Topanga Creek Watershed Erosion and Sediment Delivery Study 2000-2001

FINAL REPORT

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Executive Summary

This study discusses the nature and magnitude of erosion and sediment yield in the Topanga Creek watershed, southern California, during the 2000-2001 water year and makes recommendations for the future management of the system. Constrained mostly to public land and to one water year, and limited by available resources, the study nevertheless presents a large amount of new information regarding the physical system, pertinent to future management and restoration efforts within the watershed.

Topanga Creek watershed covers about 50 km^2 of the central Santa Monica Mountains, and breaches the active anticlinal axis of these mountains in an antecedent stream that reaches Santa Monica Bay in a small fan delta. The upper basin is relatively open although streams become increasingly incised downstream. The lower basin is narrow and deeply incised by lower Topanga Creek. The watershed is underlain by late Cretaceous through Miocene bedrock, coarsely clastic in the south, becoming finer toward the north, which began emerging from the ocean in late Miocene time. Over the past 125 thousand years (ka), the watershed has continued to rise at a mean rate of 0.30 m ka^{-1} in response to seismic and aseismic forcing.

Hydroclimatic forcing of the geomorphic system reflects the Mediterranean-type climate regime - warm wet winters typified by episodic rainfall/runoff events, mass movement, and unpredictability; warmer dry summers typified by dry ravel. Vegetation filters the effect of hydroclimatic impacts on hillslope and stream processes. Chaparral and coastal sage vegetation covers 75% of the watershed, woodland and woodland-savanna a further 10%. Burrowing mammals make large amounts of soil available for erosion. Fire also affects erosion by consuming vegetation, most recently in the fire of autumn 1993. Human disruption of the watershed is considerable - from single family homes, roads and trails, and imported water. Human impacts have changed the playing field for erosion and sediment delivery.

In terms of methodology, erosion and sediment yield were investigated in three spatial systems - hillslopes, stream channels, and river mouth - and also observed along major roads. The spatial systems form an erosional-depositional cascade in which sediment eroded from hillslopes may move to tributaries, thence to the mainstream, and eventually to the sea. However, there are ample opportunities for storage within the cascade. Very rarely does hillslope sediment reach a tributary stream in one event, except where debris flows occur, while storage within stream channels and the estuary postpones delivery to the sea. Sampling schemes were designed to capture as much information as possible about these systems.

On hillslopes, which represent 99% of the basin and thus have by far the highest erosion potential, erosion and sediment yields were sampled using 40 erosion sites in 6 locations. These sites were stratified by slope declivity, slope aspect, vegetation, and substrate. Sediment captured by downslope troughs provided a mean daily sediment yield in g m^{-2} d^{-1}, and by extrapolation a value for comparative denudation analysis. The resulting data revealed considerable noise. In general, highest erosion rates (4-14 g m^{-2} d^{-1}) occurred during and shortly after rainfall/runoff events on steep, north- and west-facing slopes underlain by coarse clastic sediment only partially protected by chaparral and coastal sage recovering from fires over the past 15 years. This is partly predictable but the inability of chaparral and associated plants to protect slopes several years after a fire is surprising. Lowest erosion rates (0.03-0.3 g m^{-2} d^{-1}) occurred throughout the year on low, south- and east-facing slopes on fine clastic substrate and covered by grassland and oak savanna. Such sites afford excellent canopy protection and soil cohesion against rainsplash erosion and overland flow under low intensity rainfall/runoff events. However, this result is misleading because grassland sites, notably those covered by dense shallow root mats of alien grasses, become unstable at higher rainfall intensities, leading to debris flows. Rainfall intensities during the 2000-2001 water year only neared the threshold intensity required to trigger debris flows for four hours - in the later evening of 10 January, 2001, and little happened beyond small debris flows along the northern interfluve. Oak woodland sites generated higher yields because, with a more continuous canopy, grassland disappears and oak litter only partially protects bare soil.

No fire consumed watershed vegetation during the study period, so there could be no direct assessment of the effects of fire on erosion and sediment yield. However, the higher yielding sites were those where chaparral/coastal sage vegetation had burned most recently, notably in the Old Topanga fire of November 1993. Although other factors influenced these high yields, this confirms that the more intense fires lead to increased erosion under post-fire conditions. The upper Garapito basin, spared fire for 40 years and containing a dense vegetal canopy and abundant fuel, should be managed with great care, especially because its creek is an effective sediment delivery system.

Debris flows as a distinct category of hillslope processes can be predicted for winters with more frequent, intense, and persistent rains, especially on steep slopes unprotected by vegetation, covered by alien grasses, and underlain by mudstone and claystone which may then reach their yield limits. Debris flows are important because they quickly yield abundant sediment to stream channels, thereby transforming normal floods into non-Newtonian (Bingham) flows with potentially devastating consequences. Deep-seated landslides and rotational slumps were not a significant factor during the 2000-2001 water year but many pre-existing landslides, notably adjacent to streams in the central basin, remain near the threshold for slope failure. Their hydrologies and vegetation cover, together with human imprints from septic tanks and road drainage, should be managed with care.

Variable erosion rates imply that longer-term denudation within the watershed will also vary. Extrapolating sediment yield into annual mass wastage indicates surface denudation ranging from a low of 0.004 m ka^{-1} to a high of 1.88 m ka^{-1}. Rates exceeding 0.30 m ka^{-1} exceed the mean rate of tectonic uplift. *In extremis*, the highest rates would reduce the basin to sea level in <150 ka, or little more than a glacial-interglacial cycle. Whereas this is unlikely to occur, denudation rates in excess of 0.30 m ka^{-1}, notably on 30° slopes, on coarse clastic substrate, and under recently burned chaparral, pose a major challenge for watershed management. The erosion potential of the watershed is defined in terms of eight morpholithogical units, each characterized by relatively distinct erosion and mass movement signatures, and by sediment yield within a predictable range of calibers.

Roads were investigated because of the perception that road berms yield abundant sediment to streams during rainfall/runoff events. It proved impossible to instrument these berms but paved roads were observed repeatedly during the study period. Along Topanga Canyon Boulevard and Old Topanga Road, which together have a margin length of over 42 km, small berms comprise 29% of total margin, medium berms 8%, large berms 3%, cut banks 46%, and the remainder is open frontage. There are also 80 official culverts along these roads.

Road berms were subject to frequent reworking by highway authorities and private property owners before, during, and after rain events. During rain events they were also prone to surface erosion and their outer rims to occasional failure. However, the root causes of perceived berm problems lie in road construction and maintenance. Within the Topanga Creek watershed, road construction usually involves the need, first, to cut into hillslopes and fill the outside slope in order to provide a sufficiently wide right-of-way and, second, to provide adequate drainage for the impermeable road surface, including the provision of side ditches, culverts and downspouts. Both during and after heavy rains, cut banks along most roads yield surface flows, seepage waters, mud and coarser debris. Cut banks may also fail in landslides and rotational slumps. These cut banks are the primary source of sediment reaching road surfaces. Thus, for reasons of safety and trafficability, such debris is removed expeditiously by the highway authorities to outside berms and, where abundant, either trucked from the problem site or dumped into nearby stream channels.

Further, certain stretches of road, especially in the narrow lower canyon, have been constructed beneath high unstable cliffs on the inner side, and perilously close to creek banks on the outer side, the latter often requiring protection by riprap and other devices. Such protection in turn deflects stream energy and generates problems nearby. Elsewhere, often on public lands far removed from paved roads, many fire roads and recreational trails are yielding to accelerated erosion, gullied by inadequate drainage and poorly placed culverts, eroded by hikers, bikers and hooves, and poorly maintained, if at all.

Such erosion and sediment yield problems, whether they be along paved roads or hiking trails, are seemingly the price paid for access, recreation, and fire control. If the watershed had neither residents, nor visitors, nor commuters, nor any need for fire protection, there would be no need for roads and trails. Existing roads could be put to bed. More realistically, given the human clamor for roads, every attention should be given to best management practices, from paved roads to trails. This should begin with careful maintenance of cut banks and landslide reaches by highway authorities and property owners alike. The number of culverts could also be increased to shorten reach length contributing drainage to individual culverts. Cut banks rather than berms are the principal source of debris. Small berms are commonplace and relatively harmless, large problem berms are a small percentage of the total and could be modified or removed. However, as long as the Topanga Creek watershed caters for people, road problems are unlikely to disappear.

Erosion and sediment delivery in stream channels were investigated by recognizing 23 reaches at 9 locations for initial observation and then selecting 18 of these for repeat survey during the water year. Of these 18 reaches, 8 were along the mainstem of Topanga Creek, the remainder on Santa Maria (1), Garapito (3), Greenleaf (1), Red Rock (2), and Old Topanga (3) creeks. The hydraulic geometry of these reaches was computed for successive survey intervals and a value of net scour or fill computed for each interval. Incidental kinematic variables and suspended load were measured, and bedload sampled, when time and conditions permitted. Discharge data from the Topanga gauging station, near the Route 27 road bridge 3 km from the ocean, were also considered.

Following the 70-day autumn dry spell ending 7 January, channel reaches were subject to frequent changes during winter 2001, during and after larger hydrograph peaks. As a result of mid-January flows, the largest of the water year, the upper reaches showed net scour, the middle reaches net deposition, and the lower reaches net scour. Later, in February, the pattern became more complex as discrete slugs of sediment were remobilized and then redeposited farther downstream. By mid-March, scour had again returned to much of the system, which then desiccated and stabilized. No channel reaches showed persistent fill and only one reach showed persistent scour, namely the reach immediately downstream of the Topanga Creek confluence with Old Topanga Creek. Channels were re-examined for bank failures and change during spring and summer 2001, but little change was observed.

Observed patterns of scour and fill are explained by the greater delivery of water and sediment to streams from hillslopes and channel banks in the upper basin, followed by deposition in the reduced stream gradients of the middle basin above the Topanga-Old Topanga confluence, and then scour farther downstream. Furthermore, the pulsing nature of sediment delivery and the stochastic storage patterns observed within the middle basin ensured that measured suspended sediment data were not readily equated with reality. Such are the gradients of lower Topanga Creek and its tributaries that sediment reaching Topanga village, and especially the head of the main canyon near Fernwood, moves through to the estuary runout zone with little to impede it.

Garapito and Santa Maria creeks emerged as major contributors of suspended and bedload sediment during the study period, especially upstream from their confluence. Several coarse clastic depositional lobes were found in lower Garapito Creek and in the mainstem of middle Topanga Creek. These lobes were probably related to friction-dominated debris flows with a strong sediment-support matrix, or to transitional liquefied flows in which sediment was partially supported by escaping pore fluids until dewatering occurred. There is thus a probable hazard from Bingham-type flows, as well as from Newtonian viscous flows, in these reaches. Santa Maria Creek yielded mostly fine clastic sediment. The Old Topanga Creek system, including Red Rock Creek, was a far less active erosion and sediment delivery system during the study period, probably because flows were less and channels were better stabilized by riparian woodland and engineering structures. However, a large quantity of loose hillslope sediment remains stored within this system and will likely be mobilized in future high magnitude storm events.

Over the longer term, the Topanga Creek watershed appears to be experiencing a change in stream regime. Along many reaches, floodplains are being incised and channel banks appear less stable, for example in Upper Topanga, Garapito, and Santa Maria creeks. Whereas these changes could be attributed to climatic change crossing hydrodynamic thresholds, there is no compelling evidence to support this. More likely, the impact of discharged imported water, concentrated road runoff, vegetation conversion, and other land-use changes have combined to disrupt the system inherited from earlier times. Morphological evidence suggests that this change in regime began about 30 or 40 years ago.

The river mouth, between the Pacific Coast Highway Bridge and Santa Monica Bay, was the focus of repeat surveys during the 2000-2001 water year. These surveys captured the essential morphodynamics of the two phase system, and related observed changes to hydrodynamic forcing by fluvial discharge, wave climate, and changing ocean levels. In essence, the river mouth is protected from high wave energy by its sheltered location in Santa Monica Bay, by the effect of the fan delta on wave refraction, and by limited tidal range. Thus for most of the year, the river mouth exists as a modestly wave-dominated barrier-lagoon system. Under these circumstances, the barrier remains intact and the lagoon gains water from low stream discharge, wave overwash and influent tidal seepage, and loses it by effluent seepage and evaporation. With positive budgets, the lagoon may rise to a threshold whereby it spills seaward but the overall integrity of the barrier is not jeopardized. While the barrier is closed, however, the lagoon generally atrophies from suspended and dissolved fluvial sediment inputs, wave overwash, aeolian sand, human interference, and eutrophication.

In contrast, during high streamflow events, Topanga Creek breaches and removes the barrier along a 60-80-m wide front. For a few hours, depending on the magnitude of the discharge, the constraining highway bridge generates a fully turbulent jet with great erosive capacity. Thereafter, the sediment flushed seaward at this time soon transforms the river mouth into a friction-dominated estuary characterized by a complex of middle-ground bars which progressively restrict the outflowing recessional discharge.

Finally, the following recommendations are made regarding the erosion and sediment delivery system of the Topanga Creek watershed.

1. Hillslopes should be managed to minimize accelerated erosion, sediment yield and mass movement, particularly with respect to vegetation cover, fire policy, and steep erodible slopes near stability thresholds. In particular, steep bare slopes deprived of vegetation by fire or human activity should be stabilized by planting of native shrubs, staggered to inhibit overland flow.

2. Roads and trails should be managed with respect to reducing cut-bank and berm erosion, drainage needs, and restoration of gullied trails. Cut banks, the principle source of eroded debris, should be maintained under stabilizing vegetation. More culverts should be provided along paved roads to diminish runoff concentration. All culvert downspouts should be constructed to inhibit erosion, specifically by extending them to the nearest channel, rather than allowing them to terminate above erodable slopes. Road widening and protective engineering structures should not impact negatively on stream-channel stability and processes.

3. Stream channels should be managed as natural systems, implying as far as possible the removal of extraneous debris and inappropriate structures, provision for healthy riparian vegetation and effective erosion control, and special concern for stream segments prone to persistent erosion. Interaction between roads and stream channels should be monitored at frequent intervals in order to recognize and manage problems arising from accelerated erosion.

4. The river mouth should be managed for recreational safety and appropriate surf break. Any proposed widening of the Pacific Coast Highway bridge will increase spatial erosion potential and threaten existing structures on the adjacent beach. Any attempt to inhibit erosion by "hard" engineering structures will have adverse effects on beach stability and increased erosion. In such circumstances, "soft" engineering solutions (beach nourishment) may be preferable but there is no immediate source of suitably graded material, and such a solution would modify the surf break, at least temporarily. Beach erosion cannot be resolved based on Topanga Creek sediment inputs alone.

5. Lagoon restoration is feasible but the physical constraints on restoration, particularly the nature of water and sediment budgets in a restored system and the need for adequate circulation, should be incorporated into restoration goals. Dredging of sediment from the largely infilled historic lagoon will generate massive physical and ecological stress over the shorter term. Over

the longer term, a lagoon thus enlarged would provide a trap for subsequent sedimentation. Lagoon restoration would thus involve long-term dredging and maintenance implications. Further, for an enlarged lagoon to provide suitable habitat, rather than a stagnant swamp, it would need an effective circulation system that combines both fluvial and marine inputs. The attempted restoration of Malibu lagoon immediately upcoast failed because of poor design, inadequate circulation and input of significant volumes of anthropogenic runoff from the upper watershed.

6. Studies of watershed erosion and sediment yield should continue, aided by improved instrumentation and technical infrastructure. In this way, the momentum developed in this study can be maintained and the Topanga Creek watershed can come to serve as a model for small basin analysis.

The conclusions and summaries presented in this report are those provided by Dr. Antony R. Orme to the Resource Conservation District of theSanta Monica Mountains.

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1. Topanga Creek Watershed as a Physical System

Drainage basins may be viewed as erosional-depositional cascades in which materials move from hillslopes to tributary channels, from tributaries to mainstreams, and eventually through estuaries to the sea. Such cascades offer ample scope for storage of sediment, such that it cannot be assumed that materials derived from hillslope or channel erosion will move directly to the sea. Thus studies of erosion and sediment delivery must make allowance for storage and reworking of sediment over the long term. This study seeks to evaluate the role of hillslope and stream-channel erosion and sediment yields within the Topanga Creek watershed by sampling within one water year, 2000-2001. It provides baseline data against which to measure subsequent changes so as to derive a time series for future watershed management.

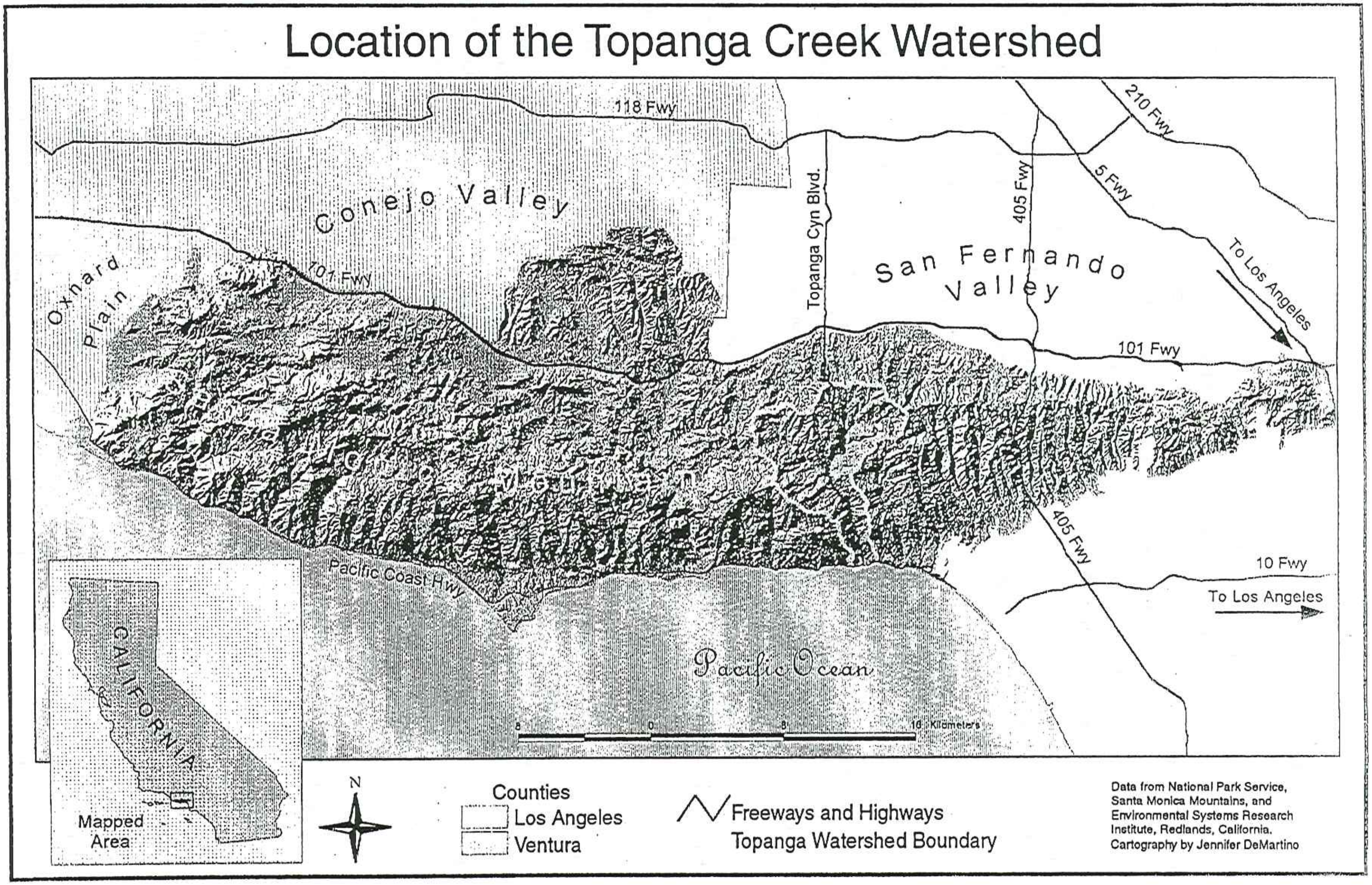
Topanga Creek drains a 50 km^2 watershed in the central Santa Monica Mountains (Fig. 1-1). Its pear-shaped drainage basin reaches 781 m above sea level; its north-south axis is 11 km long; and its east-west axis in the upper basin is 9 km wide. The dendritic drainage pattern comprises the south-flowing Topanga Creek (14.4 km long) and its main tributaries, Old Topanga (6.4 km) and Garapito creeks (4.4 km) (Fig. 1-2). Linking Garapito Creek with the mainstem below the Garapito confluence forms a stream 15.5 km long which is really the system's main artery.

The broad upper basin is less rugged and its streams less steep than the narrow lower basin with its impressive 4-km long canyon. Below the canyon, Topanga Creek reaches Santa Monica Bay via a narrow floodplain, 1.8 km in length, the lower part of which contains a small lagoon. In early historic time, this lagoon was larger than today but it has since been constrained by sedimentation and human interference. For much of the year, the lagoon is closed to the ocean by a barrier beach but, after winter rains, Topanga Creek drains directly seaward via a small friction-dominated estuary.

In essence, within Earth's gravitational context, erosional-depositional cascades are subject to two principal forcing factors, namely tectonism and climate, and function through several filters including vegetation, fire, and human impacts (Orme, 2001). The following discussion outlines some of the salient features that are pertinent to erosion and sediment transfers within the Topanga Creek watershed.

1.1 Tectonic Framework

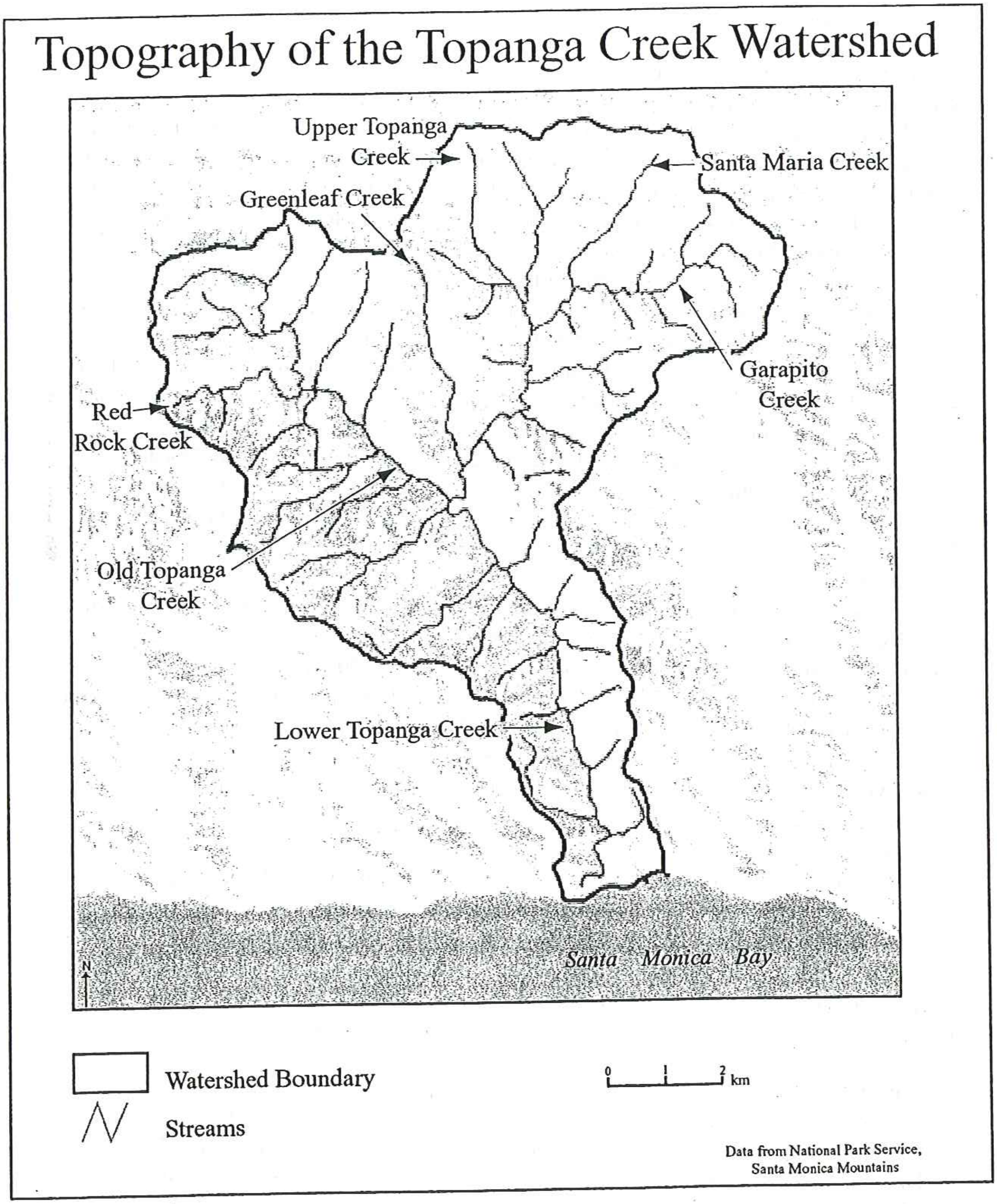
Tectonism provides the geological structures, rock distributions, and initial gradients within which erosion and deposition occur. The Santa Monica Mountains are a broadly anticlinal structure that extends 75 km from the Los Angeles River Narrows westward to Point Mugu. Although cored by Mesozoic metasediments and granitic intrusions, the mountains are dominated by late Cretaceous and Cenozoic clastic sediments. The Topanga Creek watershed is formed in the south on late Cretaceous and Paleocene marine sandstone and conglomerate (Dibblee, 1992, 1993). These rocks are overlain unconformably in the central basin by Oligocene and Lower Miocene sandstone and conglomerate of the non-marine Sespe and marine Topanga formations, the latter associated with hypabyssal and volcanic rocks. These are in turn overlain unconformably in the upper basin by Upper Miocene sandstone, siltstone and claystone of the Modelo (Monterey) Formation. In general, the geological framework becomes younger, less



Location of the Topanga Creek Watershed

Data from National Park Service, Santa Monica Mountains, and Environmental Systems Research Institute, Redlands, California. Cartography by Jennifer DeMartino

Figure 1-1.



Data from National Park Service, Santa Monica Mountains

Figure 1-2.

consolidated, and less resistant to erosion from south to north. Pervasive fracturing and faulting also favor erosion, especially towards the south.

The structural axis of the mountains passes from east to west through Topanga village. Thus the broad upper basin is underlain by mostly north-dipping rocks prone to dip-slip mass movement, especially in the Topanga and Modelo formations. The mostly south-dipping structures astride the main canyon farther south are complicated near the coast by north-dipping thrust faults along the Las Flores and Malibu Coast fault systems.

Complex forcing mechanisms along the developing Pacific-North American plate boundary caused the Santa Monica Mountains to begin emerging from the ocean in late Miocene time (Nicholson et al., 1994; Orme, 2000)). Whereas the details need not concern us, of significance to the present study is that the mountains have continued to rise through a combination of seismic and aseismic motions ever since. Late Pleistocene shorelines observed both east and west of Topanga Canyon indicate uplift rates of 0.30 m ka^{-1} over the past 125 ka, probably linked to massive left-lateral transpression along the Malibu Coast Fault (Orme, 1998). This uplift is reflected in the Topanga Creek drainage network, the northern portions of which have been raised into broad upland basins while the southern mainstem and its immediate tributaries plunge down linear to convex profiles to the coast. This affects stream velocities and sediment delivery downstream. Rapid tectonic uplift has also created unstable terrain unusually prone to erosion and mass movement.

The most recent event relevant to the present study is the last major eustatic rise of sea level, the Flandrian transgression, which drowned the lower portion of Topanga Creek and formed a narrow estuary (Orme, 1990, 1991, 2000). This transgression achieved maximum rates of 20 m ka^{-1} between 15 and 8 ka, subsequently slowed, but has continued over the past 4 ka at rates of between 1 and 2 m ka^{-1}. Sedimentation over the recent past has exceeded this sea-level rise, progressively restricting accommodation space within the estuary. This process has been influenced by anthropomorphic actions.

1.2 Climatic Environment

Climatic forcing of erosion and sediment delivery occurs through the agency of precipitation leading, depending on surface properties, to rainsplash erosion, sheet flow and throughflow on hillslopes, to Newtonian channeled flows and non-Newtonian debris flows on hillslopes and in streams, and to groundwater storage and flow that may lead to deep-seated mass movement. The nature, magnitude, frequency, intensity, and persistence of precipitation events are thus important to the erosional-depositional cascade.

The Topanga Canyon watershed shares the Mediterranean-type climate characteristic of coastal southern California, namely relatively warm, wet winters and warmer dry summers. This cycle is related in winter to the eastward passage of mid-latitude cyclones and associated frontal systems from the North Pacific Ocean. Because storm tracks usually pass inland to the north of the region, precipitation locally is normally associated with trailing cold fronts whose vertical motion and orographic enhancement yield variable but sometimes intense rainfall. Winter storms passing along more southerly tracks are less common but may yield persistent rainfall, for example in the unusually heavy rains of winter 1992 (Raphael et al., 1994). Winter-style frontal precipitation may occur anytime from October to May, but most heavy rain falls over Topanga Canyon during January, February and March.

Summer conditions are dominated by the North Pacific anticyclone centered north of the Hawaiian Islands. This sets up a relatively stable northwesterly circulation off the California coast which, in passing inland across the cool California Current, brings advection fog to the coast. Such fog is an important element in coastal ecology and may yield trace precipitation in rain gauges. Occasional rain may also fall from June to September from summer thunderstorms associated with moist monsoonal flows into southern California from the south and southeast, and from tropical cyclones moving northwest off western Mexico. Such rains are, however, rare and did not occur locally during the 2000-2001 water year.

Apart from a general assumption of winter rain and summer drought, predictability is not a strong feature of this climate. Oscillations in Pacific-North American teleconnections and in El Niño-Southern Oscillation events produce high inter-annual and intra-annual variability in rain-producing storm events, exemplified most recently by the very wet El Niño-related winter of 1997-98 and the unusually dry La Niña-related winter of 1998-99, and by the variability within these winters (Orme et al., 2000). Annual precipitation at the Topanga rain gauge during 1997-98 was 892.06 mm, but during 1998-99 was just 349.54 mm, and in 2000-2001 was 456.25 mm. Such variability, together with the inherent unpredictability of the rainfall-runoff response, should be embedded in all management scenarios for the Topanga Canyon watershed.

