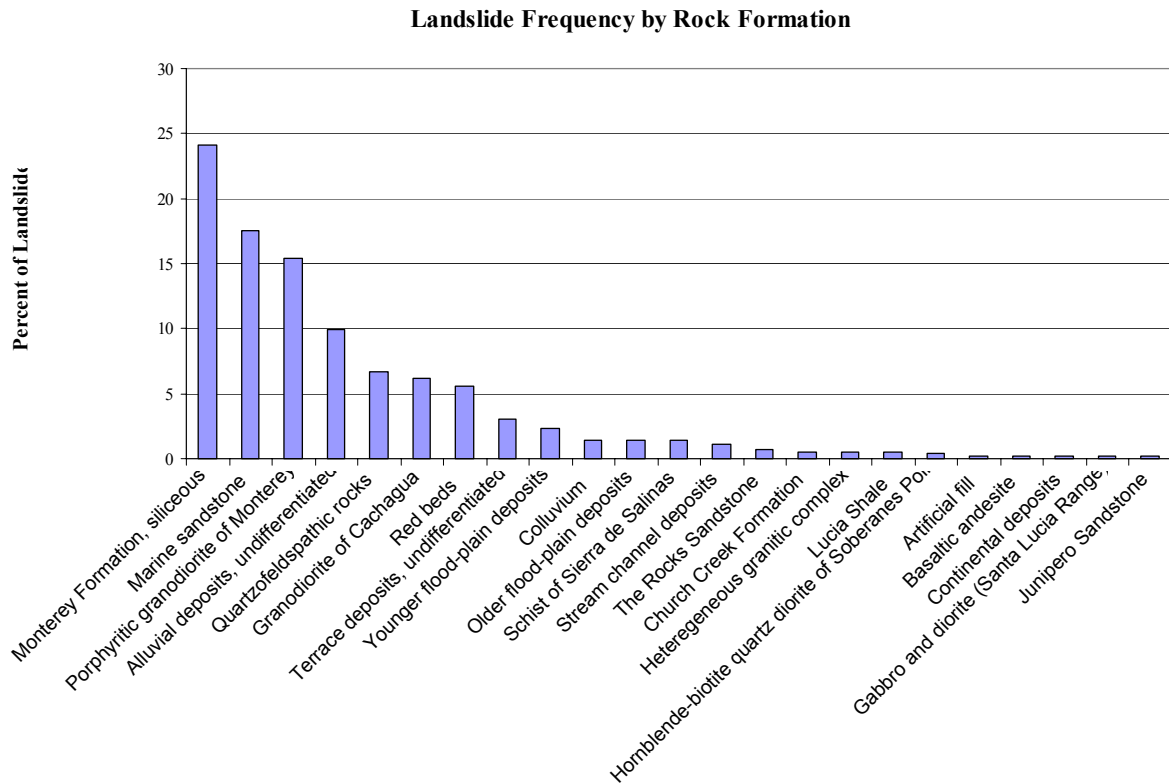
Figure 7: Relationship between mapped Quaternary landslides and rock Formations of the Carmel Valley. Data derived from maps of Rosenberg (2001: Appendix A–2).

Landslide Frequency by Slope Angle
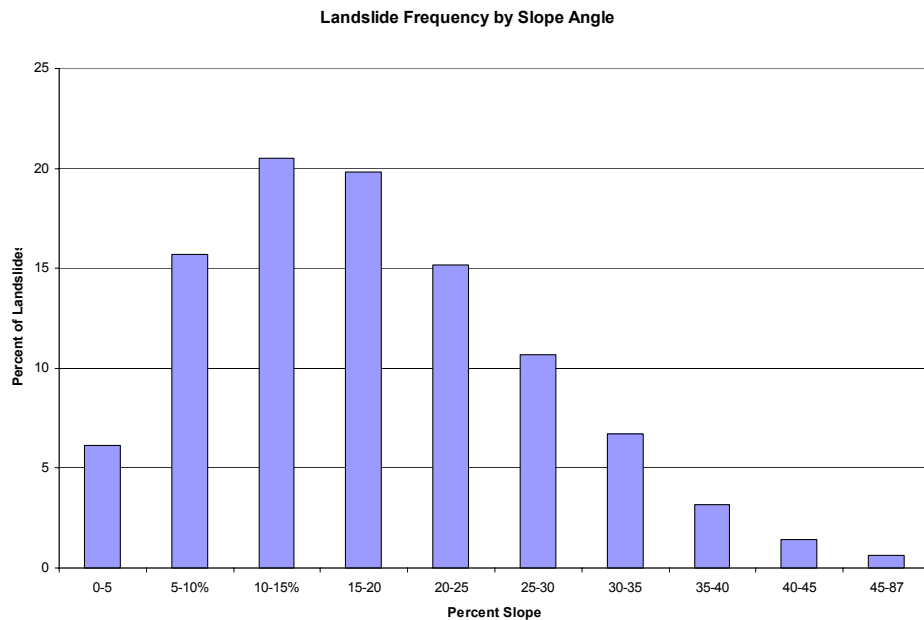
Figure 8: Relationship between mapped Quaternary landslides and hill slope gradient in the Carmel Valley. Data derived from maps of Rosenberg (2001; Appendix A–2) and 30 m DEM (Newman, et al., 2003).

Figure 7 indicates that approximately 57% of the landslides in the watershed are restricted to three specific rock types: Monterey Shale, Tertiary Sandstone and a granitic rock type called Porphyritic Granodiorite of Monterey (Appendix A-2). Over 85% of all past mapped landslides occurred on slopes less than 30% grade (Fig. 8). Of note is that County ordinances and the Carmel Master Plan prohibit grading on slopes greater than 30% grade (CVMP, 1996; Appendix C).

5.3 Erosion

Mountains erode to the sea through the influences of gravity, water, and gradient. The chief erosive processes in the Carmel Valley are bedrock landslides, shallow soil slips, rock fall, stream incision and widening, and slope gullying. Regions undergoing rapid tectonic uplift, like the Carmel Watershed, maintain steep, rugged landscapes whose slopes are perennially at the threshold of failure. Grading for roads and buildings locally over-steepens these slopes, greatly accelerating the rate of slope failure and erosion. For this reason, nearly the entire Carmel Watershed is rated as highly susceptible to erosion (Fig. 9)
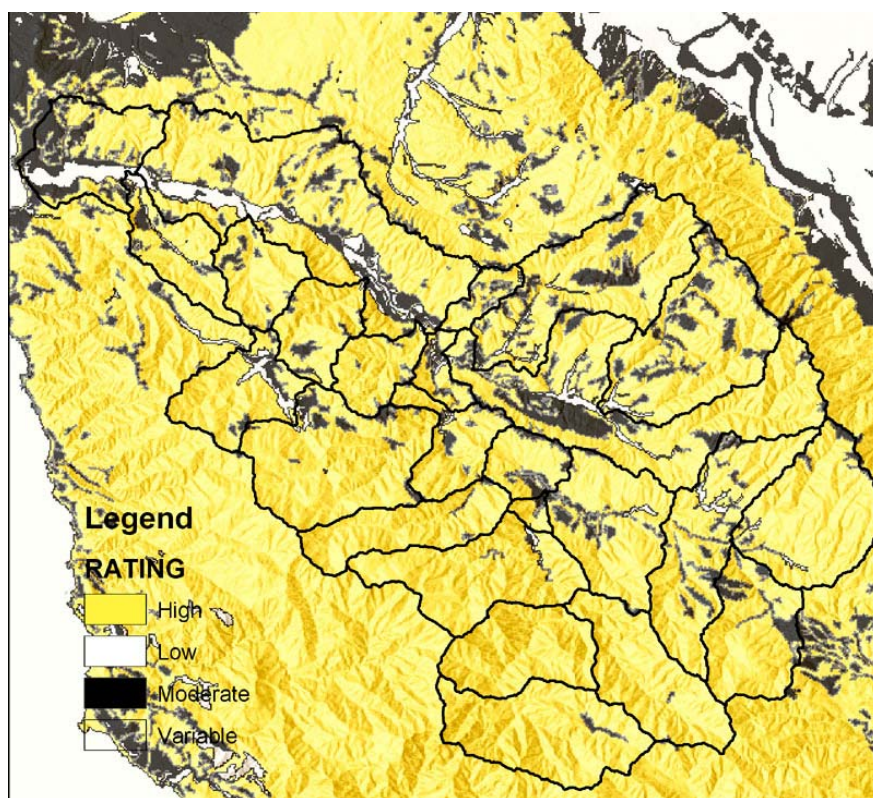
Figure 9: Erosion susceptibility in the Carmel Watershed (Rosenberg, 2001)

One benchmark of watershed condition is the amount of sediment being eroded and transported from the landscape. Although erosion is the natural process by which mountains erode to the sea, the least disturbed watersheds will typically have the lowest erosion rates. These watersheds minimize the erosional processes in two ways. First, they infiltrate much of

the rainfall that would otherwise be available to run off and erode the substrate. This is accomplished by fostering porous, non-compacted topsoil. Second, they reduce the erosion potential of the substrate by maximizing vegetative cover, which both slows the flow of water and adds strength to the topsoil. A gravel-bed river with a paucity of fine sediment in the water provides excellent salmonid habitat, good water resources for consumptive use, and an aesthetically pleasing recreational environment.

Sediment derived from the watershed can be divided into bedload, which is too large to be bounced high off the stream bottom, and suspended load, which is fine material suspended by water turbulence (Leopold et al., 1964). Bedload of the proper amount and grain size is required to maintain channel stability and spawning habitat, but too much or too little can change both the habitat quality (Dettman, 1989) and the stability of a river channel. Such changes are typical downstream from dams, which impede the natural flow of watershed sediment (Kondolf and Curry, 1986; Kondolf, 1997; Kondolf and Metzer, 1999; Watson et al., 2003).

A major source of bedload in the Carmel Watershed is the fractured granitic rocks in the steep headwaters above Los Padres and San Clemente dams (Fig. 10; Appendix A-2). These sediment
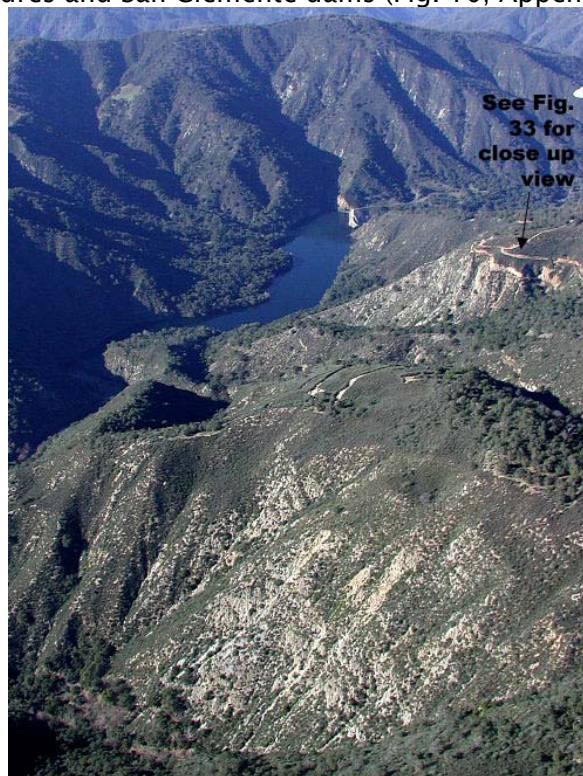
Figure 10: Steep eroding slopes of granitic rock up-valley from Los Padres Reservoir.

sources have reduced the capacities of San Clemente and Los Padres dams by 90% and 50% respectively (Entrix, 2000). Before the San Clemente Dam was constructed in 1921, the Carmel River was more dynamic, especially during major floods when bedload supplies were unlimited

(Kondolf and Curry, 1984). Rivers supplied with an extremely a high volume of bedload are commonly wide, with multiple unstable channels that switch position frequently. This was the case in the Carmel Valley following the major historic floods, when the channel migrated over 500 meters across the valley floor (Kondolf and Curry, 1984). The river also widened considerably during the 1982 floods, but that was because overuse of the Carmel aquifer impaired the riparian vegetation (Kondolf and Curry, 1986). Braided channels locally exist above San Clemente Dam, a reminder of how the Carmel River used to look periodically under the influence of high bedload conditions (Fig. 11).

When the San Clemente Dam was built in 1921, bedload transport to the lower Carmel River was significantly reduced. In response to sediment starvation, the river channel has cut downward into its bed several meters, leaving a generally narrower, single-thread channel, with a well-defined riparian corridor (Kondolf, 1981). This response is similar to the Salinas River response to dam construction (Watson et al., 2003). San Clemente Reservoir is nearly filled to capacity with the sediment it has trapped. When it is full, or when the dam is decommissioned, bedload pathways between the upper watershed and the Carmel Valley may be restored. In that event, there will be considerable channel-floodplain adjustment to the higher bedload transport conditions (MEI, 2002).

Figure 11: Braided channels in Carmel channel below confluence with Cachagua.   5775800E; 2042600N.

Large volumes of both bedload and suspended load sporadically leave the Carmel watershed. Krebs (1983) estimated that the Carmel River passed 1.9 million tons of sediment in the wet winter of 1982-1983, far in excess of the normal load of the Carmel River. Bedload was about 22% of that mass. Over half of the bedload was passed in just 1.5% of the time, while water discharge was above 3000 cfs. On the other hand, less than 1% of sediment load was passed when river was flowing less than 200 cfs, which occurred 66% of the time of the study. This strong dependence upon high flows suggests that the watershed generates and stores sediment

during normal or low-flow years, leaving it poised for extremely high transport rates during wet years. This behavior is also observed in Arroyo Seco (Watson et al, 2003), and may be typical of the Mediterranean climate (Kondolf and Smetzer, 1999).

Both bedload and suspended load sediment are being generated from all the tributaries feeding the Carmel Valley. A small subset of subwatersheds have bedload estimates, the rest do not (Table 2). As is almost universally the case in North American watersheds, it is unclear how much of this bedload material is from natural background erosion, and how much might be reduced if human impacts were reduced.

Table 2: Estimated tributary bedload sediment yield from select Carmel River tributaries. See Figure 1 for subwatershed locations. Data modified from MEI (2002). Note that unit yield was incorrectly reported in MEI (2002).

Location	Average annual sediment yield (tons)		
	Drainage area (Sq. mi.)	Bed material load	Unit yield (tons/sq.mi.)
Tularcitos, Chupines, and Rana Creeks	52	915	18
Hitchcock Creek	4.5	542	120
Garzas Creek	13.2	392	30
Robinson Cyn	5.4	521	96
Potrero Crk	5.2	99	19

Sediment "unit yield" is the rate of sediment eroded per unit of area in the watershed, so it can be used as one index of disturbance (Table 2). Hitchcock Creek stands out as a watershed that has a high proportion of bare soil to vegetated soil, perhaps associated with housing or road construction. Site visits indicate that upland areas were still contributing a great volume of excess sediment to Hitchcock Creek in 2003. Also present is a chronic small landslide that may have influenced these studies. The slide is made chronic by a county bridge # 518, which directs flow against the unstable slope.

Site visits to Robinson Creek (2003 & 2004) indicate that the estimated high sediment unit yield shown in Table 2 may have three chronic sources. First, Robinson Canyon Road is very typical of canyon roads leaving the Carmel Valley; there are numerous sites with eroding road cuts left from road construction and recent road maintenance (Fig. 12). These cuts are still locally devoid of vegetation that would typically control erosion in this area. Second, road cuts high in the canyon, not far from the divide, have over steepened very weathered sandstone of the Chamisal Formation (Appendix A-2), leading to large gully formation and shallow landslides (Figs. 13 and 14). Third, there is house and road construction in the canyon, which typically results in increased slope erosion, despite the usual erosion control measures.

Figure 12: Road ditch along Robinson Canyon Road carries sediment derived from eroding road cuts directly to a culvert leading to a tributary creek bed.
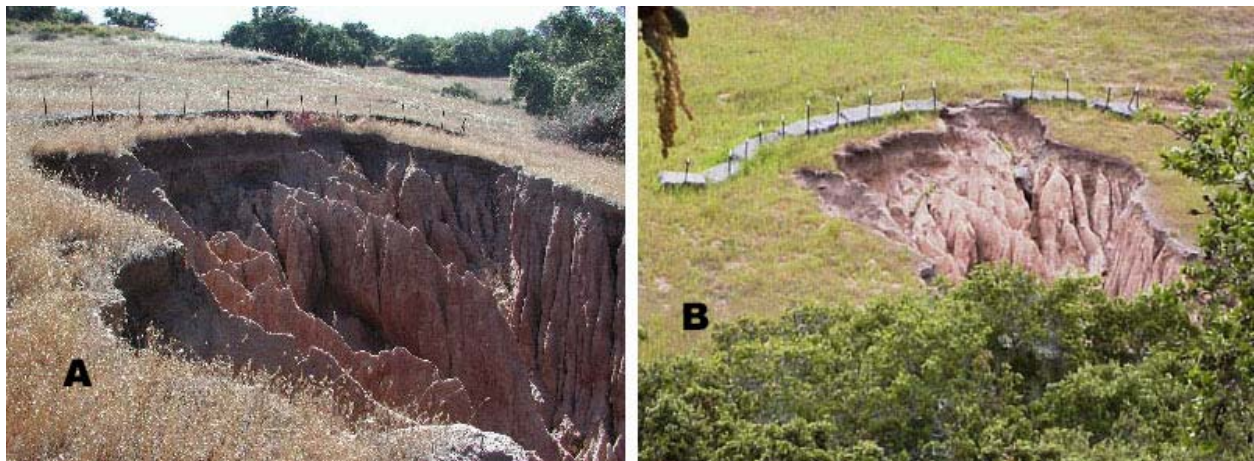
Figure 13A: Head of large gully eroded into weak Chamisal Formation. Gully likely formed from road cut on Robinson Road. There is no indication of destabilizing factors higher on the slope. Photo from June 2003. Figure 13B: Same location as Figure 13A. Photo from April 2004. Note that the gully head has breached the hay bales indicating growth, even in year without high precipitation.

Tularcitos Creek stands out among the lowest in terms of estimated unit yield, which is a surprising result considering the evidence for locally high erosion rates we present later. We believe that the relatively low sediment yield here reflects the relatively drier conditions, and consequently lower water yield in this part of the Sierra de Salinas (Fig. 15).