1.3 Biological Environment

Hydroclimatic forcing of erosion and sediment delivery is strongly affected at the surface by vegetation filters. Vegetation influences hydrologic regimes through its effect on interception, infiltration, evapotranspiration, and runoff, each of which affects the availability of surface water for erosion and sediment transport. Furthermore, the net effect of vegetation change, including that caused by fire or human impacts, is a disruption of the water cycle and of biological barriers to erosion and mass movement.

A mix of chaparral and coastal sage associations clothes about 38 km^2 or 75% of the Topanga Creek watershed (Franklin et al., 1997; Dagit et al.; 1999; DeMartino, 2001). (Fig. 1-3) Mature associations provide good watershed protection from raindrop impact and surface erosion, but more commonly fire and human disturbance have created a patchwork of shrubs and bare ground which affords much less cover. A further 5 km^2 or 10% of the watershed is covered by native oak, walnut, and riparian woodland. Many of the oaks are interspersed with grassland in an oak savanna. Open grassland, comprising either native or non-native species, is rare beyond the upper basin. Most of the remaining 15% of the watershed has been subject to significant human intrusion, including planting of non-native species. This disruption of the native vegetation has generated adjustments to the erosional-depositional cascade, generally accelerating slope processes and reducing channel stability.

Certain small mammals also influence erosion, most notably the pocket gopher (*Thomomys* spp.) whose burrowing activities affect near-surface hydrology and eject large, but as yet unquantified, volumes of earth at the surface.

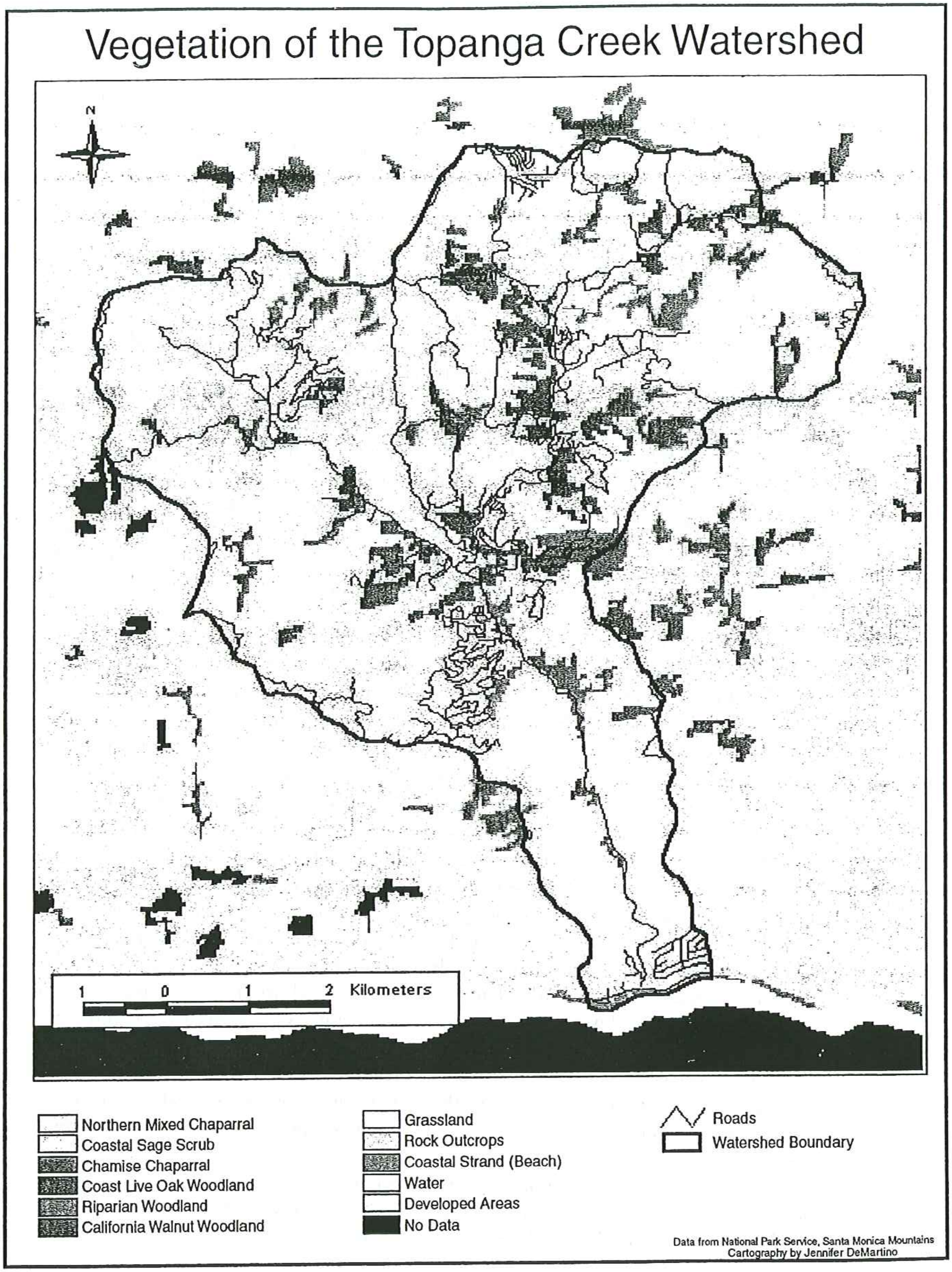

Vegetation of the Topanga Creek Watershed
N
1 0 1 2 Kilometers
Northern Mixed Chaparral
Coastal Sage Scrub
Chamise Chaparral
Coast Live Oak Woodland
Riparian Woodland
California Walnut Woodland
Grassland
Rock Outcrops
Coastal Strand (Beach)
Water
Developed Areas
No Data
Roads
Watershed Boundary
Data from National Park Service, Santa Monica Mountains
Cartography by Jennifer DeMartino

Figure 1-3.

1.4 Fire History

Fire is a recurrent feature of the Topanga Creek watershed, favored particularly by summer drought, outflowing Santa Ana winds, and the flammable nature of the chaparral and coastal sage vegetation. The removal of plants and plant litter by fire exposes the surface to raindrop impact, overland flow and dry ravel, modifies soil structure and texture, and increases water repellency.

Charcoal fragments in alluvial deposits reflect recurrent fires and concomitant changes to watershed ecology during prehistory. However, it is the fires of the last 30 years that are most relevant to this study. Some portions of the watershed, notably in the upper Garapito Creek basin and Greenleaf Canyon, have not burned for more than 30 years (RCDSMM, 1999; DeMartino, 2001). Except where disturbed by human activity, the vegetation here is often dense, affording protection against erosion, but these conditions could change significantly in future fire scenarios. Vegetation in the lower basin was burned in 1973 but has become re-established. In contrast, a swift moving fire in autumn 1993 consumed most of the vegetation west of Old Topanga Creek and locally farther south, west of the main canyon. Vegetation in these areas has yet to recover sufficiently to provide good protection. The effects of both arson and of government fire-control policies on the magnitude and frequency of fire events continue to be hotly debated. In the absence of fire during the 2000-2001 water year, this study could not address related impacts directly, but certain inferences are made.

1.5 Human Imprint

The least predictable and most troublesome variable in the erosion scenario is the impact of human activity on the natural system. Before 1900, the watershed was relatively pristine, influenced benignly by a few indigenous peoples and marginally by Euroamerican ranching. Since around 1900 (Topanga Post Office was established in 1908), the watershed has been colonized in a somewhat erratic way (York, 1992). Today, some 12,000 people live in the basin, in an enterprising array of single family homes. Most early settlement occurred along Route 27, Topanga Canyon Boulevard, and Old Topanga Canyon Road, but homes have since spread into the hills and spilled over into the upper basin from the San Fernando Valley.

From an erosion viewpoint, the impact of these developments is broadly three-fold. First, to a greater or lesser extent, each home site with its access route and septic-tank sanitation disrupts the natural landscape and drainage system. To protect often thoughtless development, a wide variety of devices have been introduced to counter erosion and mass movement. Many of these devices exacerbate rather than control natural forces, for example by deflecting stream energy away from natural paths. Second, to provide access to these homes and a route for people wishing to move between the San Fernando Valley to the coast, a complex network of roads and tracks have been constructed, further disrupting slope stability and drainage. Roads and trails have also been built for recreation purposes in state-owned lands. Fire access roads are present on major interfluves and locally elsewhere. Third, the importation of water to the basin for domestic and irrigation purposes has probably changed hillslope and stream hydrologies, for example by lowering the threshold for mass movement and increasing low flows in local streams.

Whereas this study is not designed specifically to address all issues caused by such developments, it is evident that the playing field for erosion and sediment delivery within the watershed has been significantly altered by human impacts. This becomes most apparent during major storm events, like those of winter 1980, when natural hazards, such as landslides and stream erosion, pose very real threats to life and livelihood. Thus, everyone concerned with the watershed, from individual residents, commuters and recreationists to highway authorities and other government agencies, should be aware of, and seek to minimize, the deleterious impacts of their activities.

2. Methodology

The methodology employed in this project was designed to maintain the highest standards of quality control and assurance in watershed and coastal geomorphology. The research project was developed in the context of the following matrix:

Table 2.1 Research Matrix

A Identification of Variables	1 Precipitation	2 Stream Discharge	3 Marine Variables	4 Hillslope System	5 Roads	6 Channel System	7 River Mouth
B Collection of Data							
C Tabulation & Presentation of Data							
D Analysis & Interpretation of Data							
E Conclusion & Recommendations							

Of the above variables, raw hydrodynamic data concerning (1) precipitation, (2) stream discharge, and (3) marine variables were derived from government agencies and developed for interpretation. The remaining variables concerning (4) the hillslope system, (5) roads, (6) the channel system, and (7) the river-mouth system were based on original field observations and measurements. Field work was supported by remote sensing, notably vertical aerial photographs at a 1:6000 scale obtained on 9 October 1997.

2.1 Hydrodynamic Data

Precipitation

Hourly precipitation data relevant to the project were obtained from the Malibu, Cheseboro and Topanga gauges maintained by the California Department of Forestry (CDEC, 2001), National Park Service (CDEC, 2001), and Los Angeles County Department of Public Works (2001), respectively. These data, subject to the accuracy and precision of the gauges, were converted to metric units to 0.01 mm.

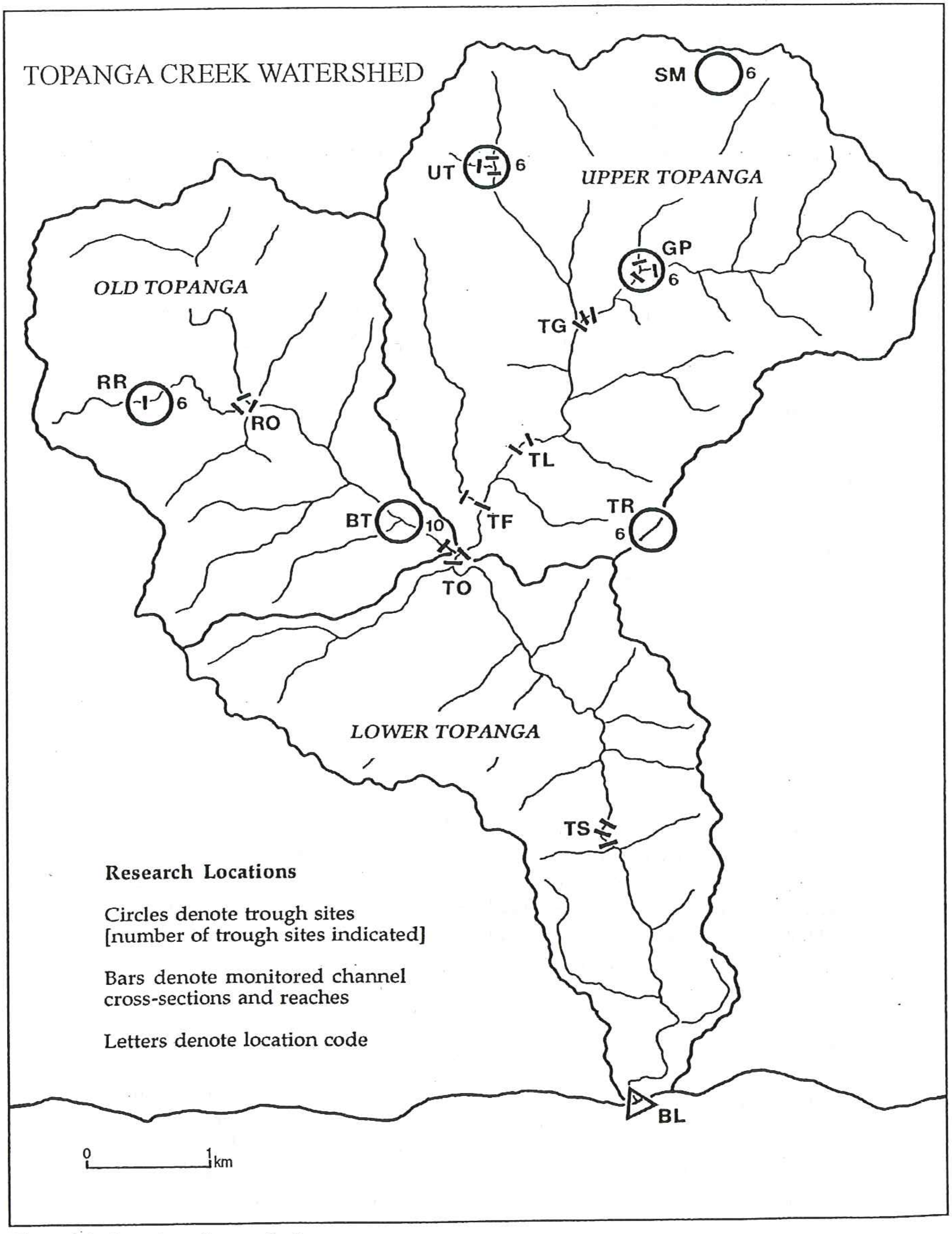


Figure 2-1. Location of research sites

Stream Discharge

Stream data relevant to the project were provided by the Los Angeles County Department of Public Works (2001) from gauging station F54C-R on Topanga Creek near the Route 27 road bridge, approximately 3 km north of the Pacific Ocean. These are hourly stage data, including daily maxima and minima, measured to 0.01 feet and converted to discharge data in cubic feet per second from the stage-discharge rating curve developed for this station. These data were converted to metric units and augmented by data collected during specific stream-profile surveys using a Marsh-McBirney Electronic 201D Portable Water Current Meter with a precision of 0.01 meters per second for velocity, and stage data surveyed to a precision of 0.001 m.

Marine Variables

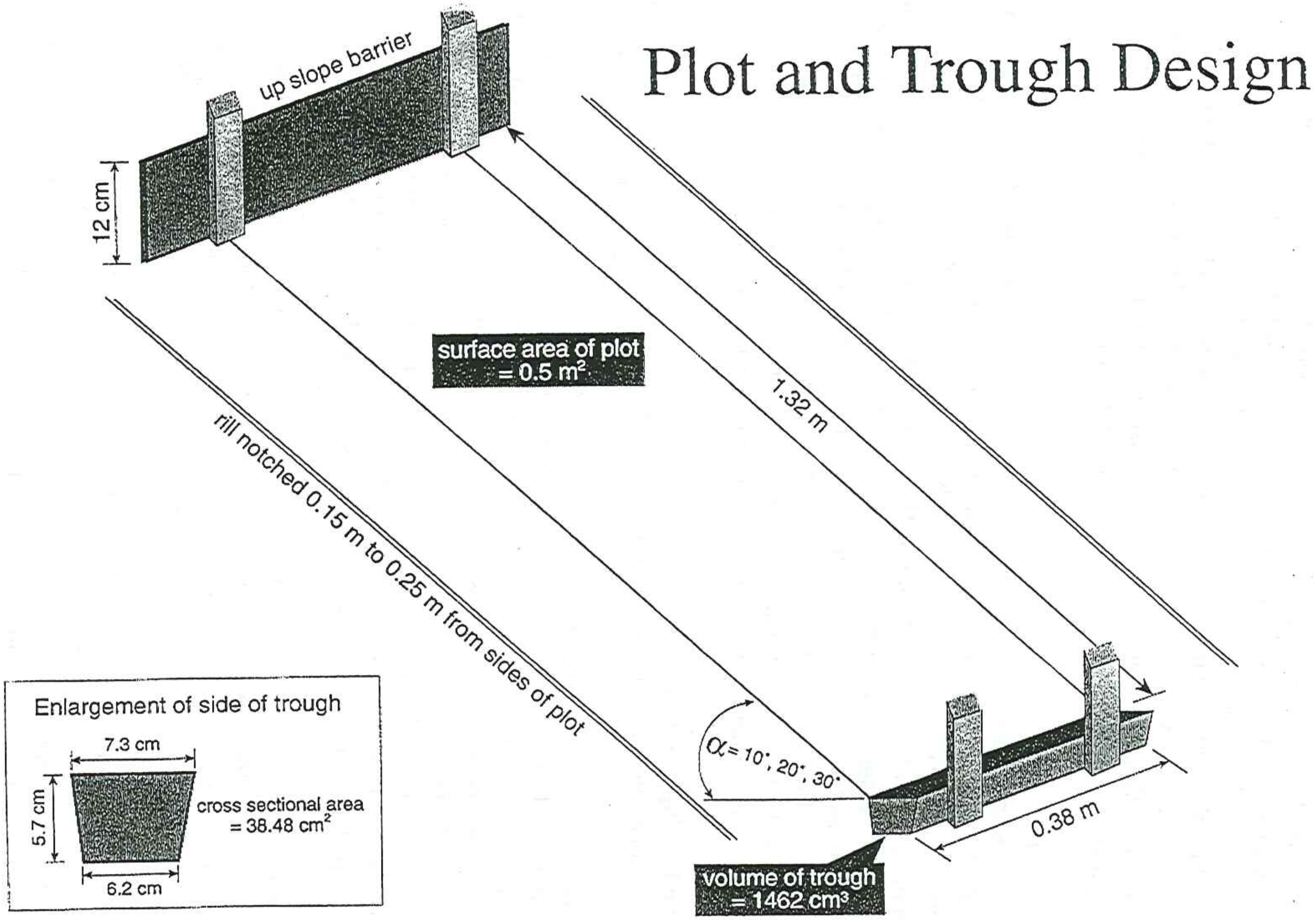
Data concerning hourly wave climate were derived from the Santa Monica Bay Buoy, CDIP 02801, maintained by the Scripps Institution of Oceanography (University of California) at 33° 51.20' N 118° 37.90' W, bearing S by W (192°TN) 21 km from the mouth of Topanga Creek (CDIP, 2001). The pertinent data were mean wave height (m), wave period (s), and wave direction (°TN). These data provide surrogates for nearshore wave energy and wave-induced currents. Ocean-level data were provided by the National Ocean Service from Tide Gauge 9410840 at Santa Monica Pier 8 km southeast of Topanga Creek (NOS, 2001). These data reflect the environment at the mouth of the Creek and were augmented by observations during specific surveys.

2.2 The Hillslope System

Preliminary field reconnaissance during late October and November 2000 identified six localities within the watershed wherein the hillslope system as a sediment source could be expected to yield useful information (Fig. 2-1). Each locality presented a different type of slope environment in terms of substrate and vegetation cover. Within five of these six localities, six sites were defined in terms of 10°, 20°, and 30° slopes and two differing aspects (e.g., north vs. south). At the remaining locality, 10 sites were defined at 20° slopes, 5 with an east aspect, 5 with a west aspect, and then subdivided between oak woodland and oak savanna. In short, the field sample comprised 40 sites, stratified in terms of substrate, vegetation, slope, and aspect. This far exceeds the number of sites involved in previous studies, many of which have been confined to one site, albeit often instrumented.

The methods used at these 40 sites were based on prior experimentation (Orme et al., 1996; Schwarz, 1995, Stege, 1996). At 36 sites, a 0.5 m^2 erosion plot was defined and given an upslope baffle, side ditches, and a downslope trough with a maximum capacity of 1462 cm^3 (Fig. 2-2). Each trough was inserted flush with the ground surface so that it collected sediment reaching it from the erosion plot as a result of overland flow (wet erosion) or dry ravel (dry erosion). For comparison with these constrained sites, four 20° sites were not given an upslope baffle or side ditches (see Chapter 4).

Following installation and depending on available personnel and site accessibility, sediment reaching each trough was collected at regular intervals during dry spells and, as far as possible, just before and just after each wet spell. Sediment was extracted by trowel, bagged and labeled. To minimize operator variation, the collection process was conducted by us or by a trained assistant. Care was taken not to disturb the trough or the



Plot and Trough Design

Figure 2-2. Erosion plot and trough design erosion site, and to ensure that the trough was well seated at the start of each new sample period. Because the number of erosion sites far exceeded the number originally proposed, and because troughs are superior to erosion pins in providing useful information, erosion pins were not used in this study.

Each sediment sample was air dried and weighed in the laboratory using a Sartorius Electronic Balance to precision of 0.01 grams dry weight. This value was converted to sediment loading per sample interval ($g\ d^{-1}$), which was in turn transformed into sediment yield ($g\ m^2\ d^{-1}$) and tabulated. The raw data sheets also included, as necessary, observations regarding organic matter, sediment caliber and any unusual features. Such data permit better understanding of the nature of hillslope erosion in the watershed. Every attempt was made during the sampling, collection, and measurement stages to ensure the accuracy and precision of measurement. Analysis and interpretation of these data are presented in Chapter 4.

The long-term denudation implications of these sediment yields are also discussed and a map of erosion potential based on data collected for the Topanga Creek watershed is provided (Fig. 4-24). USGS 1:24,000 topographic quadrangles for the watershed (Topanga, Canoga Park, Calabasas, Malibu Beach) provided the base map. Data from published geological maps were augmented by field work and remote sensing. Eight morpholithologic units are defined, their erosion potentials ranked, and the caliber of the sediment flux outlined.

2.3 Roads

Roads within the Topanga Creek watershed, both paved and unpaved, are a potential source of sediment to the stream channels within the basin. Road berms often represent from 0.5 to 3.0 m^2 of unconsolidated rock waste in cross-section which extend alongside roads above actively eroding stream banks. Such berms may also be eroded by overland flow along roads. In addition, the excavation of cut banks and the construction of roadside ditches and culverts afford further potential for erosion and sediment delivery to streams.

To address these issues, roadside berms along major public rights-of-way were repeatedly observed during the study period. It soon became apparent, however, that instrumentation of these berms would be impossible, even had appropriate instruments been available. Almost constant danger to field personnel from passing traffic, persistent disturbance by vehicles parking on or driving near berms, and frequent destruction and reconstruction of berms and cut banks by private property owners and highway authorities, all conspired to render meaningful quantification of road berms and cut banks impossible. However, the volume and erosion potential of these berms were evaluated as far as possible. Also, the drainage of certain unpaved public roads and trails was assessed and estimates made of accelerated erosion resulting from construction and maintenance practices, or lack thereof.

2.4 The Stream-Channel System

Sediment reaches streams in two principal ways - from overland flow and dry ravel on hillslopes, and from mass movement, including debris flows, landslide activity, and rock falls. In addition, sediment in storage within stream channels and their banks may be re-entrained by fluvial processes, while overbank flow may re-entrain sediment stored in floodplains and distant sideslopes. Human impacts in watersheds may deliver further sediment to streams, for example through the erosion or failure of unsealed roads and berms. All these processes are active at one time or another in the Topanga Creek watershed. Once sediment reaches a stream channel, whether or not it is transported, how far it is transported prior to deposition, and the caliber of the sediment load depends largely on stream competence and capacity, which are functions primarily of velocity and discharge.

In order to evaluate this process-response system, 23 reaches were initially identified at 9 locations within the watershed, 6 along the mainstem of Topanga Creek, the remainder along Old Topanga Creek, Red Rock Creek, Garapito Creek, and Santa Maria Creek (Fig. 6-3). Of these reaches, 18 were selected for repeat survey during the study period, to the limit of available human resources. These reaches were selected to address the extent to which stream channels serve as a sediment source and sediment sink within the system. Repeat surveys involved defining specific cross-sections with survey markers, surveying of channel dimensions at intervals, recording coordinate data to the record, and graphing observed profiles. Field data were surveyed and recorded to within 0.01 m.

From the survey data, the hydraulic geometry of the surveyed stream channels (width, depth. length, area, hydraulic radius, width-depth ratio, and slope) were measured. The magnitude of net scour and fill in each channel reach was then established for survey intervals, giving values for change at a section in m^2 to within 0.01 m^2.

Data concerning stream-channel change were related to kinematic variables derived from the stage-discharge rating curve established for the Topanga stream-gauge (Fig. 3-1), and from additional measurements of water stage and velocity made during each channel survey. The latter data did not necessarily reflect the kinematic variables responsible for channel changes, most of which responded to major flow events when it was too dangerous for direct measurement.

Stream conditions permitting, occasional data relating to suspended sediment discharge were obtained during the study using a USDH-48 depth-integrating wading sampler. Suspended sediment concentrations were determined by laboratory filtration and weighing, and expressed in milligrams per liter. The mean caliber and sorting (mm) of bedload in transit downstream were sampled.

2.5 The River-Mouth System

The major question for management of the estuary-ocean interface is to what extent the river-mouth system changes throughout the year. To address this question, it was originally envisaged in Task 1E of the RCDSMM Scope of Services that a series of 5 cross-sections would be sufficient between the Pacific Coast Highway and the ocean. However, it soon became apparent that a more thorough survey was necessary. Accordingly, repeat surveys designed to capture the changing morphodynamics of the river-mouth system were conducted. Elevations and relevant features within the public domain, extending 140 m alongshore and 170 m cross-shore, were recorded to within 0.01 m. The end product is a sequence of maps of the river mouth that reflect the changing morphodynamic state of the barrier-lagoon system or open estuary during the 2000-2001 water year. These states are interpreted in terms of the hydrodynamic data discussed above. This information provides input to the debate regarding the viability of lagoon restoration.

3. Hydroclimatology of the 2000-2001 Water Year

3.1 Atmospheric Circulation, Storms and Precipitation

Precipitation events for the 2000-2001 water year are defined in Table 3.1 and described below with reference to hourly precipitation received by gauges at Malibu, Cheseboro and Topanga. The Malibu automatic gauge is maintained by the California Department of Forestry at an elevation of 480 m above sea level in the mountains 2.5 km southwest of the Topanga Creek watershed, near the Saddle Peak Road interfluve above Fernwood. This gauge reflects precipitation associated with rain-bearing storms approaching Topanga from the west and southwest, as enhanced by the local mountains. This is most representative of precipitation likely to impact the watershed as a whole (Fig. 3-1). The Cheseboro gauge, maintained by the National Park Service at an elevation of 503 m above sea level 9 km northwest of Topanga Canyon, captures precipitation associated with storms approaching from the northwest, subject to less orographic enhancement over open dissected plateau country. The Topanga Patrol Station gauge, maintained by the Los Angeles County Department of Public Works at an elevation of 227 m near the floor of Topanga Canyon, should reflect precipitation within the central canyon area. This gauge's specific location usually yielded slightly higher precipitation values than the Malibu site during the 2000-2001 water year.

Eight wet spells occurred in the Topanga Creek watershed during the 2000-2001 water year, bracketed within ten dry spells (Table 3.1). The nature and intensity of these wet spells are critical to understanding the hydroclimatic forcing of geomorphic events within the watershed. For discussion, the values are rounded to the nearest millimeter.

Dry 1. October 1-25, 2000: The first 25 days of the water year were characterized by a continuation of the drought conditions that had typified the preceding summer. No precipitation occurred.

Wet 1. October 26-29, 2000: A brief period of weak frontal activity with two precipitation events occurred from October 26 to 29. Topanga recorded 101 mm and Malibu 95 mm during this wet spell. This early storm series did not seriously disrupt the general atmospheric circulation which was soon reestablished.

Dry 2. October 30, 2000 - January 7, 2001: This 70-day interval saw a return to the locally dry conditions of earlier weeks as the zonal circulation of the North Pacific Ocean carried storm tracks well to the north of southern California. A series of relatively weak winter storms were forced northward by continuing high pressure over the Great Basin and thus passed northeastward across Oregon, Washington and British Columbia. However, the development of high amplitude Rossby waves in the upper troposphere then allowed storms to penetrate southward towards the Gulf of Mexico bringing cold conditions to mid-continent. In early January, easterly winds associated with outflowing surface winds from the Great Basin and inflow towards a low pressure cell over northwest Mexico, favored the spread of fire in San Diego County.

Table 3.1: Wet Spells (mm) for the 2000-2001 Water Year, Malibu, Cheseboro and Topanga

Wet Spell	Malibu		Cheseboro		Topanga*	
	event	cumul.	event	cumul.	event	cumul.
October 11					[1.02]	1.02
1. October 26-27	74.93	74.93			81.28	
29	20.32	95.25			19.30	
subtotal	[95.25]	95.25	[21.59]	21.59	[100.58]	101.60
2. January 8	5.84	101.09			5.08	
10-11	136.14	237.24			166.63	
12	20.32	257.56			22.35	
subtotal	[162.31]	257.56	[114.30]	135.89	[194.06]	295.66
3. January 24	12.70	270.26			13.21	
26	25.40	295.66			23.37	
subtotal	[38.10]	295.66	[30.73]	166.62	[36.58]	332.24
4. February 7	0.25	295.91			1.02	
10	21.34	317.25			25.40	
11-13	86.11	403.35			87.37	
14	0.25	403.61			0	
subtotal	[107.95]	403.61	[83.57]	250.19	[113.79]	446.03
5. February 18	1.78	405.38			1.02	
19-20	20.83	426.21			27.43	
subtotal	[22.61]	426.21	[4.83]	255.02	[28.45]	474.48
6. February 23	3.05	429.26			3.05	
24-25	14.48	443.74			21.34	
25-26	50.04	493.78			67.06	
26	2.29	496.06			3.05	
27-28	12.45	508.51			13.20	
March 1					1.02	
subtotal	[82.30]		[66.29]	321.31	[108.72]	583.20
7. March 4-6	[90.42]	598.93	[80.52]	401.83	[89.41]	672.61
8. April 6-7 744.75	[35.81]	634.75	12.19	414.02	[33.53]	706.14
9. April 20-21	[16.26]	651.01	11.18	425.20	-	706.14
Grand Total		653.03		425.96		706.14

Note: All values are rounded to nearest 0.01 mm. Grand total includes spring and summer fog drip. Discrete events at Malibu and Topanga are shown for October-February wet spells.

From January 4 to 9, high pressure over the Great Basin began weakening and the sub-polar jet stream began moving along a more southerly track. Scattered drizzle and light rain occurred locally across southern California as a weak low pressure cell over northwest Mexico drifted north. On January 5-6, stratiform cloud over the Santa Monica Mountains heralded the approach of a trough of low pressure from the west and this eventually yielded light rain on January 8. This was the first measurable rain since October 29, a period of 70 days.

Wet 2. January 8-12, 2001: This rainy interval produced the first significant precipitation of the winter months. Rainfall came in three events amounting to 194 mm at Topanga, where 167 mm fell on January 10-11, including 33.53 mm during one hour before midnight and intensities exceeding 14 mm hr^{-1} during the preceding two hours. This event was associated with a deep low pressure system passing inland over northern California whose trailing cold front brought a 200-km wide belt of precipitation to southern California from between north and west. Rainfall on January 12 was linked to atmospheric instability behind this front. These rain events satisfied antecedent moisture deficits in the watershed. Cumulative rainfall for the water year was now 296 mm at Topanga.

At Malibu, 6 mm fell on January 8; 136 mm on January 10-11; and 20 mm on January 12, for a total of 162 mm During the January 10-11 event, Malibu rainfall intensities exceeded 14 mm hr^{-1} for 4 hours between 2000 and 2400 hours on January 10. Cumulative precipitation for the water year was now 258 mm.

Dry 3. January 12-23, 2001: This interval saw a return to dry conditions, variously warm to cool, as surface high pressure again became established over the Great Basin and such weak storms as did develop over the central Pacific were again deflected northeastward over the Pacific Northwest.

Wet 3. January 24-26, 2001: An increase in high cloud on January 23 heralded the approach of weak cold fronts from the northwest which brought rain on January 24 and again on January 26, with light scattered instability showers following each event. Topanga recorded 37 mm for these two events. Cumulative precipitation for the water year now amounted to 332 mm at Topanga.

At the Malibu gauge, the January 24 event yielded 13 mm between 0400 and 1100 h; the January 26 event 25 mm between 0400 h and 1800 h. Cumulative precipitation for the water year at Malibu was now 296 mm.

Dry 4. January 29-February 6, 2001: Following these brief rain events, an upper tropospheric ridge of high pressure along the California coast and surface high pressure over the Great Basin once again deflected Pacific storm activity to the north. Warm drying conditions prevailed to February 7.

Wet 4. February 7-14, 2001: Precipitation during this spell was related to the eastward passage of a succession of weak to moderately deep low pressure cells across central California, to secondary lows off southern California, and to trailing cold fronts moving spell amounted to 114 mm at Topanga, but most rain fell in two events – 25 mm on February 10 and 87 mm on February 11-13. Cumulative precipitation for the water year to February 14 amounted to 446 mm at Topanga. A total of 108 mm fell at Malibu, for a cumulative total of 404 mm.

Dry 5. February 15-17, 2001: A short dry spell with clearing conditions occurred between rain events.

Wet 5. February 18-20: The eastward passage of lows along the latitude of the California-Oregon border, with trailing cold fronts farther south, brought two pulses of light rainfall to the Topanga area. Topanga recorded 1 mm and 27 mm respectively. Cumulative precipitation for the water year now amounted to 474 mm at Topanga. Malibu recorded 2 mm on February 18 and 21 mm on February 19-20 for a cumulative total of 426 mm..

Dry 6. February 21-22, 2001: A further short dry spell occurred.

Wet 6. February 23- March 1, 2001: Precipitation during this spell was associated initially with low pressure off central California and then, from February 24 onward, with a cut-off low that formed and stalled for 3 days off the California coast before moving eastward on February 28. This synoptic situation spawned continuous overcast conditions with five rain events totaling 109 mm at Topanga. Precipitation occurred mostly as drizzle, but 67 mm of light to moderate rain fell at Topanga between noon on February 25 and 2 am on February 26. Cumulative precipitation for the water year now amounted to 583 mm at Topanga. Malibu recorded 82 mm during this wet spell for a cumulative total of 509 mm.

Dry 7. February 29-March 3, 2001: A further short dry spell occurred.

Wet 7. March 4-6, 2001: 89 mm of precipitation fell at Topanga in one prolonged event associated with a low pressure cell that stalled off central California, with a slow-moving cold front to the south. Cumulative precipitation for the water year now amounted to 673 mm at Topanga. At Malibu, 90 mm of precipitation fell bringing the cumulative total to 599 mm..

Dry 8. March 7-April 5, 2001: The remainder of March was relatively dry with occasional light fogs which produced no measurable precipitation.

Wet 8. April 6-7, 2001: A weak upper level trough brought cloudy conditions to southern California from the northwest on April 4, eventually yielding 36 mm of moderate rain and hail at Topanga from 2300 h on April 6 to noon on April 7. Cumulative precipitation for the water year now amounted to 706 mm at Topanga. A total of 36 mm of moderate rain and hail fell in Malibu during this time, for a cumulative total of 635 mm.

Dry 9. April 8-19, 2001: The passage of an upper level low pressure system produced brief spells of localized cold rain and hail to the Santa Monica Mountains on April 9, but these were significant only at higher elevations and were not recorded in or near the Topanga Creek watershed. Hydrologically, the period April 8-19 was thus dry.

Wet 9. April 20-21, 2001: A low pressure system off central California was associated with a trailing cold front which brought initially cloudy and then rainy conditions to the Santa Monica Mountains from the west. Light rainfall began on the afternoon of April 20 and was briefly moderate during the early hours of April 21 before passing eastward. This spell yielded 16 mm of precipitation at Malibu and but none at Topanga, for a cumulative total of 651 mm and 706 mm respectively.

Dry 10. April 22-September 30, 2001: After April 21, weather patterns characteristic of the transition from spring to summer became established. During late April and May, a relatively stable atmospheric circulation led to early morning and late evening fog and low stratus. Hydrologically this translated into condensation on exposed surfaces with fog drip from the vegetation cover. Occasional dry frontal activity related to low pressure systems farther north led to brief cool windy conditions following frontal passage but no rainfall.

The period from June through September witnessed full summer conditions in the Topanga Creek watershed. Despite the episodic occurrence of late night and early morning coastal fog, and of weak monsoonal conditions over the southwest United States and northern Mexico, the watershed experienced no storm activity and no measurable rainfall during this time. The close of the water year saw Hurricane Juliette moving northwest off western Mexico, bringing humid conditions but no rainfall to southern California.

Fog drip during this lengthy dry spell augmented precipitation for the water year, leading to year-end values of cumulative precipitation of 653 mm at Malibu and 706 mm at Topanga. Cheseboro to the northwest recorded 426 mm during the water year.

3.2 Runoff Regime

Higher stream flows within Topanga Creek, as recorded at the Topanga gauging station maintained by the Los Angeles County Department of Public Works, generally reflected the precipitation regime defined above, as shown in Figure 3-1. However, on-site flow measurements during this study showed that the stage gauge did not provide an accurate record of low flows during the year. Reaches within both main and tributary channels often lacked surface flows during autumn 2000 and summer 2001, although ponding, effluent seepage and subsurface moisture occurred.

Of the higher flows, eight of the wet spells were reflected at the gauging station during and shortly after rain events (Figure 3-1). The late October wet spell was only modestly reflected because much of the incident precipitation went to groundwater recharge. The January 8-12 wet spell produced the most prominent spike of the year, followed by three distinct spikes during the wet spells from mid-February to early March. The light rain events of January 24-26 were not reflected at the gauge but comparable light rain events in April, superimposed onto baseflow, showed minor spikes. Baseflow contributions increased slightly after the January rains, more so after mid-February, and were measurable through June 2001. The runoff regime is discussed further in the context of the channel system in Chapter 6.

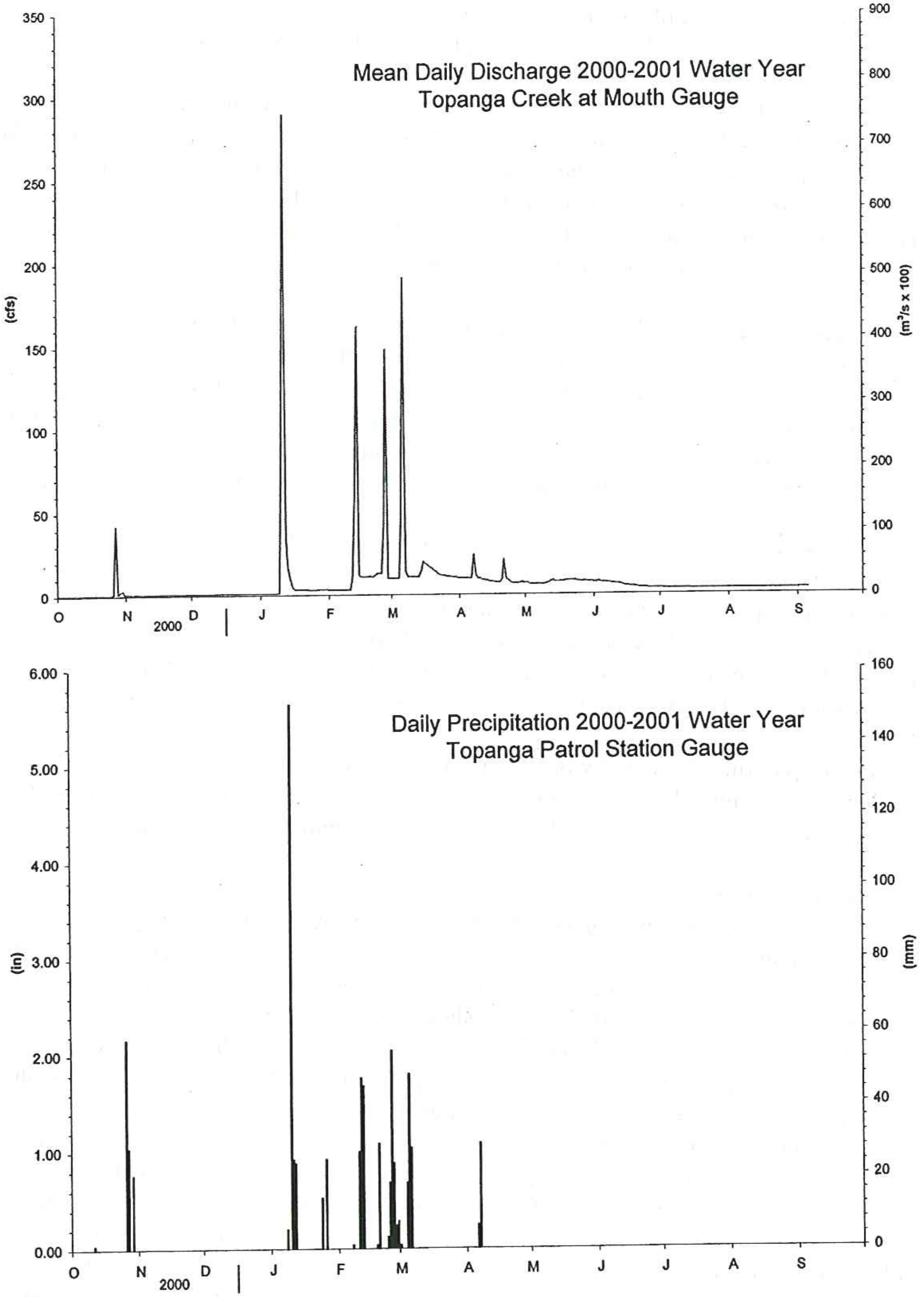


Figure 3-1. Precipitation and discharge, 2000-2001 Water Year

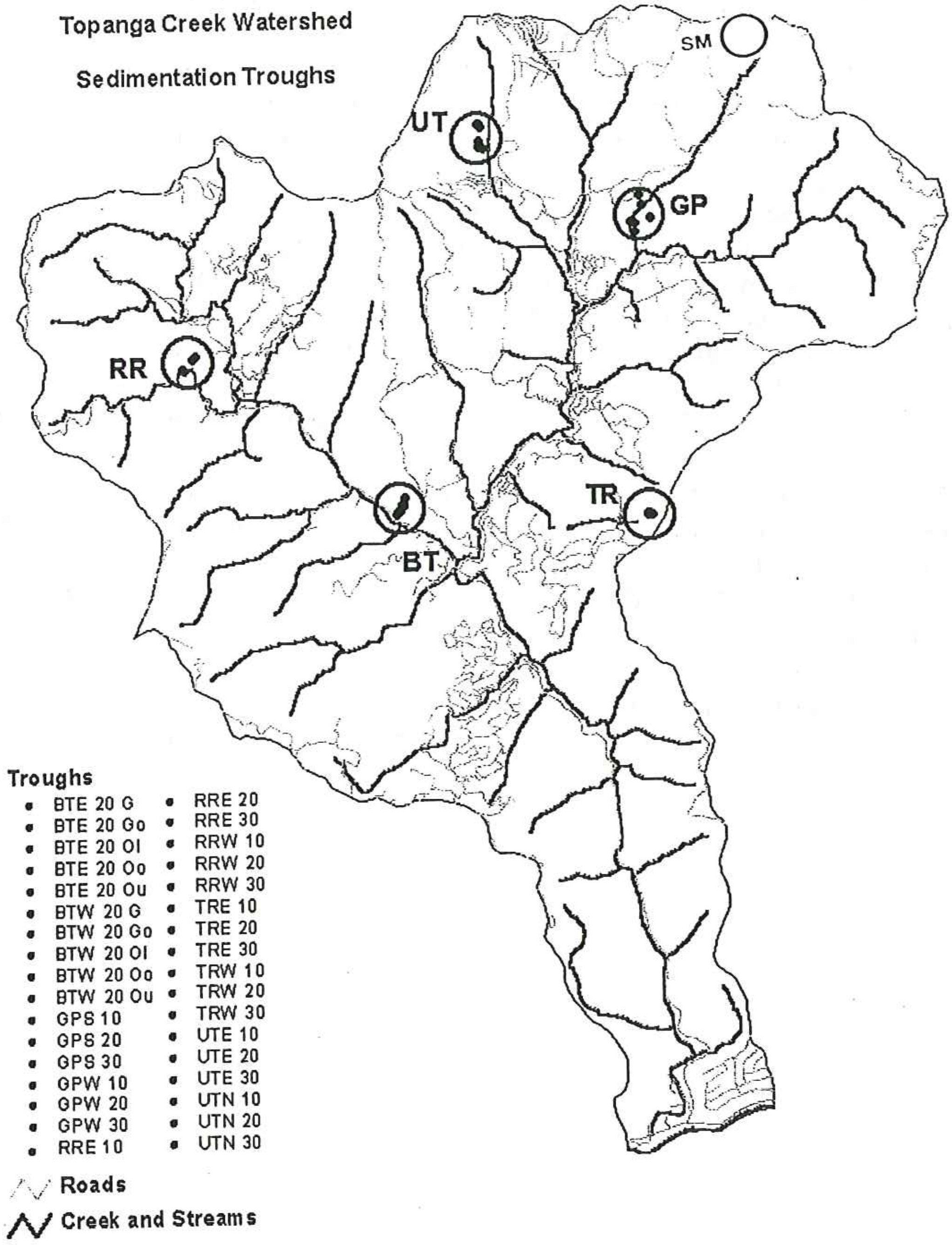
3.3 Synthesis

Hydroclimatic conditions for the 2000-2001 water year were unexceptional and precipitation totals at six stations in the southern California region (Oxnard to the west, Santa Paula to the northwest, Saugus to the northeast, Mount Wilson and Los Angeles Civic Center to the east, and Los Angeles International Airport to the southeast) recorded only 107% above the 30-year average (NOAA, 2001). Similarly, the three stations used in this study, Topanga, Malibu, and Cheseboro, recorded precipitation only slightly above average. This is helpful for management purposes because the hillslope and channel responses observed in this study may be considered normal, that is they have the highest probability of recurrence. However, as stated earlier, past experience shows that it is the exceptional conditions, specifically intense or persistent, high magnitude precipitation events leading to slope failure and stream floods, that are the most important triggers of geomorphic and sedimentologic change within the region.

Table 3.1 and Figure 3-1 emphasize three aspects of importance to surface relationships, namely: (1) individual rain events whose intensity influences rainfall-runoff relations on hillslopes and in stream channels; (2) cumulative totals within wet spells which affect soil saturation, overland flow, slope failure, and post-event stream discharge; and (3) the duration of ensuing dry spells which influence residual soil moisture, dry ravel on hillslopes, and the persistence of low flow and no-flow events in stream channels.

During the entire water year, precipitation totals at the Topanga gauge exceeded 25 mm hr^{-1} for just one hour within the year, from 2300 hrs to midnight on January 10 when 33.53 mm occurred, and exceeded 14 mm hr^{-1} only during five additional hours. The threshold at which widespread slope failure could be expected to occur is around 25 mm hr^{-1}. This was consistent with observations at the Malibu gauge, which did not experience any precipitation above 25 mm hr^{-1}. Thus precipitation, when it occurred, was mostly light, occasionally moderate, but never heavy--an abnormal situation for the region whose implications for earth-surface processes are discussed below.

Figure 4.1 Location of Sediment Trough Sites



4. The Hillslope System as a Sediment Source

Hillslope erosion and sediment transfers in the Topanga Creek watershed occur through several mechanisms, primarily in response to storm-related precipitation and resulting changes in slope hydrology that generate overland flows and debris flows. In addition, rockfalls and deep-seated landslides may occur many days or weeks after precipitation events. Furthermore, dry ravel occurs between precipitation events and may be accentuated by animal activity and fire. Hillslopes are thus, to a greater or lesser extent, sources of sediment throughout the year but there is a paucity of real data concerning the frequency, magnitude and intensity of erosion and sediment production. This project was designed to offer insight to hillslope processes during one water year, thereby providing information on hillslope erosion within the Topanga Creek watershed hitherto not available.

4.1 Hillslope Sampling

As outlined in Chapter 2.2, 40 sites at 6 localities were used to sample hillslope erosion and sediment mobility within the upper and central watershed (Fig. 4-1). Mass movement was also investigated. Conditions within the small lower watershed, mostly inaccessible private property at the time of the study, were extrapolated. Sample sites were as follows:

Upper Topanga [UT]: 6 sites in grassland overlying claystone and siltstone of the Modelo Formation, and alluvium derived there from, near the confluence of three intermittent streams in the uppermost reach of the mainstem of Topanga Creek. Of these, 3 have a north aspect and 3 an east aspect. Each set includes a convex slope catena at 10°, 20°, and 30°.

Santa Maria [SM]: 6 sites overlying the Modelo Formation near the headwaters of Santa Maria Creek. Of these, 3 represent a convex slope catena with a south aspect in grassland overlying claystone and siltstone of the Modelo Formation, and 3 a concave catena with a west aspect beneath chaparral overlying siltstone and sandstone of the same formation. Each set involves sites at 10°, 20°, and 30°.

Garapito [GP]: 6 sites near the confluence of Santa Maria and Garapito creeks. Of these, 3 south-facing sites overlie complex indurated slope deposits, probably an unmapped landslide on sandstone of the Lower Topanga Formation, now stable, beneath oak woodland, and involve 10°, 20°, and 30° slopes of south aspect. The other 3 west-facing sites represent a concave grassland catena of 30°, 20°, and 10° slopes on a transition from sandstone substrate to a fluvial terrace.

Trippet Ranch [TR]: 6 sites near the crest of a knoll formed of basaltic andesite of the Conejo Volcanics at the eastern margin of the watershed 0.5 km east of Trippet Ranch. Of these, 3 sites lie on a west-facing convex catena at 10°, 20° and 30° beneath oak savannah (scattered oaks amid grassland). The other 3 sites lie at similar angles on an east-facing convex catena beneath chaparral.

Backbone Trail [BT]: 10 sites on the Backbone Trail where it crosses Old Topanga Creek, all on 20° slopes. Of these, 3 east-facing sites lie in oak woodland (1) and oak savanna (2) west of the creek, and 3 west-facing sites in oak woodland (2) and oak savanna (1) east of the creek. On each side of the creek, 2 open sites (1 each under oak woodland and oak savanna) were established without upslope barriers or side ditches for

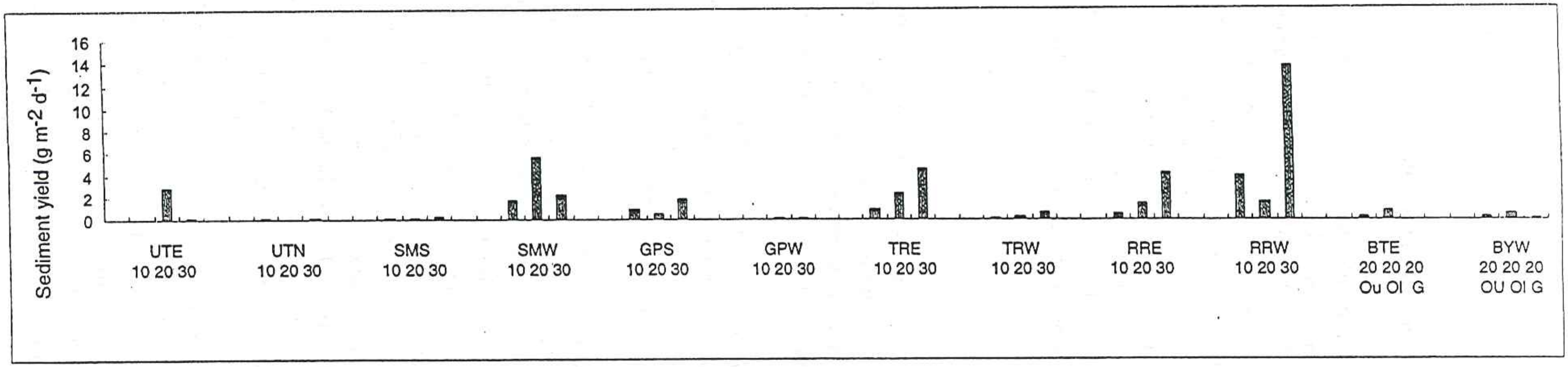


Figure 4.2 Mean daily sediment yeild for each erosion plot

comparison with constrained sites. These sites occupy colluvial soil and landslide deposits involving sandstone and siltstone facies of the Lower Topanga Formation.

Red Rock Canyon [RR]: 6 sites in Red Rock Canyon on hills above the Ranger Station, each representing a 10°, 20° and 30° slope catena. Of these, 3 have a east by south aspect, and 3 a west by north aspect. These sites overlie bare soils developed on variably consolidated, coarse sandstone and gravel of the Sespe Formation, dipping north to northwest beneath chaparral.

4.2 Overland Flow Erosion, Dry Ravel, and Sediment Yields

4.2.1 General observations

Following installation of the 40 erosion plots in November and December 2000, eroded hillslope sediment captured by each trough was collected between 10 and 19 times during the water year. Depending on personnel availability and weather prediction, collection was synchronized as far as possible before and after wet spells. Some 658 samples were collected for these sample intervals, the data from which are presented in Tables 4.1 through 4.7, presented as appendices to this chapter.

Table 4.1 found in Appendix A presents erosion data for each plot by sample period (date) and interval (days) in terms of total dry weight/organic weight (grams), sediment yield (grams per square meter per day), and sediment caliber (modal class). Table 4.2 (also in Appendix A) presents summary data for each plot for the period of record (total days). Table 4.3 (Appendix A) stratifies these data into wet and dry intervals and shows wet season values as a factor of dry season values.

Tables 4.4 through 4.7 further stratify these data in terms of slope declivity, slope aspect, vegetation category, and geological substrate. The following interpretations focus on the common denominator of mean daily sediment yield. This value is extrapolated to an annual sediment yield (t km^{-2} yr^{-1}) in Tables 4.2 and 4.4 through 4.7 in order to derive values for long-term denudation rates. The following analysis and discussion are based on these tabular data, presented for clarity as graphical plots and regressions.

4.2.2 Nature of Erosion and Sediment Yield

As shown by Figure 4-2 and Table 4.2, sediment yields varied significantly both within and between erosion plots during the 2000-2001 water year. Sediment yields ranged from numerous zero values at several sites during the later dry season to as much as 106 g m^{-2} d^{-1} for one site during one wet spell. As discussed below, most erosion plots yielded some sediment continuously during most of the study period and these yields correlated in varying degrees with environmental variables -- temporally with wet and dry spells, and spatially with specific conditions imposed by slope declivity, slope aspect, vegetation category, and substrate.

The total dry weight of material derived from each erosion plot comprised both mineral or organic sediment (Table 4.1, Appendix A). As shown in Figure 4-3, mineral sediment correlates strongly with total dry weight (r^2=0.98), although this involves a strong element of autocorrelation. Nevertheless, small organic debris (twigs, leaves, insects) became significant when sediment yields were low, notably during dry spells, but insignificant relative to mineral sediment with higher loading and during and immediately after wet spells. Figure 4-4 suggests that organic content diminishes as a

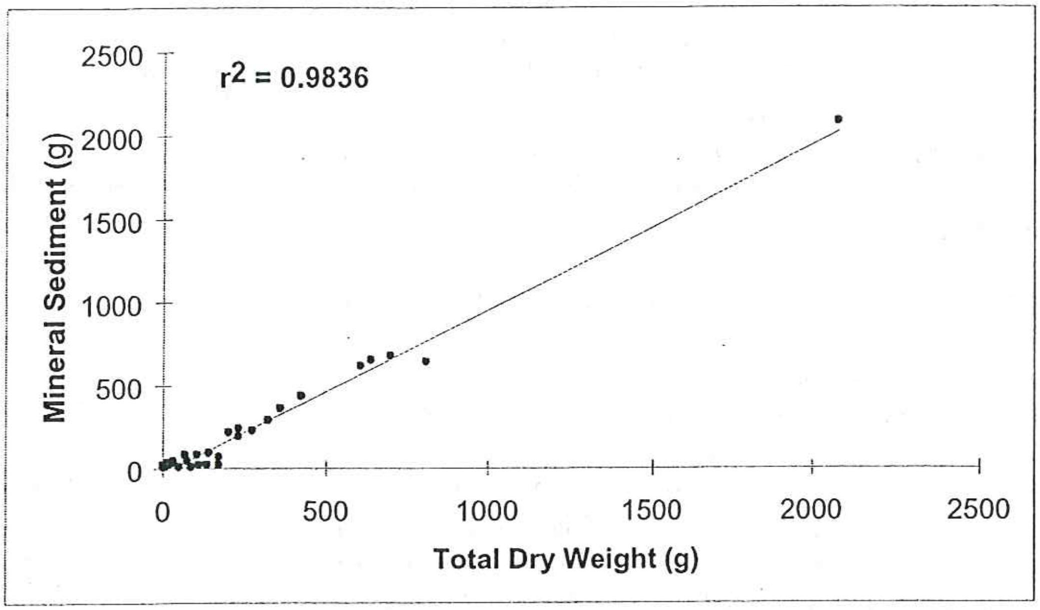


Figure 4.3 Relationship between mineral sediment and total dry weight of eroded Sediment (all plots)

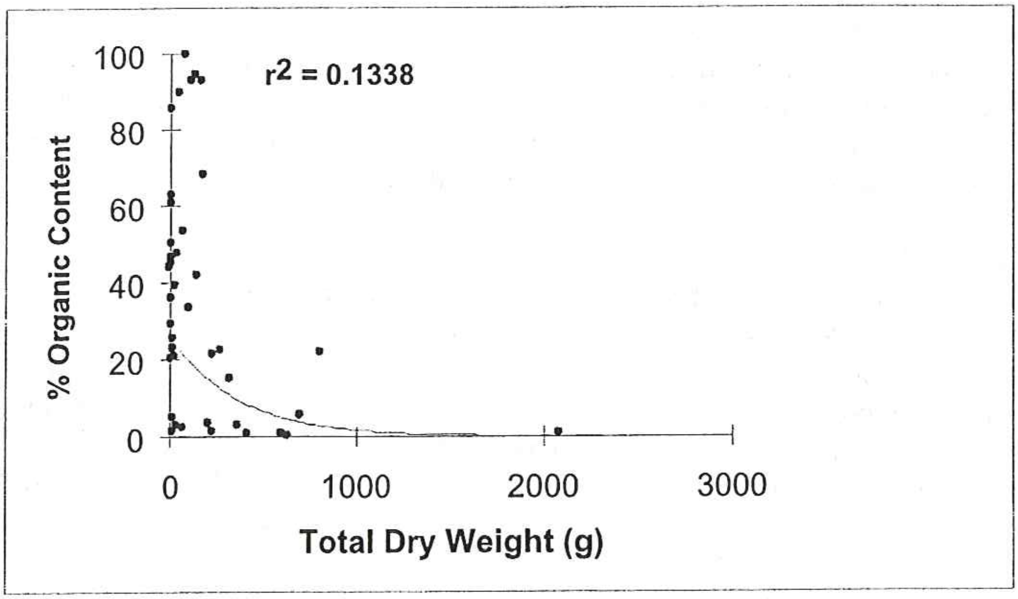


Figure 4.4 Relationship between percent organic matter and total dry weight of eroded Sediment (all plots)

weak negative exponential function (r^2=0.13) as total dry weight of eroded sediment increases.

Mineral sediment yields from the erosion plots ranged from rock chips and pebbles in the gravel category (>2 mm) to silt and clay (<0.63 mm). Rock chips were frequent products of the Conejo Volcanics, some basaltic clasts reaching 40 mm in long axis and 22 g in weight. Small pebbles (4-8 mm), grit (2-4 mm), and very coarse to coarse sand (2-0.5 mm) were common in sediment yielded by the Sespe Formation. Medium sand was comparatively rare but fine to very fine sand (0.25-0.063 mm) locally more widespread. Silt (0.063-0.004 mm) was the predominant material yielded by the Modelo Formation in the upper watershed. Silt, with lesser amounts of clay and fine sand, often appeared in the erosion troughs as clods, cohesive when damp after rain spells but powdery on desiccation. With higher clay content, clods remained cohesive on drying. With respect to hillslope transport mechanisms, all clods responded as small angular gravels, participating in ravel during dry spells, but disaggregating in water to form the fine suspended load of rills and streams. Modal sediment caliber and sediment yield are critical variables in the designation of erosion potential within the watershed.