Of note is that estimated sediment-rating graphs show that Tularcitos Creek moves a disproportionately high sediment load with relatively little flow, and then, as water flow increases, the sediment rate is comparable to other tributaries (Fig. 16).
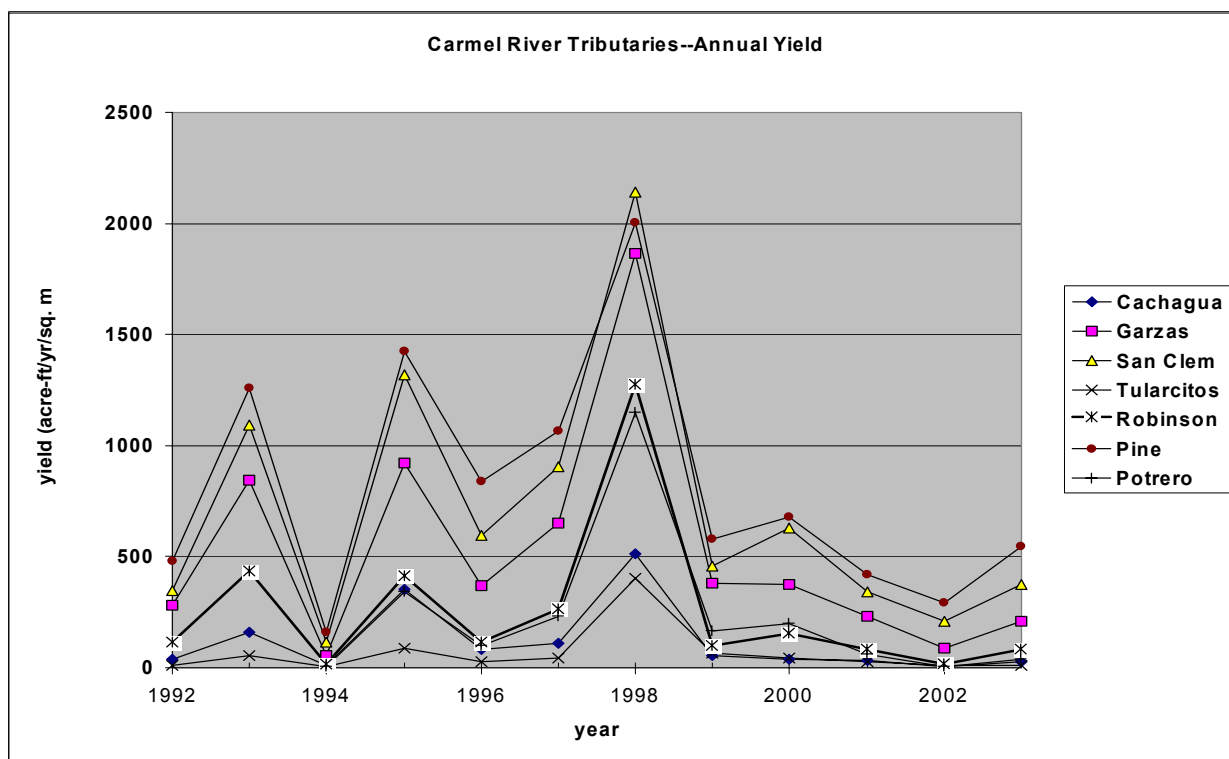
Figure 15: Annual water yield of gauged tributaries in acre–feet/year/mi². Data from James (2004)

We interpret that inflection in the Tularcitos graph to mean that there is an overabundance of sediment, but that it is mostly very fine grained bedload material that is easily flushed downstream with relatively low flows. Once the fines are removed, the Tularcitos sediment rating is comparable to other channels, up to a discharge value of approximately 200 cfs (Fig. 16).

Although Figure 16 suggests that significant sediment measurement data exist, including measurements at over 1000 cfs, it is clearly based upon synthesis of data from very few studies, and at much lower flows (MEI, 2002). As sediment yield is one obvious barometer of watershed condition and departure from optimum conditions, we highly recommend that frequent bedload and suspended load monitoring become a regular part of future watershed management.
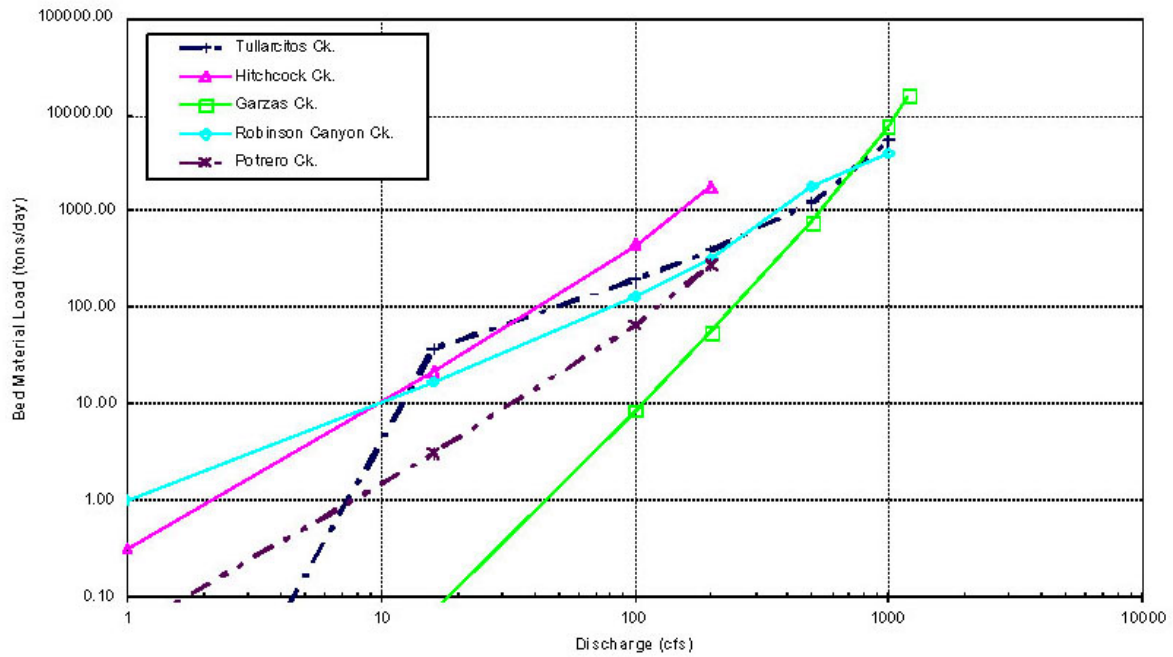
Figure 16: Estimated sediment rating relations for select tributaries to the Carmel River (MEI, 2002). Bottom axis is water discharge (ft³/s); Vertical axis is bed material load (tons/day).

An abundance of fine sediment is supplied to the near-creek region by the great number of soil slips and gullies in the Chupines drainage of the Tularcitos watershed (Fig. 17).
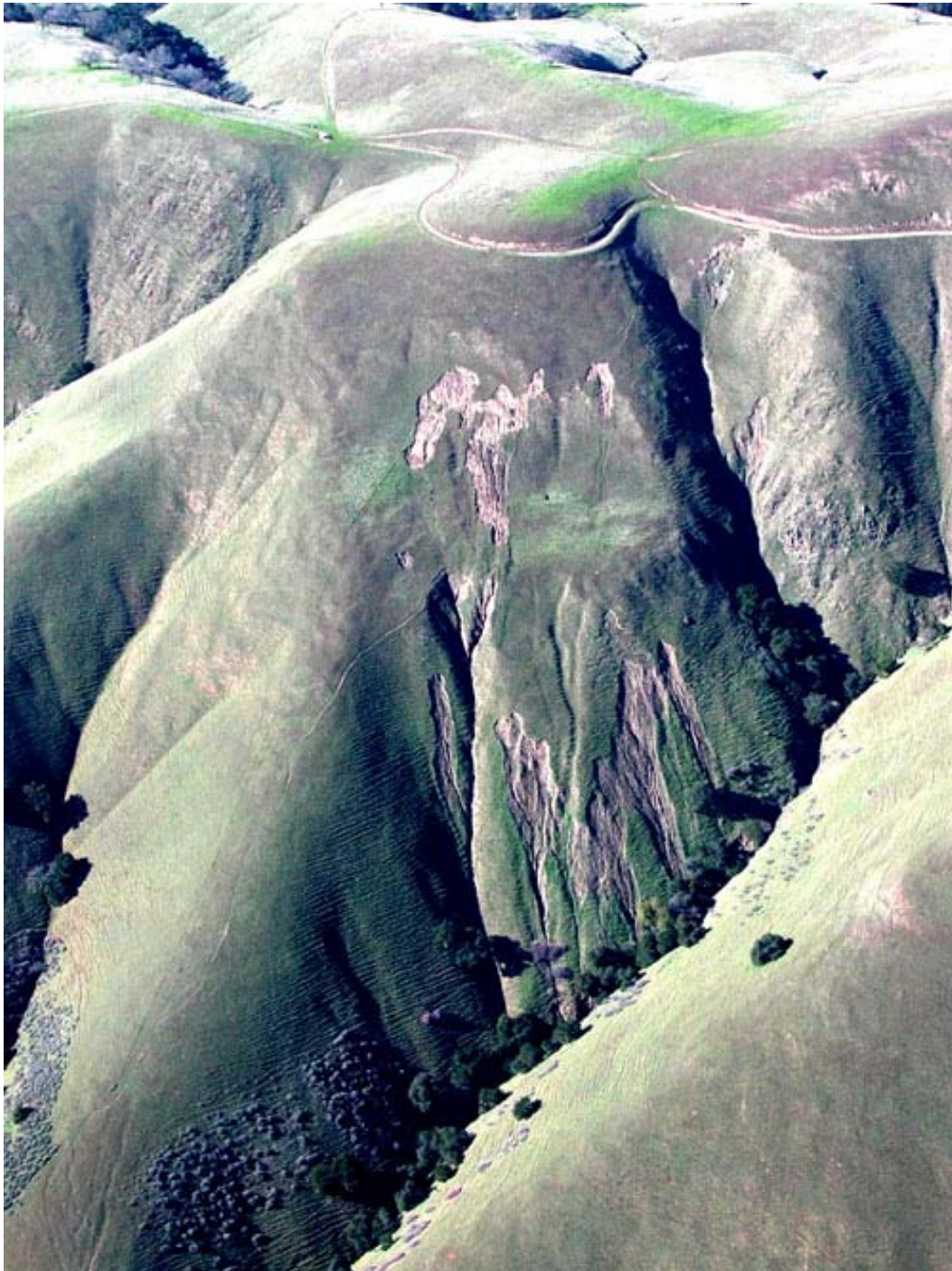
Figure 17: Soil slips in steep slopes that form the divide between Chupines Subwatershed and Toro Creek Watershed. Also note the bare road cuts that can also be a source of excess sediment in wet weather. See Figure 53 for close up terraced hillslope. 5784700E; 2077600N.

These kinds of landscape disturbances commonly transport fine material to the creeks because they ordinarily cut through soil rather than bedrock. Miles of the Carmel River below Tularcitos were blanketed by a great volume of sand and fine sediment discharged from the Tularcitos drainage following the strong winter storms of 1983 and 1998 (Kondolf and Metzer, 1999). The episodic behavior in Tularcitos sediment transport suggests that a great volume of loose sediment derived from gullies, river banks and soil slips is locally- stored during most years when tributaries do not flow enough to move the sediment down-valley. This stored sediment is then liberated in torrents during sporadic very severe winter storms.

5.4 Fire

"An average of 25,000 acres are burned annually by wildfire in Los Padres National Forest. While there are many positive ecological benefits from periodic fire in chaparral ecosystems, such as rejuvenation of watersheds and wildlife habitat, wildfires within the "wildland urban interface" can be catastrophic. Some of the largest and most destructive fires in California's history have occurred within or adjacent to Los Padres National Forest" (LPNF, 2004).

Wildfire is a significant part of the Carmel Watershed natural history, with an estimated pre-1900 fire frequency of 21 years in the Santa Lucia Range (Matthews, 1989). Fire suppression in recent decades has generally made fires more infrequent, but more intense. Three important physical consequences of wildfire in the Carmel Watershed are 1) extremely high post-fire sediment yield, 2) impacts of fire fighting and suppression activities, and 3) sediment derived from infrequently maintained fire roads.

The Marble Cone Fire (1977) is one of the best-documented recent large forest fires in the region. Sediment transported down the Arroyo Seco Watershed immediately following that fire contributed the equivalent of the entire Salinas Watershed annual sediment load in one season; the river was still processing the bedload sediment slug five years later (Watson et al., 2003).

Hecht (1981) noted that the upper Carmel River filled with sediment immediately after the Marble Cone Fire. The estimated sediment yield to the Los Padres Reservoir in the single winter following the fire was approximately 555 acre-feet, representing over a third of the capacity loss that has occurred since the dam was built (Hecht, 1981). Hecht (1981) also noted that the habitat values were largely restored by the end of the first year, with virtually complete recovery after three years. Likewise a U.S. Geological Survey study found that minimal additional siltation occurred in Los Padres Reservoir during monitoring of winter runoff of 1978 and 1979 (USGS, 1979). USGS (1979) concluded that very rapid revegetation of burned slopes helped to reduce erosion to pre-fire rates. The rapid return to pre-fire sedimentation yield is no doubt the result of the extremely wet post-fire winter that washed the majority of available loose sediment down slope in the first season.

Not all large fires contribute enormous sediment loads. The Carmel Watershed had a total of 16,373 acres within the Kirk Fire burn boundary (LPNF, 1999). A total of 16,346 acres were within watersheds draining into Los Padres Reservoir (LPNF, 1999). Despite the significant acreage, the fire apparently did not markedly influence the rate of reservoir infilling (Entrix, 2000). This disparity in sediment runoff between the Marble Cone and Kirk fires, likely underscores the importance of intensity and amount of rainfall in the immediately subsequent winter season, before seedlings can sprout. The Marble Cone fire was immediately followed by 35.48 inches of rain, whereas the Kirk Fire preceded an average rainfall of 20.37 inches. Those rainfall amounts are from the San Clemente Dam gauge (James, 2004), and certainly underreport the true rainfall affecting the burned upper watershed.

Small fires might have little immediate impact, but can add long-lasting, incremental, chronic sediment sources. A recent small fire in the Bear Subwatershed (Fig. 1), still marked by blackened hills in 2003, and a fresh firebreak, has resulted in severe gullying. Gullying in this case resulted from devegetation, which increased the runoff rates and velocities from subsequent winter rains. Devegetation was the result of both the fire and the significant firebreak constructed as a fire suppression tool.

6   Hydrology

This section describes and analyzes the general climate, the flow of water through the watershed, and the risks of flooding. The section describes both the surface water resources and groundwater resources, emphasizing that the two are inseparable in the lower Carmel Valley. We also describe evidence that the lower Carmel Valley resource is, in part, supported by inter-annular storage and release of water from the upland bedrock aquifers.

6.1   Climate and Precipitation

The Carmel watershed currently has only one source of water, direct precipitation. The precipitation that is left after loss to evaporation and use in transpiration is naturally divided into surface flow and groundwater flow. Thereafter, groundwater can convert to surface water and surface water can infiltrate to groundwater as physically dictated by local water abundance, geologic substrate, annual season, human consumption, and antecedent conditions. An accurate assessment of the amount of rainfall captured by the watershed, and a map of its complex downslope pathways, are critical bases for projecting resource sustainability and making long-term development plans for each subwatershed of the region. For planning purposes, both the average hydrologic conditions and the extremes should be anticipated. Both strong floods and crippling drought have their place in recent Carmel Valley history.

The Carmel Valley has a mild Mediterranean climate. Average annual precipitation falls mainly as rain, and varies between 14 inches at the mouth and 41 inches in the Santa Lucia Mountains (Fig. 18; references in Rosenberg, 2001,).
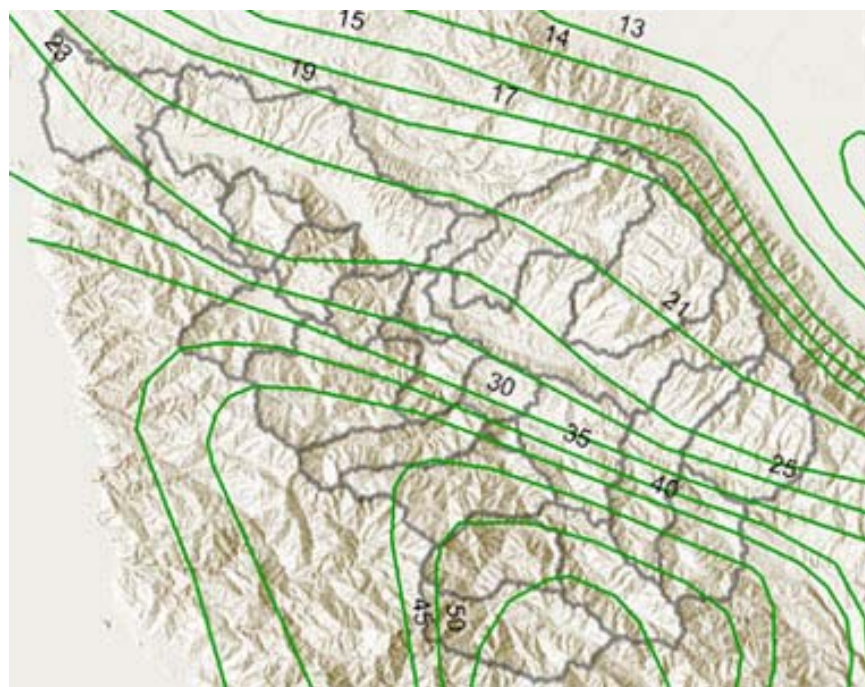

Figure 18: Contours of average annual rainfall in the Carmel Watershed (Rosenberg, 2001).

The Santa Lucia Range is the first topography that the great Pacific storms encounter as they swirl in toward land. The coriolis effect spins the storms that advance upon our coast counterclockwise, so the storm fronts tend to strike our coast from the southwest, directly against the crest of the Santa Lucia Range at the Carmel River divide. This geometry produces a significant orographic effect that harvests a high volume of rain along the southwestern margin of the watershed, leaving regions as near as the Carmel Valley in a rain shadow where far less precipitation falls.   Three subwatersheds here (Pine, Garzas, and Black Rock/San Clemente) produce 27% of the annual Carmel flow, but compose only 15% of the Carmel watershed area (Table 3; Fig. 1).   The Santa Lucia region of the Carmel watershed is the major source of water reaching the lower valley, presently making it the major water source for the greater Monterey Peninsula. Because of the substantial role these subwatersheds play in providing water resources for the Carmel River and beyond, they should be managed with water quantity and quality as the highest priority.

In contrast, to the high yield from the peaks of the Santa Lucia Range, the combined flow from the Tularcitos, Rana, and Chupines subwatersheds of the Sierra de Salinas produces only 4% of the annual discharge of the Carmel River, but occupies 23% of the whole watershed. This value appears low considering that the region represents roughly one quarter of the watershed and receives approximately 20 in of annual rainfall (Fig. 18). Considering the typical pathways of water, the low surface water yield must be the result of combined higher than average evapotranspiration, shallow infiltration, and deep aquifer recharge.   Evaporation from the soil is expected to be high on these generally south-facing slopes, where incident sun radiation is higher.

Watershed management decisions in the Carmel Valley should be water conservative considering that both the most recent decades of rainfall records and older tree-ring records indicate that the region is frequently subjected to drought conditions. An index of historic rainfall variability in the basin is the long-term record maintained at San Clemente Dam since 1922 (Fig. 19). Analysis of this and other records indicate that the Carmel Valley has endured six droughts since 1902, where drought is defined as two or more successive years of dry or critically-dry conditions (James, 2004).   The State Water Resources Control Board recently added the Carmel River to its list of seasonally fully appropriated streams, noting that, "In normal and wet years, supply exceeds demand, but the area is subject to climatic variability and the impact of multi-year droughts. Since 1976, the Peninsula has endured two extended periods of mandatory rationing; 18 months in 1976 to 1977 and 28 months in 1989 to 1991" (SWRCB, 1995b). The Carmel River discharged approximately 83,400 acre-feet to the sea in 1996, a year with near average precipitation (22.4 in; Table 3).