Some animal disturbance of erosion sites was common throughout the study period as a result of activity by earthworms, insects, burrowing mammals, packrats, and occasional larger mammals. Such activity is normal to the slope environment and is therefore integrated with the results without further comment. In one instance, however, at UTE 30 between 24 April and 28 June 2001, a gopher colony invaded the site, temporarily generating sediment yields far in excess of the norm. The resulting high sediment yields have been discounted in the following analysis, where the site is presented as UTN 30*. Also, site SMW 20 was marginally influenced by packrat midden construction during the year and yielded organic debris and soil clods in excess of anticipated values. As this activity continued intermittently throughout the year, the data are included. The role of gophers and other organisms is important for preparing soil for erosion and enhancing throughflow and pipeflow. Both spatially and over the longer term, such animal activity probably exceeds the role of human disruption and merits further investigation beyond the scope of this study.

4.2.3 Temporal Distribution of Sediment Yields

Figure 4-5 plots cumulative erosion of mineral sediment against precipitation events for the Topanga station for the 2000-2001 water year. Although several erosion plots were established in November 2000, these were not in place in time to capture the effects of the late October wet spell. Thus all data have been normalized to zero on December 6, by which time all plots were functioning. Cumulative erosion data are shown separately for the 6 erosion plots in Red Rock Canyon and the remaining 30 constrained plots (the 4 open plots [BTE 20 Oo and Go, BTW 20 Oo and Go] are not appropriate for further analysis).

In general, the effect of rainy-season precipitation and runoff is readily evident in Figures 4-5. Significant erosion began with the January 8-12 wet spell and continued through the April 6-7 wet spell. Dry intervals between wet spells saw reduced but not insignificant erosion while the prolonged summer drought after April 7 continued to see some erosion from dry ravel and animal disturbance.

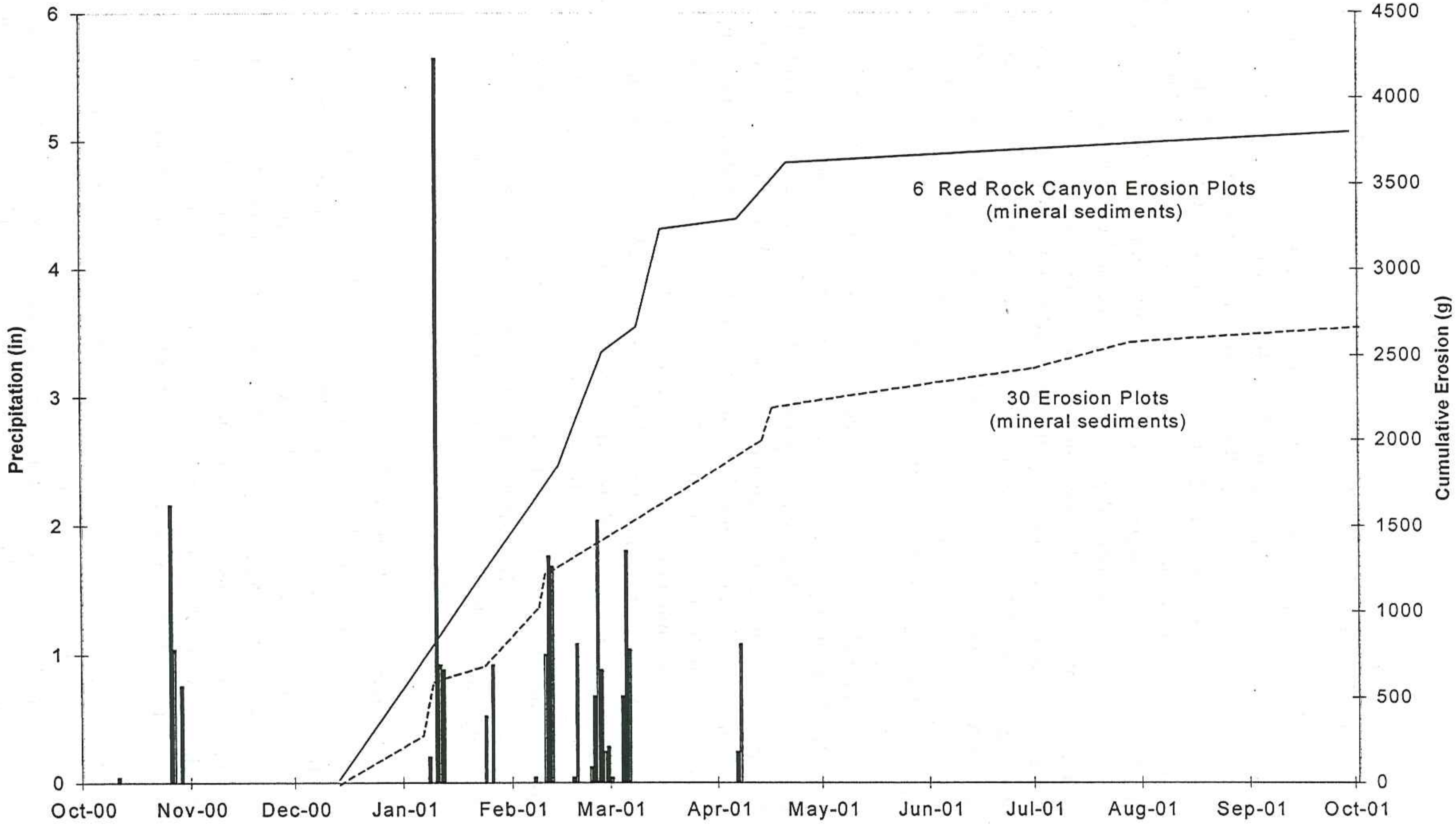


Fig. 4-5. Cumulative erosion and precipitation record, Topanga Creek watershed, 2000-2001 water year. Cumulative erosion is the cumulative dry weight of all mineral sediment from each erosion plot. Precipitation is the Topanga Patrol Station record described in Chapter 3.

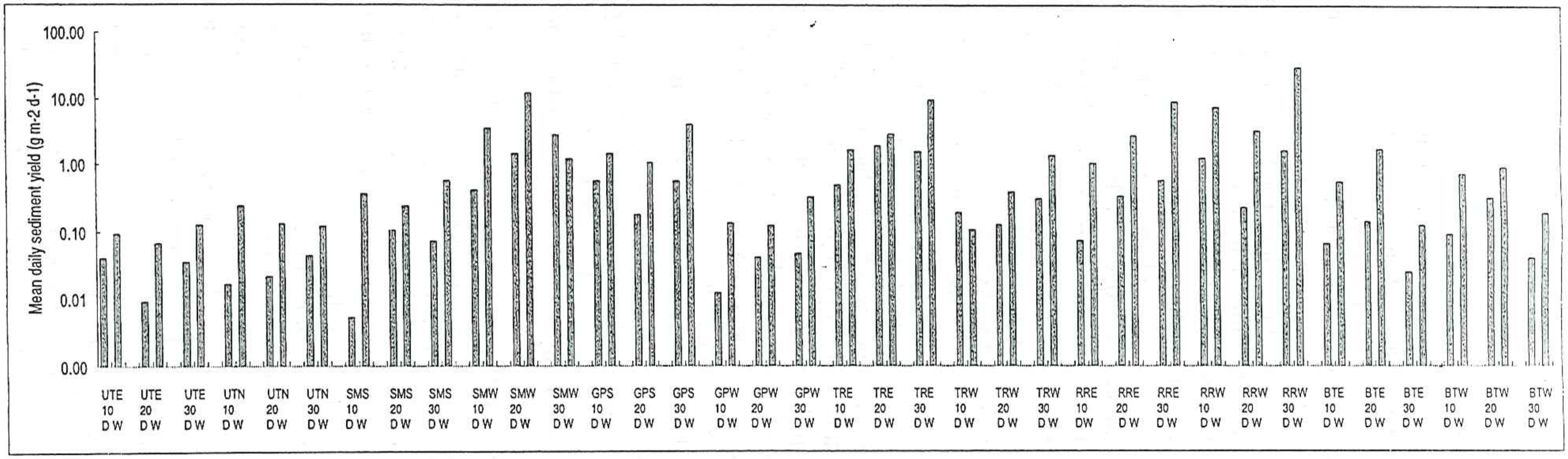


Figure 4.6 Mean daily sediment yeild (g $m^{-2}d^{-1}$) for each erosion plot, declivity, And dry (D) vs wet (W) spell as per Table 4.3

In detail, however, the relationship between wet spells, dry intervals and erosion is more complex. Whereas one may anticipate increased surface erosion with increased rainfall, the quality of the precipitation (magnitude, frequency, persistence, intensity), the antecedent moisture and hydrophobicity within the soil, and the nature and duration of desiccation (duration and intensity of temperature and wind effects) during ensuing dry spells all influence the erosional response. The field data indicate, for example, that drizzle and light rain initially diminish the potential for surface erosion of dry soils by increasing particle cohesion and surface sealing. However, where light precipitation persists, a threshold is reached wherein surface sealing promotes overland flow and initiates particle detachment, especially among coarser materials. During ensuing dry spells, erosion often diminishes as overland flow ceases but, as soils desiccate and lose cohesion, so sediment yields again increase as a result of dry ravel. In contrast, heavier rainfall on near-saturated soils soon produces increased erosion from overland flow. These observations are derived from a careful assessment of the quantitative relationship between precipitation properties revealed by the Topanga and Malibu gauges and the sediment yields for each plot. Further evaluation of these relationships requires continuous measurement of antecedent moisture, precipitation properties, infiltration capacity, throughflow, and overland flow for each site before, during and after every precipitation event. Such a study was beyond the scope of the present project. Despite qualifications, the following relationships were observed.

The 70-day dry spell between 29 October and 8 January produced little dry ravel except on steeper slopes unprotected by the vegetation canopy, most notably on 30° slopes within Red Rock Canyon. Unprotected slopes also recorded a few grams of airfall deposition following Santa Ana winds. Abundant leaf litter accumulated in many troughs and incidental animal disturbance was locally noteworthy.

The wet spell of 8-12 January, the wettest of the year, yielded a significant increase in hillslope erosion and sediment delivery, which on steeper slopes was several magnitudes in excess of prior dry-spell values. Slopewash of small organic debris also occurred. The relatively intense rainfall from 2000 h to 2400 h on 10 January was mostly responsible for this increased erosion.

The following dry spell of 13-23 January saw little erosion and sediment delivery, in large measure because the soil surface had been well sealed by moisture during the preceding rains and had insufficient time to desiccate. The light rains of 24-26 January revealed a modest increase in erosion. In the following dry spell of 27 January-6 February, the soil dried more thoroughly and dry ravel again occurred, generally at levels higher than in the autumn dry spell.

During the four wet spells of February and early March a significant increase in hillslope erosion and sediment delivery occurred, most notably during the rains of 10-13 February. On steeper slopes, sediment yields were considerably in excess of dry-spell values. Intervening dry spells saw less erosion, largely because the soil surface had been sealed by moisture during the preceding rains and there was insufficient time for complete desiccation between wet spells. However, as surface soils desiccated in the month-long dry spell after 6 March, so dry ravel became more important, again at levels above those of the autumn and early winter dry spells.

Sediment yields in April were well constrained by sampling. The first brief wet spell on 6-7 April generated a small amount of erosion. Thereafter, as slope environments desiccated at varying rates, temporal patterns were for a while slightly erratic. From May through September, all surficial hillslope materials desiccated and many erosion plots were yielding little or no sediment by late summer. Nevertheless, mineral sediment continued to move during these summer months as a result of dry ravel and animal activity, notably on steeper slopes underlain by non-cohesive clastic material. Small amounts of organic debris continued to accumulate in many troughs.

4.2.4 Effect of Precipitation Seasonality

Figure 4-6 and Table 4.3 (Appendix A) present collated data for each site during the dry and wet seasons. For 30 erosion plots (excluding Red Rock Canyon), the dry season combines two periods - (1) from sampling initiation to 5 January 2001 (troughs were sampled this day because the synoptic situation heralded rain, although it did not rain locally until 8 January; and (2) from 24 April to 30 September, 2001. The dry season for these 30 troughs thus represents a record of between 192 and 215 days. The wet season represents the 109 days between 5 January and 24 April 2001, a period during which rain actually occurred on only 28 days but, except for surface drying, soils remained damp throughout. The 6 plots in Red Rock Canyon were sampled differently, comprising a 182-day dry season and a 123-day wet season.

Dividing the total dry weight of sediment (g m^{-2}) by days of record shows the relative significance of the dry and wet seasons to erosion (Table 4.3, Appendix A). Ignoring end members, at all but two sites wet-season erosion exceeded dry-season erosion by a factor of between 2 and 17. At two sites, dry season erosion was greater - at SMW 30 because of enhanced packrat activity at nearby SMW 20 during the dry season; and at TRW 10, a low-yielding site throughout the year. These results are no surprise to those familiar with Mediterranean-type environments, but they do provide real data on seasonal erosion not previously available for this region.

4.2.5 Effect of Precipitation Magnitude and Intensity

To analyze the relationship between erosion and precipitation variables, the data on total dry weight of eroded sediment presented in Table 4.1 (Appendix A) were grouped into six wet spells for which discrete data were available for precipitation magnitude and intensity from the Malibu and Topanga gauges. For each wet spell, the sediment data were collated for all 36 erosion plots (n=216) and a subset isolated for the 6 Red Rock Canyon plots (n=36). From these data, mean erosion (g) was calculated for each wet spell. Precipitation magnitude was defined as total precipitation (T) for a specific wet spell. Precipitation intensity was defined by identifying the maximum 60-minute intensity (I_{60}) for Malibu and the maximum 15-minute intensity for (I_{15}) for Topanga. A combined precipitation factor, T x I_{60} or I_{15}, was used to explore for a more complex relationship, if any. The mean erosion values and precipitation variables for each of the six wet spells were then subject to regression analysis.

Mean erosion from all 36 erosion plots for each wet spell correlates quite well with Topanga precipitation magnitude (r^2=0.65) and this relationship is incorporated to some extent in the combined factor (r^2=0.52) (Figs. 4-7, 4-8, 4-9). However, the relationship with 15-minute precipitation intensity is quite low (r^2=0.37), in part because of a statistical artifact which causes the 15-minute intensity values to cluster but perhaps also because intensities within the lower canyon are not representative of events on the higher hillslopes.

Again, as with all plots, mean erosion from the 6 Red Rock Canyon plots for each wet spell correlates strongly with Topanga precipitation magnitude (r^2=0.92), modestly with the

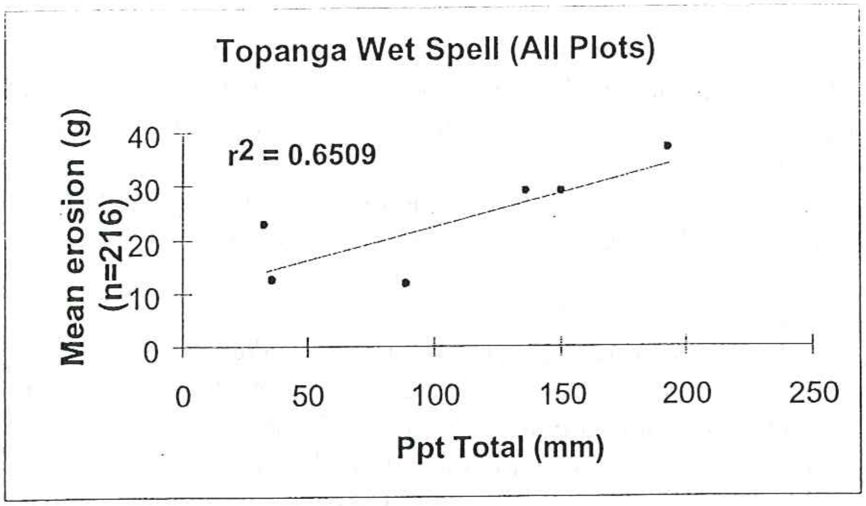


Figure 4.7 Mean erosion for all plots vs wet-spell total precipitation (mm)

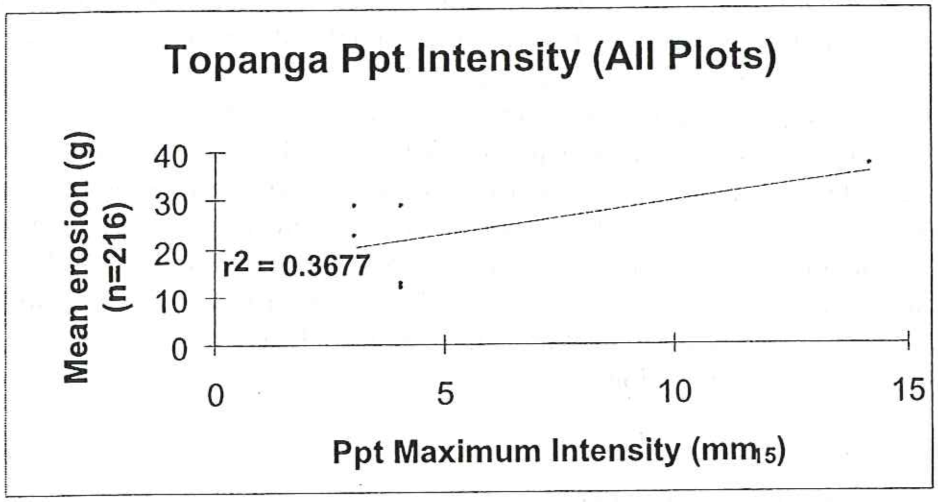


Figure 4.8 Mean erosion for all plots vs maximum intensity of precipitation (mm_{15})

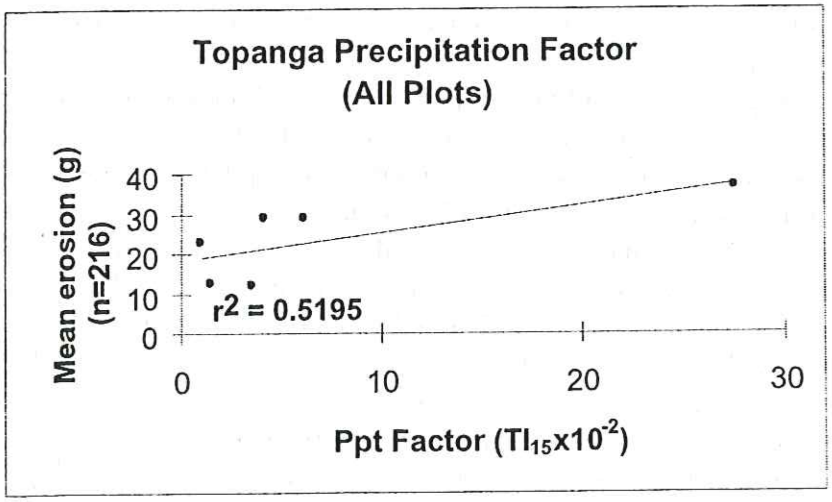


Figure 4.9 Mean erosion for all plots vs precipitation factor ($TI_{60} \times 10^{-2}$)

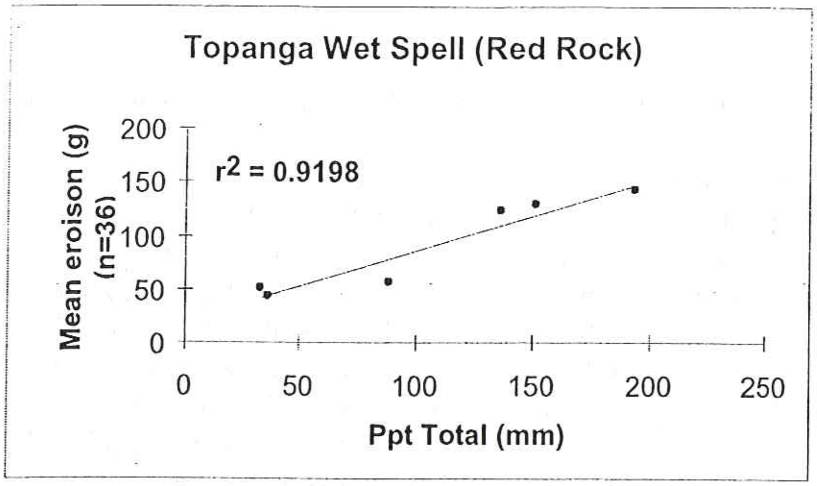


Figure 4.10 Mean erosion for Red Rock Canyon vs wet-spell total precipitation (mm)

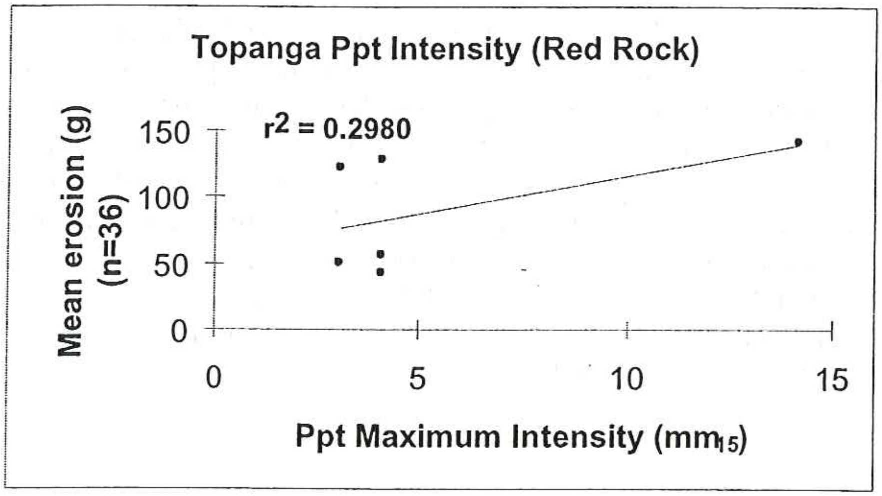


Figure 4.11 Mean erosion for Red Rock Canyon vs maximum intensity of precipitation (mm_{15})

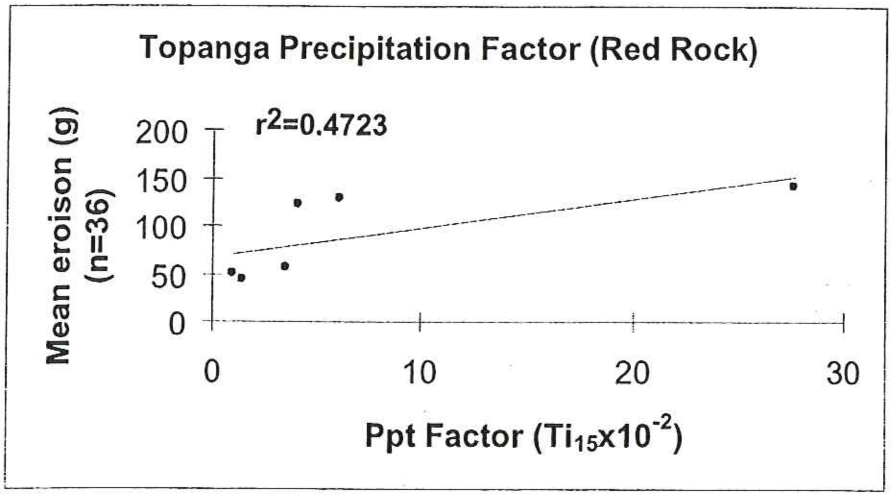


Figure 4.12 Mean erosion for all Red Rock Canyon vs precipitation factor ($TI_{60} \times 10^{-2}$)

combined factor (r^2=0.47), and weakly with precipitation intensity (r^2=0.30) (Figs. 4-10, 4-11, 4-12).

Mean erosion from all 36 erosion plots for each wet spell correlates quite well with the Malibu precipitation variables (Figs. 4-13, 4-14, 4-15). The strongest correlation is between mean erosion and 60-minute precipitation intensity (r^2=0.64), indicating that erosion increases as precipitation intensity increases. The correlation with the combined precipitation factor is slightly lower (r^2=0.61), and with lower still with magnitude (r^2=0.55).

Mean erosion for the 6 Red Rock Canyon plots for each wet spell correlates most strongly with Malibu precipitation magnitude (r^2=0.79), but relatively weakly with 60-minute precipitation intensity (r^2=0.45) and the combined factor (0.46) (Figs. 4-16, 4-17, 4-18). This suggests that, with respect to the relatively non-cohesive sands and grits derived from the Sespe Formation, the precipitation amount is alone sufficient to trigger particle movement and that the larger the amount (i.e., duration rather than intensity), the more sediment that will move.

In summary, Topanga precipitation amounts would seem to be relatively good predictors of erosion magnitude; Malibu amounts only slightly less so. Conversely, Malibu 60-minute precipitation intensities are significantly better predictors of erosion magnitude than Topanga 15-minute intensities, probably because the latter are relatively unrefined, favoring clustering, whereas the former are abetter reflection of the time it takes for intensity to influence slope processes. Short bursts of high intensity rainfall are less effective in mobilizing sediment than longer bursts, especially where antecedent slope moisture is low. The combined factor, though used by other researchers, did not add significantly to the level of explanation. Correlations between Red Rock Canyon erosion data and both Malibu and Topanga precipitation magnitudes are consistently higher than for all 36 plots, indicating greater statistical noise within the latter group.

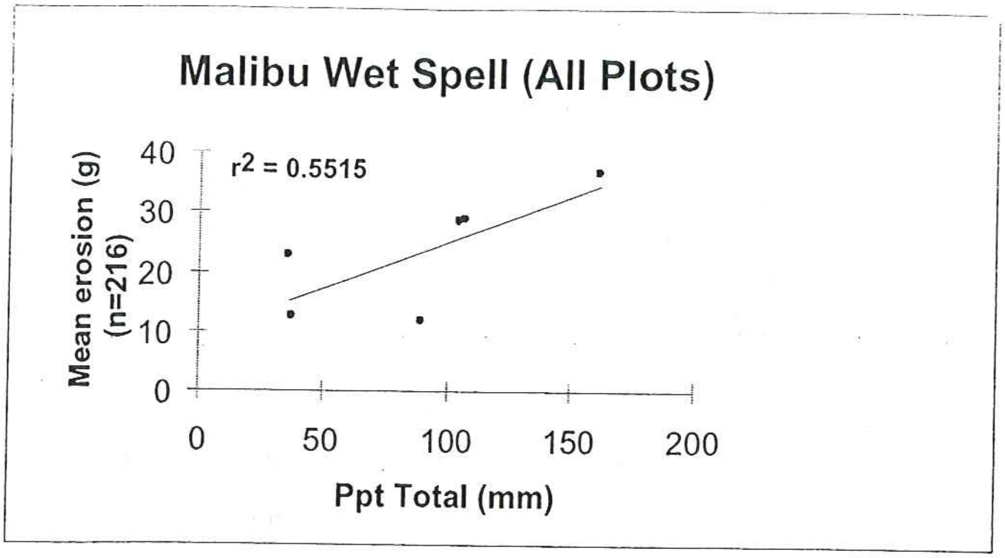


Figure 4.13 Mean erosion for all plots vs wet-spell total precipitation (mm)

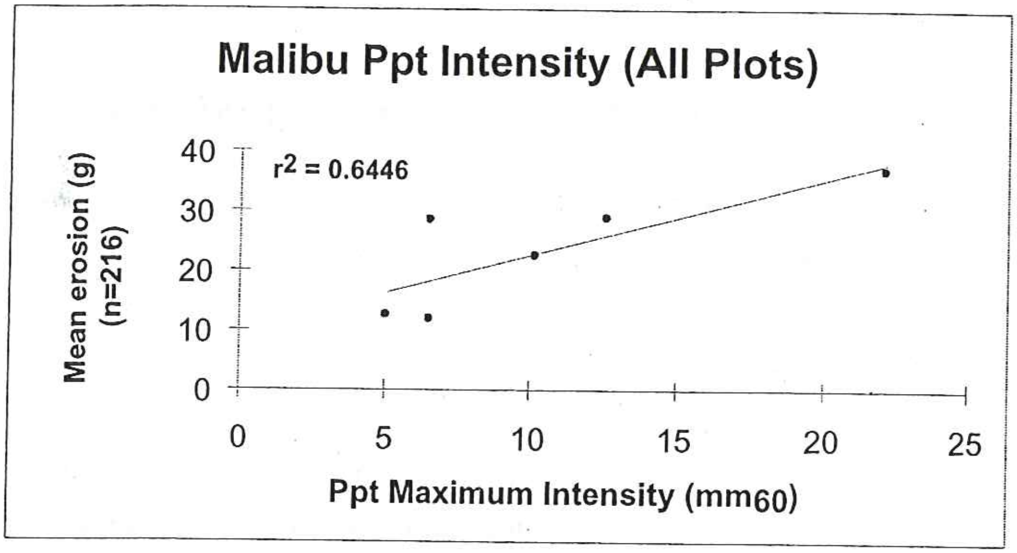


Figure 4.14 Mean erosion for all plots vs maximum intensity of precipitation (mm_{60})

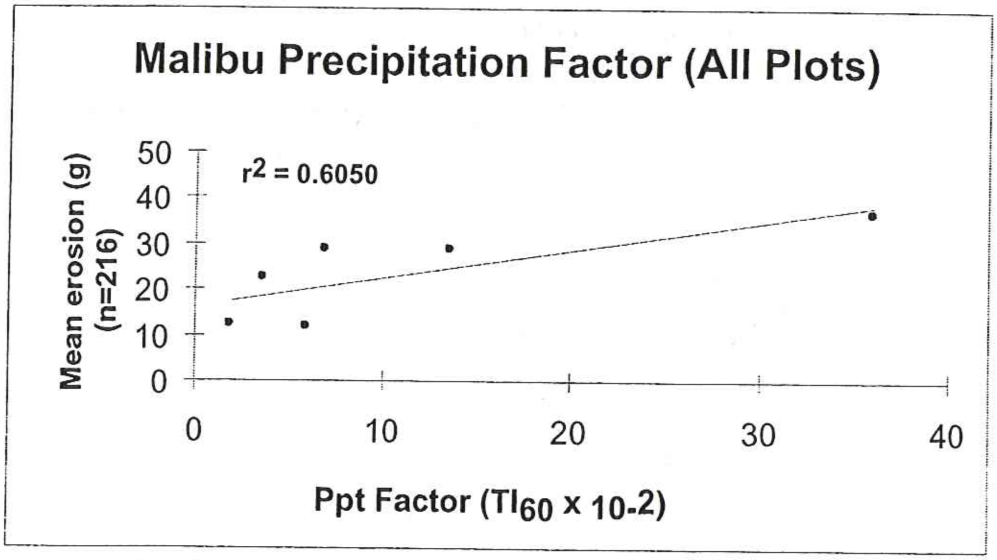


Figure 4.15 Mean erosion for all plots vs precipitation factor ($TI_{60} \times 10^{-2}$)
Plot reflects mean mean value of erosion, 216 plots, for each of 6 wet spells

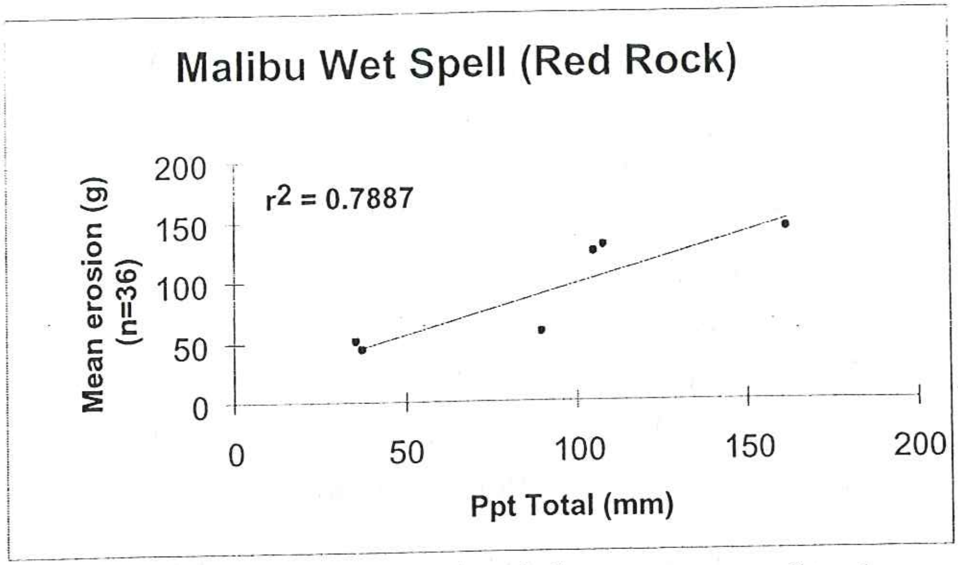


Figure 4.16 Mean erosion for Red Rock Canyon vs wet-spell total precipitation (mm)

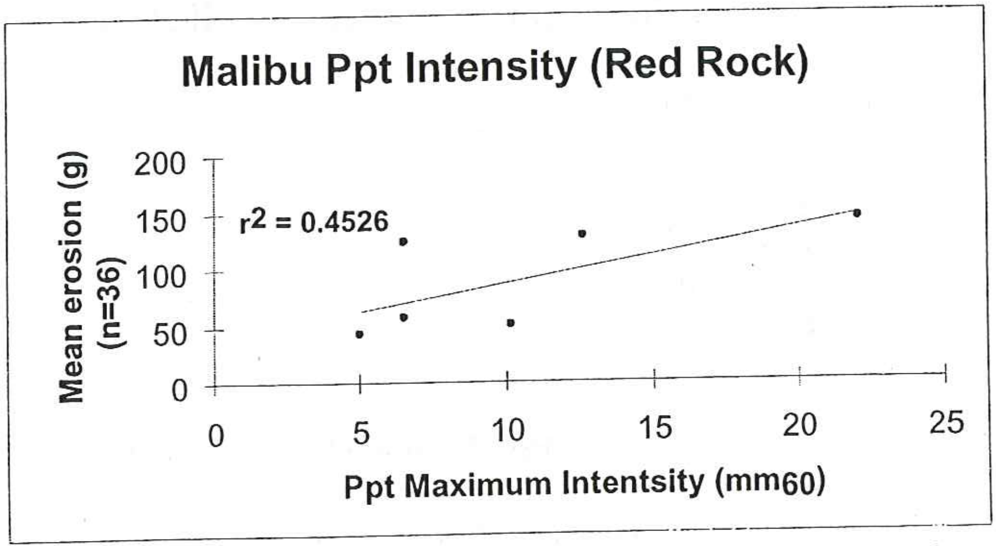


Figure 4.17 Mean erosion for Red Rock Canyon vs maximum intensity of precipitation (mm_{60})

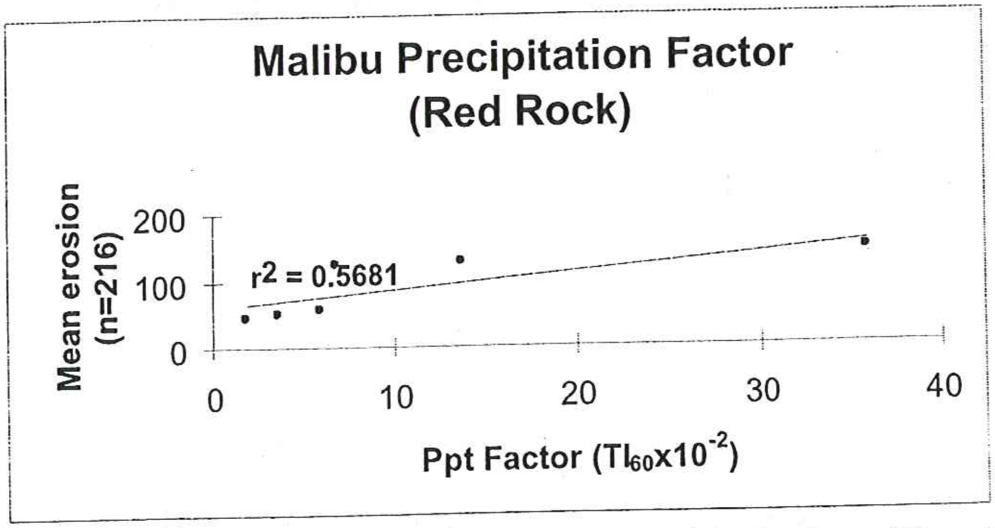


Figure 4.18 Mean erosion for all Red Rock Canyon vs precipitation factor ($TI_{60} \times 10^{-2}$)

4.2.6 Effect of Slope Declivity

The sampling design was chosen to evaluate the effects of three slope categories on hillslope erosion and sediment yield during the study period, as shown in Tables 4.1 and 4.2 (Appendix A). There is much noise in these data. Thus, for clarification, Table 4.4 and Figure 4-19 present summaries for all sites within each slope category.

Assuming that overland-flow erosion is zero in flat (0°) areas, Table 4.4 and Figure 4-19 reveal an increase in mean daily sediment yield between 0° and 10°, but little difference in yield between 10° and 20° slopes. A significant increase in mean daily sediment yield occurs between 20° and 30° slopes. In other words, hillslope erosion functions within relatively narrow margins from 10° to 20°, but on steeper slopes accelerates either by crossing a threshold at which slope processes intensify or by reaching a point in some positive exponential function whereby particle entrainment is facilitated (Fig. 4-20). The precise nature of this acceleration would vary with other factors, such as vegetation cover and substrate, and could be revealed by controlled experimentation, say at 1° intervals, throughout numerous slope catenas. Whereas this is beyond the scope of this project, it points the way to future study. In any case, it stresses the need to manage slopes above 20° with considerable care, especially with respect to vegetation change, and to manage slopes below 20° so as to avoid lowering the threshold for accelerated erosion. Management also applies to impacts such as fire-road grading and placement of culvert downspouts.

Figure 4-19 Mean Daily Sediment Yield vs. slope declivity

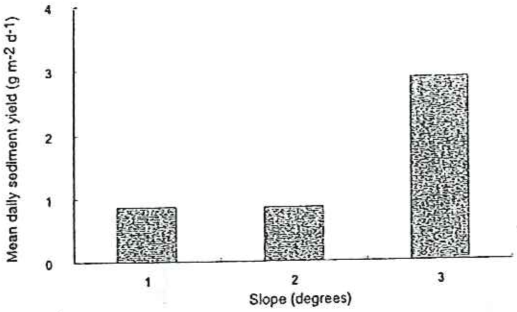
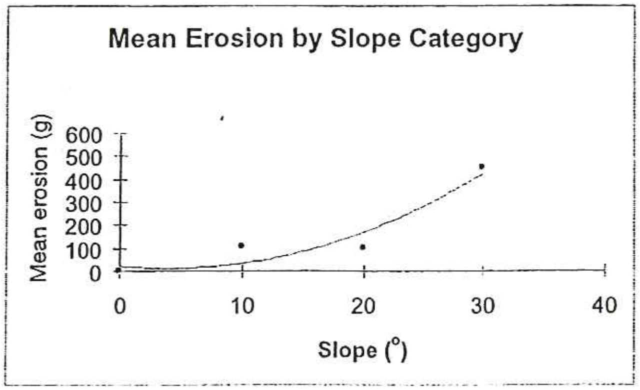


Figure 4-20 Mean erosion vs. slope category. Mean erosion is the value of total erosion for each slope category where 10^0n=10, 20^0=16, 30^0=10 for 2000-2001 water year.



4.2.7 Effect of Slope Aspect

The sampling design also sought to evaluate the effect of four slope aspects on hillslope erosion and sediment yields, as shown in Tables 4.1 and 4.2 (Appendix A). Again, there is much noise in the data but Table 4.5 and Figure 4-21 present a summary of results for each aspect group.

Table 4.5 and Figure 4-21 show that mean daily sediment yields are highest on north-facing slopes, followed by west-facing and, after a considerable gap, by east- and south-facing slopes. These data are to some extent influenced by the unusually high yields on RRW and SMW 20 sites, but partly countered by high yields on east-facing TRE and RRE sites.

The above relationships are readily explained because precipitation during the wet season approached the watershed mostly from the west-to-northwest octant. Rainsplash and particle detachment were thus most effective on slopes exposed to these approaches. Slopes facing the northwest to northeast octant also remain damper between rains, thus leading more quickly to surface sealing and saturated overland flow during subsequent rains. High yields on certain east-facing slopes were due to crest effects and to vegetation cover and substrate discussed below.

Figure 4-21. Mean daily sediment yield (g m^{-2} d^{-1}) by aspect and declivity

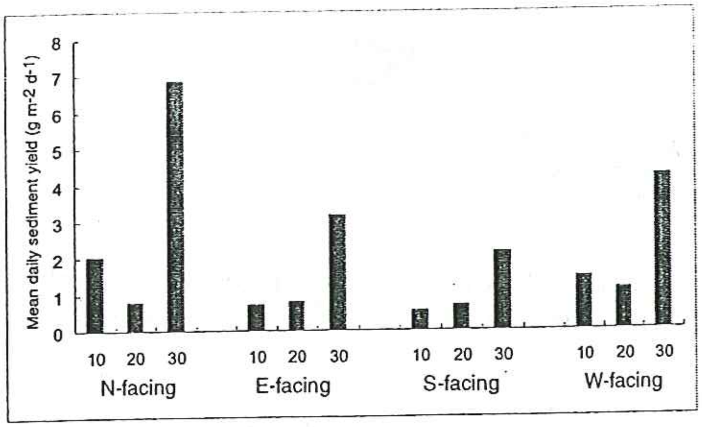


Table 4.4. Hillslope Erosion and Sediment Yields per Slope Declivity, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
10^0	3018	1290.44	0.43	0.86	312.13
20^0	4962	2119.89	0.43	0.85	311.87
30^0	2953	4235.14	1.43	2.87	1046.95

Table 4.5. Hillslope Erosion and Sediment Yields per Slope Aspect, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
North-facing	1824	2964.55	1.63	3.25	1186.47
East-facing	3667	2339.28	0.64	1.28	465.69
South-facing	2682	1510.90	0.56	1.13	411.24
West-facing:	4590	4684.73	1.02	2.04	745.07

North-facing comprises UTN 10, 20, 30; RRW 10, 20, 30
East-facing comprises UTE 10, 20, 30*; TRE 10, 20, 30; RRE 10, 20, 30; BTE 20 Ou, 20 Ol, 20 G
South-facing comprises SMS 10, 20, 30; GPS 10, 20, 30; RRE 10, 20, 30
West-facing comprises SMW 10, 20, 30; GPW 10, 20, 30; TRW 10, 20, 30; RRW 10, 20, 30;
BTW 20 Ou, 20 Ol, 20 G

Table 4.6. Hillslope Erosion and Sediment Yields per Vegetation Category, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
Grassland	3520	185.99	0.05	0.11	38.57
Chaparral	3630	6458.13	1.78	3.56	1298.72
Oak savanna	1908	240.30	0.13	0.25	91.94
Oak woodland	1875	761.10	0.41	0.81	296.32

Grassland comprises UTE 10, 20, 30*; UTN 10, 20, 30; SMS 10, 20, 30; GPW 10, 20, 30
Chaparral comprises SMW 10, 20, 30; TRE 10, 20, 30; RRE 10, 20, 30; RRW 10, 20, 30
Oak savanna comprises TRW 10, 20, 30; BTE 20 Ou, BTE 20 G; BTW 20 G
Oak woodland comprises GPS 10, 20, 30; BTE 20 Ol; BTW 20 Ou, BTW 20 Ol

Table 4.7. Hillslope Erosion and Sediment Yields per Substrate, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
Fine clastic	2617	142.76	0.05	0.11	39.82
Medium clastic	4614	2251.10	0.49	0.98	356.16
Coarse clastic	1830	3854.04	2.11	4.21	1537.40
Volcanic	1872	1397.52	0.75	1.49	544.97

Fine clastic comprises UTE 10, 20, 30*; UTN 10, 20, 30; SMS 10, 20, 30
Medium clastic comprises SMW 10, 20, 30; GPS 10, 20, 30; GPW 10, 20, 30; BTE 20 Ou, 20 Ol, 20 G; BTW 20 Ou, 20 Ol, 20 G
Coarse clastic comprises RRE 10, 20, 30; RRW 10, 20, 30
Volcanic comprises TRE 10, 20, 30; TRW 10, 20, 30

4.2.8 Effect of Vegetation Category

The sampling design also included stratification by four broad vegetation categories, namely grassland, chaparral/coastal sage, oak savanna, and oak woodland. Vegetation influences surface erosion in several ways but primarily through (1) interception of precipitation, wind, and solar radiation by cover foliage, (2) friction to overland flow imposed by emergent vegetative stems, and (3) stability provided by root systems. Each of the four broad categories defined is subject to further modification dependent on the density and composition of the vegetation. During the growth season, for example, alien grasses such as European wild oats provide a more complete cover, and thus more protection against surface erosion, than native bunch grasses, but their dense root systems in the top 0.5 m of the soil reduce infiltration capacity and thereby promote enhanced throughflow and soil slippage, commonly a prelude to debris-flow activity (Orme, in Raphael et al., 1992). Conversely, chaparral and coastal sage shrubs vary greatly in the protection they afford, reflecting plant density and canopy structure, which in turn reflect fire history. Relatively open chaparral recovering from fire offers little protection to underlying slopes, but protection increases as cover, including associated weeds, expand in the post-fire recovery period (Orme, 1996; Schwarz, 1995; Stege, 1996). The complex relationship between vegetation and erosion was beyond the scope of this study, but the four categories defined point the way to further research.

Table 4.6 and Figure 4-22 shows that grassland slopes yielded least eroded sediment during the study period. This is because the tight network of emergent roots, especially among alien grasses, severely restricted overland flow erosion. Values from oak savanna, namely grassland studded with occasional oak trees, were little higher, for similar reasons. As oak woodland came to dominate, so the underlying grass cover diminished and sediment yields increased.

More dramatically, and regardless of substrate, the chaparral/coastal sage community present at 12 sites yielded high quantities of eroded sediment, some 33 times the grassland values. This may surprise those familiar with Mediterranean-type environments, where sclerophyllous shrubs may offer dense canopy protection against raindrop impact and thick litter protection against overland flow. However, because the chaparral/coastal sage community in the Topanga Canyon watershed has been ravaged at more frequent intervals by intense fires, which consume canopy and litter alike, and by local human disturbance, the sites evaluated are afforded much less protection than should be expected. Management of the watershed should seek to minimize the frequency and effect of intense fire and human disturbance in order to reduce the unnaturally high sediment yields from these environments.

Figure 4-22 Mean daily sediment yield (g m^{-2} d^{-1}) by vegetation category and declivity

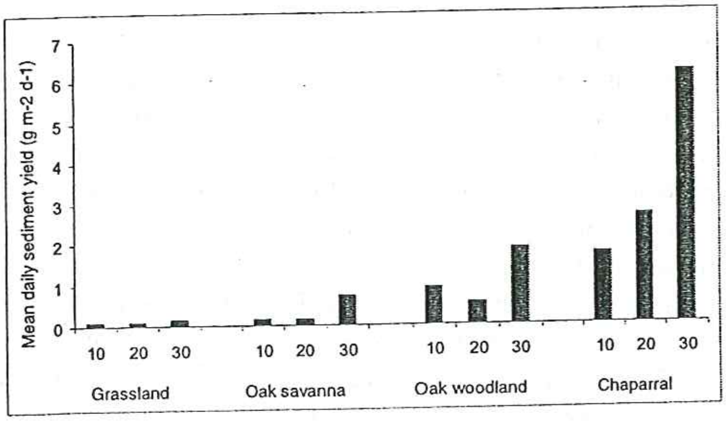
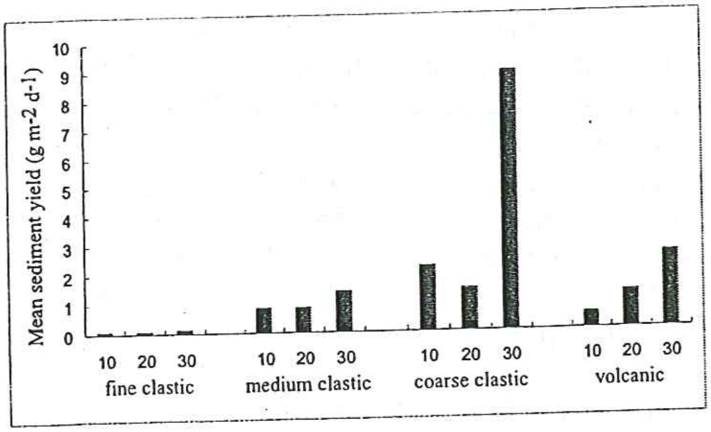


Fig. 4-21. Mean daily sediment yield (g m^{-2} d^{-1}) by vegetation category and declivity

Figure 4-23 Mean daily sediment yield (g m^{-2} d^{-1}) by substrate and declivity



4.2.9 Effect of Substrate

The sampling design also considered the effect of substrate on erosion by locating erosion sites within the four principal categories of substrate found within the watershed, namely fine clastic sedimentary rock (<0.063 mm), medium clastic sedimentary rock (0.063-1.00 mm), coarse clastic sedimentary rock (>1.00 mm), and volcanic and hypabyssal rock. The results are shown in Table 4.7 and Figure 4-23.

Fine clastic rocks, derived from claystone and siltstone members of the Modelo Formation in the upper watershed, yield little sediment to overland flow and almost none to dry ravel. This is because these materials, though often thinly bedded and weakly consolidated, become readily cohesive in the presence of moisture and clod when dry. Cohesion in turn limits particle detachment under lighter rains on lower slopes, notably under the tight constraints of a grass cover. However, with persistent and rainfall on steeper grassy slopes, these materials may yield to soil slippage and mobilize as debris flows. Once detached and entrained by overland flow or as debris flows, these materials are an important source of the fine fraction delivered to sediment plumes that flush into Santa Monica Bay after significant rainfall-runoff events.

Medium clastic rocks, derived from sandstone members of the Modelo Formation and of the Lower and Upper Topanga Formations of the middle and upper basins, yield much more sediment to overland flow and dry ravel. This is because these materials are less cohesive when wet and, rather than clodding, disintegrate on drying to form grain flows. These materials are the principal source of the fine to coarse sand fraction of the suspended sediment load in local streams, and a modest source of beach sand.

Coarse clastic rocks, derived from very coarse sandstone and gravel of the Sespe Formation found mostly in the northwest basins and along the eastern perimeter, yield remarkably large volumes of sediment, averaging 35 times that from fine clastic substrate. Gravel lithologies comprise sandstones of various origins, together with a variety of intrusive, metasedimentary and metavolcanic rocks from distant sources, all moderately to well rounded by prior transport. Despite ribs of indurated sandstone and conglomerate, the Sespe Formation contains many units that are very poorly consolidated, notably in the Garapito and Red Rock basins. These yield readily to overland flows and are the principal source of bedload and coarse suspended sediment load reaching streams within the watershed. However, they are frequently stored for long periods within terraces or as floodplain deposits before re-entrainment and delivery to Santa Monica Bay. The gravel fraction is the principal source of the distributary pebble, cobble and boulder bars that form, or reappear, at the river mouth during flood events. Paleocene and Cretaceous units minimally present in the lower and northeast watershed, but not sampled, respond similarly to indurated members of the Sespe Formation and also contribute to the coarse fraction of Garapito Creek and to distributary deposits at the river mouth.

Volcanic and hypabyssal rocks, mainly basaltic andesite derived from the Middle Topanga Formation across the middle of the basin, contribute less sediment than the coarse clastic rocks, but more than the medium to fine clastic rocks. This is because the materials are litholigically fused but pervasively fractured from weathering working along structural weaknesses. Under the protection of oak savanna at the TRW sites they yield little material, but under open chaparral at the TRE sites they commonly yield a bimodal sediment of fines and chips of basaltic andesite, some in excess of 20 mm and 20 g. Pebbles from this source are a recognizable part of the finer bedload in local streams.

4.2.10 Fire Scenario

As with other forms of vegetation change, the removal of plants and plant litter by fire exposes the surface to dry ravel and to increased raindrop impact and surface runoff. But fire is unusual for the suite of changes that it initiates before actual erosion. For example, fire modifies soil structure and texture, and thereby infiltration and runoff, by generating very high surface temperatures (~600-1000°C) that destroy organic matter, consume nutrients, and fuse soil particles (DeBano et al., 1979). Fire also modifies water repellency, present to some extent in most soils, by vaporizing the waxy organic substances responsible for hydrophobicity at the surface, and then translocating and condensing this matter farther down the soil profile. In chaparral, coastal sage, and certain woodland soils, this can lead to the accumulation of dense water-repellent layers beneath the surface that inhibit infiltration and lead to increased rilling and shallow debris flows (DeBano, 1981; Wells, 1987).

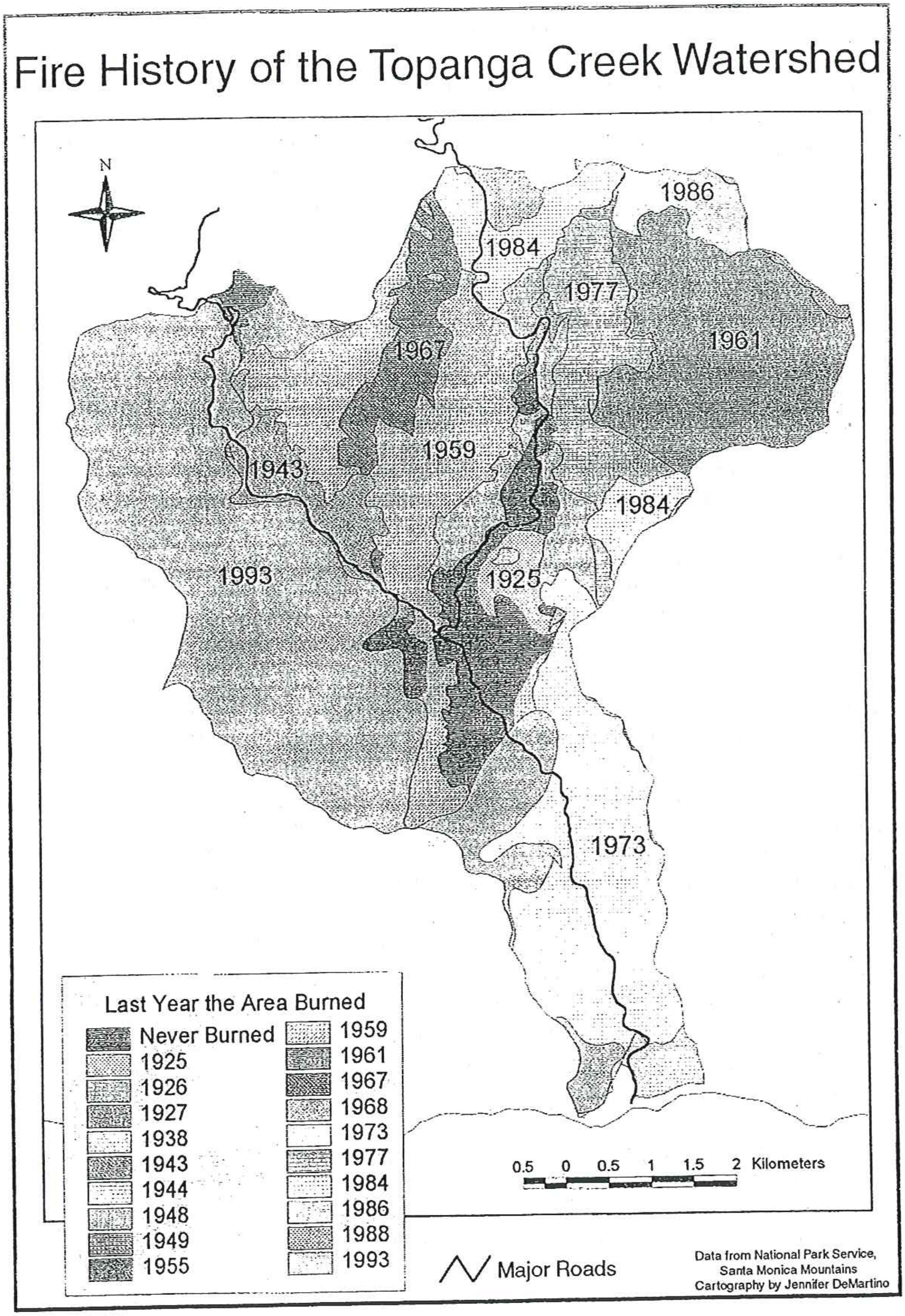
As the vegetation slowly recovers, the impact of fire on erosion begins to diminish. Vegetation recovery in chaparral is a slow process but, in the most common scenario involving autumn fires towards the close of the dry season, begins with the winter rains which encourage weedy ground covers and stump sprouting of perennial plants whose roots have been less damaged by fire (Orme et al., 1996). Initially, owing to increased water repellency, much rain transforms quickly to Hortonian overland flow and shallow ash-laden debris flows. It is at this stage that most post-fire erosion occurs. Gradually, however, infiltrating rainfall reduces water repellency, throughflow increases, and groundwater recharge begins. However, surface erosion remains at elevated levels until the perennial vegetation canopy is fully restored, and that takes several years depending on the survivability of root systems, seedling dynamics, and other factors.

No fire affected the Topanga Creek watershed during the 2000-2001 water year. Thus it was not possible to measure directly the impact of fire on erosion and sediment yields through its destruction of the vegetation cover and changes in soil properties. However, it is possible to draw certain inferences from the hillslope erosion data.

Sites with a relatively recent history of fire are among the highest providers of sediment (Fig 4-24). Thus the Red Rock Canyon sites (RRE, RRW), just within the margins of the November 1993 fire, have high yields throughout the year from overland flow, creep, and dry ravel. These yields include the highest mean daily value of all - 13.65 g m^{-2} d^{-1} at RRW 30 (Table 4.2, Appendix A). This is strongly related to the open nature of the recovering chaparral cover, but is also a reflection of friable substrate and exposure to incident rains from westerly and northwesterly storms. Thus the role of fire is suggestive rather than conclusive. Sites recovering from somewhat older fires also yield relatively high amounts of sediment. Thus the TRE sites which burned in 1973 and 1977 yield quite high values from fractured but less friable basaltic andesite beneath partly open chaparral, while the SMW sites which burned in 1986, even allowing for packrat activity, also have enhanced yields. Sites where grassland either predated fire or invaded burned sites, such as the BTE sites, yield little sediment, in part because of the effective protection provided by grass against 2000-2001 rainfall/runoff events.

Areas which have long been spared fire produced modest to low sediment yields. The upper Garapito Creek basin is particularly noteworthy because the chaparral here has not burned since 1961 (National Park Service data; see also DeMartino, 2001). With a 30-year fire cycle, high fuel potential, and abundant litter, a fire in this basin could

Figure 4.24



Data from National Park Service,
Santa Monica Mountains
Cartography by Jennifer DeMartino

have serious downslope and downstream repercussions, especially because Garapito Creek is a effective mover of delivered waste (see Chapter 6).

Recent studies have clearly demonstrated the impact of fire on nearby watersheds such as Cold Creek and Big Sycamore Canyon in the Santa Monica Mountains (Schwarz, 1995; Stege, 1996; Orme et al. 1996; Orme et al., in preparation). In upper Cold Creek, measurements during major storm events following the Old Topanga fire of November 1993 showed that sediment yields from burned sites exceeded those from unburned sites in 30-year old chaparral by two orders of magnitude, even allowing for differences in micromorphology and soil properties (Stege, 1996). Here and in Big Sycamore Canyon, post-fire vegetation growth, especially the rapid growth of the vine *Calystegia macrostegia*, began to limit erosion as the winter rainy season progressed (Schwarz, 1995).

4.3 Mass Movement

The erosion plots were designed to provide data on hillslope erosion by overland flow, dry ravel and creep during wet and dry spells. However, during and immediately after wet spells, sediment may also be moved downslope and to streams by debris flows and landslides, which the erosion plots cannot capture. Thus, after each significant rainfall event during the water year, a portion of the Topanga Creek watershed was investigated in order to identify fresh debris flows and landslide occurrence.

Very little mass movement occurred in the watershed during the 2000-2001 water year. Of the 8 wet spells, only the moderate rains in the late evening of January 10 generated significant soil slippage and debris-flow activity. Although these debris flows were not observed until the following morning, it is reasonable to suppose that they occurred between 2000 and 0000 hrs, four hours during which 71 mm of rain fell at the Malibu rain gauge, including 22 mm in the hour before midnight. The Topanga gauge recorded 34 mm during the hour before midnight but much less during the preceeding four hours. Past experience suggests that precipitation of this intensity may trigger debris flows on near-saturated slopes, depending on specific soil and infiltration properties.

Numerous small soil slips and resulting debris flows were noted, especially on higher slopes but only one of these, on the western perimeter of the Santa Monica Mountains Conservancy land, contributed sediment directly to a stream channel and this dewatered shortly thereafter. Small residual debris flows and sediment splays probably related to the 8-12 January wet spell were subsequently observed in some remote locations associated with fire-road drainage and culvert downspouts, notably along the eastern watershed perimeter. Debris flows involving both mineral sediment and organic debris were also noted over short stretches of several tributaries in the upper basin. These were probably facilitated by the large residue of organic debris available in stream channels following the preceding growth season.

No debris flows were observed on quasi-natural hillslopes during February, March and April 2001. This may be explained by the low intensity rainfall of this period. On the other hand, the persistent nature of the February rains favored hillslope infiltration and this led to some slight reactivation of existing unstable terrain, including landslides in the middle part of Topanga Canyon between the Garapito and Greenleaf Creek confluences. No further reactivation occurred as a result of the March and April rains.