Fritts and Gordon (1980) report that we should view the historic Carmel record (Fig. 19) 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.

Carmel Watershed (2004)

Table 3: Subwatershed size and water data. Data from GIS analysis and James (2004)

Region[1]	Subwatershed Name	Area (sq. km)[2]	Drainage Above Mouth (sq. km)[3]	Drainage Above Mouth (sq mi)	Guaged Area (sq. mi)[4]	% of Flow [5]	Flow in 1996 (ac–ft/yr)[6]	Yield in 1996 (ac–ft/yr/sq. mi)[7]
SL	Hitchcock Creek	12	12	5	5	1	1820	396
SL	Robinson Canyon	14	14	5	5	2	619	115
SL	Potrero Creek	16	16	6	5	1	506	97
SL	Upper Las Garzas	20	20	8				
SL	Pine Creek	21	21	8	8	7	6550	840
SL	Upper Finch Creek	24	24	9				
SL	Miller Canyon	27	27	11				
SL	Blue Creek	34	34	13				
SL	Lower Las Garzas	15	34	13	13	8	4890	370
SL	Black Rock/San Clemente Creek	41	41	16	16	12	9310	597
SL	Bruce Fork	24	57	22				
SL	Lower Finch Creek	35	49	19				
SL	Cachagua Creek	29	78	30	46	4	3840	83
SL	Los Padres Dam	32	116	45				
SL	Lower Los Padres Dam	2	118	46				
SL	Lower Cachagua Creek	10	206	80				
SL	San Clemente Dam	14	282	110				
SL	Lower San Clemente Dam	6	432	169				
SS	Klondike Canyon	6	6	2				
SS	Bear Canyon	34	34	13				
SS	Rana Creek	42	42	16				
SS	Chupines Creek	43	43	17				
SS	Tularcitos Creek (hydrology in this row is combination of Tularcitos, Chupines, and Rana Creeks)	60	145	57	56	4	1650	29
CV	Mid Carmel River	76	608	238				
CV	Lower Carmel River/Lagoon	24	656	256	252	100	83430	331

Notes: 1). SL= Samta Lucia Range, SS=Sierra de Salinas Range, CV = Carmel Valley. 2) Area of subwatershed. 3) Area of land that contributes flow to the mouth of the subwaterhsed (includes upstream subwatersheds). 4) Area contributing flow to a MPWMD guage near the mouth of the subwaterhsed (James, 2004). 5) Total flow from the subwatershed from 1993 to 2003 normalized to the flow at the Highway one bridge (James, 2004). 6) Total volume of water exiting the subwatershed in 1996 (James, 2004). 7) Volume of water exiting the watershed per square mile of land in the subwatershed in 1996.
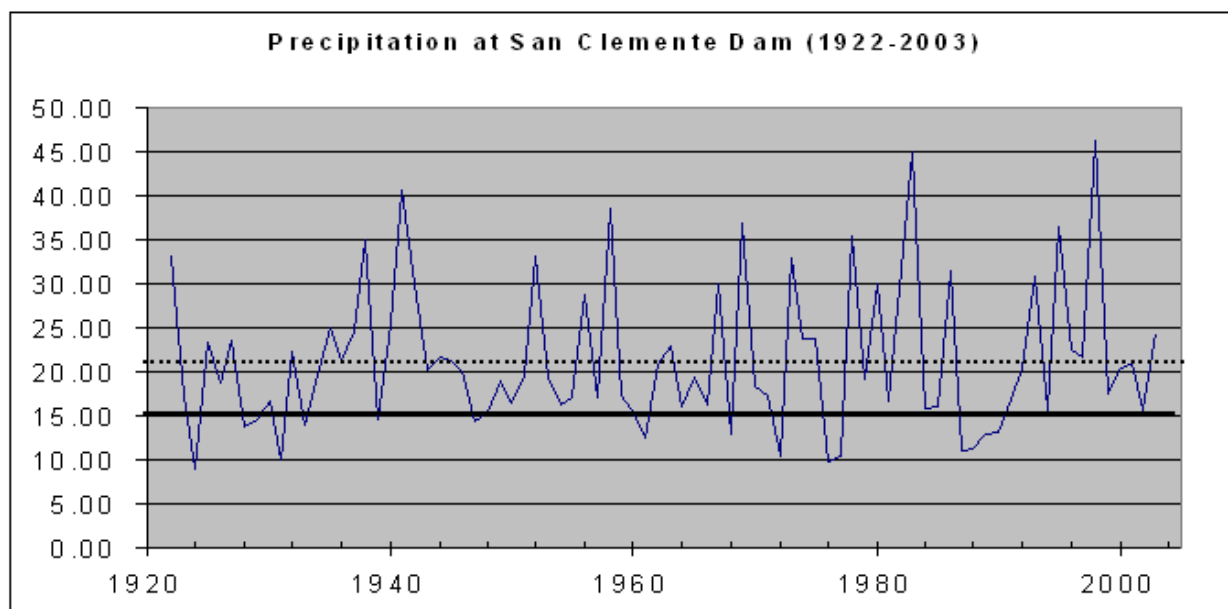
Figure 19: Rainfall at San Clemente Dam since 1922. Dotted line is average (21.37 inches). Bold line approximates the level of rainfall giving rise to hydrologically "dry years" reported in James (2004). Rainfall values below that line approximately correspond to hydrologically "critically dry years." Cal-Am data from James (2004).

6.2 Hydrologic Cycle

The sustainability of water supplies for human uses and ecosystem health requires the development of a balanced approach to water management. The needs of fish and humans are sometimes at odds, so compromises are inevitable if both components of the watershed are to thrive into the future. The starting point for such management is the development of a water budget, a sensible accounting of the resource. The budget should recognize the myriad pathways of water through the hydrologic cycle and quantify where water is gained, lost, stored, and transported in the watershed system.

An example of a well-estimated hydrologic budget along the Santa Lucia Range was produced as part of the baseline study before the Santa Lucia Preserve development was permitted (Table 4).

Table 4: Hydrologic Budget in the broader region extending beyond Upper Garzas subwatershed. Modified from RSC-EIR (1994).

Water use	% of rainfall
Evapo-transpiration	64%
Stream flow	23%
Groundwater recharge	13%

The budget shows that rain is the only source of water in the region. If that value is considered to be 100% of the resource available on an annual basis, then the budget can be presented as percent of the rainfall. Sixty–four percent of the rain is lost to evaporation or used by the the broader ecosystem for survival and growth. The amount left over is potentially usable resource as infiltrated groundwater and stream flow. Some of that remaining resource must be left to maintain a healthy riparian ecosystem and to supply human demands in the watershed and beyond. A hydrologic budget in the Sierra de Salinas would include more evaporative losses, and subsequently less resource for stream flow and groundwater recharge. The two main differences are 1) the effect of more direct sunshine on the southern facing range, and 2) less precipitation to saturate soils.

During a rainstorm, water that reaches the soil will either evaporate, infiltrate to groundwater or runoff, depending mainly upon soil condition, slope, vegetative cover and antecedent moisture conditions. Nearly all of the rain falling in the first few storms in the Carmel watershed infiltrate into the summer–desiccated soil rather than runoff. At some point relatively early in the rainy season, the rainfall rate exceeds the ability of soil to draw water, and overland flows begins (Fig. 20).
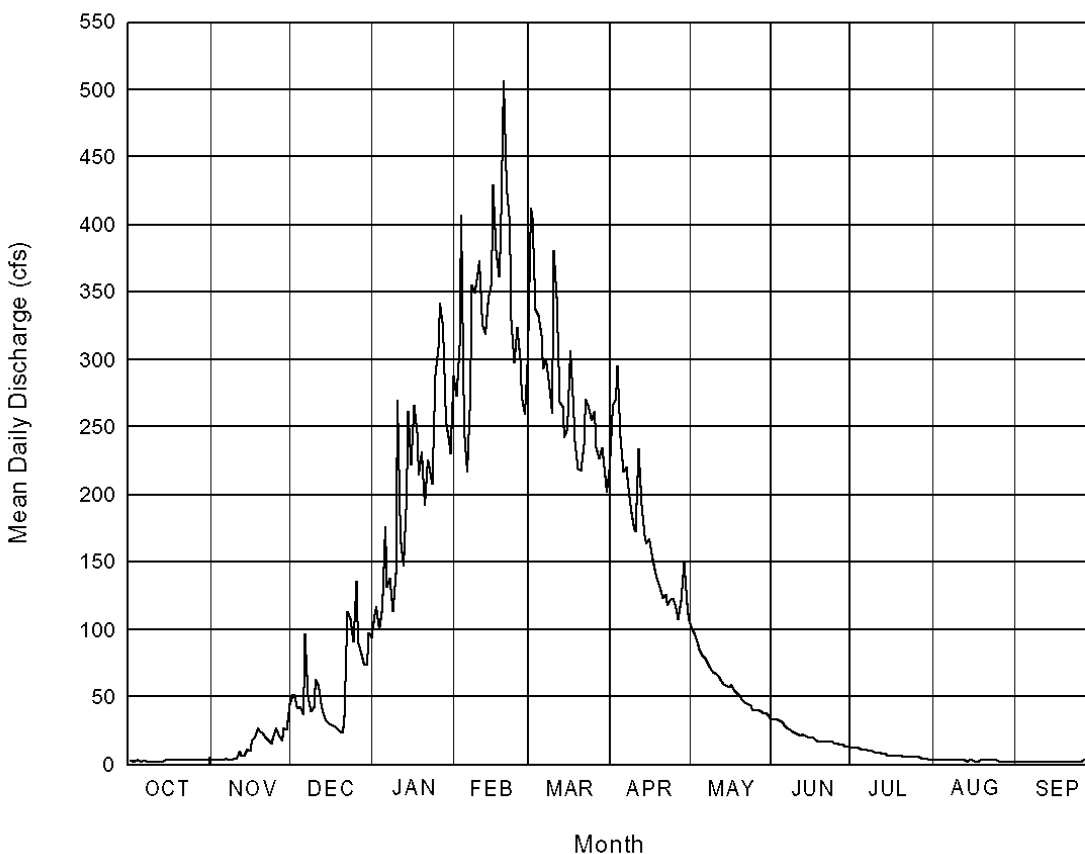
Figure 20: Average annual hydrograph at the U.S. Geological Survey gauge located at Robles del Rio, not far from the Carmel Village (MEI, 2002).

The portion of the water that reaches a tributary or the Carmel River will either infiltrate through the bed, infiltrate through the banks, support riparian plants, evaporate, or will continue flowing to the sea.

The Carmel River keeps flowing long after a single storm has passed, and for several months after the last rain of the season, because much of the rainfall that originally infiltrated to the soil flows slowly down slope underground to emerge as springs and seeps that contribute the surface water resource (e.g., RSC-EIR, 1994). Thus the soil, which serves to retard the flow of rainwater to the Carmel River, serves the human community in several critical ways.

1. reduces flood hazard by lowering the peak discharge from a storm,
2. increases the time between the peak of the storm and the peak flood hazard,
3. maintains flows in the river between storms, and during the six-month dry season (Fig. 20).

This last point has several benefits including increasing the storage of water in the major Carmel Valley aquifer, maintaining year-round fisheries, and maintaining a healthy corridor of riparian vegetation. All of those benefits are contingent upon the free flow of the water from upland areas to the valley bottom both as overland flow and delayed discharge of groundwater.

A critical role of vegetated, non-compacted soils is the storage, transport, and release of rainfall to channels long after the rains have stopped. That is the only natural mechanism for achieving perennial flow, which the Carmel River may have enjoyed prior to construction of the San Clemente Dam (Williams, 1984). Well-managed landscapes can augment those natural soil functions even in the face of urban development if the functions are well understood, preserved, and enhanced. The Carmel Valley Master Plan contains numerous references to proper watershed management that includes preserving aquifer recharge areas, native soils, and native vegetation, and further suggests deliberately planning to retain urban storm-water run-off for aquifer recharge (CVMP, 1996).

6.3 Surface Water

Surface water in the Carmel River comes has four main sources, direct run-off from rainfall, releases from dams, seeps and springs of groundwater, and return-flow from urban uses including irrigation, septic systems, and waste-water treatment plants. Once water has reached the river channel, it has several potential sinks including groundwater withdrawals in the Carmel Valley, flow to the sea during winter months, evaporation from the stream surface, and transpiration and growth of streamside vegetation. All private or public water diversion, retention, or withdrawals from the watershed tributaries and upland aquifers that include consumptive use have a cumulative impact on the volume of water in the lower valley river/aquifer system. Although most individual claims to water are an insignificant proportion

of the watershed hydrologic budget, the collective effect of water use throughout the watershed has resulted in the stream being fully appropriated in summer months (SWRCB, 1995b).

The Carmel Valley can be considered to be a "U"-shaped bedrock bathtub with a thick layer of sand in the bottom. The sand at the bottom is the major unconfined aquifer for regional water supplies (e.g., Kapple et al, 1984). The sand and water rest above the low permeability bedrock of the valley. When water flows through the Carmel Valley, it occupies both the surface river channel and a subterranean river flowing within the sand beneath the channel (Kondolf and Curry, 1982; Maloney, 1984). This geometry makes groundwater and surface water the same resource (SWRCB, 1995a); managing one requires managing the other. Currently the surface water resource is impaired because the shallow sub-stream aquifer is overpumped by approximately 11,000 acre-feet/yr (SWRCB, 1995a).

Many of the Carmel watershed streams go dry annually, leaving fish populations at risk.   Most of the small headwater streams located high in the watershed do not have enough shallow groundwater to sustain them through the summer. The lower reach of the Carmel River goes dry annually because the surface water percolates downward through the gravel in its bed, replacing the water removed by municipal and private wells that tap the sands and gravels underlying the riverbed. The resulting drop in the water table resulted in impaired riparian vegetation and consequent enormous loss of land to bank erosion in the early 1980's (Kondolf and Curry, 1986). Presently, the riparian zone of the lower Carmel Valley owes its existence to miles of seasonally-deployed irrigation systems that counteract the overdraft of the unconfined aquifer.

Of critical importance to sustainable fisheries is the maintenance of year-round surface water at various reaches in the Carmel River with the appropriate seasonal range of discharge, temperature, and chemistry. The success of anadromous fisheries does not hinge upon the Carmel River being perennial, but there are minimum conditions that must be met to sustain the population.   There must be sufficiently large winter flows to present significant opportunities for fish migration to and from the sea, but not every year.   Likewise summer flows must be of sufficient local volume to provide cool, well-oxygenated, protected habitat for fish that will remain in the river during the dry season. These low summer flows must also be able to dilute septic return flow to a level that is not toxic to the fish population. Other benefits of summer surface flow would include a healthy riparian forest (Kondolf and Curry, 1986), reduced stream bank erosion (Kondolf and Curry, 1986), and the aesthetic appeal of flowing water.

6.3.1 Tributary hydrology

The Monterey Peninsula Water Management District (James, 2004) maintains stream gauges on several of the tributaries in this region (Table 3). The tributaries generally flow in concert with the regional rainfall patterns (Fig. 21), but also show effects of groundwater influence. Water years 1992, 1996, 1997, 2000, and 2001 are years with approximately average rainfall at San

Clemente Dam (Fig. 21). The corresponding tributary discharges across the watershed are markedly different during those years with average precipitation. As an example, the flow from San Clemente Creek in 2001 was 5000 acre-feet, but was 10,000 acre-feet in 1996 and 2000. We note that an average year following a wet year (e.g., 1996 and 2000) is more likely to have a higher annual discharge than will an average year that does not follow a wet year or series of wet years.

We interpret that observation to indicate that the upland bedrock aquifers are storing a significant proportion of each winter's rain, and then slowly releasing that stored resource to augment tributary flow to the lower valley, with the effect lasting a year or more. We note that the effect is rapidly diminished with time, as in the decrease in annual yield between 2000 and 2001 during average rainfall years (Fig. 21). Bedrock groundwater apparently contributes to surface water flow in the year or two following a year with high rainfall, and then the contribution rapidly tapers off as the water tables lose elevation, perhaps losing their connections to springs and seeps.

This crude graphical assessment is supported by autocorrelation analysis we performed on the tributary flow data of James (2004). Autocorrelation analysis that first removes the direct influence of annual rainfall, suggests that the upland aquifers can store, and then gradually release to tributary streams, a volume of water approximately equal to their annual or biennial recharge volume.

Further, the effect of antecedent drought on discharge is apparent in the 1994 "critically dry" year. The rainfall in 1994 was approximately the same as the low annual rainfall of 2002, but the runoff in the upland tributaries was disastrously low in 1994. From 1987 to 1991, the Carmel watershed sustained a severe drought of two dry years and three critically dry years (Fig. 21). This period of low rainfall was apparently enough to deplete nearly all the easily accessible upland groundwater springs. So low were the reserves that the normal and wet years of 1992 and 1993 were not enough to forestall the effects of the low 1994 rainfall. Again we take this relationship between tributary flow and antecedent rainfall as an indication that robust upland groundwater resources are critical for maintaining surface flows in the Carmel Valley. If the tributaries are dry, there is less resource supplied directly to the Carmel River and its subjacent shallow aquifer. The likely mechanism for the observed inter-annual variation in tributary flow is groundwater storage.