During the wet spells of February, March and April, it was hypothesized that under certain circumstances the thresholds for slope stability could yet be exceeded as a result of downward percolation, and that further movement, though unlikely in view of modest winter rainfall totals, could occur in the coming months. As it transpired, there was no significant further renewed or fresh landslide activity during the water year. To the limits of scale, all existing and fresh mass movement phenomena were confirmed and mapped, and are presented in Figure 4-25.

Despite the paucity of debris flows during the 2000-2001 water year, such activity remains a potential hazard for watershed occupance and management. Small soil slips, measuring say 10 m^2, can easily yield a tonne of debris and mobilize into a debris flow in a few seconds, entraining more material downslope. Saturated grassy slopes underlain by fine clastic materials are particularly prone to slippage, especially towards the end of the rapid growth season for alien grasses in March and April. Assuming that intense precipitation on near-saturated and saturated hillslopes will recur in the future, the natural system should be managed to minimize such occurrences. This implies reducing the area converted to alien grasses and restoring coastal sage, chaparral, and oak woodland wherever feasible (Orme and Bailey, 1970, 1971; Orme, in Raphael, 1992). The human system should also be managed carefully to inhibit the concentration of overland flow into zero-order basins where soil slips and debris flows are commonly initiated. This implies careful consideration of road runoff and culvert placement, both with respect to improved road surfaces and unpaved roads.

4.4 Long-Term Denudation Rates

The variable hillslope erosion rates and sediment yields discussed above imply that long-term denudation rates will also vary. Denudation may be defined in terms of linear surface lowering per unit time, normally as cm ka^{-1}. In an early study, Stabler and Dole (1909) used river loads to estimate that the surface of the United States was being lowered at a mean rate of 3.3 cm ka^{-1}. Later, Judson and Ritter (1964) estimated that denudation rates within the United Sates ranged from 4 cm ka^{-1} on the Atlantic Coastal Plain to 17 cm ka^{-1} on the Colorado Plateau. To extrapolate from local stream loads to a subcontinental area is clearly a challenge (Walling and Webb, 1996). In like manner, the large hillslope data set presented here offers an opportunity for placing erosion in the Topanga Creek watershed in a broader perspective.

The mean daily hillslope sediment yields discussed above are extrapolated into the t km^{-2} yr^{-1} in Tables 4.2 and 4.4 through 4.7. Assuming a mean density of 2.65 g cm^{-3} for the eroded waste, present denudation rates in the Topanga Creek watershed range from a low of 0.42 cm ka^{-1} to a high of 188 cm ka^{-1}. The high rate implies that the Topanga Canyon watershed would be washed into the sea in less than 150 ka, or little more than a glacial-interglacial cycle.

Any value in excess of 30 cm ka^{-1}, the mean rate of tectonic uplift over the past 125 ka (Orme, 1998; see Chapter 1), means that those areas are being lowered at rates faster than they are being raised. Thus, the mean denudation rate for all 30° slopes is 39.27 cm ka^{-1}, for all chaparral environments is 48.63 cm ka^{-1}, and for all coarse clastic substrates is 57.74 cm ka^{-1}. Stream loading might reveal similar values but the data are more variable and less reliable. An alternative approach would be to take that portion of the sediment load transferred from Topanga Creek and deposited in Santa Monica Bay, but those data are presently indistinguishable from other sediment in the bay, and beyond the scope of this study.

Owing to the assumptions involved, the above extrapolations should be treated with caution. For example, the mean density of eroded waste varies from 1.5 to 3.0 g cm^{-3}. Hillslope sediment yields vary from year to year, and there is at yet no time series of data beyond the present study. Mass movement on a scale not seen during 2000-2001 could well increase sediment yields substantially in very wet years. Thus it is very unlikely that denudation rates will remain steady - they may increase or decrease in response to climate and human forcing. Mean tectonic uplift may also accelerate or decelerate, and is in any case the mean product of seismic pulses and aseismic creep. And 1000 years are a long time.

Nevertheless, the data presented here represent the first attempt to approach the long-term implications of erosion from a large hillslope data set in the Santa Monica Mountains. Because it was not possible in this study to investigate private land in the watershed, the relative significance of natural and human-induced contributions to the ongoing denudation scenario awaits further study. From the management perspective, the data offer an interesting insight into local geomorphic processes, namely that much of the Topanga Creek watershed is unraveling at a very rapid rate.

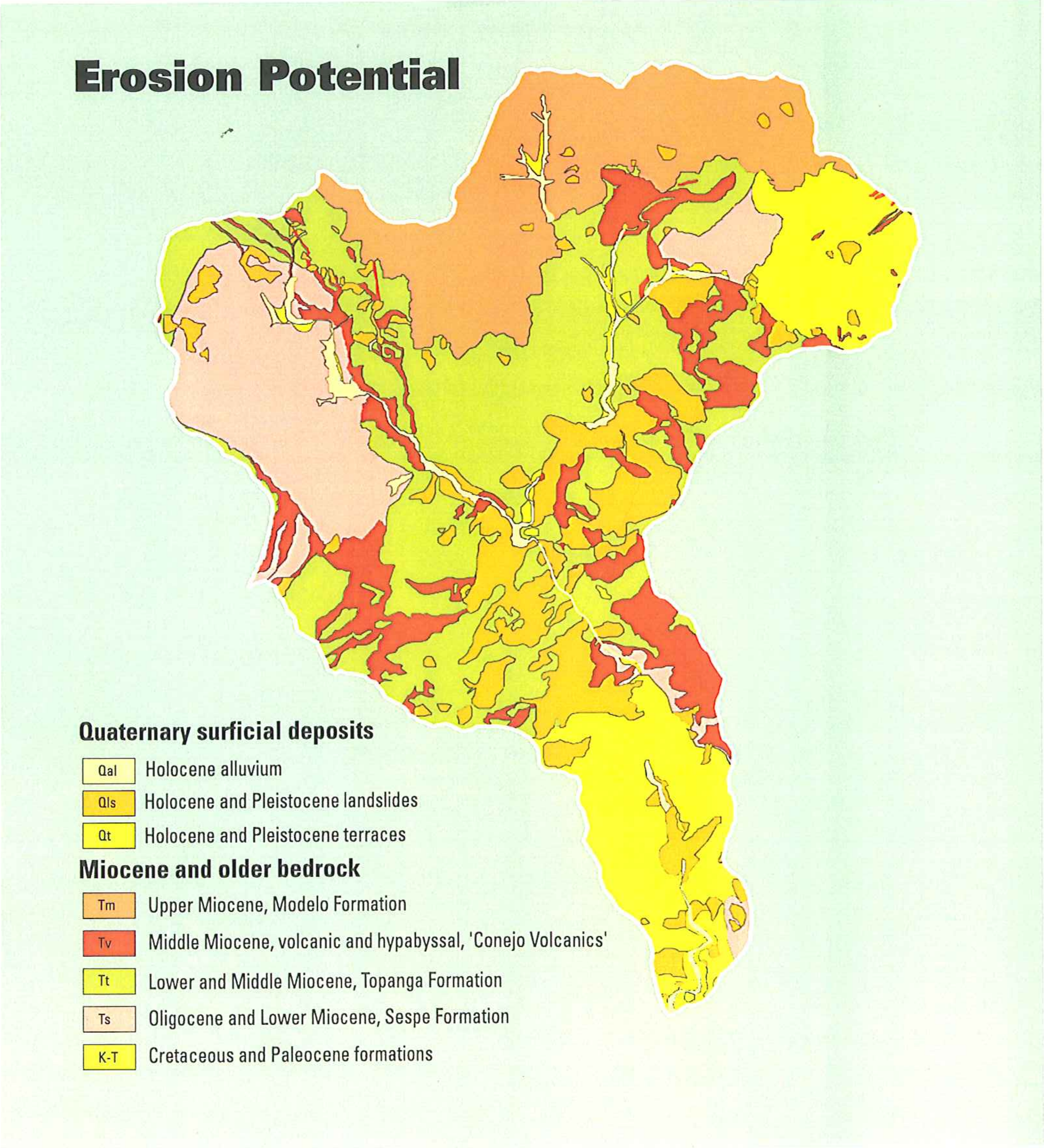
4.5 Erosion Potential

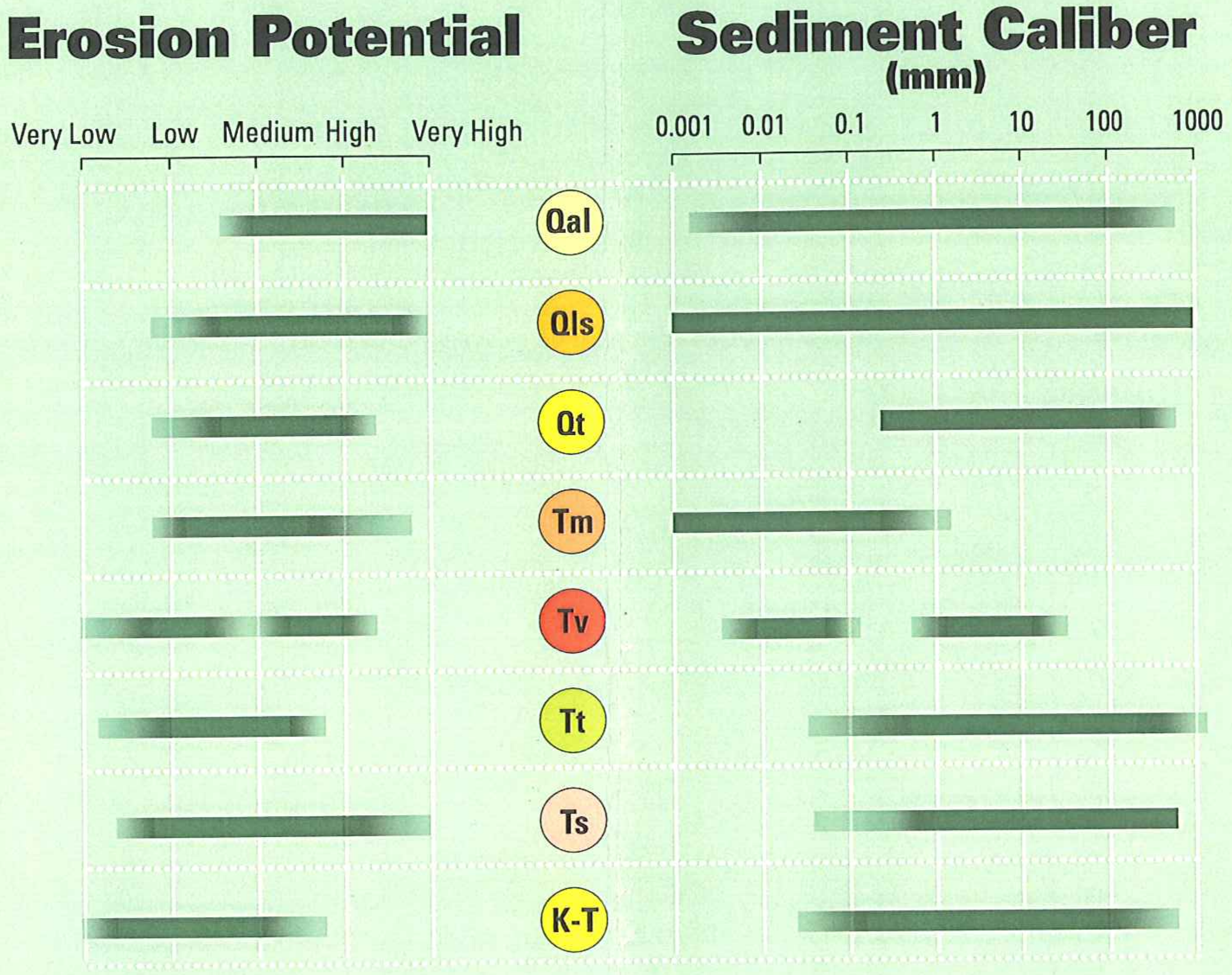
In concluding this chapter, a map entitled *Erosion Potential of the Topanga Creek Watershed* is presented as Figure 4-25. This map was initiated early in the study from existing data and field reconnaissance. It was subsequently revised by combining the hillslope-erosion and mass-movement data discussed above with field observations in and adjacent to stream channels. Table 4.1(Appendix A), provides the raw data for sediment yield and sediment caliber from which Figure 4-25 is developed. The map uses as its base the USGS 7.5 minute quadrangles covering the watershed (Topanga, Malibu Beach, Calabasas, and Canoga Park), and the geological data overlain on this base, published by the Dibblee Geological Foundation (Dibblee, 1992, 1993) and modified by our field investigations.

Eight morpholithological units are identified in terms of potential erosion and sediment caliber. Each of these is predicted to yield a distinctive geomorphic response to hydroclimatic and gravity forcing. In approximate geological succession from oldest to youngest, but not necessarily in terms of increasing erosion potential, these units comprise the following:

K-T: This unit comprises relatively resistant sandstone and conglomerate members of Upper Cretaceous and Paleocene age, straddling the K-T boundary, that reinforce some of the steepest slopes within the lower watershed and upper Garapito Creek. These marine and nearshore formations, the oldest and most lithified in the watershed, yield slowly to weathering and often form prominent cliffs. The conglomeratic units contain much granitoid, metavolcanic and metasedimentary debris derived from Cretaceous and earlier orogens. This unit has low to medium erosion potential but contributes coarse clastic debris to stream channels and is an important source of pebbles, cobbles and boulders moving downstream towards the river mouth.

Figure 4.25 Erosion Potential of the Topanga Creek Watershed, based on data collected during 2000-2001 Water Year





Note: Mass movement may occur in any bedrock unit, especially on steep slopes undermined by streams. However, slide potential is highest in the Topanga Formation, whereas flow potential is highest in the Modelo Formation.

Ts: This unit comprises sandstone and conglomerate members of late Oligocene and possibly Lower Miocene age, the Sespe Formation. It is unique in the bedrock geology of the watershed in being of non-marine origin, having been deposited mostly as alluvial fans and plains. It is distinctive in that it yields a 'red bed' image typical of continental deposition under semiarid conditions. Granitoid and metasedimentary rocks, especially quartzite, form prominent clasts within a coarse sandstone matrix. The unit is variably lithified but where poorly consolidated members are exposed, they yield large quantities of coarse clastic debris to hillslope erosion and stream channels, most notably in Red Rock Canyon and in middle Garapito Creek.

Tt: This unit comprises variably resistant siltstone, sandstone and conglomerate members of Lower to Middle Miocene age, the Topanga Formation, that underlie most of the central part of the watershed. The conglomerates contain abundant granitoid, metavolcanic, and quartzite clasts in a sandstone matrix, mostly deposited in a marine or nearshore environment. Sandstone and conglomerate members are often strongly lithified, of low erosion potential, locally cliff-forming, and yield medium to coarse clastic debris to stream channels. Where unprotected, siltstone and occasional claystone members are more erodible and locally contribute fine clastic sediment to streams.

Tv: This unit comprises volcanic and hypabyssal rocks, the Conejo Volcanics and associated dikes and sills, interbedded with or intruded into the Topanga Formation, generally towards the middle of the latter and thus of Middle Miocene age. The volcanics were extruded into a marine environment and often reveal characteristic pillow lavas. This unit is dominated by basaltic andesite, locally resistant but more commonly well fractured and subject to rapid weathering, especially of its mafic constituents, at and near the surface. Its erosion potential and sediment yield are distinctively bimodal, comprising angular chips of basaltic andesite and fine-clastic sediment. For this reason, it is distinguished from sedimentary units of the associated Topanga Formation.

Tm: This unit comprises weakly resistant claystone, siltstone and friable sandstone of the Modelo (Monterey) Formation of Upper Miocene age, deposited under deep to shallow marine conditions. It underlies much of the upper watershed. This unit has medium to very high erosion potential and is the source of much fine sand, silt and clay which, on reaching stream channels, is readily transported in suspension to beyond the river mouth. Under dry conditions, this unit yields clay chips to dry ravel; with light rains, it tends initially to seal and resist surface erosion; under heavier rains it both erodes and is prone to slope failure, with a high potential for debris flows.

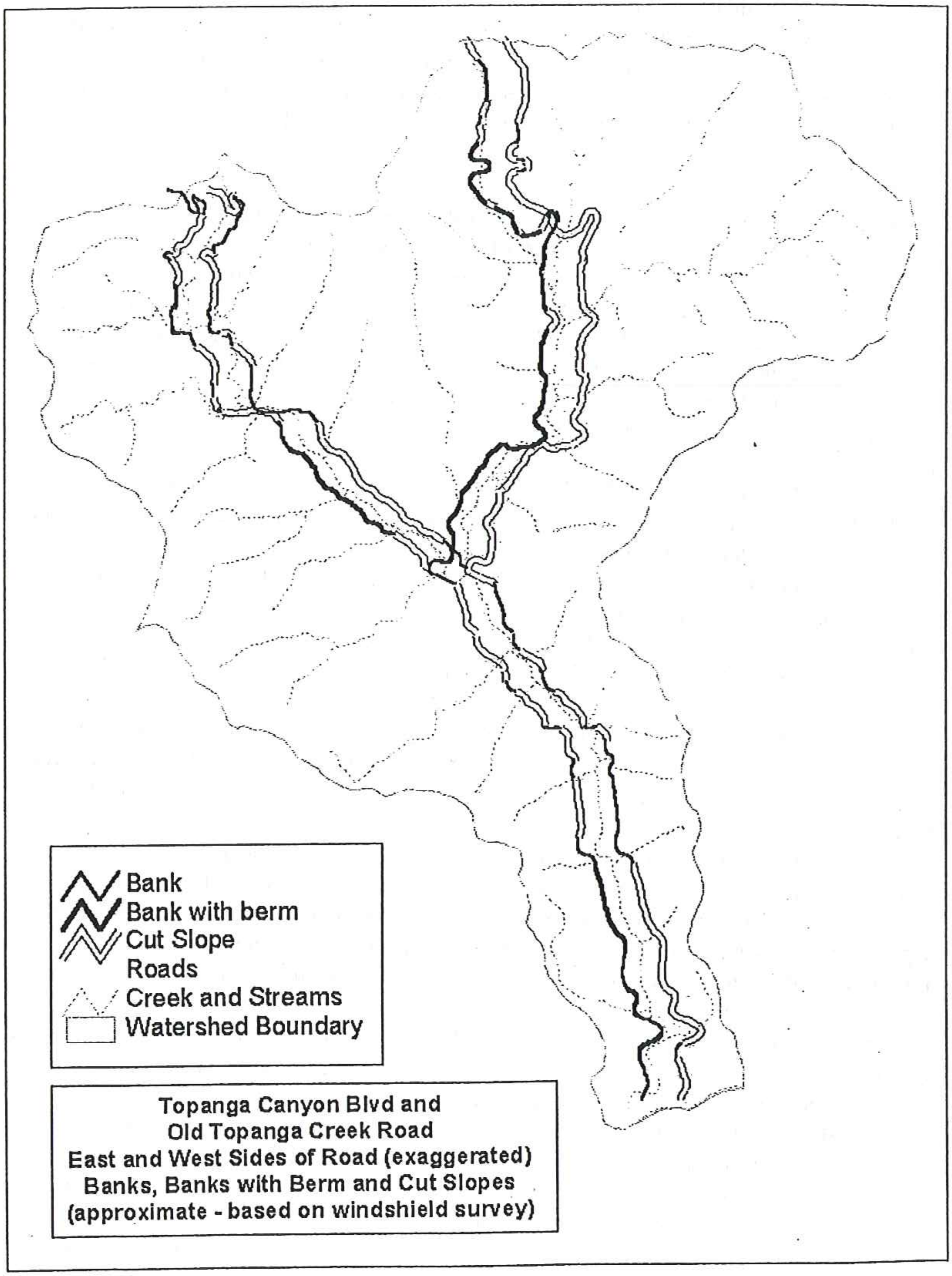
Qls: This unit comprises landslides of Quaternary age derived from mass movement of older units. Existing geological maps do not differentiate between active and inactive landslides, or between flows and slides, but field observations suggest that several old landslides are relatively stable while others are active or potentially active. The latter are a potential major source of debris of widely varying caliber to stream channels. The Tt unit is prone to landslide activity because of swelling clays found in the finer clastic and interbedded volcanic and hypabyssal members. The Tm unit is prone to debris flows under high magnitude and persistent rainfall.

Qt: Quaternary terrace deposits, usually of pebbles, cobbles and boulders in a medium to coarse sand matrix, are under-represented on existing geological maps but are a potential source of erodible coarse clastic debris above modern stream channels. Such deposits usually lie alongside modern stream channels, notably in Garapito Creek, but they also form raised areas within the main flood path of Topanga Creek.

Qal: Holocene alluvium in existing stream channels and valley fills has medium to very high erosion potential and is an important and immediate source of a wide range of sediment sizes. This is material in temporary storage within the fluvial system, but readily available for re-entrainment by stream flow, especially as stream capacity and competence rise during flood events. This material is also prone to net scour by longer-term changes in stream regime. Many private properties in middle Topanga Canyon are presently in harm's way from incision and re-entrainment of Holocene alluvium over the past 30-40 years.

Figure 5-1 Generalized Locations of Road Cuts and Berms

Limitations of scale prevent description of segments , 100m long and of various berm categories



5. Roads as Sediment Sources

Roads and trails are sources of sediment throughout the watershed. As human artifacts, roads accelerate erosion above levels that would occur under natural conditions. Berms of unconsolidated debris along road margins have been perceived as especially problematic sources of sediment to nearby streams. This chapter argues that cut banks that produce the road spoils gathered into the berms are the more significant problem. The location of cut banks and berm piles along the main arteries of Topanga Canyon Blvd. and Old Topanga Canyon Rd. are illustrated in Figure 5-1.

5.1 Paved Roads

In practice, it proved impossible to quantify the magnitude of erosion from road sources. Danger from traffic, destruction of erosion markers by vehicles and pedestrians, and frequent regrading of roads by highway authorities and private property owners all confounded field sampling. It would need an army of observers, closely spaced along roads, day and night, wet and fine, to define precisely the nature and magnitude of road erosion. Nevertheless, main roads through the watershed, namely Topanga Canyon Boulevard and Old Topanga Canyon Road, were monitored frequently during and after rain events throughout the study period; and lesser paved roads, dirt roads and trails were investigated as occasion permitted.

Topanga Canyon Boulevard and Old Topanga Canyon Road were measured to establish the relative importance of berms, cut banks, and open areas along their margins (Table 5.1). Road length was doubled to define the total road margin. Berms were subdivided into three categories by sampling their cross-sectional area, which ranged from triangular through trapezoidal to rectangular. Small berms were defined as less than 1 m^2 in area, which usually meant a footprint of <2 m and a height <0.5 m. Medium berms ranged from 1 to 3 m^2, usually those with a footprint from 1 to 3 m and a height from 0.5 to <2 m. Large berms, greater than 3 m^2, had a footprint usually >3 m, and a height from >1 to <3 m. Berms typically carry a light cover of annual grasses, usually alien species, but some are bare. They may be augmented by fresh sediment or removed at any time by blading operations along the roads. Cut banks were defined as road margins that had been excavated at one time or another to widen the road, thereby steepening the sideslope. Cut banks range from low bluffs and landslide toes to vertical cliffs, variably covered by alien grasses and scattered shrubs and small trees. Some cut banks are locally protected by retention devices, from chicken wire to concrete beams. Open areas occur where neither berms not cut banks are present, notably at road junctions, parking lots, and property frontages, for example in Topanga village and on flat land nearing the coast.

Table 5.1 shows that small berms constitute 29%, medium berms 8%, and large berms 3% of the 42.4 km total road margin of Topanga Canyon Boulevard and Old Topanga Canyon Road. Small berms are dominant along Higher Topanga Canyon Boulevard and Old Topanga Canyon Road. Medium to large berms are dominant along Lower Topanga Canyon Boulevard where the need to sidecast debris from cut-bank failures and to constrain road runoff through the main canyon are important. Much of the large berm value here derives from a 200-m long feature - more a dumping ground than a true berm - between the boulevard and Topanga Creek 500 m north of Pacific Coast Highway. This area is used to dump road debris, during clean-up operations following

Table 5.1. Roadside Berms, Cut Banks, and Culverts along Major Roads

	HTCB (m)	LTCB (m)	OTCR (m)	Total (m)	%
Berms, <1 m^2	6300	2200	3600	12,100	29
Berms, 1-3 m^2	1100	2000	100	3200	8
Berms, >3 m^2	300	1000	0	1300	3
Cut Banks	7400	6500	5700	19,600	46
Open	500	2100	3600	6200	14
Total Road Margin[1]	15,600	13,800	13,000	42,400	100
Official Culverts[2]	32	23	25	80	
Road Length (m)	7800	6900	6500	21,200	

HTCB - Higher Topanga Canyon Boulevard
LTCB - Lower Topanga Canyon Boulevard
OTCR - Old Topanga Canyon Road

[1] Road length x 2

[2] Number from Caltrans via RCDSMM (excludes private culverts)

rain events and slope failures, both from within and beyond the watershed. This material is later quarried opportunistically for construction and landscaping material, but meanwhile it may impinge on the integrity of the runout section of the creek. Assuming a mean cross-section of 0.5 m^2, 2 m^2, and 5 m^2, respectively, small berms contain 6050 m^3, medium berms 6400 m^2, and large berms 6500 m^3 of material. Thus the large berms, despite their small presence, are an important potential source of sediment and should be managed accordingly or removed. In many areas, the road shoulder has been extended significantly beyond the road right-of-way, especially in the lower canyon area. At these locations, the creek channel has been constrained, stimulating landslides downstream as a result.

Cut banks comprise 46% of the total road margin along Topanga Canyon Boulevard and Old Topanga Canyon Road, a high value that just exceeds the total berm value of 40%, but understandable in view of the canyon character of these roads. Normally, cut banks line one side of these roads while berms and often the creek channel line the other. During and after erosion events, soil and rock waste shed from the cut banks are generally delivered naturally by surface flows or bulldozed onto opposing berms, sometimes beyond and into the creeks. Otherwise, either directly along inside ditches and from berm erosion, this waste moves to culverts from which it is shed into nearby creeks. The two main roads contain 80 official culverts for this purpose, and many more unofficial structures.

Roadside berms, cut banks and culverts maintained their integrity reasonably well throughout the 2000-2001 water year. The canyon segment of Lower Topanga Canyon Boulevard was prone to rock falls and sediment wash from adjacent sideslopes and small channels during the heavier October, January and February rains. One road segment north of the gauging station was frequently mantled with slopewash debris from the cut slope which presented hazardous driving conditions, but was soon removed by the highway authorities. Seepage and sloughing from the toes of earlier landslides were also seen in Higher Topanga Canyon Boulevard, notably north of Lake Topanga, but there was no wholesale landslide blockage of these roads during 2000-2001, although the potential for massive blockage remains. The dumping ground near the mouth of Topanga Canyon also saw much coming and going. However, the main roads survived as well as could be expected in a difficult environment, and the highway authorities were vigilant in seeking to keep roads open during the wet spells.

The primary problem confronting public roads is that they are deemed necessary by local residents, visitors, and commuters alike. Therefore, they have been provided, under often difficult engineering conditions, and must now be maintained - and in the limited space available. Cut banks are the principal sources of sediment, probably supplying at least 80% of the debris generated by road systems. During wet spells, they readily yield debris far in excess of natural hillslopes, debris that must be removed for reasons of safety and trafficability. Ditches at the base of these cut banks, and berms on outside road margins, serve to direct water and sediment towards culverts and thereby to streams. Roads are graded and maintained accordingly.

The number of culverts could be increased to spread the load more evenly and culverts should be constructed in such a way as to minimize downspout erosion. Above all, culverts should be inspected and maintained regularly, before the rainy season and then at intervals during winter. All this is consistent with the best management practices for highway maintenance, and to our knowledge is being implemented. The dumping ground above the mouth of Topanga Creek should be closed. From an earth-science perspective, and biological objections notwithstanding, there is no reason why such debris should not be dumped directly into the sea, for which it was ultimately destined under natural erosion scenarios. There, wave and current action would winnow the debris, moving the coarser fraction onshore to replenish beaches while removing the finer fraction to deeper water.

Private roads as a potential erosion and sediment source could not be evaluated under the constraints of the project but qualitatively such properties appear to yield a highly variable response dependent on such management practices as vegetation clearance, grading, access links, runoff controls. Most private owners are aware of the need for reasonable access to their property via some driveway or trail, but maintenance levels vary considerably. Private developments are also impacting Saddle Peak Road along the southwestern interfluve, readying debris from road and site grading and construction for delivery into Hondo and Dix canyons.

5.2 Dirt Roads and Trails

Dirt roads and trails within the watershed raise special issues, particularly in some potentially troublesome locations. Although provided with the best of intentions, for example for recreation and fire protection, these roads and trails often have high erosion potential and can yield a wide range of debris, from silt to cobbles, depending on local substrate, the character of engineered cut and fill practices, and provisions for drainage. Several dirt roads and trails were examined repeatedly during the 2000-2001 water year. This discussion focuses on three specific examples.

First, the Summit-to-Summit Mountainway across the northern interfluve between Topanga Canyon Boulevard and Old Topanga Road, was investigated immediately after the relatively heavy rains of January 10-11, 2001. The steep headwaters of the drainage system here had been viewed earlier as potential sites for erosion and mass movement, especially related to trail construction. The short paved road west from Topanga Canyon Boulevard to the water towers is well engineered and its drainage is carried in long downspouts far down potentially unstable hillslopes. Farther west the situation is more problematic. For example, 18 small slope failures were observed below the dirt trail as a result of the January 10-11 rains, one of which slipped from a 5-m wide, 0.3 m deep headwall and transformed into a full debris flow, traveling 300 m downslope before dewatering. This segment contains evidence of recent disturbance, including human manipulation of the natural drainage system and widespread gopher activity which exacerbates slope failure.

Second, where dirt Mulholland Drive impinges on the northeast interfluve it is reasonably well maintained, but this cannot be said for the Temescal Fire Road which diverges from Mulholland Drive to pass around the eastern headwaters of Garapito Creek. This fire road is much gullied and yields sediment from these gullies toward both Garapito Creek and neighboring Temescal Creek. One stretch of fire road has a continuous down-gradient for about 1 km before reaching a culvert which must accommodate large volumes of runoff. The result has been 4 m of erosion below the short downspout. Given the necessity for fire roads within this watershed, it is incumbent upon the fire-road authority to provide for proper maintenance and for culverts with long downspouts at reasonable intervals. We recommend a thorough evaluation of fire roads throughout the basin.