Under historic watershed management strategies there was very little flow in the Carmel River near the Carmel Valley Village when annual rain fell below approximately 10 inches (Fig 22). Recent changes in dam operation and water extraction strategies have lead to more frequent surface water flows past the Village since 1977 (Fig. 23). The increase in summer dam releases has undoubtedly improved aquatic habitat and water quality during the dry months, but has not noticeably affected the response of the watershed to years of high or low rainfall (Figure 24).
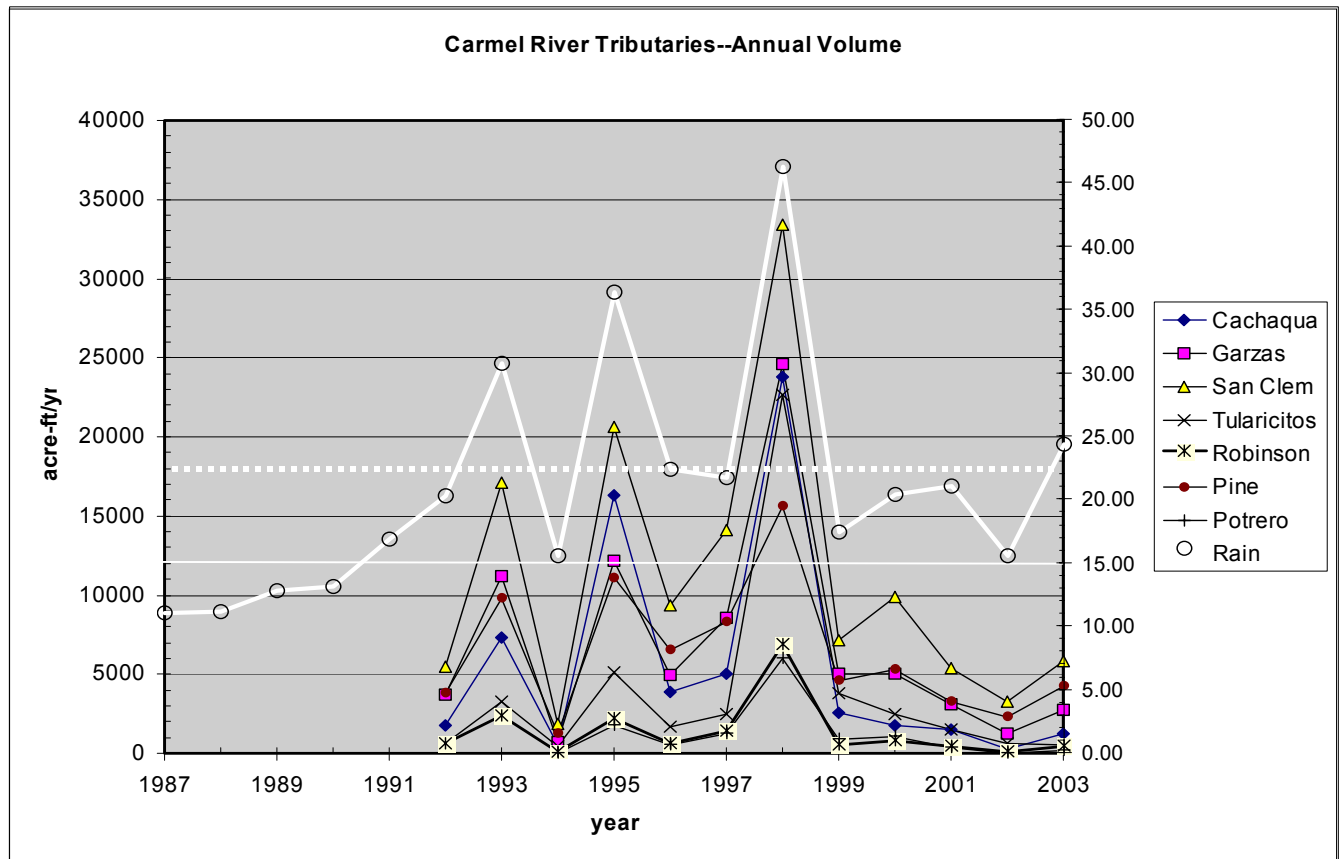
Figure 21: Annual volume of flow from gauged tributaries. Right-hand axis is annual rainfall at San Clemente Dam. Average rain (21.37 inches: 1922 to 2004) is plotted as a dashed white line. Threshold for "critically dry years" is fine white line. All data, including Cal-Am rainfall, from James (2004).
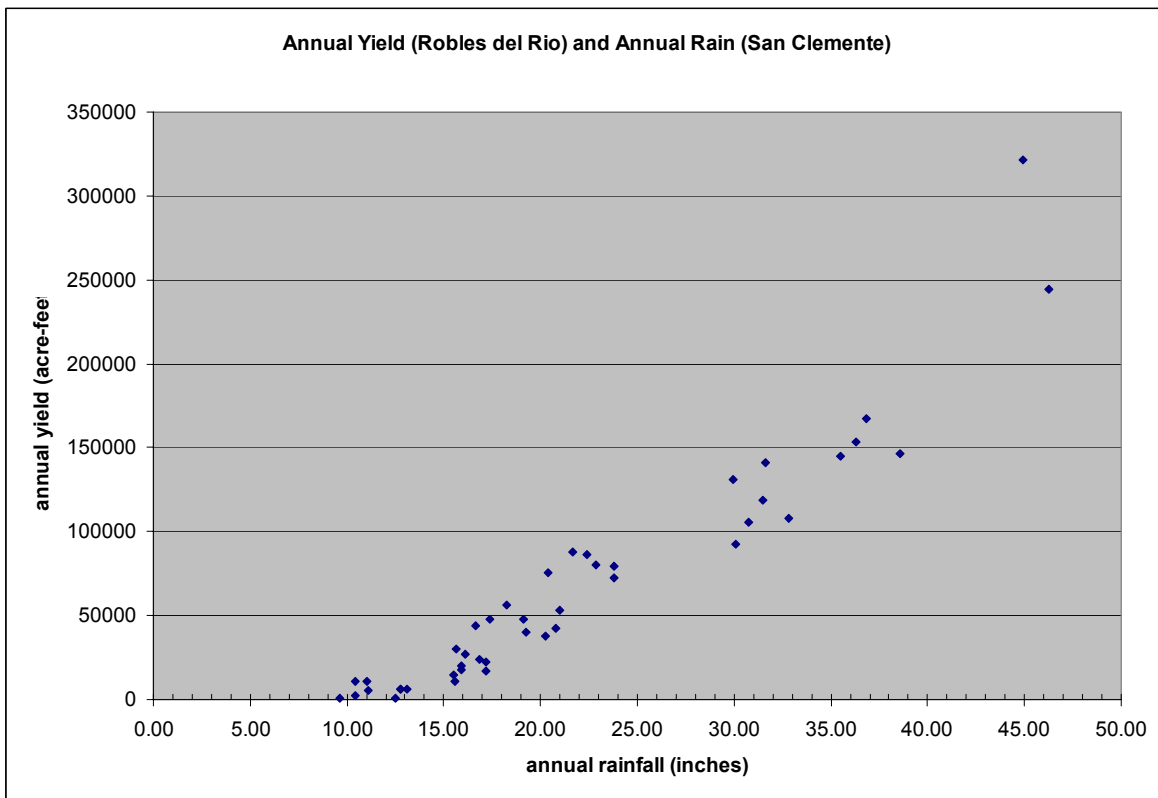
Figure 22: Total annual water yield past Robles del Rio Gauge as a function of annual rainfall at San Clemente Dam. Data from Cal-Am as reported in James (2004) and U.S.G.S. stream flow records.
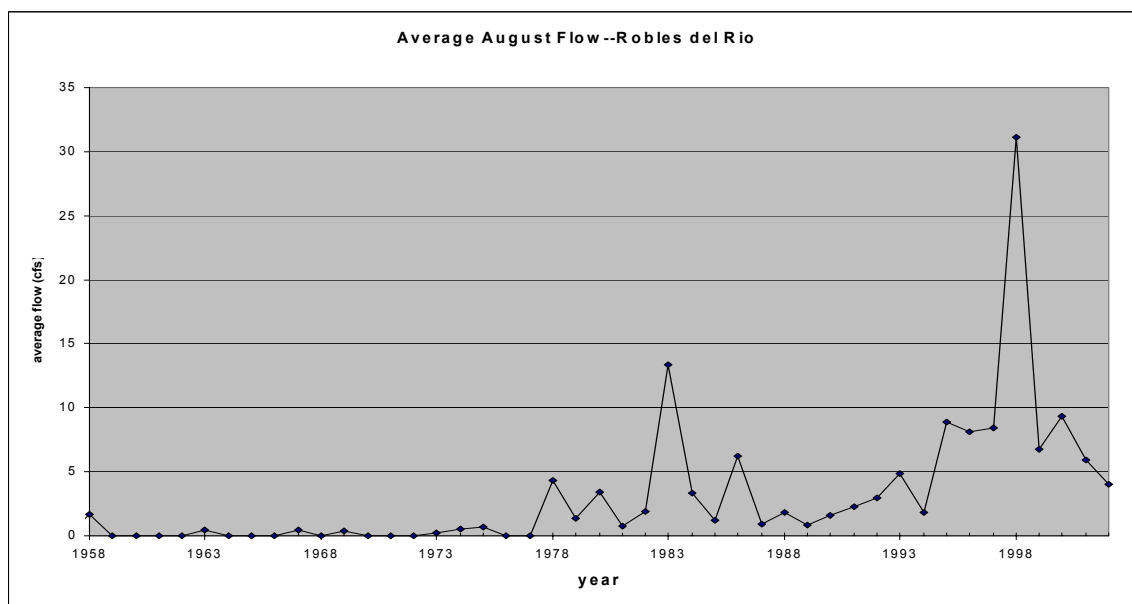
Figure 23: Average August discharge (cfs) at the Robles del Rio Gauge from 1958 to 2002. Data from U.S.G.S. stream flow records.
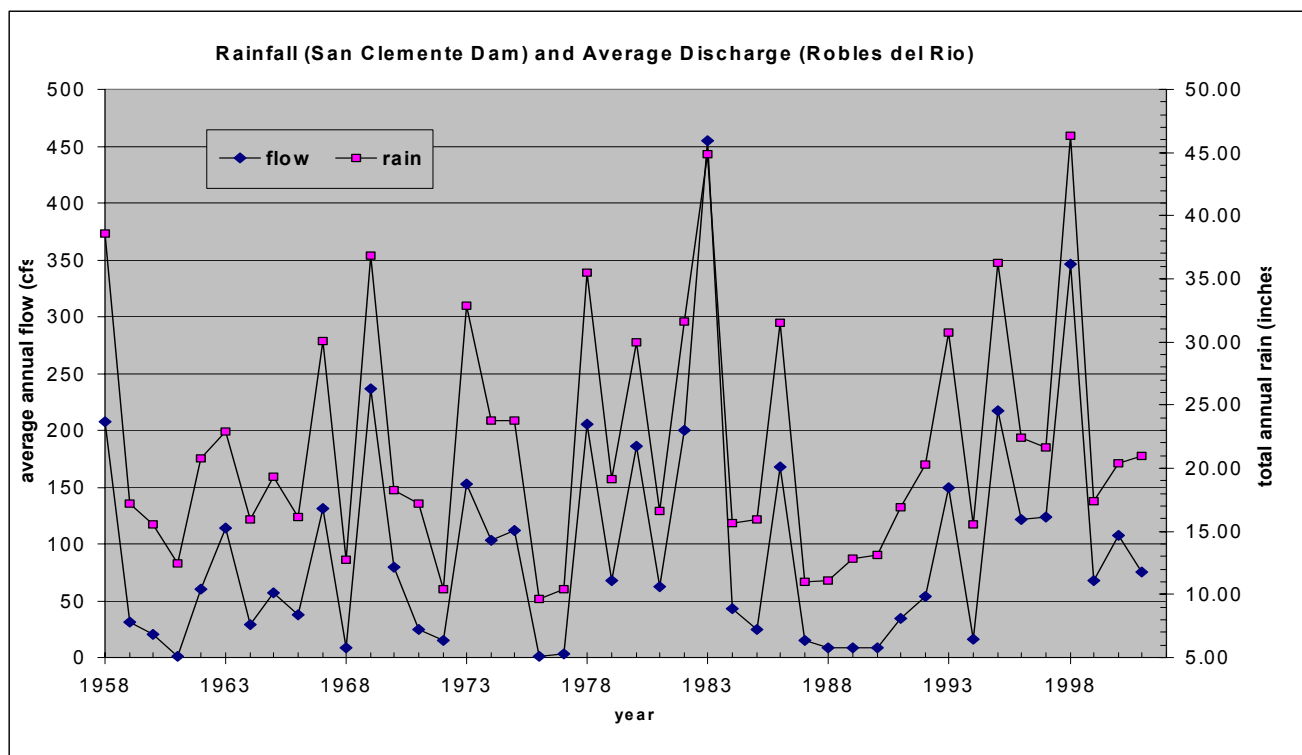
Figure 24: Average annual flow at the Robles del Rio stream gauge and total annual rainfall at San Clemente Dam from 1958 to 2001. Data from Cal-Am as reported in James (2004) and U.S.G.S. stream flow records.

6.3.2 Floods, FEMA Floodplain, and Monterey County Regulations

The landscape inundated by floods can be classified by the recurrence interval of the flood in question. Urban development requires mapping, and certain zoning restrictions, on the 100 year floodplain, the region that will be flooded approximately 10 times in the next 1,000 years (Fig. 25). Some practical tenets regarding the 100-year floodplain are important for land use and valley-bottom zoning (Mount, 1995).

1. There is no implied timing of 100-year floods. Two could occur in the same year or in successive years. The Carmel Valley experienced its largest historic floods in 1862 ($\approx$500-year flood), 1911 ($\approx$100-year flood) and in 1914 (unknown magnitude) (Kondolf and Curry, 1983; Williams, 1984).
2. The estimated magnitude of the 100-year flood, and its estimated area of inundation are moving targets. They will change with every year that provides a new significant flood, as occurred on the Carmel River in both 1995 and 1998.
3. It is highly unlikely that the present regulatory position of the 100-year floodplain is the true position of the 100-year floodplain.
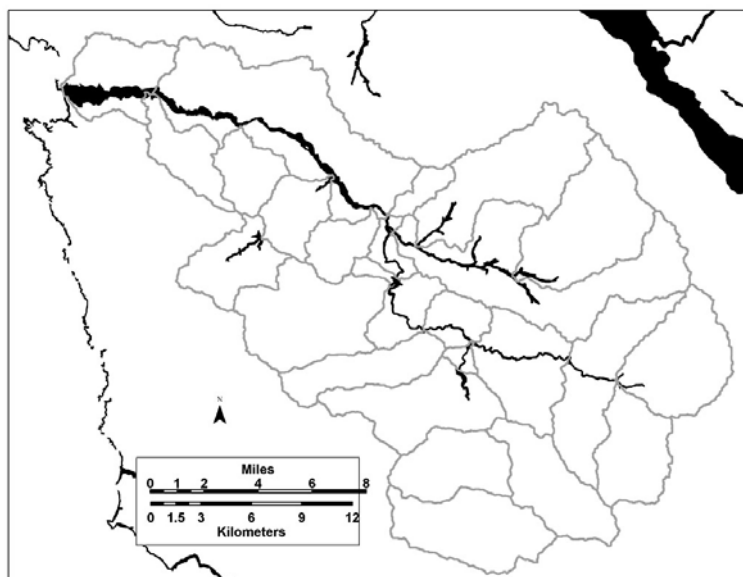
Figure 25: Approximate boundaries of the 100-year floodway in the Carmel Watershed (FEMA, 1996).

As determined by Monterey County, construction of structures, grading, or any activity that requires a permit from a government agency shall not be permitted within 200 feet of a riverbank or within the 100-year floodplain (floodway), unless a special permit is granted. The floodway is, by County definition, that area shown on maps prepared by Nolte Engineers for the Federal Emergency Management Agency titled, Preliminary Flood Boundary and Floodway Map (Monterey County Zoning Ordinance 21.64.130).

Using Log-Pearson Type-III analysis of the annual daily peak discharge records from the U.S. Geological Survey gauges at "Robles del Rio" it is clear that the 100-year floodplain is very imprecisely known (Table 5; Fig. 26).

Table 5: Estimated flood magnitudes at the "Robles del Rio" USGS gauge for selected recurrence intervals using data from 1955 to 2001. Data in Appendix C.

Flood recurrence interval (years)	Discharge (cfs)	Lower 95% (cfs)	Upper 95% (cfs)
2	2,350	1,570	3,520
5	6,170	4,660	8,190
10	9,100	6,680	12,400
25	12,700	7,800	20,800
50	15,200	7,800	29,400
100	17,400	7,600	39,900

Notes: "cfs" is cubic feet per second. Lower 95% and Upper 95% are the bounds of the 95% confidence interval for the listed discharges.

recurrence interval (years)
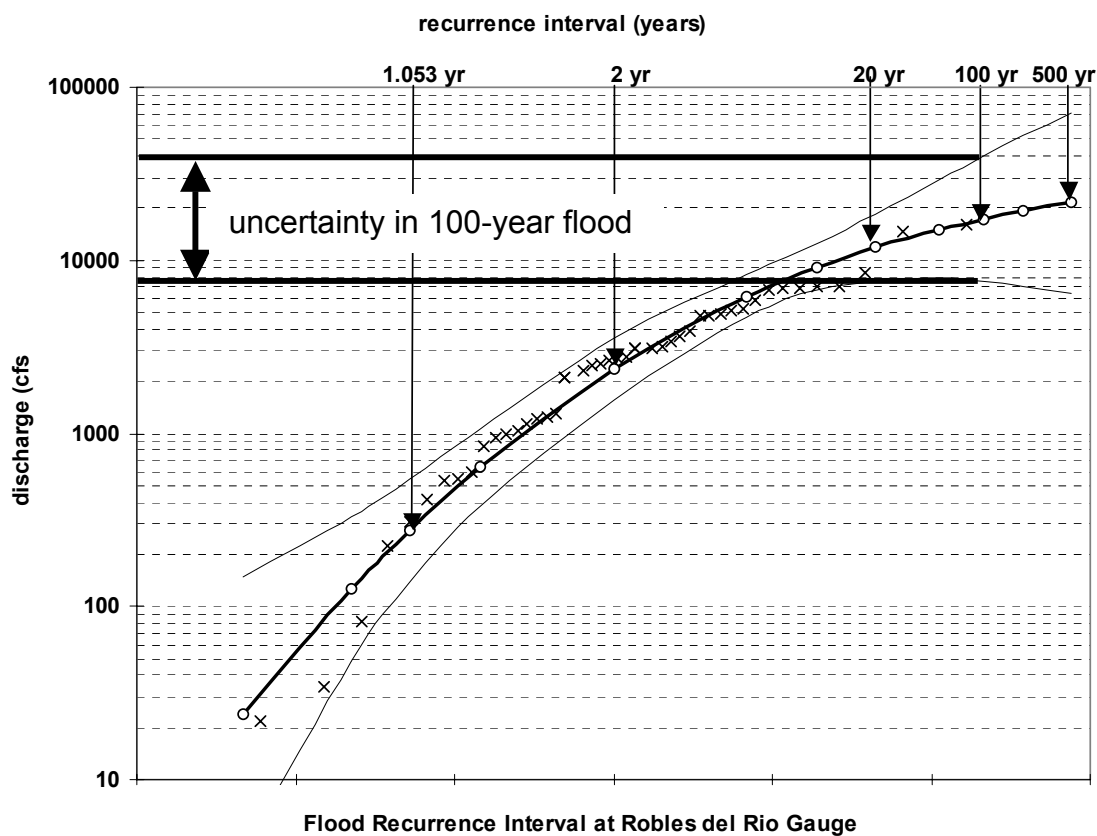
Figure 26: Plot of Carmel annual floods. Bold line is the calculated relationship between discharge (cfs) and recurrence interval (years). The fine lines are the upper and lower 95% confidence limits on the relationship. Log Pearson Type–III analysis using regionalized skew for Robles del Rio U.S.G.S. gauge data from 1955 to 2001.

The greatest flood during the 48 years of gauge operation was the 1995 flood with approximately 16,000 cfs. That event roughly corresponds to the 65–year flood. The next highest flood caused significant damage in 1998 with a 14,700 cfs flow (Fig. 27).

Figure 27: Flood damage near "Mission Fields" neighborhood following the 1998 Carmel River flood. Photo courtesy of Edward Murphy.

Although the regulatory boundary of the Carmel 100-year flood is clearly defined by the County of Monterey (Monterey County Zoning Ordinance, 21.64.130), the true position of that river shoreline is highly imprecise. At the Rio del Robles Gauge, not far from the Carmel Village, the best estimate of the 100-year flood discharge is 17,400 cfs, using standard flood frequency analysis.   However, given the nature of the data set, the estimated 100-year flood lies somewhere between approximately 8,000 cfs and 40,000 cfs. This high degree of uncertainty in assessing the 100-year flood and floodplain arises in part from a short record length (Appendix C) the severe skew of the Robles del Rio discharge data, and the skew of its log transform variate, which is one parameter used in flood statistics.

Extensive urbanization from the narrows to the mouth of the Carmel River lies within the 100-year floodplain, leaving Carmel residents and businesses at risk of significant loss (Fig 25).   For example, levees bound the Carmel channel upstream from Highway one but have not protected the valley bottom from the calculated 100-year flood (Fig. 28).
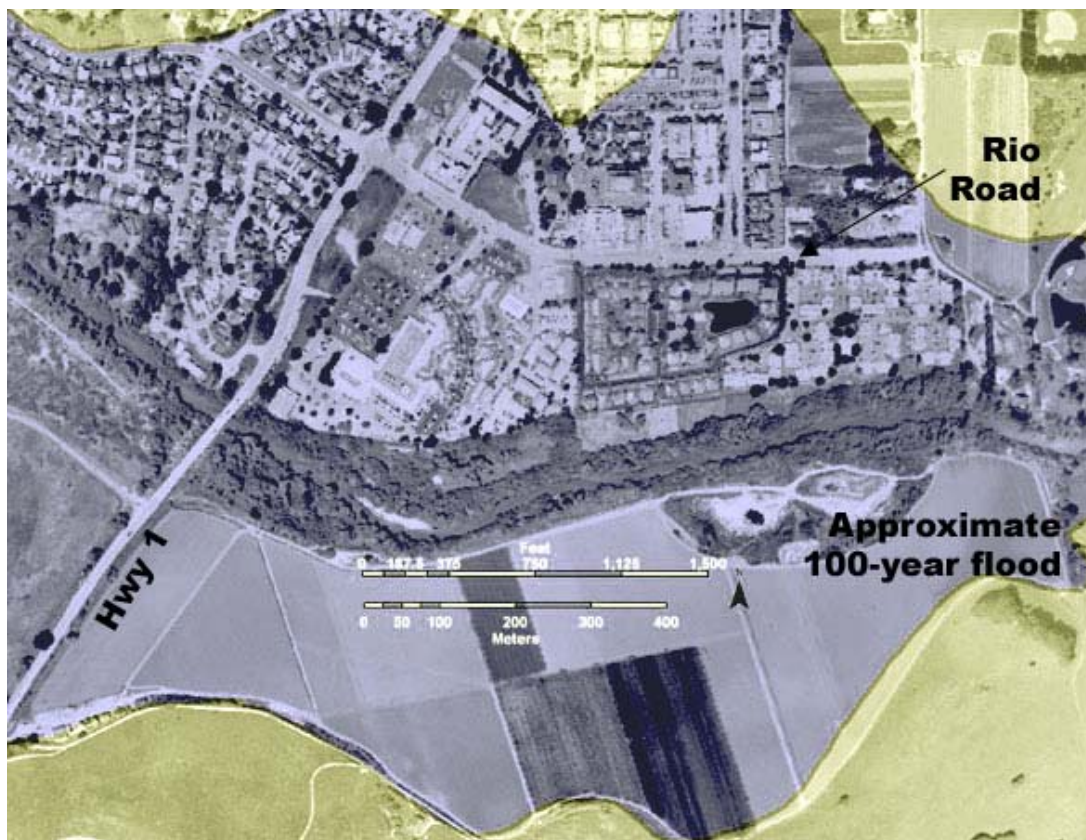
Figure 28: Example of urban development that would be affected by the estimated 100-year flood. Approximate affected area shown in blue (FEMA, 1996). Levees exist along both sides of the Carmel River upstream (right) of Highway One. Background photo from MEI (2002).

The result of the levees is to protect developed land from moderate flows, but also to encourage urban development by fostering a false sense of security about flood hazard on the Carmel River floodplain. The latter result will ultimately lead to very significant economic losses when high magnitude floods occur. Further, the moderate floods that are confined in the levees will be directed downstream instead of laterally onto the floodplain, so flood hazards are increased downstream where residential areas exist on the floodplain. Although we do not assign cause and effect for recent floods, the developments downstream from the Carmel levees have suffered significant flood damage in recent years (Fig. 27). More recently, a levee located opposite the Mission Fields development has been notched to provide flood relief and flood storage on the southern floodplain of the river.

6.4 Groundwater

There are two types of aquifers present in the Carmel watershed. By far the most prolific water resource is the unconfined alluvial aquifer underlying the bed, floodplain, and terraces of the Carmel River (e.g., Logan, 1983; Kapple et al, 1984). The second resource comprises the myriad subtle bedrock aquifers in the complex geology underlying the hills rimming the watershed. Whereas the capacity and hydraulics of the alluvial aquifer underlying the river is well assessed, the upland aquifers that supply the large ranches and a growing number of residences are more complex and less well understood. Of general interest to resource managers and developers is how much development (what extraction rate) those bedrock aquifers can sustain over the long hall, including periods of drought. Also of interest is the impact of upland water use on down-valley water supplies and riparian habitat.

6.4.1 Unconfined Alluvial Aquifers

The Carmel River and its tributaries lie upon bedrock or thin deposits of river sediment in the upland areas of the watershed. At a point about 16 miles from the mouth of the river, the bedrock becomes buried in a layer of river sediment that grows in thickness downstream. This wedge of silt, sand, gravel, cobbles, and boulders derived from local mountain erosion, grows in thickness from about 30 feet near San Clemente Dam to somewhere between 100 feet and 200 feet thick near the mouth of the valley (Kapple, et al., 1984; Stall Gardner and Dunne, 1991; EIP Associates, 1993). The width of the valley fill grows downstream from 300 feet to 4500 feet (Kapple et al., 1984). This prism of sediment that covers the bedrock and supports the Carmel River channel comprises the unconfined Carmel Valley Aquifer. The youngest deposits are the most productive part of the aquifer. The sedimentary deposits underlying the terraces along the valley margins are less productive, but do contribute water to the main unconfined aquifer locally (Oliver, 1991).

The Carmel Valley aquifer is highly permeable, recharging rapidly after extended dry periods. About 85% of recharge is through the bed of the Carmel River, with additional water coming from tributaries, direct precipitation, inflow from subsurface bedrock, and return flow from septic, and irrigation systems (MPWMD/ACOE, 1994). Water is lost primarily through pumping.

Upstream diversion of water and large-scale pumping currently dry up the river in lower Carmel during summer months. Prior to 1985, Cal-Am withdrew about 45% of its water from wells in the Carmel valley and Seaside aquifers. In April of 1985, the district approved limited Cal-Am surface water diversions from San Clemente Reservoir to reduce impacts to instream resources, and required that Cal-Am produce at least 71% of its water from these wells. The current usable storage of the Carmel Valley aquifer is estimated at 28,500 AF (MPWMD/ACOE, 1994).

6.4.2 Upland Bedrock Aquifers

The Carmel River and its tributaries occupy a dendritic network of bedrock canyons cut into the Coast Ranges (Fig. 2). The canyon walls and hills are veneered with a thin soil and colluvium mantle that supports the forest chaparral and pasture. A greater thickness of loose sediment, derived from the continuous canyon cutting and hillslope erosion processes, partially fills the canyon bottoms, including the Carmel Valley, and most of the Tularcitos and Cachagua subwatersheds. The bedrock framework of the watershed underlying the soil and alluvium is also a significant aquifer.

The general bedrock geology includes, from oldest to youngest, metamorphic rocks, granitic rocks and sedimentary rocks. The sedimentary rocks include both sandstone and the Monterey Shale. All of these rock types hold exploitable groundwater resources in either intergranular porosity or fracture porosity. Based upon extensive well drilling and hydrologic testing in the Santa Lucia Range, this column of rocks can be considered one, unconfined aquifer with a single water table (RSC-EIR, 1994).

6.4.3 Recharge areas and flow paths

General recharge areas have been mapped and described in the Carmel Valley (Fig. 29). These are generally regions that have the following characteristics. The soil must be porous and permeable so that water can penetrate downward; the permeable substrate beneath the soil must be thick enough to store a significant volume of water in an unconfined aquifer setting; and there must be water applied to that surface over a significant period of the year so that there is opportunity for a significant volume of surface water to fill the unconfined aquifer. These are the characteristics of riverine or lake (reservoir) environments that exist above young poorly consolidated sediments.

Rosenberg (2001) dismisses the use of the upland aquifers of the Santa Lucia Mountains and Sierra de Salinas for large-scale water needs of Monterey County, citing extremely limited recharge opportunities. Although these upland aquifers are deemed insufficient for sustainable large-scale exploitation, two questions remain regarding their use for smaller residential developments. First how much withdrawal is sustainable, given the competing needs of the upland residences, Cal-Am water withdrawal in the Carmel Valley, and aquatic/riparian ecosystems? Second, what are the recharge areas and how much recharge is occurring? These questions may have different answers in different subwatersheds, given the variability in soils,

rock type, and annual precipitation. Therefore recharge zone preservation strategies may differ regionally as well.
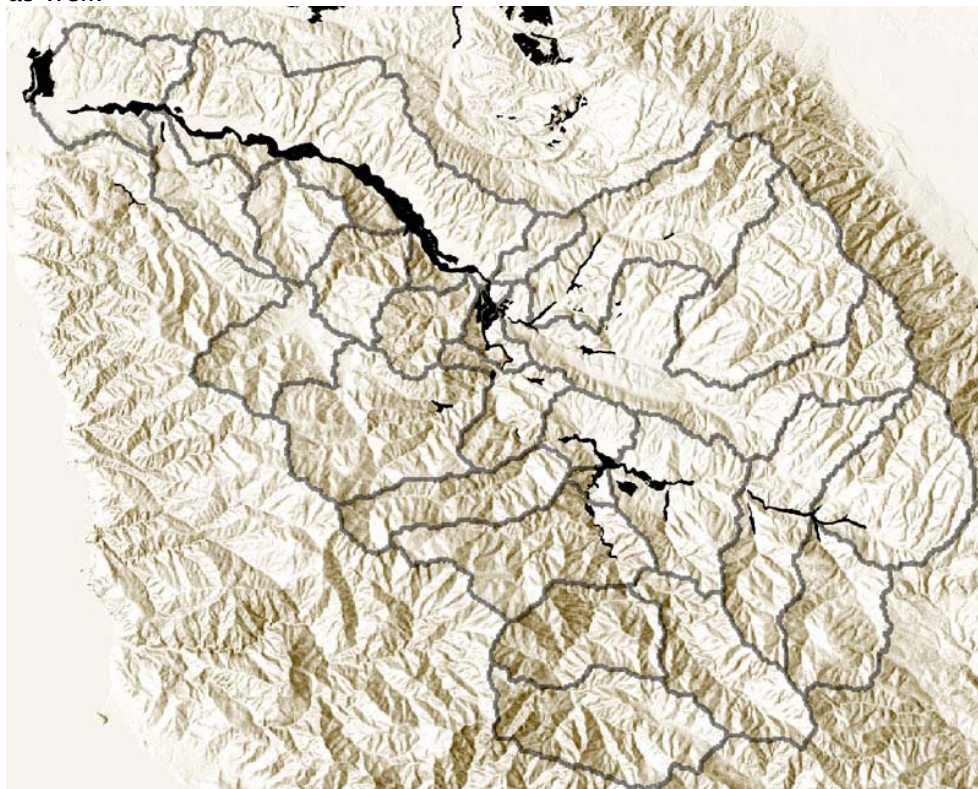
Figure 29: Recharge areas for alluvial aquifers of the Carmel Valley (Rosenberg, 2001).

Using the Santa Lucia Range as an example, approximately 13% of the rainfall received each year infiltrates to the subsurface (Table 4; RSC-EIR, 1994). Over the area of the Santa Lucia Preserve, this infiltration is estimated to provide groundwater recharge of 6800 acre-ft/yr, far in excess of the proposed demands of the Santa Lucia Preserve residential development (RSC-EIR, 1994). However, there are no external boundaries holding the groundwater under the Santa Lucia Preserve, so in pre-development conditions, that 6800 acre-ft/yr either stayed in the ground, raising the local water table, maintained perennial local stream flow along springs and seeps, or was also discharged to the surface far from the ranch along regions of springs and seeps where steeply descending topography intersected the regional water table (RSC-EIR, 1994). So, a less predictable effect of upland water use is the more general impact on the regional flow and discharge of groundwater to off-site resources, both in terms of annual volume and seasonal timing, which are key to sustaining aquatic habitat throughout the watershed. The predicted surface water impacts of groundwater withdrawal from the Santa Lucia Preserve project are low enough to be technically immeasurable (RSC-EIR, 1994), large enough to require mitigation (GMPAP, 1993), and still vehemently contested (VCSC, 2003).

With regard to upland bedrock aquifer recharge, at least one of following three scenarios must exist.

      1. Influent upland rivers and stock ponds contribute substantially to bedrock aquifers,

2. The general broader landscape captures rainfall in sufficient quantity to infiltrate 100's of feet to the regional bedrock water table, or

3. The groundwater resource is, broadly-speaking, fossil water that was charged in a previous, wetter climate, or watershed geometry.

Detailed maps of the water table along the Santa Lucia Range indicate that the water table closely follows topography, rising under ridges, dropping along slopes, and "V"-ing under valleys (RSC-EIR, 1994). This geometry clearly implicates scenario two above, that significant recharge is distributed across the landscape. Anderson (1985) further indicates that recharge of the bedrock aquifer beneath Monterra Ranch occurs across the general landscape, rather than from rivers or ponds, but suggests that there are specific regions that are more important than others. Therefore a reasonable management strategy would be to clearly map the significant bedrock aquifer recharge zones in upland areas of the watershed, and to protect those regions from any development requiring impervious cover, devegetation, soil compaction or other disturbance. Maintaining porous soil conditions and vegetation that retards runoff (slowing the surface water) will facilitate infiltration to the bedrock aquifers.

7 Descriptions and Issues of Specific Subwatersheds and Regions

For this report, the Carmel Watershed is divided into 25 subwatersheds (Fig. 1; Table 3). Subwatersheds are separated by the major hydrologic divides (ridges) within the basin, and named for the principle tributaries or trunk river that drains the region. Each of these subwatersheds, to varying degrees, contributes water, sediment, large wood, organic matter, aquatic habitat, fish migration barriers, heat, energy, and pollution to the Carmel River, lagoon, and National Marine Sanctuary. Below we describe the hydrologic and physical conditions of each subwatershed or groups of similar subwatersheds. For our discussion, we begin with watersheds mainly located southwest of the Carmel River, along the Santa Lucia Range. We then turn to the northeast where grass and chaparral dominated subwatersheds of the upper Cachagua and Tularictos drainages line the Sierra de Salinas Range. Lastly we focus on the main-stem Carmel River and the smaller tributaries in the mid-Carmel and Lower Carmel/Lagoon regions.

7.1 Santa Lucia Range

The southwestern flank of the Carmel Watershed is the well-forested northern terminus of the Santa Lucia Range (Fig. 1; Appendix A-1). It shares a divide with the Arroyo Seco Watershed and several important coastal Creeks of the Big Sur Coastline, including Garrapata Creek, San Jose Creek, and Little Sur River. The upper watershed is mostly undisturbed forest and chaparral with few dirt roads and trails. Sporadic housing developments and cabins are present in the relatively flat areas of the Upper Garzas and San Clemente drainages. The developments in both subwatersheds utilize bedrock aquifers and have the largest water impoundments of the Carmel watershed, outside the two Cal-Am reservoirs. Part of the watershed is in the Los Padres National Forest. Most of the subwatersheds in this region contribute water to the Los Padres and/or San Clemente reservoirs. Significant vineyards and housing developments are present in the Cachagua and Lower Finch subwatersheds. Small communities and ranches are present in Cachagua, and Lower Finch. A new housing development lines the crest of Tularcitos Ridge. There are a considerable number of homes and roads in lower reaches of Hitchcock Canyon and Robinson Canyon.

7.1.1 Geology

The rocks exposed in this part of the watershed are a complex assemblage of pre-Cenozoic granitic and metamorphic rocks, with a minor amount of Cenozoic sedimentary rocks (Appendix A-2; references in Rosenberg, 2001). In much less abundance are young sedimentary deposits (alluvium) present in the canyon bottoms and low-gradient regions. The topography of the region is very rugged with very steep headwater streams near the divide. The ruggedness of the Santa Lucia Range is the result of rapid, ongoing, tectonic uplift of this part of the California coast (Ducea et al., 2003; Anderson and Menking, 1994). As the landscape rises, the rivers flowing across the land gain potential energy and slice downward through bedrock, leaving geologically young, steep, V-shaped canyons (Fig. 30, V-Canyon).
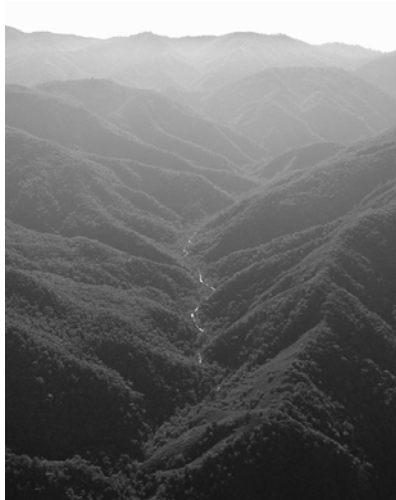
Figure 30: Quaternary (<2 million year) uplift of the Santa Lucia Range is evinced by rugged "V"-shaped valleys with steep side slopes.

Other evidence for the rapid Quaternary rise of this part of the Carmel Valley includes the presence of triangular, ridge-front facets, uplifted river terraces, and a straight mountain front along the mapped trace of the Tularcitos Fault (Fig.31). The Santa Lucia Range has risen at least 1000 m along the Tularcitos Fault (Geomatrix 1985), with considerable evidence of Holocene motion (<10,000 years) (Curry, 1984).
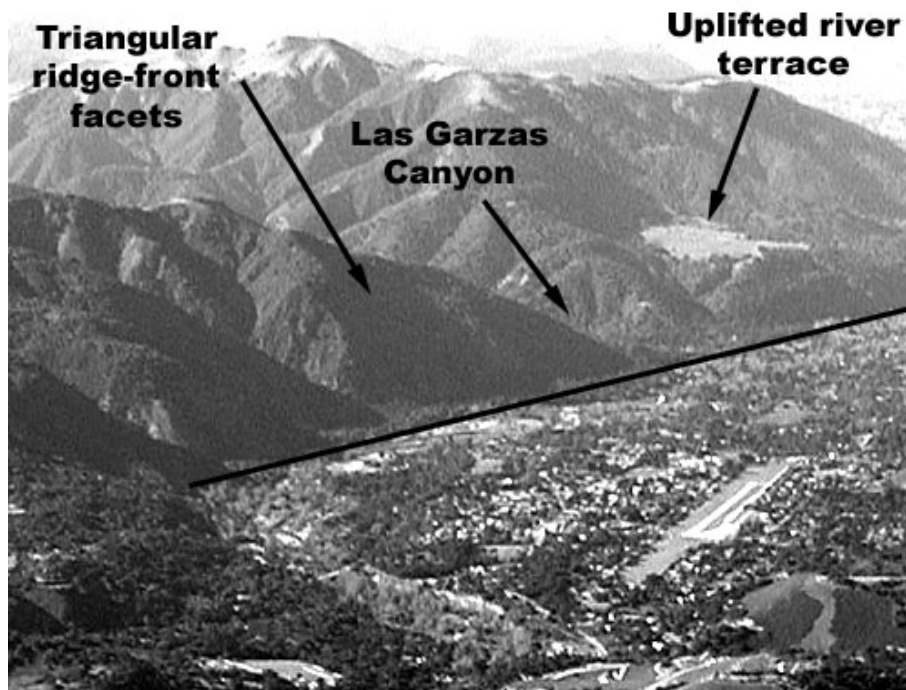
Figure 31: Evidence for recent fault activity and mountain uplift along the Tularcitos Fault (dark line). Oblique aerial photo toward the west.