Lastly, within the Trippet Ranch, now converted to recreational use under the stewardship of the Department of Parks and Recreation, there are significant problems resulting from ill-maintained dirt roads and trails. This is a valuable recreational resource close to a vast urban area and is understandably impacted. Many trails leading from the Ranch to the eastern interfluve have been severely rutted by hikers, bikers, and horses in such a way that surface drainage now uses these ruts as water courses, deepening them and removing sediment downslope to newly formed sumps. One dirt road, originally a ranch trail leading from the eastern interfluve downhill toward the Ranch has seen its drainage overwhelm existing ditches and culverts and develop a new course across open grassy and unstable terrain towards an old stock pond. Much erosion has occurred here, involving the loss of 300 m^3 of earth from one 50-m reach and forming a gully now 2-4 m deep and 1-3 m wide. Lesser incisions are observed upstream and downstream and one cross-section deepened by 0.2 m during the mid-January rains and a further 0.3 m during February 2001. Prior attempts have been made at erosion control but these have failed and some small oak trees, roots exposed, are now falling into the erosion gully.

Dirt roads and trails pose major problems for maintenance, especially where recreational use if high and maintenance budgets are low. Many such trails occur on ridges and their erosion may not seem problematic. However, sediment derived from trail erosion is often directed into headwater channels which, during larger storm events, have the capacity to transport such debris far downstream. It is incumbent, therefore, upon all stewards of public lands to devise ways in which to minimize excessive erosional impacts. More attention should be given to appropriate drainage controls for impacted surfaces, including the provision of well graded ditches and culverts of appropriate size and spacing, and to restoration of lands and trails to their former ungullied state. This will entail temporary closure of certain trails until erosion control is complete.

6. The Channel System as a Sediment Source and Sink

6.1 Segmentation of the Channel System

Gradients of stream reaches are important indicators of transport efficiency within fluvial systems. Stream velocity correlates positively with channel slope and inversely with roughness which for a given value increases at lower velocities. Other things being equal, discharge of water and sediment thus increase as gradient increases. Stream channel gradients are also useful indicators of the development of fluvial systems and of the primary controlling variables, tectonism and climate. Consequently, the gradients of the principal stream channels within the Topanga Creek watershed were investigated and integrated with the stream-sampling plan. These are presented in Table 6.1 and Figure 6-1.

In general terms, the tabular and graphical review of the gradients reveals that the Topanga Creek watershed is an unusual system. It comprises two principal parts, divided at a point 500 m south of the Dix Canyon confluence with the mainstem. In the upper part, Topanga Creek and its tributaries exhibit negative exponential profiles (~concave) typical of developing drainages. The mean gradients of the principal streams--Topanga Creek, Garapito Creek and Old Topanga Creek--are relatively low (<0.05), except in the Glenview segment (0.253), and lower Santa Maria Creek (0.080). Indeed, gradient, hydrology and geomorphology all indicate that Garapito Creek is the true headwater of Topanga Canyon. The poorly adjusted creeks in Hondo and Greenleaf canyons are much steeper.

Within the upper part of the watershed, there is also evidence for an earlier, relatively open, drainage basin. This is seen most notably in the mainstem of Topanga Creek above Glenview, and to a lesser extent in upper Santa Maria and Greenleaf Creeks. This early basin is represented by a broad terrace above the western sideslopes of the upper basin between Glenview and the Greenleaf confluence, and above the eastern sideslopes from near the Trippett Ranch to opposite Fernwood. The presence of deformed Miocene sediment but the absence of Pliocene sediment suggest that this early basin is of Pliocene age, formed during the initial emergence of the Neogene sea floor. The low structural dips (<20°) and gently rolling nature of this early basin suggest that it has not been strongly deformed during the subsequent Quaternary deformation of the lower canyon region. However, regional uplift of Quaternary age is undoubtedly responsible for the incision of this early basin by the present drainage system.

In the lower or main canyon part from near Dix Canyon to the mouth, the mainstem exhibits a steep, almost linear profile while the creeks in Dix, Brookside and an unnamed canyon show linear to positive convex profiles. These profiles are almost certainly a reflection of accelerated tectonic uplift involving extensive faulting within a steep anticlinal flexure. Thrust faulting related to the Las Flores and Malibu Coast fault systems near the coast has presumably caused crustal shortening across lower Topanga Canyon and this is reflected in the steep southward dips, locally up to 75°S, of Cretaceous and Paleogene rocks south of the Dix Canyon confluence and the Tuna Canyon fault system. Because Neogene rocks are also locally involved in this deformation, it is likely that tectonic uplift reached its maximum during the Quaternary and is continuing episodically at the present time.

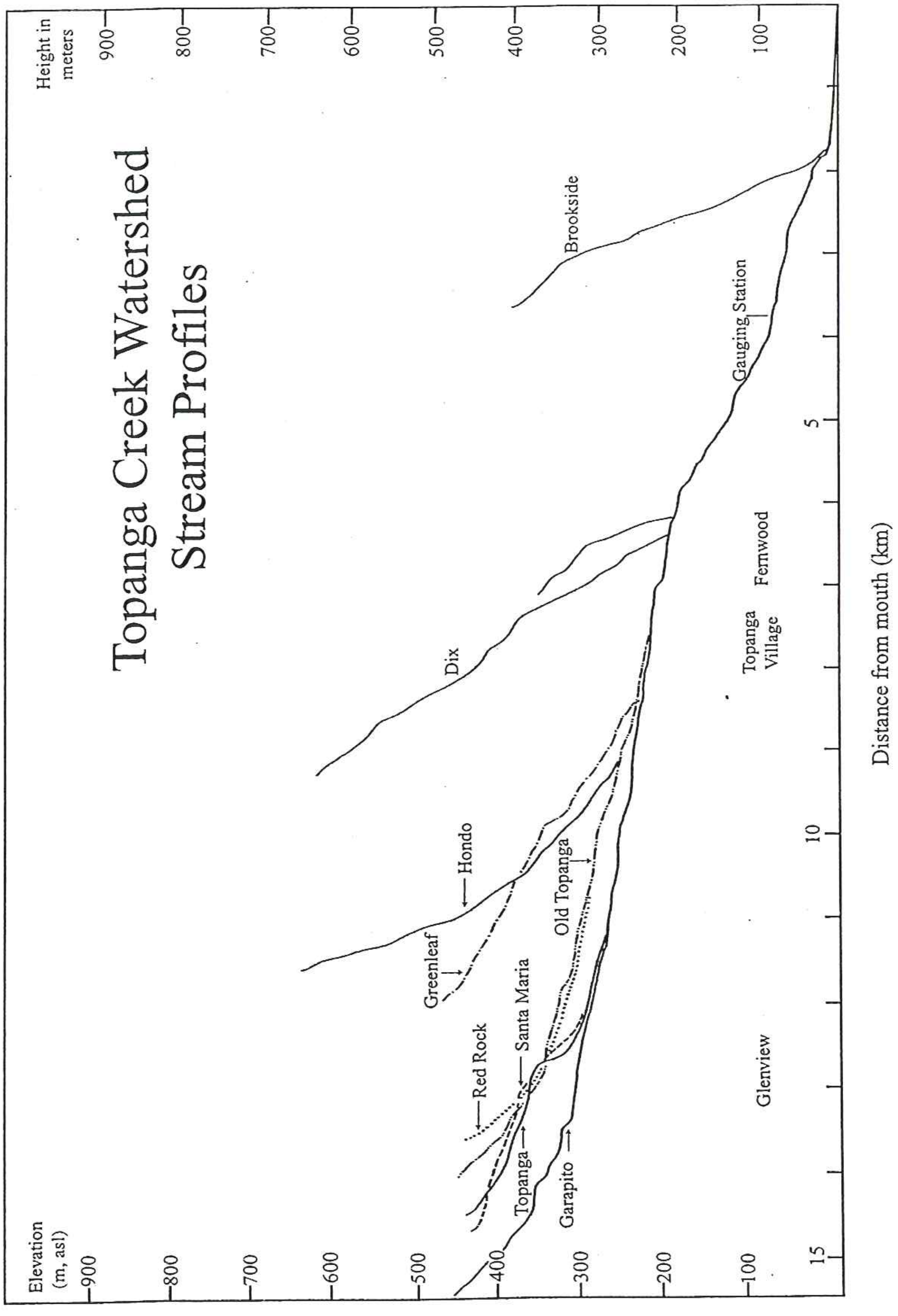
Table 6.1. Gradients of Stream-Channel Reaches within Topanga Creek Watershed (Fall divided by Reach Length)

Creek	Reach	Distance (m)	Gradient
Topanga Creek	Source-Glenview top	1700	0.041
	Glenview	150	0.253
	Glenview base-Old Topanga	4950	0.020
	Glenview base-Dix Canyon	6650	0.020
	Main Canyon: Dix-Estuary	4100	0.045
	Estuary	1800	0.008
	Overall: Source-Mouth	14,400	0.030
Garapito Creek	Source-Topanga Creek	4400	0.042
	Overall: Source-Mouth	15,500	0.030
Santa Maria	Source-Break	1550	0.034
	Break-Garapito	950	0.080
Greenleaf	Source-Topanga Creek	3550	0.067
Old Topanga	Source-Topanga Creek	6400	0.032
Red Rock	Source-Old Topanga	2300	0.053
Hondo	Source-Topanga Creek	2550	0.149
Dix	Source-Topanga Creek	2900	0.145
Unnamed	Source-Topanga Creek	900	0.178
Brookside	Source-Topanga Creek	1900	0.201

In hydrodynamic terms, these observations imply that upper Topanga Creek and its main tributaries are behaving in a predictable manner, with sediment entrained and evacuated from steeper slopes and deposited temporarily in lower-gradient reaches immediately downstream. This is supported by field observations which reveal episodic pulses of erosion and sediment storage within these channels.

Lower Topanga Creek is dominated by the main canyon which serves as a chute to evacuate debris reaching its head 500 m below the Dix Canyon confluence. Debris rarely accumulates within this canyon, other than temporarily within incised meander bends, but begins to be deposited as the gradient lessens 1.8 km above the river mouth. The bedrock channel for a further 600 m above the Dix Canyon confluence reveals that net scour and sediment loss are presently working their way upstream from the main canyon.

Figure 6-1 Stream Profiles in the Topanga Creek Watershed



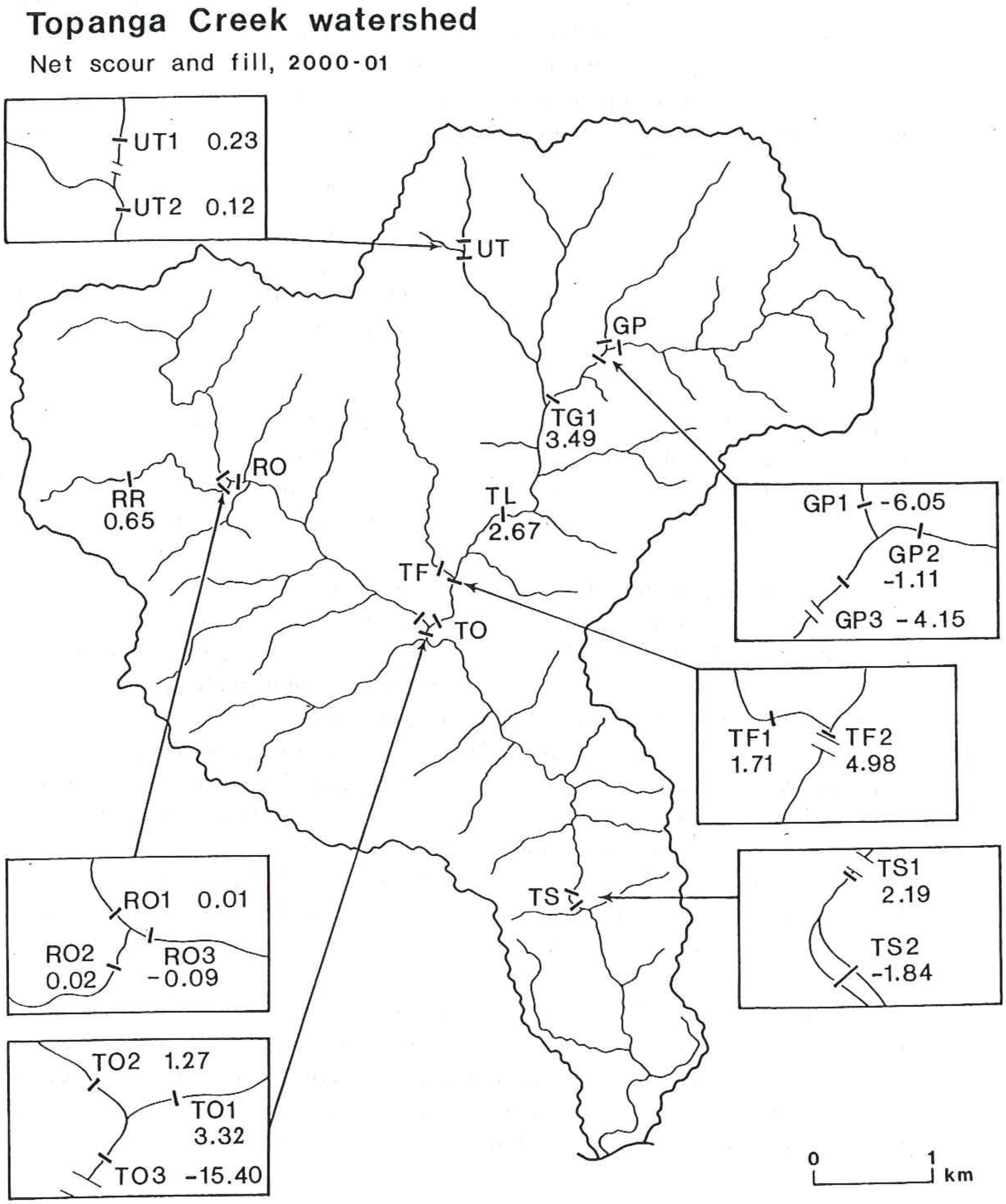


Fig. 6-2. Locations of channel cross sections.

6.2 Study Reaches

Twenty three stream-channel reaches at 9 locations were initially identified to define important components of the Topanga fluvial system, including headwater reaches, intermediate reaches, and significant tributary reaches and confluences (Fig. 6-2). These sites reflect the segmentation of the channel system discussed above. Of these, 18 reaches were the focus of repeat surveys before and after specific rainfall-runoff events, as follows:

The sites in the Upper Topanga Creek Watershed comprise:

Upper Topanga [UT]: 2 cross-sections in the valley bottom near the confluence of two tributaries with the mainstem of Topanga Creek 1 km south of its northern interfluve, designed to reveal geomorphic changes, if any, attributable to runoff in the headwater region.

Santa Maria-Garapito confluence [GP]: 3 cross-sections near the confluence of Santa Maria and Garapito creeks, one on each creek above the confluence, one below the confluence near the old bridge. These were designed to reveal the effects of varying runoff from two very different sub-basins, one underlain by Miocene siltstone and claystone, the other by Cretaceous and Oligo-Miocene sandstone and conglomerate.

In the middle portion of the watershed, sites comprise:

Garapito Creek near Topanga Creek confluence [TG]: 1 cross section on Garapito Creek below the Route 27 bridge across Garapito Creek, designed to reveal the effects of combined runoff and sediment delivery from the Garapito and Santa Maria sub-basins immediately above the confluence with Topanga Creek.

Topanga Creek at Lake Topanga [TL]: 1 cross-section upstream of the landslide that temporarily restrained flow in Topanga Creek, midway between the Garapito Creek and Old Topanga Creek confluences. This reach was designed to monitor the backwater effects, if any, of renewed mass movement.

Topanga Creek at Greenleaf Creek confluence [TF]: 2 cross-sections, one on Greenleaf Creek above the confluence, the other on Topanga Creek just below the confluence, designed to integrate the impact of Greenleaf Creek flow with mainstream effects.

Topanga Creek-Old Topanga Creek confluence [TO]: 3 cross-sections near the confluence designed to reveal changes, if any, attributable to discrete flow and sediment yields in each creek, and in combination below the confluence. One site was located on Old Topanga Creek [TO2], one on Topanga Creek above the confluence [TO1], and one below the confluence near the road bridge [TO3].

In the Old Topanga Creek sub-drainage sites comprise:

Red Rock Canyon [RR]: 1 cross section near the Ranger Station was designed to evaluate the effects of runoff from a steep sub-basin underlain by Oligo-Miocene sandstone and conglomerate of the Sespe Formation.

Red Rock Canyon-Old Topanga Creek confluence [RO]: 3 cross-sections above and below the confluence of Red Rock Canyon and Old Topanga Creek designed to show the effects of contrasting runoff-sediment regimes in the two sub-basins.

Topanga Creek-Old Topanga Creek confluence [TO]: Of the 3 cross-sections noted above, one was in the Old Topanga Creek drainage [TO2].

Lower Topanga Creek stream gauge site [TS]: 2 cross-sections in Topanga Creek, one below the main road bridge, the other downstream at Elkhorn, designed to show the effects of runoff and sediment delivery as the mainstream emits from the steepest segment of the bedrock canyon to the north prior to the reduced gradient downstream. In view of the transport-dominated chute provided by the main canyon, these were the only reaches chosen for study along lower Topanga Creek. The river mouth (BL) was the focus of repeat surveys discussed in Chapter 7.

6.3 Channel Erosion and Sedimentation

The 18 specific reaches discussed above were surveyed initially during November and December 2000 and subsequently tied by benchmark leveling to sea level datum. Although these survey reaches were not surveyed prior to the first wet spell of October 26-29, they were defined prior to the second wet spell of January 8-12.

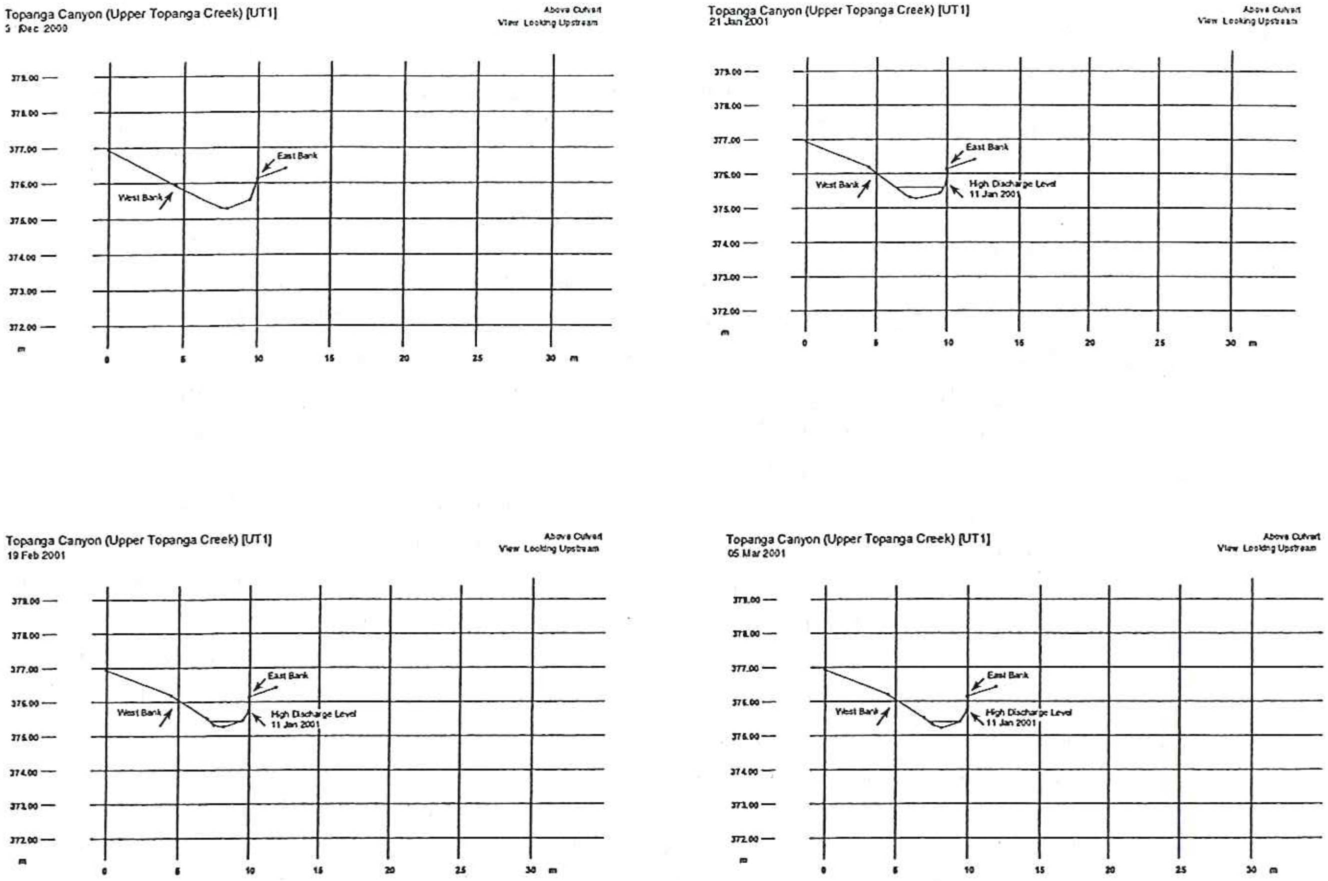
Repeat surveys indicated a modest but erratic amount of stream-channel incision in the higher and lower reaches, with deposition in the middle reaches, as a result of the January 8-12 wet spell. This spell generated moderate flows in most channels and their effective hydraulic radius increased by a factor of between two and ten. However, although hydraulic and geometric variables increased substantially and riparian grasses and shrubs were flattened by these flows, little bank erosion occurred, presumably because neither these flows nor hydraulic pressure from bank materials reached thresholds at which significant bank failure could occur. Further, bank materials had considerable capacity for infiltration as a result of the preceding lengthy dry period.

The effects of subsequent wet spells and flow events on these stream channels were also observed during February and March. Repeat surveys showed a modest but erratic amount of stream-channel erosion as a result of these rains, with partial recovery by sedimentation during subsequent dry intervals. Whereas little bank erosion was observed to result from January flows, the modest flows of February and early March triggered local bank failures. These occurred most notably in lower Topanga Canyon between the gauging station and the Brookside confluence where Topanga Canyon Boulevard approaches the channel on constructed fill which is prone to failure. The saturating rains and higher flows of February and early March presumably increased hydraulic pressure in these materials leading to localized bank failure. Slightly elevated flows resulting from the early April rain event did not initiate new bank failures or measurable channel changes. For the remainder of the water year, the reaches and cross-sections remained largely as they were in March.

6.3.1 Investigation of Specific Reaches

Stream discharge (the volume of water per second flowing through a given cross-section at a point in time) was measured in the field during each survey (see Chapter 2). When accessibility to the channel was limited, discharge was calculated using the Manning formula (Barnes, 1977). Locations of cross sections are provided. All are within UTM Zone 11 (NAD27 meters).

Figure 6.3 Upper Topanga [UT1] Cross Sections



Upper Topanga [UT1]: This narrow, incised cross section was located in Summit Valley Park near the upper ridge of the watershed. The site is found above a small culvert designed to channel streamflow beneath a trail. Alluvial fill at this site ranges from gravel to clay. Both banks are covered with willows and mulefat. The surrounding area is thickly covered with alien grasses. Cross sections are illustrated in Figure 6-3. Based on the observations, this location experienced a net gain in sediment during the course of the study.

UTM: 3777281, 352396	Elevation: 413 meters (1355')

3 December 2000 – 21 January 2001: Water levels reached near bankfull stage (0.65 m depth) on 11 January in response to the rainfall event of 8-12 January, based on field observations taken on 12 January. Calculated peak discharge on 11 January was 1.3107 m^3s^{-1}.Measured discharge on 12 January during a second pulse of flow equaled 0.0026 m^3s^{-1} with a measured suspended sediment load of 0.77 mg l^{-1}. During the observation interval, there was a loss of 0.60 m^2 of material, primarily from the eastern bank and channel bed.

21 January – 19 February 2001: Water levels again rose during this interval, especially in response to the 8-14 February rainfall event. A calculated peak discharge on 13 February was 0.1267 m^3s^{-1}. During the interval, there was a gain of 0.78 m^2 of material to the channel derived primarily from a small west bank failure.

19 February – 5 March 2001: This interval experienced three precipitation events. The first, 18 – 20 February, was modest in size and produced minimal flow. The second event, 23 – 28 February, was moderate in size, and built upon the antecedent moisture of the prior event. The third event, 4 – 6 March was moderate in size and produced a measurable discharge on 6 March of 0.1076 m^3s^{-1} with 600 mg l^{-1} suspended sediment which was characterized by buff and chocolate colored residues. During this interval there was a modest gain of 0.05 m^2 of material within the channel.

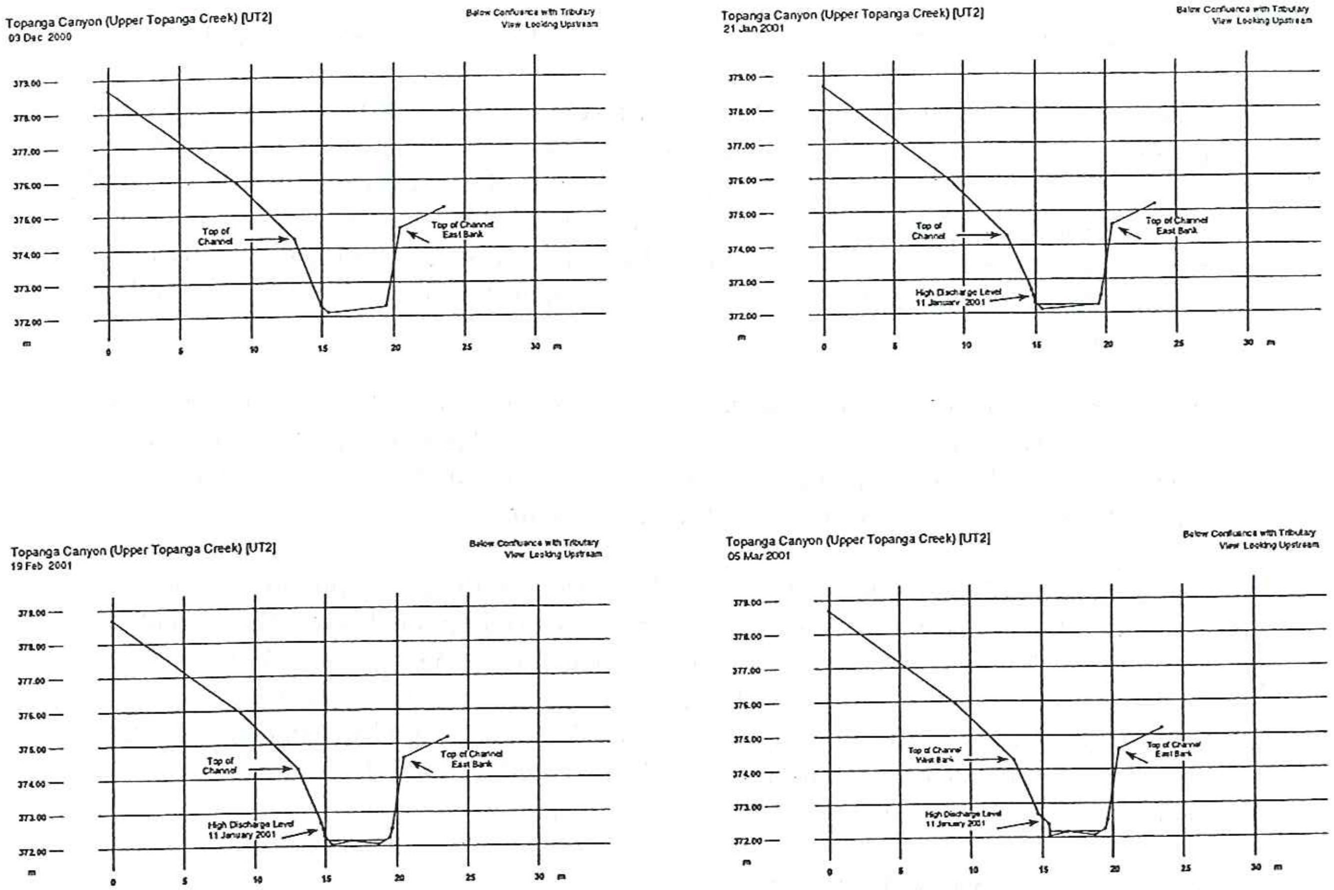
Erosion and Deposition Summary:

21 January	-0.60m^2
19 February	+0.78 m^2
5 March	+0.05 m^2

Net Change in Channel: +0.23 m^2

Suspended Sediment Summary:		Measured Discharge:
12 January	0.77 mg l^{-1}	0.0026 m^3s^{-1}
6 March	600 mg l^{-1}	0.1076 m^3s^{-1}

Figure 6.4 Upper Topanga [UT2] Cross Sections



Upper Topanga [UT2]: This deeply incised reach was located downstream from the culvert in Summit Valley Park, just a few meters downstream from UT1. The channel banks were near vertical with a 2.0 – 2.6 m difference between the channel bed and potential bankfull stage. The channel bed was choked with walnut and arroyo willow, and human artifacts, including portions of tile walls, roofs, and concrete slabs. The reach is developed in poorly sorted alluvium ranging from coarse gravel to clay. Cross sections are illustrated in Figure 6-4. As was found for the upstream site, this location experienced a net deposition of sediment during the course of the study.

UTM: 3777476, 352311 Elevation: 381 meters (1249')

3 December 2000 – 21 January 2001: Water levels reached a stage of nearly 0.45 m during the storm event of 8-12 January, based on observations of the bank on 12 January, though superelevation may have occurred owing to the large volume of prior in-place channel bed debris. Measured discharge on 12 January was 0.0034 m^3s^{-1}, with a measured suspended load of 37.383 mg l^{-1}. A peak calculated discharge of 0.9696 m^3s^{-1} occurred on 11 January. During this interval, however, there was no net change in the channel.

21 January – 19 February 2001: Water levels rose again during this interval, especially in response to the 8 – 14 February rainfall event. A calculated peak discharge on 13 February was 0.0545 m^3s^{-1}. During the interval, there was a modest gain of 0.30 m^2 of material in the center of the channel, likely derived from sediment trapped by vegetation and other debris.