Of note is that the verdant, wet, Franciscito Flats area owes its existence and low gradient to a series of relatively young faults that have modified the otherwise very steep terminus of the Santa Lucia Range (Appendix A-2). The "San Clemente Thrust" fault has raised a ridge of granite that gradually dammed the valley. The resulting lower gradient reach of Upper Garzas Creek deposited a flat, fertile wedge of water-filled alluvium whose resource value was realized 3000 years ago when the Ohlone Indians called it home (CSP, 2004). The continuation of the same fault zone to the southeast provided a relatively easy topographic path for placing the road that connects Garzas and San Clemente/BlackRock watersheds.

7.1.2 Hydrology

As described above, the Santa Lucia Range watersheds enjoy a relatively high annual precipitation (Fig. 18). The rain is mostly lost to evaporation and used by plants, with the remainder spilling down steep creeks to the Carmel Valley or percolated to bedrock aquifers (Table 3; Fig. 21).

7.1.3 Los Padres Dam, Blue Creek and Bruce Fork Subwatersheds

These watersheds have virtually no development, yet they have a naturally high bedload sediment yield, especially immediately after wildfires. The combination of high annual rainfall, steep slopes, highly weathered and fractured granitic rock (Fig. 10), and powerful streams provides a very high natural sediment yield from these basins, especially high in the Bruce Fork and Blue Creek subwatersheds. The watersheds upstream from the rock-and-earth-fill Los Padres Dam (Fig. 32) generate approximately 42,000 tons of bedload per year (MPWMD/ACOE, 1994), which has reduced the original 3130 acre-feet capacity of Los Padres Reservoir by approximately 50% to 1569 acre-feet (Entrix, 2000).

Figure 32: Los Padres Dam and Reservoir.

Because the steep granitic slopes are so susceptible to erosion, they are unsuitable for urban development and road construction (Fig. 33). The upper portion of the Los Padres reservoir is filling with sediment derived from these unstable slopes (Figs. 34).

Figure 33: Abandoned dirt road located along steep granite slopes in Los Padres Dam Subwatershed is still contributing to slope instability. Note the talus cone at base of slope indicating high rates of sediment generation. See Figure 10 for location. Vertical view of 5779400E; 2032600N.

Figure 34: upper reaches of Los Padres Reservoir are filling with bedload sediment. Vertical view.

7.1.4 Miller Fork and Upper Finch Subwatersheds

Miller Fork and Upper Finch Creek are well-vegetated watersheds with sparse roads (Fig, 35). Los Padres National Forest Service "Stream Habitat and TES Occupancy Reports" for Miller Creek dating between 1957 and 1999 describe abundant steelhead trout in Miller Fork. The Carmel Road climbs up to the Arroyo Seco Watershed divide along the upper reaches of Finch Creek. The creek channel is generally incised, with eroding banks. Excess sediment is presently filling geomorphic pools.

Figure 35: Overview of well-forested Upper Finch Subwatershed. View toward the South.

7.1.5 Lower Los Padres, Cachagua and Lower Cachagua subwatersheds

Tularcitos Ridge is the northeastern boundary of the Cachagua drainage. The ridge has a high density of roads, some of which may be sediment sources. The top of the ridge has a new housing development as well. There are vineyards and other kinds of agriculture present in this region. Minor landsliding is present along Tassajara Road.

Lower Cachagua Creek Subwatershed has a locally braided channel system just downstream from the mouth of Lower Los Padres subwatershed (Figs. 1 and 11). Braiding is evidence for a very high sediment load. Lower Los Padres Subwatershed is not a likely source of bedload material since it lies directly below the Dam, and reconnaissance of the creek bed in Lower Los Padres Dam Subwatershed indicated moderate turbidity in the water, but no excess bedload. Two potential sources of excess sediment exist. First, perhaps this sediment is left from partial sediment purge of Los padres Reservoir that occurred after the Marble Cone Fire (Clive Sanders, personal communication, 2004). Second, there is a severely eroding reach of Conejo Creek located farther up stream (see Fig. 50a).   It is this eroding reach of Conejo Creek that is may also be the source of sand that has turned Cachagua Creek from a gravel bed stream to a sand-bed stream, with less habitat diversity.

7.1.6 Pine Creek, Black Rock/San Clemente, San Clemente Dam and Lower San Clemente Dam Subwatersheds

These subwatersheds are among of the highest water producers in the basin (Table 3) because they catch the high rainfall associated with the tall Santa Lucia divide. The rain falls on densely vegetated soils, so it is directed into groundwater rather than immediate runoff. There is high landslide susceptibility in the steep granitic slopes of the San Clemente Dam and Lower San Clemente Dam Subwatersheds. A variety of sediment sources, including wildfire have reduced the capacity of the San Clemente reservoir from 1400 acre-feet to 147 acre-feet in 1998 (Entrix, 2000). All roads constructed across the steep canyon walls in this region are significant sediment sources.

San Clemente Dam Subwatershed has the largest active landslide in the Carmel Watershed. It is a chronic sediment source that is helping to fill San Clemente Reservoir (Fig. 6). Higher in the San Clemente Watershed is a private airstrip and house (Fig. 36). The construction of the airstrip in 1972, led to a massive debris flow that temporarily dammed the Carmel River upstream from the San Clemente Dam, and contributed to the infilling of the reservoir (Fig. 4; Matthews, 1989). Aerial reconnaissance of the region indicates that the affected creeks are still eroding material from tall unstable banks.
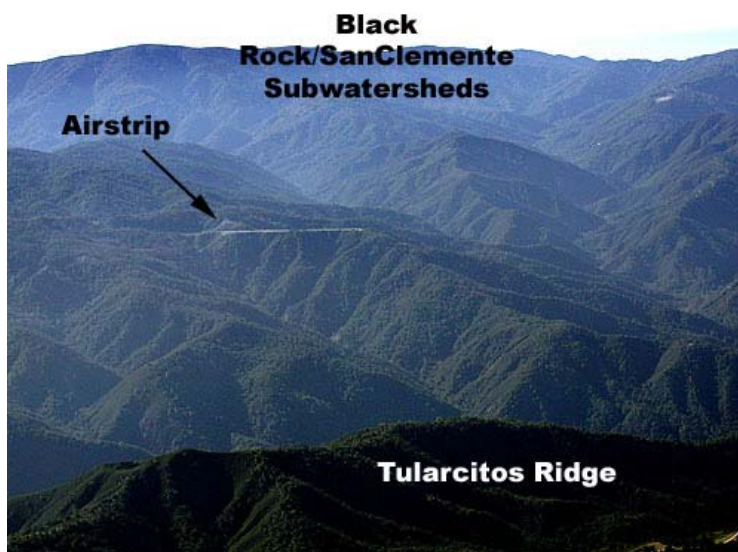
Figure 36: Private airstrip on divide above San Clemente Dam Subwatershed. View to southwest shows well-vegetated Santa Lucia Range.

Rosenberg (1998) mapped and analyzed a large landslide located downstream from San Clemente Dam near the trout-rearing facility in Sleepy Hollow. The 4900 cubic-yard slide was the result of El Nino storms destabilizing a poorly placed and constructed powerline road. The substrate is weathered metamorphic rocks crushed and weakened by the adjacent Cachagua fault. (Rosenberg, 1998).

Rogers Johnson and Associates (1986) mapped large old rotational and translational slides, old debris flow/slides, and recent debris flow/slides of less than 100 years old. Slides are prevalent in steep regions underlain by the quartzofeldspathic metamorphic rocks, porphorytic Granodiorite of Monterey, and Granodiorite of Cacahaqua (Appendix A-2). Our GIS analysis indicates that the Granodiorite of Monterey has more mapped landslides than any other formation except for the Monterey Shale (Fig. 7). Most of the mapped slides are associated with undercutting along the outer bends of the Carmel River and its tributaries (Rogers Johnson and Associates, 1986).

There is one significant housing development in Black Rock/San Clemente Subwatershed. There are also a disproportionate number of poorly maintained dirt roads along the ridges leading to the upper watershed (Fig. 37). These roads very likely produce a great volume of sediment to the creek bed during severe rain events. Several poorly maintained recreational or fire roads should be decommissioned in this watershed. The lake at the development traps bedload derived from the upper watershed, but is too small to significantly reduce suspended fines, except during low flow seasons.

Figure 37: Examples of poorly-maintained dirt roads on steep slopes down valley from the small lake on San Clemente Creek.   5750400E; 2047600N.

7.1.7 Upper Garzas and Lower Garzas Subwatersheds

Garzas Creek is split into an upper and lower subwatershed, divided at the outlet of Moore's Lake (Fig. 38), which occupies low ground in San Franciscito Flats. Garzas Creek has headwaters high on in the Santa Lucia Range where there is high annual precipitation, and the entire watershed is densely forested with lesser patches of grassland. The combination of high precipitation and good hydrologic condition makes the watershed among the finest in terms of yield and annual contribution to the Carmel Valley (Table 3). Land use in the Upper Garzas

watershed is low-density housing, golf courses, infrastructure for water production and waste-water treatment for the Santa Lucia Preserve housing development.

Figure. 38: View of well-vegetated Upper Las Garzas Subwatershed across Moore's Lake.

Sediment sources in Upper Garzas watershed include local clearing and grading for home construction and road construction/maintenance. The upper watershed has a diffuse network of dirt roads that likely represent diffuse sediment sources during the rainy season. All excess bedload sediment derived from Upper Garzas is trapped in Moore's Lake before the water flow exits the lake into the headwaters of Lower Garzas Creek. It is likely that a significant amount of suspended load also settles in the Lake as well. The water exiting Moore's Lake was somewhat turbid (no measurement taken) and greenish when observations were made in June of 2003 and April of 2004, suggesting that the water has suspended algae, typical of a shallow pond environment with high nutrient content.

Lower Garzas Creek is virtually pristine except for some homes low in the watershed. A small dam that was formerly used to impound water was recently notched (Fig. 39) to facilitate adult trout passage to spawning ground upstream, and young trout migration downstream in lower flow conditions.

Figure 39: Private low dam on Lower Las Garzas Creek is now notched for fish passage.

7.1.8 Robinson, Hitchcock, and Potrero Subwatersheds

These watersheds are relatively more urbanized than the previously described Santa Lucia subwatersheds. Robinson Canyon has a considerable wealth of intact forest (Fig 40) and picturesque sandstone outcrops. The canyon also has too much sand eroding from road cuts, stream banks, gullies, and soil slips (Figs. 12, 13a, 13b, and 14). Near those erosion sites, road workers had graded excess sediment from the road surface or ditches onto the shoulder of the road where the next rains would wash the spoils directly into the creek bed (Fig 41). There is also an un-maintained road cut erosion repair that is producing fine sediment (Fig. 42). Jute net technology is an effective erosion control if the substrate is well-prepared, the net is well-staked, and the site is properly maintained while vegetation has a chance to grow through the netting. Nascent gullies are locally exposed where the jute net has become unstaked (Fig. 42). The net is "hanging" above the ground in much of the installation, leaving young plants unable to reach the net, and allowing erosive water flows beneath the net (Fig. 42).

Figure 40: Densely vegetated landscape in upper Robinson Canyon. View to the west from Robinson Canyon Road.
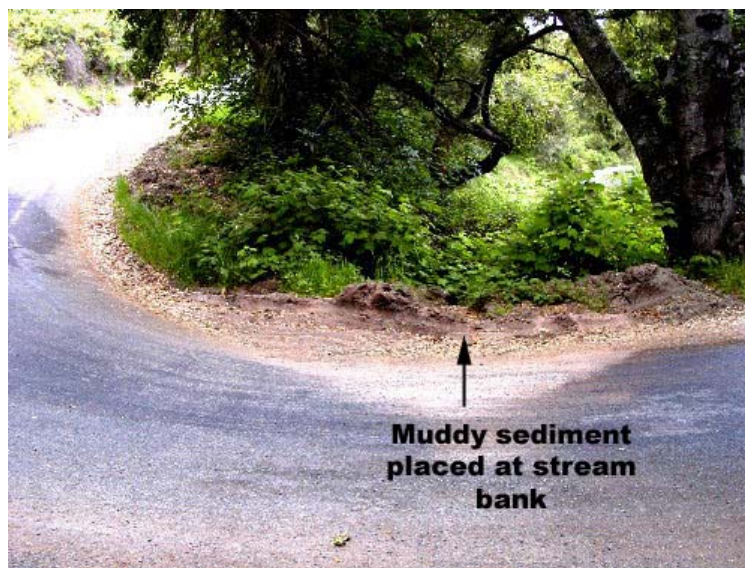
Figure 41: Sand and mud moved to roadside near edge of tributary channel.

Figure 42: Planted jute net erosion control on steep road cut in Robinson Canyon.

All the erosion sites illustrated in Robinson Canyon have their roots in standard road placement, road construction, and road maintenance practices. Each incidence of erosion here seems small, yet the net result is excess fine sediment that fills cobble pools, decreasing the ability of trout to fully utilize this otherwise spectacular watershed.

Hitchcock Creek has excess sand and granule-size, granitic sediment entering the channel from roads and grading on the west side of the watershed. As discussed in the earlier section on erosion (Table 2), Hitchcock Creek has been a chronic source of sediment for at least the last 20 years (Matthew's, 1983). There is a small amount of farming or large gardens on the slopes above Hitchcock Creek that might contribute sediment as well. The creek bed has a step-pool morphology that is now modified by sand in the geomorphic pools. Steep narrow creeks like Hitchcock are robust; they have the energy to flush sediment out and rapidly return to pristine conditions once the chronic sediment sources are removed. The chronic presence of excess sediment suggests that illegal grading activities are common in that watershed (CVMP, 1996; Appendix C). The downstream edge of County bridge #519 is a formidable trout migration barrier because of a high jump, and no landing pool. County bridge #518 directs flow at the toe of a small landslide, ensuring a constant supply of sediment to the creek. Residents living

downstream from County bridge #516 had piled loose sediment at the waters edge. This considerable volume of sediment likely entered the stream following the next rain and flow events. The mouth of Hitchcock Creek has old automotive tires for bank protection and grade control. An abundance of filamental algae throughout the creek indicated the presence of excess nutrients, a common indicator of leaking domestic septic systems.

Potrero Creek has an incised channel, excess fine sediment, and complex migration barriers. Potrero Creek is chiefly underlain by Monterey Shale, which hosts the greatest number of mapped landslides in the region (Fig. 7). The lower watershed has a very high density of mapped landslides (Appendix A-2) and is recognized for its modern landslide susceptibility (Fig. 5). Clearly, care must be taken in further development of this canyon. Low in the subwatershed the creek passes residential and golf course land use. The culverts installed to pass the Potrero flows under the streets are now problematic for trout migration. Closer inspection of all the potential impediments to fish passage in this creek is warranted. The culverts beneath Valley Knoll Road and the culvert located by the Tennis Courts upstream from there are problematic. For example, the culvert at the tennis courts is set too high above the bed of the creek because of post-construction bed degradation, and there is no landing pool once a fish makes the jump to the undercut concrete platform supporting the culvert. (Fig. 43).

Figure 43: Undercut concrete culvert foundation is an impediment to trout migration. The jump lacks a "landing pool." View upstream.

7.2   Sierra de Salinas: Upper Cachagua, Tularictos and Klondike Drainages

The upper reaches of the Cachagua drainage and the sub-basins of the Tularcitos drainage are cut into the Sierra de Salinas, forming the northwestern flank of Carmel Watershed. The landscape, climate, ecosystems and land-use differ markedly from the Santa Lucia range described above.   The land tends to be more arid, with significantly lower annual rainfall. Hastings Natural History Preserve at the mouth of Bear Canyon subwatershed reports a rainfall average of 21.3 inches/yr (HNHP, 2004).   The landscape is also more accessible than along the Santa Lucia Range.   The land has traditionally been used for cattle ranching, with the impacts of overuse locally apparent.   The region has sparse ranches set in a broad, annual grassland, oak forest, and chaparral ecosystem (Fig. 44 rana fork; Appendix A-4).

Figure 44: Rana Creek is drainage on the left. Oblique aerial photo toward the northeast.

7.2.1 Geology

The slopes of the Sierra de Salinas are underlain by a relatively weak metamorphic rock termed the "Schist of Salinas" (Appendix A-2).   Also present in fault slivers adjacent to the Schist are granitic rocks and Tertiary sedimentary rocks including Monterey Shale and sandstone.   The presence of both the highly weathered schist and Tertiary sedimentary rocks creates a geologic framework that is highly prone to erosion and soil slips, especially where there is a combination of steep slopes, dirt roads, and heavy cattle use.

7.2.2 Bear Canyon Subwatershed

Bear Canyon Subwatershed has a low density of dirt roads supporting minor cattle ranching, chiefly in headwaters of Madrona Canyon. There is recent severe gullying associated with recent burns along the upper watershed slopes (5827950E; 2030890N). Local road related chute erosion is locally present (5025090E; 2028100N). Local cattle over-utilization of grassland pasture is apparent (5812600E; 2031683N). There is minor gullying of pasture located on ranch land adjacent to Hastings Natural History Preserve (5809260E; 2034200N).

Robertson Creek, not far above its confluence with Finch Creek, is typical of incised creeks in the Carmel Watershed; it has locally tall banks (> 2 m) exposing loose valley-bottom deposits to erosion. The road along Robertson Creek provides examples of typical dirt road architecture in the Carmel Watershed, and the associated impacts. The road has well-maintained drainage ditches that collect runoff and sediment from the road surface and adjacent slopes (Fig. 45). These ditches concentrate flow, and carry a high sand load to the Robertson Creek through sub-road drainage culverts (Fig. 46).

Figure 45: Road ditch on dirt road near Robertson Creek.

Figure 46: Sand carried from roadside ditches (e.g., fig. 45) to a culvert leading to Robertson Creek.

Nearly every culvert visited during this study of the Carmel Watershed is typified by Figures 47 and 48, showing the inlet and outlet of the same corrugated drainage culvert beneath the dirt road by Robertson Creek. These universally-used corrugated culverts concentrate high flows from above into a narrow, high-velocity flow that literally hoses the downstream part of the creek bed, akin to a hydraulic mining operation. Nearly every creek bed located downstream from such a culvert is deeply incised with tall, raw erodible banks. It would be difficult to estimate the enormous volume of excess sediment that has been liberated into the Carmel River and National Marine Sanctuary because of the erosion caused by undersized, poorly installed, culverts.
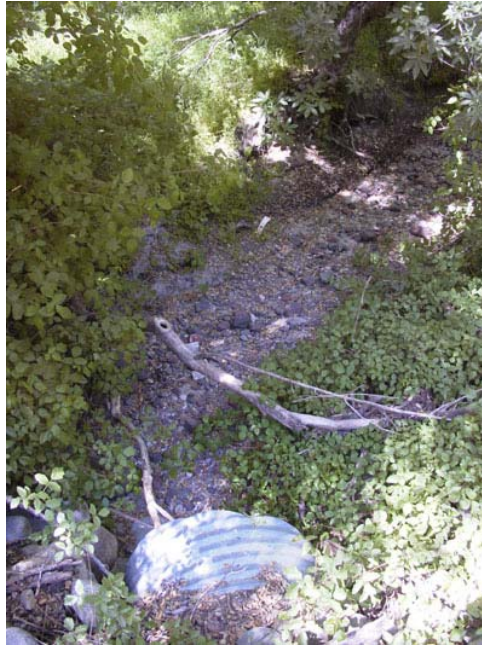
Figure 47: Creek bed is at grade with inlet to typical corrugated culvert.

Figure 48: Creek bed is deeply incised at exit of culvert shown in Figure 47. The creek here had 3 m tall eroding banks because of the hydraulic erosion from water leaving the culvert.

7.2.3 Northern half of Lower Finch

The northern half of Lower Finch Subwatershed lies in the easily eroded slopes of the Sierra de Salinas underlain by Tertiary sedimentary rocks. Cattle overuse is locally present in the grassy valleys. Deeply-incised creeks are present where they exit the culverts under Carmel Valley Road (Fig. 49). The watershed is used for cattle grazing with local evidence of over-utilization, including erosion around feeding/ watering stations (5809620E; 2036300N) and hillside gullies. Down valley from the confluence of Corral Viejo Creek and Conejo Creek (Appendix A1) there is

a reach of deeply incised channel (Figs. 50A and 50 B). The channel downcut and widened, mobilizing a considerable volume of sediment eroded from older valley-bottom sediment. When creeks cut downward they also provide space for local groundwater to exit, thereby reducing the water storage capacity of the valley bottom aquifer and leaving the valley bottom much drier. Both upstream and downstream from the tall raw banks, willows have established a robust barrier between channel flow and the unstable banks. This natural regeneration of riparian/floodplain vegetation can be considered a model for stabilizing the rest of this river reach and the associated side gullies. Riparian plants reduce erosion by slowing floodwater and by adding erosion resistance with root systems that bind soil particles. The cause of this downcutting event is unclear, but it is common for deep erosion to migrate up-valley after it is initiated, so the cause may be located lower in the watershed. Erosion is presently fostered by the culvert beneath Carmel Valley Road (Fig. 50B).

Figure 49: Gully eroded in meadow downstream from culvert under Carmel Valley Road.

Figure 50A: Deeply incised channel near Carmel Valley Road in Conejo Creek of the Lower Finch Subwatershed. Vegetation has begun to recover along base of steep banks. Pickup truck for scale. Stream flow is top to bottom
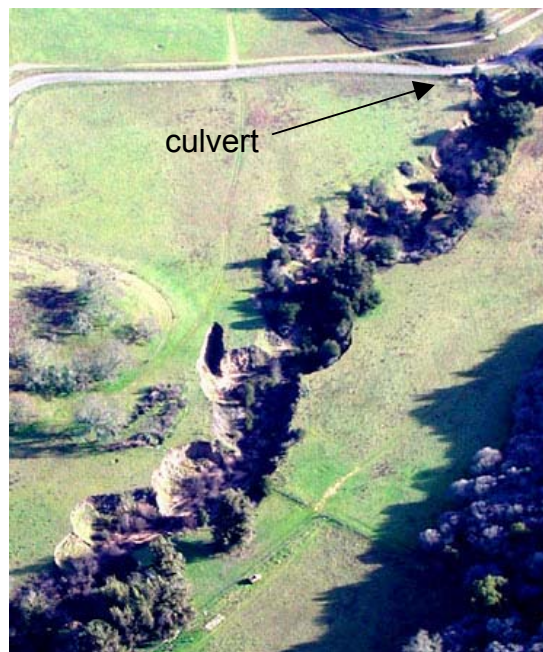

Figure 50B: Broader view of region near Figure 50A. Note culvert beneath Carmel Valley Road. Further reconnaissance indicates that the culvert made this incision worse.

7.2.4 Tularcitos and Rana Creek Subwatersheds

Rana Creek and the upper reaches of the Tularcitos drainage have a low density of dirt roads, and evidence of minor grazing (or a heritage of grazing) along the divide of the Sierra de Salinas. With only minor exceptions, these watersheds are in exemplary condition, with respect to others along these slopes. In particular the land still maintains a robust diverse vegetative cover, with little evidence of modern human impacts and excess sediment generation. The steeper slopes along the valley walls are well stabilized with natural chaparral and oak woodland, the ridges are grassland, and the valley bottoms are intact oak woodland (Fig. 44). Despite the more arid conditions on this side of the valley, riparian vegetation is present along most of the valley bottoms. Stream bank erosion, while present, is far less than in adjacent lands. The few roads and abandoned roads cut into these watersheds are sources of excess sediment.

There is a broad northeastward bow to the trace of Tularcitos Creek as it passes by Sycamore Gulch and Rana Creek Subwatersheds (Appendix A-1). The low ridgeline that forces that bend is an ancient landslide deposit. The Tularcitos slide is one of the largest landslides in California, and likely owes its genesis to local high-magnitude Earthquakes along the Tularcitos fault zone (personal communication, Robert Curry, 2004).

7.2.5 Sycamore Gulch

Sycamore Gulch is a small tributary to the lower Tularcitos drainage (Appendix A-1). For its small size, the Sycamore Gulch region of the Tularcitos watershed has a great density of sediment sources including landslides (Fig. 51), soil slips, gullies, and poorly maintained roads. The presence of "terrecettes," the parallel paths that contour around hills in cattle country, indicates that modern or historic over grazing is a contributing element to the soil instability in the watershed (Figs. 51 and 52; Trimble and Mendel, 1995). This degraded landscape resulted from heavy utilization of steep land underlain by landslide prone sedimentary rocks, including the Monterey Shale (Fig. 7).

Figure 51: Landslide in Tertiary sedimentary rocks of Sycamore Gulch drainage. Landslide run out is greater than 600 feet long.   5782215E; 2063480N
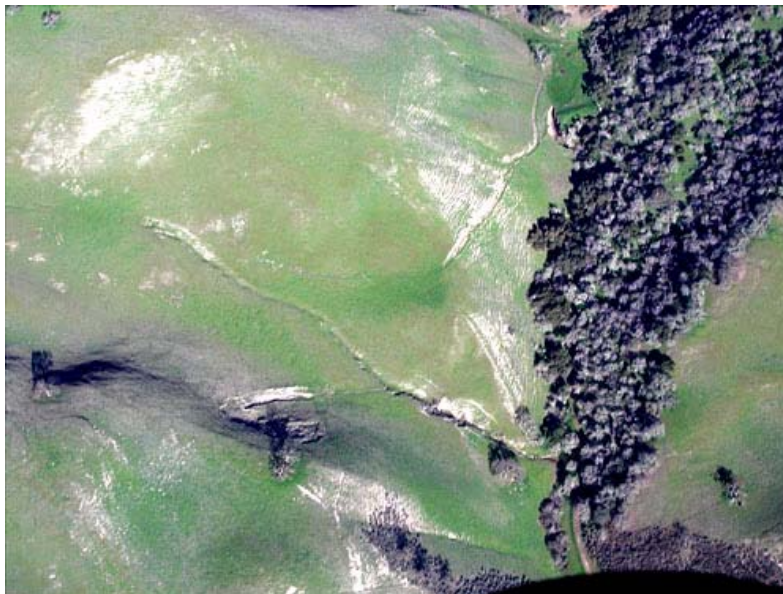
Figure 52: Terrecettes in Sycamore Gulch drainage.

7.2.6 Chupines Creek Subwatershed

The Chupines Creek Subwatershed is chiefly annual grassland with swaths of oak woodland and chaparral in the drainages. The rolling hills and easy access of this land has no doubt made it a favorite for cattle ranchers since Europeans first arrived. It is still extensively used for cattle, and bears signs of modern over utilization (fig. 17).   The most obvious indication of

overgrazing is the pervasive cattle terrecettes throughout the extensive grasslands of the watershed (Fig 53).

Figure 53: Terrecettes across steep slopes in Chupines Subwatershed.

Other sources of excess sediment include abundant unstable road cuts, soil slips, and gullies (Fig 54). It is clear that some of the numerous dirt roads in this region were graded across slopes greater than 30% grade (Figs. 54 and 55; 5791500E 2079700N), perhaps prior to, but in conflict with, policies of the Carmel Valley Master Plan (Appendix C).

Figure 54: Landslides, gullies and unstable road cuts are abundant sediment sources in Chupines Subwatershed. Note grazing terrecettes on steep slopes.

Figure 55: Steep road crosses steep slope.

There is also evidence of rapid stream bank erosion in creeks with little or no riparian vegetation (Fig. 56). An impaired riparian zone can be the result of cattle access to the creek banks and bed. This impaired reach of Chupines Creek represents an opportunity to demonstrate the effects of cattle exclusion and riparian plantings on sediment yield.

Figure 56: Chupines Creek with impaired riparian corridor.   81750E; 2072150N.

Along the ridge dividing Chupines from Toro Creek there is a stock pond in danger of breaching by gullies (Fig. 56). This pond, and a similar (but unimpaired) pond located high in Klondike Canyon, should be assessed for seismic safety, considering the risk to downstream residents.

Figure 56: Cattle stock pond in Chupines Subwatershed with gullies near earthen dam. Dots in mid-ground are cattle.   5791200E; 2081300N.

7.2.7 Klondike Canyon

Klondike Canyon lies at the intersection of ranch lands and regions with denser housing typical of the lower Carmel Valley. Like the Chupines Subwatershed, it has steep slopes underlain by weak substrate. The regions that are exposed to heavy grazing bear a disproportionate abundance of soil erosion and soil slip features.

7.3 Mid-Carmel and Lower Carmel/Lagoon

The uplands and valley bottom of the lower Carmel Valley are more urbanized than the up-valley regions previously described.   There is a higher proportion of impervious cover, storm sewer usage, and floodplain encroachment (e.g., Fig. 27). There are relatively fewer modern soil erosion and landslide problems, although there are many mapped, and the potential still exists (Appendix A-2; Fig. 7).

7.3.1 Geology

The walls of the lower reaches of Carmel Valley are mainly Tertiary sedimentary deposits, including the Monterey Shale, and their associated landslide deposits (Appendix A-2).   The small tributary valleys on the northern side of Carmel Valley, like Coyote Gulch and Berwick Canyon are locally filled with alluvium and colluvium, likely sourced from hill slopes in a wetter climate. Hydrologic changes, perhaps associated to climate change or watershed land-use changes, have locally produced large gullies in the valley fill (Fig. 58).   Artifacts including bleach bottles and fence posts (Fig. 59) excavated from the valley fill, suggests that the cycle of

valley filling and gullying is all post–European in age. Parts of the gully system that have aged without further disturbance have become naturally stabilized through natural revegetation; such gully segments can be considered to be goals for proactive gully restoration (Fig. 60).

Figure 58: Side of deep gully along northeastern flank of Mid–Carmel Subwatershed.

Figure 59: Erect fencepost exhumed by gullying in the valley bottom. Site located downvalley from Figure 58.

Figure 60: Gully naturally revegetated with native species including Buckeye, willows, and coyote bush provides model for proactive gully restoration in this subwatershed.

7.3.2 Mid-Carmel and Lower Carmel Subwatersheds

The upper watershed from Klondike Canyon to Laureles Grade Road has a high density of old dirt roads that may be sediment sources today, especially where they cross small tributary creeks or have culverts. On Miramonte Road there is a road cut through highly erodible young alluvium that is a chronic sediment source in winter rains (Fig. 61). The sediment runs down to a small creek, and then to the Carmel River. The culvert that carries that sediment under Miramonte Road is typically undersized, and has greatly incised the creek bed downstream from the culvert. There are new roads being constructed that will add impervious cover to the watershed. These new roads, in the Coyote Gulch region, for example, appear to be well constructed, and are not currently a significant source of sediment.

Berwick Canyon (Appendix A-1) and associated ridges to the west are covered with residential development and paved roads. The substrate for the houses is Monterey Shale, which is typical of this region. There is a propensity for Monterey Shale to produce landslides (Fig. 7). Since

large landslides have not occurred here recently, it is plausible that these hills only fail during Tularcitos earthquakes, or extremely wet winters.

The urban development near Berwick Canyon produces extremely little sediment runoff. The canyon has a small earthen dam that slows runoff, allowing sediment to settle and giving water time to infiltrate to groundwater. Below the dam, runoff is controlled in a concrete ditch.

Rivers are said to be in equilibrium if they are transporting the sediment supplied to them, without long term channel down cutting or filling. The Carmel River has been steadily eroding down into its bed since 1921 when its bedload was cut off behind San Clemente Dam (Hampson 1997). This down-cutting has led to a gradual lowering of the water table and drier conditions on the upper banks. When Cal-Am reduced the water table yet further, the impaired riparian vegetation could not hold up the banks against the high flows of the early 1980's, and massive bank erosion and land loss ensued (Kondolf and Curry, 1984). Since that time it has been agreed that the riparian corridor has great social and environmental value (CVMP, 1996).

Figure 61: Badlands topography resulting from road cut in erodible substrate. 5750600E; 2080430N.

Also agreed upon are the general negative impacts associated with general modifications to the near-channel region (CVMP, 1996). Other restrictions to floodway modification include alteration of the living riparian vegetation by removal, thinning, or other means, construction or alteration of levees, or the placement of fill material in the floodway or riparian corridor, and any alteration of the natural course of the river or its banks, except as a part of a flood control project planned or approved by the Monterey County Water Resources Agency (Monterey County Zoning Ordinance, 21.64.130). Despite those cautions, there is considerable channel bank modification along this stretch of the river (Fig. 62). Over 35,000 feet of hardening exist on right bank in the lower 16 miles of river. Just under 30,000 feet exist on left bank (Fig. 62).
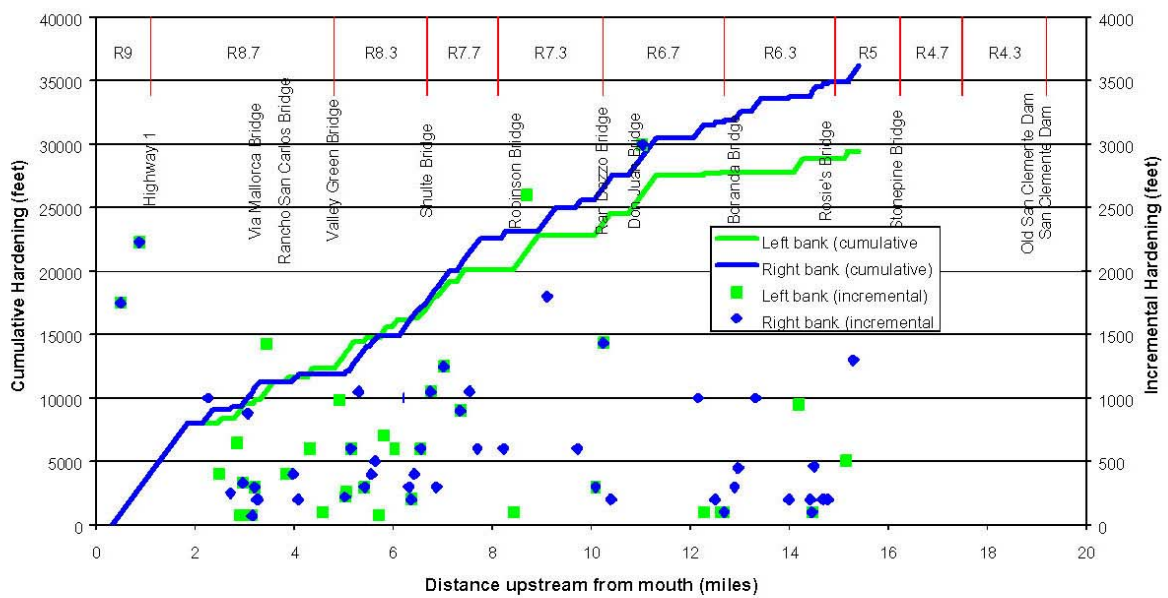
Figure 62: Graph of feet of bank hardening as a function of miles from mouth of the Carmel River (MEI, 2002).

7.3.3 Carmel Lagoon

In keeping with the present high sea level and drowned river valleys of the California Coastline, the mouth of the Carmel River is a coastal lagoon (Fig. 63).

Figure 63: Carmel Lagoon with opening to the sea.

The lagoon is separated from the Pacific Ocean by a tall beach berm during most of the year. Under natural conditions, the berm is breached when winter stream flow is high enough to top the sand and carve a path to the sea. This cycle of berm breaching and closing is critical to the life cycle of steelhead trout that enter the lagoon from the sea in order to spawn, and also occupy the lagoon as young fish that are adjusting to salt water before taking to the sea. The temperature, chemistry, and physical structure of the lagoon system are therefore critical for a sustainable steelhead trout run (see references in Casagrande and Watson, 2003). In recent years the breaching has been done mechanically (Fig. 64) to lower the chance of flooding the neighborhoods built on the floodplain (e.g., Fig. 27).

Figure 64: Connection between lagoon and sea cut by bulldozer to reduce flood risk during winter rains. Photo by Fred Watson

The following problems and solutions have been recognized in the lagoon (Personal communication, Joel Casagrande, 2004; Casagrande and Watson, 2003; Oliver, 1989; Williams and Josselyn, 1987).

Water supply--Diversion of water for private or municipal supply from the Carmel River and its underlying groundwater basin potentially reduces fresh water inflow to the lagoon, diminishing habitat for juvenile steelhead. The habitat reductions include, water area, available cover, and productivity of remaining habitat. Upstream diversion changes the timing and magnitude of natural floods, which may affect steelhead health as well. Without perennial water entering the lagoon, the water becomes very saline and low in dissolved oxygen as the summer progresses (e.g., HES, 2002). The solution could lie in appropriating more water for the lagoon following the reduction in groundwater withdrawals from the Carmel Valley aquifer (CSWQCB, 1995a). A low volume of fresh water could be produced

from the local wastewater treatment plant, assuming that the nutrient level is low enough to prevent algal blooms.

Artificial Breaching-- Artificial breaching of the sandbar (Fig. 63) reduces the frequency of flooding the lagoon wetlands, potentially leading to a shift from freshwater to saline water invertebrate species in some areas of the lagoon. Breaching lowers the water level artificially fast, potentially leaving steelhead stranded. Leaving the breach open too long after the rainy season ends results in salty conditions during the summer and early fall, but closing the breach might result in flooding. Solutions to this problem include monitoring and modeling to determine the optimum conditions for breach opening and closing to optimize conditions for residents and fish. Especially critical is determining the combination of river discharge and ocean tide at which to close the breach to avoid flooding and poor water quality.

Excess sedimentation—Excess sediment is filling the lagoon with fine material derived from the Carmel Watershed (Fig. 63). The entrance to the southern arm of the lagoon is filling with sediment (Fig. 63). That area used to be a deep pool habitat for trout. Maintaining deep pools in the southern arm may provide some relief, however, it is unclear whether the water will provide much more habitat considering the typical saline–fresh water stratification that occurs there and the likely refilling as time goes on.

Habitat Diversity and Cover—As the lagoon, including the southern arm, fills in with sediment, there remain fewer deep–water pools and other hiding places for juvenile fish to escape predation. The fish have recently been observed using a concrete pipe for cover, suggesting a paucity of natural cover. Improved habitat can be achieved through the use of anchored logs or other natural materials.

8   General Strategies for Watershed Management

Human-induced erosion has been an integral side effect of the rise of modern human culture (e.g., Hooke, 2000).   This is the situation as well in the Carmel Valley, where erosion has followed water resource depletion, infrastructure development, and ranching practices that date back to early European settlement.   Sediment load above natural background levels is now considered to be the leading non-point source water pollutant in North America today; it is becoming clear, on a global scale, that past and current landscape mismanagement is unsustainable (e.g., Hooke, 2000). Hydro Data, Inc. (1981) suggested that,

> *"The limited resources of the Carmel Valley are being exploited to their limit.   The principal resources of this valley are its beauty and climate, and they are responsible for its rampant growth in population and accompanying widespread regional development.   An increase in population requires utilization of land, water, power, fish, and wildlife, and a multitude of other natural resources that are closely interrelated."*

The reduction in water quantity and watershed quality noted in this report resulted from the cumulative effects of innumerable small anthropogenic impacts that have occurred through many decades or longer.   Restoration will likely advance in the same way; innumerable small positive impacts that eventually build to a significant change in water quality, quantity and aquatic life.

8.1   Water Quantity

It is a pitfall to base watershed management policy strictly upon short-term historic hydrologic averages without also considering the uncertainty of such averages and the likely severity of drought conditions. For example, hydrologists overestimated the average flow of the Colorado River in 1922, but locked the estimate into a multi-state agreement called the Colorado River Compact. The compact, along with a subsequent treaty with Mexico, requires Lake Powell to release 8.23 million acre-feet of water each year through the Glen Canyon Dam. Lake Powell is drying up.   All across the West, during the recent decades of enormous urban expansion, decisions about water rights have apparently been based upon several decades of above average rainfall.

> *"Continuing research into drought cycles over the last 800 years bears this out, strongly suggesting that the relatively wet weather across much of the West during the 20th century was a fluke. In other words, scientists who study tree rings and ocean temperatures say, the development of the modern urbanized West — one of the biggest growth spurts in the nation's history — may have been based on a colossal miscalculation." NY-Times, May 2, 2004*

In a sustainable watershed, the net water resource is apportioned so that stakeholders, including the broader ecosystem, have their needs met, without exceeding the net usable precipitation.   If the water budget is balanced in the Carmel Watershed, there remains, after

human needs are met, enough water to support a robust riparian corridor and anadromous fish populations. Considering the decadal-scale variability in the local annual precipitation (Fig. 19), a conservative estimate of usable water is warranted. As mentioned previously, the Carmel region is "overdue" for severe droughts that can last as long as 25 years (Fritts and Gordon, 1980). While it is not the place of this report to completely resolve the conflict, we emphasize that there is an apparent disconnect between the degree of development in the watershed and the risk of severe drought. These data beg a conservative bias when allocating water resources here.

As indicated by the need to irrigate the riparian corridor of the lower Carmel River, the water budget is terribly out of balance today. The top priority for watershed management must be the severe reduction of pumping water from the Carmel Valley aquifer. Water exports that are required to serve the greater Monterey Peninsula cannot be sustained during low flow conditions (CSWRB, 1995a, 1995b). Until that practice is terminated, there will be no more water to appropriate for perennial local needs.

8.1.1 Cumulative Impacts Result from Incremental Insignificant Allocations

It is critical to emphasize that the appropriation of the Carmel River was *permitted* bit by bit until it was suddenly found to be far over-appropriated. A sensible approach to avoiding this problem is to take a more conservative look at the overall net income to the water budget, the average input of rainfall. The estimate of total consumable water must be considerably lower than the average input if we are to remain comfortable not just during the feast years, but also during the droughts that are clearly part of the local hydrologic framework.

8.1.2 Upland Bedrock Aquifers

Based upon our recognition that upland bedrock aquifers strongly influence the overall tributary contribution of water to the Carmel River/aquifer system, we recommend regulating the private use of that resource so as to reduce the impacts of drought on tributary and main-stem river systems. The magnitude of the link between upland groundwater and valley-bottom resources may be under-appreciated, and more research is recommended before further upland communities are permitted for development.

8.1.3 Urban Technology

Local solutions to water quantity sustainability can be achieved by urban design that harvests rainfall in various ways and either uses it later, or infiltrates it to groundwater. Among these solutions is rain harvesting from rooftops and other designated impervious surfaces. A guide presenting the pros and cons of such systems is presented in United Nations Environment Programme (2004). Such systems have enjoyed widespread success in other regions, including Texas and China (TGRH, 2004; Changemakers, 2004). Infiltrating storm sewer runoff is another way to incorporate improved water retention into urban planning (CZMP, 1996).

8.1.4 Conservation

Conservation, including the use of native, drought tolerant, plants in landscaping, can play a significant role in stretching the water budget. The MPWMD has played a leading role in communicating the need, and implementing the technology, for wiser residential water usage. Conservation is a team effort where the highest participation will come from a population of stakeholders that feel equitably responsible for the outcome, where everyone is seen doing their share. It is common to hear people state that it is unfair for golf courses or hotels to use "so much water" when everyone else is tightening their belts. Whether or not this sentiment is valid, the issue must be addressed so that all stakeholders feel equitably responsible for conservation. If the golf courses and resorts in the Carmel Valley and broader water district are using more water than is required to maintain their industry, then they should be brought to task to do their share. If those industries are using state of the art conservation methods, examples of those strategies should be widely publicized to stakeholders.

8.1.5 Supplemental Sources

The state requirement to find new sources or strategies for water supply (CSWRB, 1995a) has lead to a great many people suggesting a wide range of options, none of which carries unanimous support. In many watersheds, where supply has exceeded demand, the next strategy has been to seek extra-basinal supplies. For instance, in response to a drought in the 1980's Santa Barbara voters built a desalination plant and decided to tap into the California Aqueduct system. Considering that the region around the Carmel Valley is already over-tapping local supplies, the only realistic extra-basinal water supply appears to be desalination.

8.1.6 Dams

Based upon the experience of the last several decades, dams on the Carmel River should be viewed as expensive and short-term, rather than efficient, long-term water-supply solutions.

- The combination of a fault system that can generate magnitude 7 earthquakes (Rosenberg, 2001), and an urbanized floodway (e.g., Fig. 28) makes dam construction in the Carmel Watershed an irresponsible risk to human life and infrastructure. Citing seismic safety factors, the State Department of Water Resources has directed Cal-Am to effectively decommission the San Clemente Dam by draining the reservoir before November 1, 2004 (DWR, 2003).
- High sediment yields from both natural and anthropogenic causes in the upper watershed guarantee a relatively short useful lifespan for reservoirs. The Los Padres Reservoir capacity has been reduced by approximately 50% since its 1949 construction (Entrix, 2000). The original San Clemente Reservoir capacity has now been reduced by approximately 90% (Entrix, 2000).   The sediment cannot be easily removed or routed through these filled reservoirs for both flood-hazard and ecological reasons.
- The dams pose a serious impediment to steelhead trout migration. As the water levels are lowered in San Clemente Reservoir the fish ladder will cease to function.

Any future dam project on the Carmel River should include in its proposed cost-benefit analysis, the ultimate cost of decommissioning the dam, sediment disposal, and fisheries impacts.

8.2 Sediment Load

Watershed restoration typically includes measures that improve ecosystem function and reduce sediment input form upland and streamside sources. The methods of restoration commonly include reshaping gullied upland areas to reduce flow concentration, revegetating bare soil, repairing poorly maintained dirt roads and culverts, excluding grazing from sensitive areas, reshaping and vegetating the riparian corridor, and hardening especially chronic gullies with large rock. Stream channel restoration sites have a better chance of success if upstream disturbances are not present, therefore the typical strategy is to start watershed restoration with upland regions and roads, then headwater streams, then larger tributaries and finally the main-stem rivers. Groundwater withdrawal led to extreme streambank erosion in the 1980's forcing the MPWMD to start their watershed improvement process low in the watershed. Williams (1984) summarized the sentiment of the time in the annual watershed management plan, "…only when river banks are stabilized will the problems of the upper watershed become very important." Through heroic efforts to revegetate and irrigate the droughty lower Carmel riparian corridor, the MPWMD has largely met the early challenge of stream bank erosion. Assuming that the illegal Cal-Am water withdrawals from the lower Carmel River will end (CSWRB, 1995a; 1995b), we believe that the time has come to refocus efforts on more general watershed problems, including upland erosion.

8.2.1 Dirt Roads

Dirt roads in the Carmel Watershed are a major cause of erosion that can lead to impaired streams. They all generate at least incremental excess sediment, and many are severe, chronic sediment sources. Besides general erosion from the bare road surface and surface rills, dirt road networks typically produce erosion at stream crossings (especially where an undersized culvert is poorly installed), roadside runoff ditches, cut-slope landslides, fill-slope landslides, and landslides and gullies generated by concentrated runoff (e.g., Weaver and Hagans, 1994). A widely successful protocol for reducing the impacts of both current and abandoned dirt roads in a watershed is to first estimate of the volume of sediment that will be eroded from each impaired site in the road system, and then prioritize the sites so that the worst are repaired first. This strategy will result in the most efficient use of resources for the greatest initial erosion reduction. It is typical to find that stream crossings are the leading cause of erosion in a network of roads (e.g., Smith et al., 2003). Further reflection can determine which roads are required and which should be decommissioned (Weaver and Hagans, 1994).

Since dirt roads are such a pervasive, and growing, aspect in the watershed, we highly recommend three strategies for future road construction. First, reduce the number of new roads. Second, the grading contractors or grading landowners should provide a design plan that follows the recommendations of Weaver and Hagans (1994) or a similar recent guide for rural road construction and management. Third, there must be very strict adherence to grading regulations (e.g., CVMP, 1996; Appendix C). Constructing the minimum number of roads, and only in the appropriate parts of the landscape will provide the best long-term solution.

Lastly, incremental, permitted road construction has lead to a very large cumulative watershed problem. As with other cumulative problems, it may be advantageous to determine the total density of dirt roads to permit in each subwatershed, and then to deny permit applications once the limit is met.

8.2.2 Paved Roads

Although the paved roads in the Carmel Valley are better than dirt roads in terms of general surface erosion, they do tend to concentrate flow, which causes erosion. The problems we have seen include undersized culverts, which universally lead to stream incision at the culvert exit, cut-slope and fill-slope erosion, roadside ditches, and poorly placed road-maintenance spoils. Especially problematic are road cuts through low strength substrate like the weathered Chamisal Formation in Robinson Canyon, which has led to minor landslides and severe hillslope gullies.

There are several ways that paved road-construction can be improved. The private road leading to Rancho San Carlos from Potrero Creek contains several samples of exemplary soil-erosion control on road cuts. Although the soils and climate on that road are not outwardly conducive to seedling survival or rapid plant growth, the road cuts show remarkably positive early response to the application of various stabilizing agents. If further monitoring indicates that the methods worked in the long run, the site should be viewed as a demonstration project for dressing road cuts on future roadways in the watershed.

Future improvements can include better utilization of local knowledge of weak rock formations during road planning, and education of county and city road maintenance crews regarding the placement of road maintenance spoils near creek beds. The impacts of both paved and unpaved roads are nearly universal, so minimizing new road development is the best option.

8.2.3 Cattle and Erosion

As reported above, there are certain regions in the Carmel Watershed with a disproportionately high number of landsides, gullies, and stream bank erosion problems that are periodically contributing to excess sediment loads in the tributaries and main-stem river channels. These same regions bear evidence of long-term cattle impacts, perhaps originating with the early Europeans, but certainly continuing today.

A 530 kg cow will impart a stress to the soil of approximately 260 kPa with each step on level ground (Scholefield and Hall, 1986, cited in Trimble and Mendel 1995). There is much greater pressure exerted during hill climbs as in ascending a stream bank or slope (Trimble and Mendel, 1995). This impressive stress typically results in compacted soils or sheared soils, depending upon the slope.   The net result of direct pressure from cattle hooves, documented in many studies, is reduced infiltration and increased erosion (references in Trimble and Mendel, 1995). In addition to direct soil shearing that can ad sediment to a stream, cattle sometimes eat riparian vegetation, leading to stream bank erosion.

Many of these soil erosion problems, observed in the Klondike, Chupines, Sycamore, and Lower Finch subwatersheds, have a youthful appearance, including freshly exposed soils and steep, unstable stream banks. It is quite likely that some of these erosional features formed, or were recently reactivated, by high rainfall of the El Nino rains of 1995 or 1998. Vestal and Pinter (2003) studied the root causes of 1,922 El Nino-related slope failures in similar geologic and climatic conditions on Santa Cruz Island, California. From multivariate analysis of several physical parameters that might have influenced the presence of landslides, they implicated land-use and slope angle as the leading predictors of slope stability. In terms of land use, sheep-grazed pasture was far more susceptible to landslides than non-grazed grassland. The non-grazed grassland studied on the island had been extensively utilized by sheep up until the mid-1980's, suggesting that impacted soils can regain robust stability within 15 to 20 years of grazing exclusion (Vestal and Pinter, 2003).

Permanent or managed cattle exclusion is a common watershed restoration strategy where cattle are found to be responsible for severe erosion or water resource/riparian degradation. The common strategies include, fencing riparian zones to keep cattle out of the creek banks and beds. This practice keeps cattle from foraging on the plants that keep stream banks strong; it protects the stream banks from shearing by hooves; and it has the added benefit of reducing excess nutrients and fecal contamination in surface and groundwater resources. The idea is to prevent cattle from congregating near natural surface waters. Alternative water sources, and moving supplemental feeding areas away from surface waters are important as well. Based upon site-specific conditions, periodic limited access to riparian vegetation can be part of a larger grazing plan that is sensitive to cattle impacts.

Further research is required to understand how to accommodate the practice of cattle ranching on the steep unstable grasslands in the Carmel Valley. The Santa Cruz Island study suggests that exclusion is the best solution (Vestal and Pinter, 2003), however that solution may require significant modification of the regional cattle industry.

8.2.4 Incised Streams

Broadly speaking, a watershed tends to construct a flat valley bottom that is cleaved by a river channel. The flat land adjacent to the channel is formed by frequent overbank sedimentation

and point-bar growth. Geologists refer to this flat region as the "geomorphic floodplain," if it is a depositional feature formed, and continually maintained, by the river in present watershed conditions and climate. On average, natural, undisturbed streams in the U.S. experience bankfull flow or greater once every one to two years (Leopold et al., 1964). This frequent flow has access to, and maintains, the "geomorphic floodplain." This widely held model of river dynamics is mainly based upon perennial streams in wetter climates, rather than in ephemeral streams of semiarid conditions of the southwest. The frequency of over-bank flow and the appropriate size of the bankfull channel in semiarid or Mediterranean climates, as are present in the Carmel Watershed are less well understood (Kondolf and Smeltzer, 1999)

Incised streams are those that have recently cut downward into their underlying alluvial deposits, leaving their previously constructed geomorphic floodplains too high to accommodate frequent floods. As high flows are no longer able to spread out and dissipate energy, the tall banks of the incised channel are rapidly eroded, leading to excess sediment in the water, land loss, and incremental self-restoration.

Once a chronic stream disturbance is removed, the channel of an incised stream will typically heal by eroding enough to accommodate a new geomorphic floodplain and sloping its banks enough to accommodate revegetation (e.g., Simon and Hupp, 1987; Hupp and Simon, 1991; Rosgen, 1997). The incised Upper San Pedro River recovered in approximately 50 years, with the help of improved cattle management in the watershed (Hereford, 1993). The downside to letting nature take its course is that the process of natural recovery liberates an enormous volume of sediment into the river as the banks eventually widen and recline to a lower slope angle. Therefore, it is advisable in many cases to explore proactive restoration of incised streams.

One framework for restoration designs for incised rivers is Rosgen (1997). Each incised reach will have site-specific parameters that will dictate the kind of restoration to employ, ranging from complete reconstruction of a new channel to using hard bank protection to stabilize the system in place. Reach-scale restoration should best be considered after watershed conditions or disturbances have been addressed. For example, if cattle impacts are the root of the erosion problem, then local stream restoration will have the best chance of success if it is implemented following cattle exclusion.

Many river channels in the Carmel Watershed are at least moderately incised, suggesting recent downcutting. Culverts are left hanging, bridge foundations are undercut, and high terraces locally exist beside steep-walled channels. In the Carmel Watershed, this could have been caused by several factors, including response to powerful El Nino winter flows of 1995 and 1998 (Fig. 21), lowering of base level in the Carmel River because of bedload trapping in San Clemente Dam (Kondolf and Curry, 1986), altered hydrology from land-use changes, or poor culvert design in road building. The recent stream incision process is not directly related to mountain uplift because there has been no significant fault slip in recent decades. In some

cases the root cause of channel incision may not be obvious, indicating that a bit more research will be required on many potential restoration sites before restoration is begun.

Stream restoration should be designed and implemented by skilled professionals with much experience in semi-arid conditions. The first projects should be closely monitored and adaptively managed as needed until long-term, satisfactory results are achievable. These first projects should be viewed as demonstration projects showing techniques and benefits to landowners who might then implement them on private lands.

Carmel Watershed (2004)

9   References

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10 Appendices

This report has three appendices.

10.1 Appendix A: Five poster-size maps

10.1.1   *Appendix A-1: Subwatersheds and Geography*

10.1.2   *Appendix A-2: Major Geologic Units*

10.1.3   *Appendix A-3: Land Cover*

10.1.4   *Appendix A-4: Soils*

10.1.5   *Appendix A-5: Base Map*

10.2 Appendix B: Metadata for the maps in appendix A.

10.3 Appendix C: Miscellaneous Data.

10.3.1   *Appendix C-1: Excerpts from the Carmel Valley Master Plan*

10.3.2   *Appendix C-2: Descriptions of USGS Stream Gauges*