19 February – 5 March 2001: This interval experienced three precipitation events. As with Upper Topanga [UT1], there was minimal flow in response to the 18 – 20 February event. The second event on 23-25 February produced a calculated peak discharge of 0.1024 m^3s^{-1}. The third event, 4 – 6 March, produced a measurable discharge of 0.1076 m^3s^{-1} with a 700 mg l^{-1} suspended sediment yield. As with Upper Topanga, this sediment was characterized by a chocolate colored residue. During this interval there was a loss of 0.18 m^2 of material from the channel. This loss, however, was expressed as a reduction in channel cross- section owing to collapse of a portion of the west bank.

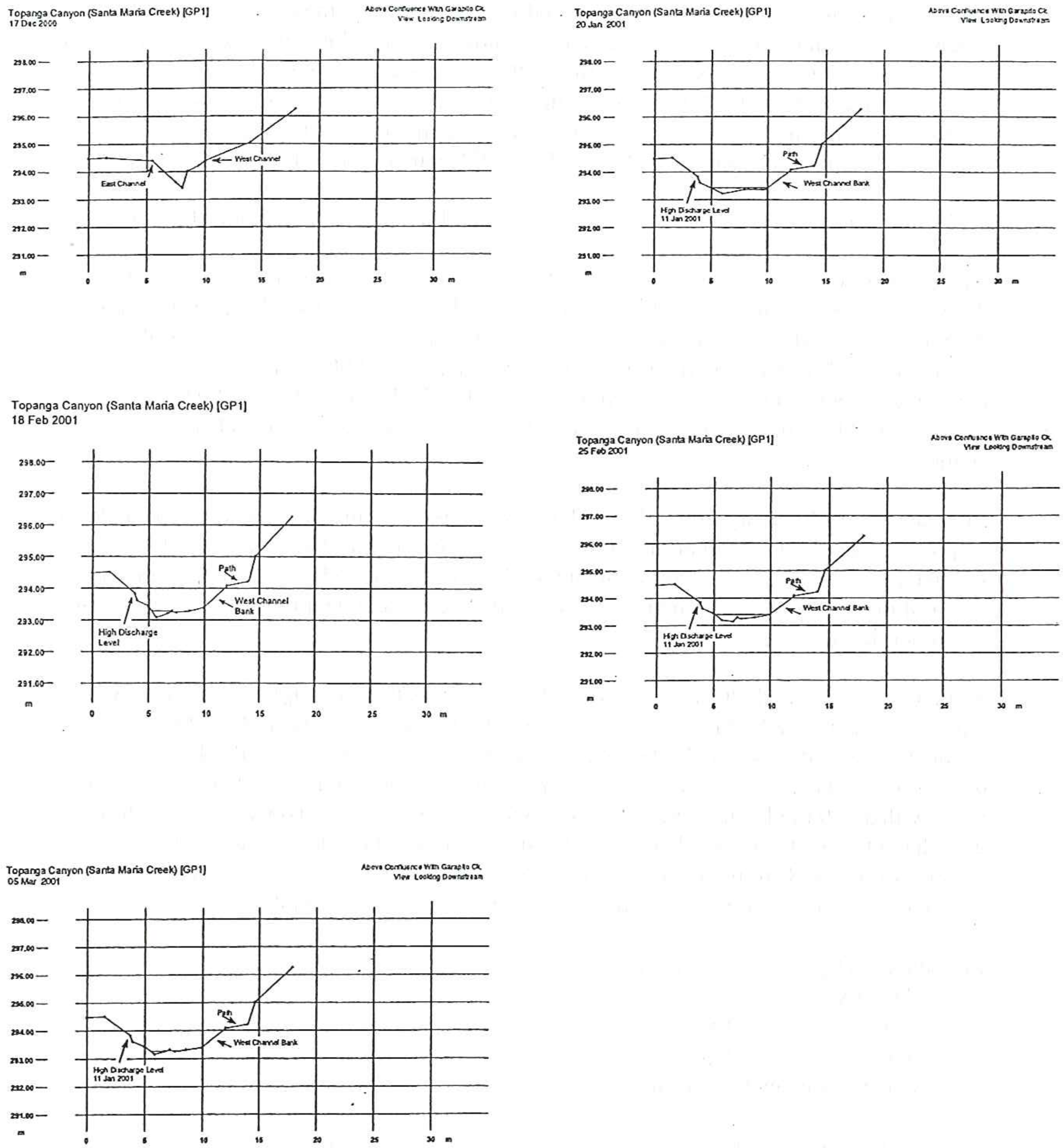
Erosion and Deposition Summary:

21 January	0.0 m^2
19 February	+0.30 m^2
5 March	- 0.18 m^2

Net Change in Channel: +0.12 m^2

Suspended Sediment Summary:		Measured Discharge:
12 January	37.383 mg l^{-1}	0.0034 m^3s^{-1}
6 March	700 mg l^{-1}	0.1076 m^3s^{-1}

Figure 6.5 Santa Maria Creek [GP1] Cross Sections


Topanga Canyon (Santa Maria Creek) [GP1]
17 Dec 2000

Topanga Canyon (Santa Maria Creek) [GP1]
20 Jan 2001

Topanga Canyon (Santa Maria Creek) [GP1]
18 Feb 2001

Topanga Canyon (Santa Maria Creek) [GP1]
25 Feb 2001

Topanga Canyon (Santa Maria Creek) [GP1]
05 Mar 2001

Santa Maria Creek [GP1]: This rock and gravel tributary of Santa Maria Creek to Garapito Creek was surveyed 30 m upstream from its confluence with upper Garapito Creek. The active cross section was narrow (< 2 m), though there was clear evidence of a potentially broader channel owing to the presence of degraded stream terraces. Bank vegetation is a mix of willows and exotic grasses, with a few native sedges. Cross-sections are illustrated in Figure 6-5. This location experienced a net loss of sediment during the course of the study.

UTM: 3776173, 353903 Elevation: 311 meters (1020')

17 December 2000 – 20 January 2001: This reach experienced overbank flow on 11 January with a calculated discharge of 1.4264 m^3s^{-1} and a measured discharge of 0.0202 m^3s^{-1}. Suspended sediment yield on that date was 145.24 mg l^{-1}. During this interval there was a loss of 6.00 m^2 of channel material owing to channel widening and deepening.

20 January – 18 February 2001: This interval experienced a modest precipitation event, 24-26 January, and a moderate event 8-14 February. There was a calculated discharge of 0.6812 m^3s^{-1} on 13 February, and suspended sediment yield of 30.77 mg l^{-1} on 18 February. During the interval there was a loss of 0.30 m^2 of channel material owing to slight incision in the channel bed along the west bank.

18 February – 25 February 2001: This interval, with a moderate precipitation episode, exploited the antecedent moisture introduced during the mid-February event, and produced water levels to 0.28 m. A calculated discharge of 0.9198 m^3s^{-1} was experienced on 25 February. During the interval there was a modest gain of 0.13 m^2 of channel material owing to contributions from west bank collapse.

25 February – 5 March 2001: This interval experienced modest precipitation 26 – 28 February, followed by a moderate event, 4 – 6 March, that produced a calculated discharge of 0.0634 m^3s^{-1} on 5 March. During the interval there was a slight gain of 0.12 m^2 of material in the mid-channel.

Erosion and Deposition Summary:

20 January	-6.00 m^2
18 February	-0.30 m^2
25 February	-0.13 m^2
5 March	+ 0.12 m^2

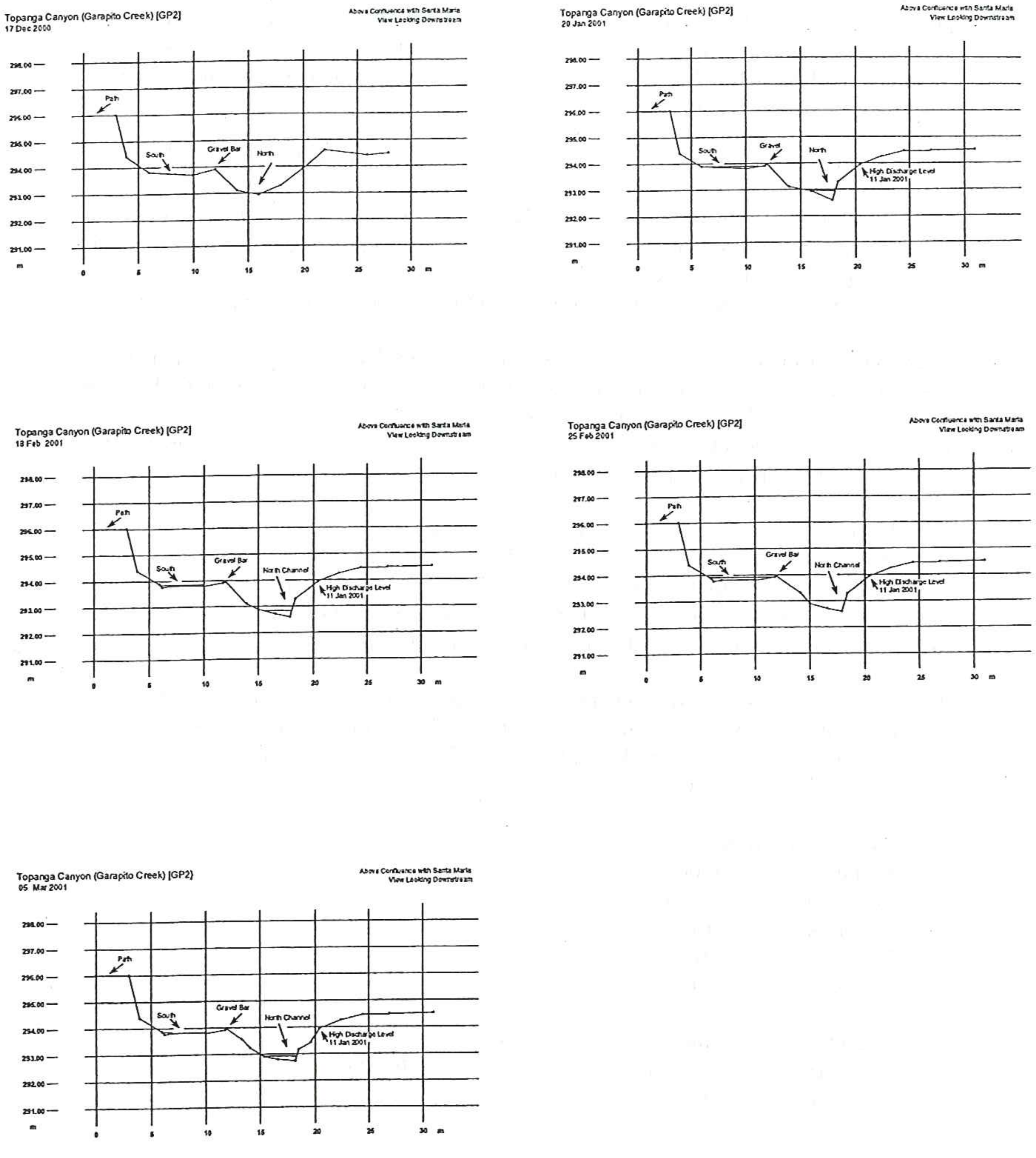
Net Change in Channel: -6.05 m^2

Suspended Sediment Summary:

11 January	145.24 mg l^{-1}
18 February	30.77 mg l^{-1}

Measured Discharge:
0.0202 m^3s^{-1}

Figure 6.6 Garapito Creek [GP2] Cross Sections



Garapito Creek [GP2]: This rocky narrow cross-section was located on Garapito Creek, 30 m upstream from the confluence with Santa Maria Creek on the Rourke Property. The reach was characterized by the presence of two distinct channels visible during low flow stages. The south channel at the start of the study was only 1 m in width and 0.2 m in depth. The north channel was more deeply incised (0.8 m). Separating the two channels was a boulder and gravel bar some 3 m wide and 0.8 m high. Tall trees (eucalyptus, oak, sycamore) provide canopy cover. The bank vegetation is mixed grasses and shrubs. Cross-sections are illustrated in Figure 6-6. As with nearby Santa Maria Creek, this location experienced net erosion during the study.

UTM: 37 6163, 353925 Elevation: 350 meters (1150')

17 December 2000 – 20 January 2001: This reach experienced peak flow on 11 January with a calculated discharge of 3.557 m^3s^{-1} and a measured discharge of 0.1158 m^3s^{-1} on the rising limb of the hydrograph. Suspended sediment yield was 100.00 mg l^{-1}. During the interval there was a loss of 1.12 m^2 of channel material owing to somewhat uniform bed scour in the southern channel and incision confined to the thalweg portion of the north channel.

20 January – 18 February 2001: This interval experienced a modest calculated discharge of 0.0395 m^3s^{-1} on 13 February and a suspended sediment load of 26.67 mg l^{-1} on 18 February. During the interval there was a loss of 0.34 m^2 of material from the north channel.

18 February – 25 February 2001: This interval produced flow in both the north and south channels with a combined calculated peak discharge of 0.2460 m^3s^{-1}. During the interval, 0.42 m^2 of sediment were added to the channel at the expense of the mid-channel gravel bar.

25 February – 5 March 2001: The reach experienced a calculated 0.2322 m^3s^{-1} discharge on 25 February and a measured discharge of 0.0637 m^3s^{-1} on 5 March. During the interval there was a loss of 0.07 m^2 of channel material derived largely from a small bank collapse in the north channel.

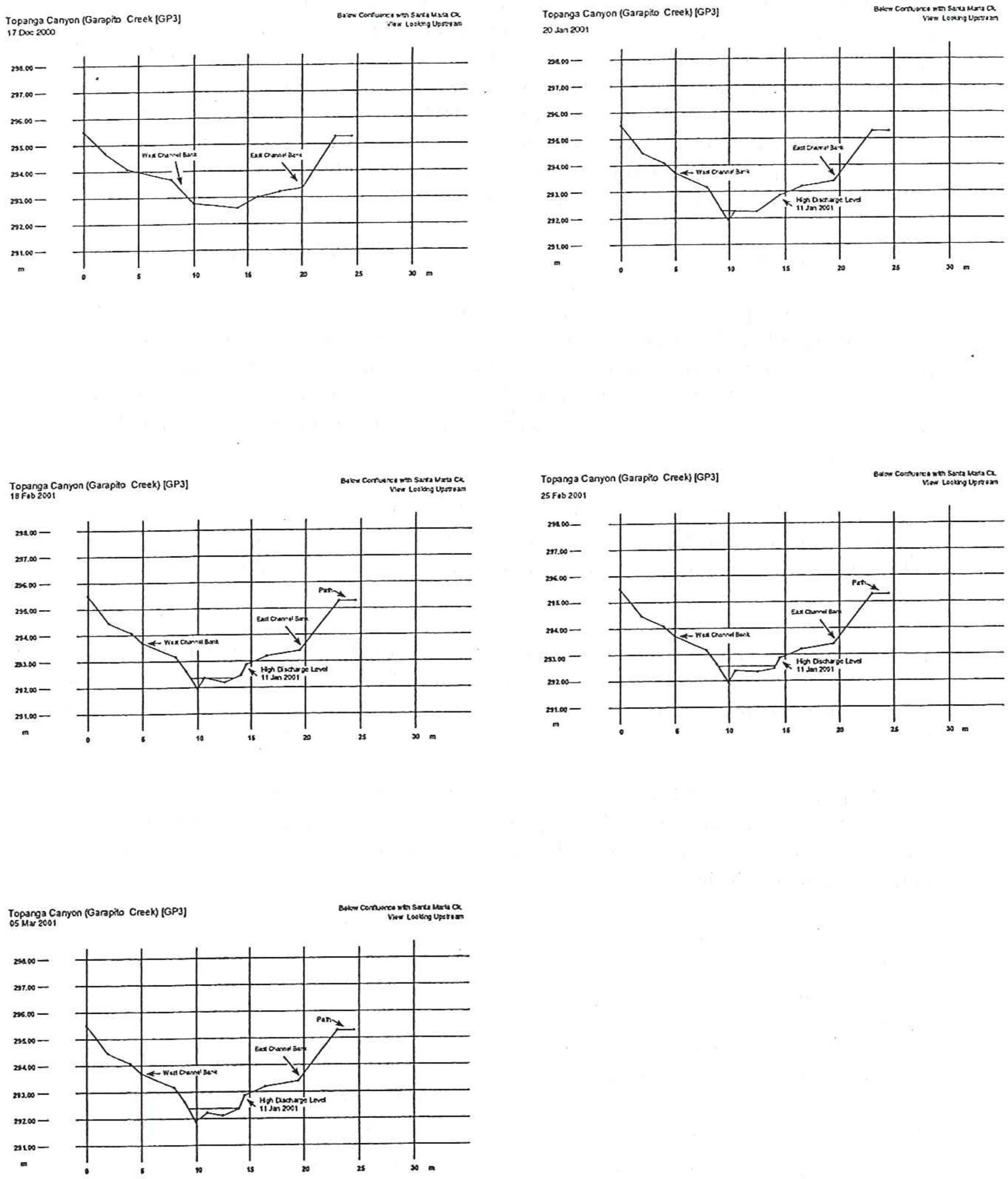
Erosion and Deposition Summary:

20 January	-1.12 m^2
18 February	-0.34 m^2
25 February	+0.42 m^2
5 March	-0.07 m^2

Net Change in Channel: -1.11 m^2

Suspended Sediment Summary:		Measured Discharge:
11 January	100.00 mg l^{-1}	0.1158 m^3s^{-1}
18 February	26.67 mg l^{-1}	
5 March		0.0637 m^3s^{-1}

Figure 6-7 Garapito Creek [GP3] Cross Sections



Garapito Creek [GP3]: This gravel and rock cross-section was located on Garapito Creek downstream from the confluence of Garapito Creek and Santa Maria Creek, and upstream from the small abandoned bridge that once constituted the overland route through Topanga Canyon to the San Fernando Valley at the beginning of the twentieth century. Set back from the bank are tall oaks and eucalyptus trees which provide broken canopy cover along the mostly open bank vegetated with grasses and shrubs. Cross-sections are illustrated in Figure 6-7. Consistent with the other two nearby sites, this location experienced a net erosion of material during the course of the study.

UTM: 3776136, 353890 Elevation: 297 meters (975')

17 December 2000 – 20 January 2001: This reach responded similarly to the upstream segment of Garapito Creek and Santa Maria Creek with a peak flow on 11 January calculated at 3.621 m^3s^{-1} and measured at 0.1141 m^3s^{-1} on the rising limb of the hydrograph. Suspended sediment yield was 88.88 mg l^{-1}. During the interval there was a 3.32 m^2 loss of channel material owing to channel incision and west bank collapse.

20 January – 18 February 2001: During the interval 0.20 m^2 of material was lost from the channel owing to east bank retreat. A calculated peak discharge of 0.4191 m^3s^{-1} occurred on 13 February.

18 February – 25 February 2001: This interval produced a calculated flow of 1.4606 m^3s^{-1} on 25 February and a gain of 0.21 m^2 material in the channel center.

25 February – 5 March 2001: This reach experienced a water depth of 0.25 m across the channel width with a calculated discharge of 0.0881 m^3s^{-1} on 5 March. During the interval there was a 0.84 m^2 loss of channel material owing to bed scour.

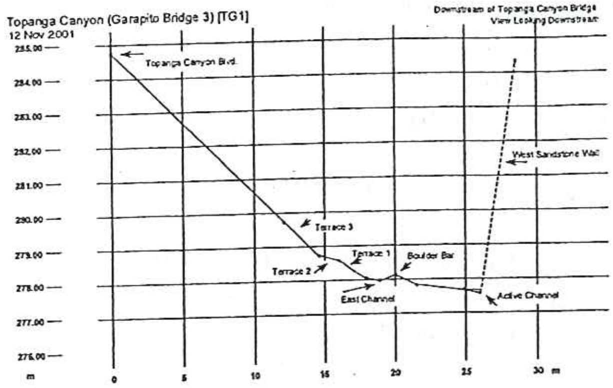
Erosion and Deposition Summary:

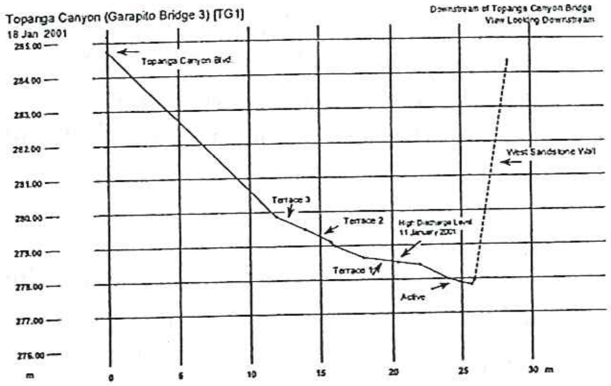
20 January	-3.32 m^2
18 February	-0.20 m^2
25 February	+0.21 m^2
5 March	-0.84 m^2

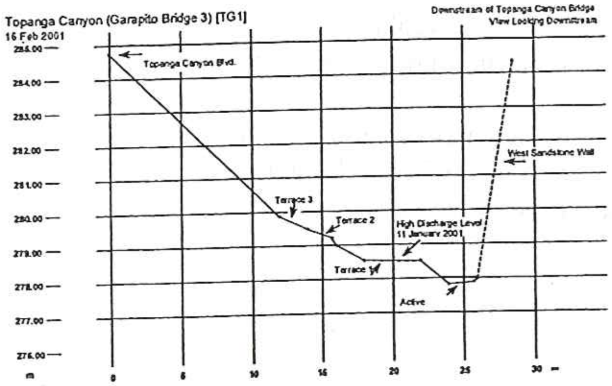
Net Change in Channel: -4.15 m^2

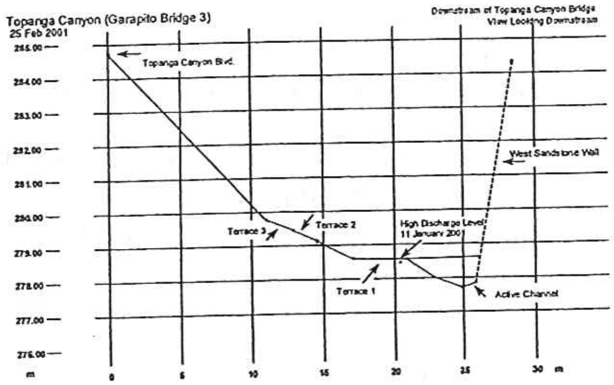
Suspended Sediment Summary:		Measured Discharge:
11 January	88.88 mg l^{-1}	0.1141 m^3s^{-1}

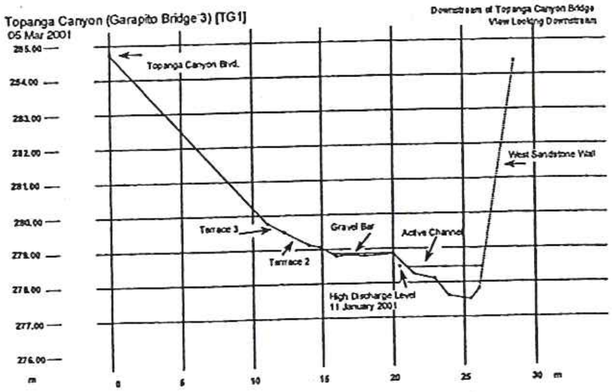
Figure 6.8 Garapito Creek [TG1] Cross Sections


Topanga Canyon (Garapito Bridge 3) [TG1]
12 Nov 2001


Topanga Canyon (Garapito Bridge 3) [TG1]
18 Jan 2001


Topanga Canyon (Garapito Bridge 3) [TG1]
16 Feb 2001


Topanga Canyon (Garapito Bridge 3)
25 Feb 2001


Topanga Canyon (Garapito Bridge 3) [TG1]
05 Mar 2001

Garapito Creek [TG1]: This cross section, located on Garapito Creek downstream from the bridge (LA CO M-56-12, 1960) on Topanga Canyon Boulevard at Cheney Road, consisted of two low flow channels divided by a boulder and gravel bar. Garapito Creek meets the main stem of Topanga Creek approximately 200 meters below this study site. The west bank of the channel was defined by a near-vertical sandstone bluff. There is dense riparian vegetation providing almost 90% canopy cover. Cross-sections are illustrated in Figure 6-8. This location experienced a net deposition of sediment.

UTM: 3775661, 353398 Elevation: 289 meters (950')

12 November 2000 – 18 January 2001: Both channels were occupied with water though the larger (west) channel was filled to 0.65 m depth following the 8-12 January storm event. Peak flow occurred on 11 January with a calculated discharge of 3.8675 m^3s^{-1}, with suspended sediment measured at 142.105 mg l^{-1}. During the interval 5.80 m^2 of material accumulated throughout the channel.

18 January – 16 February 2001: This interval included a modest precipitation event (24-26 January) and a moderate event (8-14 February). A calculated peak discharge of 0.5932 m^3s^{-1} occurred on 13 February. During the interval there was a 0.23 m^2 loss of material in the channel primarily through bed scour.

16 February – 25 February 2001: This cross-section experienced a 5-m wide water-occupied channel on 25 February with a calculated peak discharge of 1.9907 m^3s^{-1}. Suspended sediment yield was 700 mg l^{-1} on 18 February. During the interval 4.48 m^2 of material was lost from the channel, largely through erosion along the west bank of the main channel and modest bed incision.

25 February – 5 March 2001: This cross-section experienced two active channels, with a 0.8 m deep west channel at a calculated peak discharge of 2.2349 m^3s^{-1} on 5 March. Suspended sediment was 1295.24 mg l^{-1}. During the interval there was a gain of 2.40 m^2 of material that accumulated on the gravel bar.

Erosion and Deposition Summary:

18 January	+5.8 m^2
16 February	-0.23 m^2
25 February	-4.48 m^2
5 March	+2.40 m^2

Net Change in Channel: +3.49 m^2

Suspended Sediment Summary:

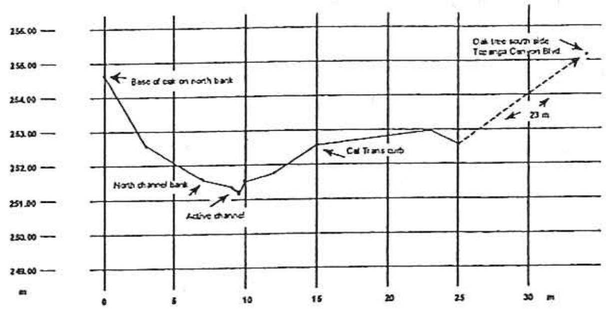
18 January	142.105 mg l^{-1}
18 February	700 mg l^{-1}
5 March	1295.24 mg l^{-1}.

Measured Discharge:
No data collected.

Figure 6-9 Lake Topanga [TL] Cross Sections

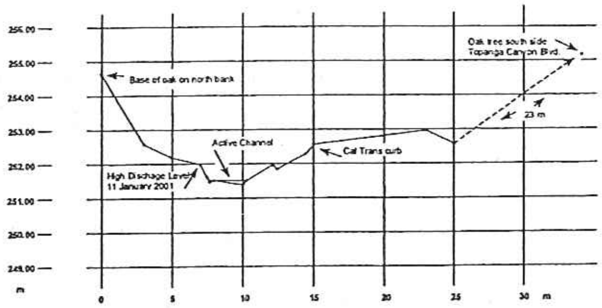
Topanga Canyon (Lake Topanga) [TL]
19 Nov 2000

At Sia Ma Crossing
View Looking Upstream



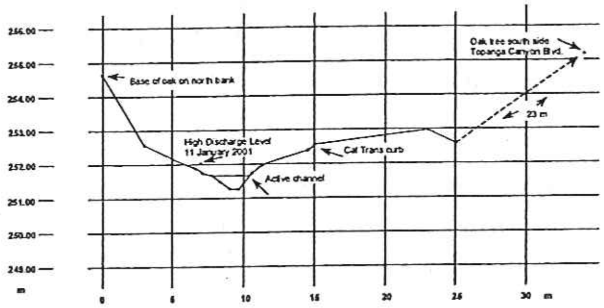
Topanga Canyon (Lake Topanga) [TL]
18 Jan 2001

At Sia Ma Crossing
View Looking Upstream



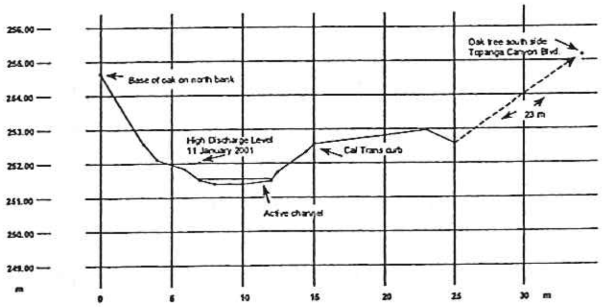
Topanga Canyon (Lake Topanga) [TL]
24 Jan 2001

At Sia Ma Crossing
View Looking Upstream



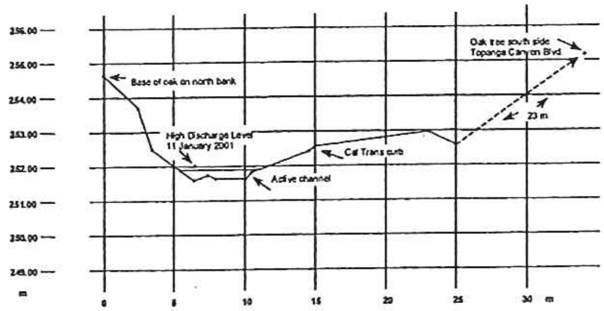
Topanga Canyon (Lake Topanga) [TL]
16 Feb 2001

At Sia Ma Crossing
View Looking Upstream



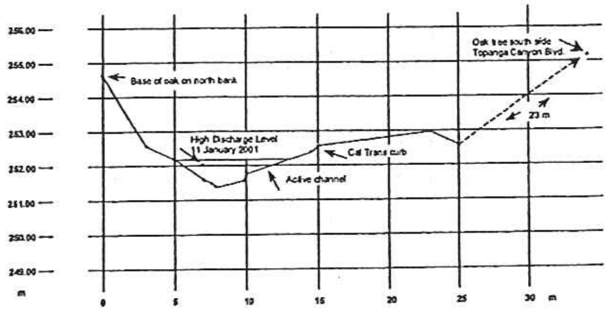
Topanga Canyon (Lake Topanga) [TL]
27 Feb 2001

At Sia Ma Crossing
View Looking Upstream



Topanga Canyon (Lake Topanga) [TL]
05 Mar 2001

At Sia Ma Crossing
View Looking Upstream



Lake Topanga [TL]: This cross-section was located downstream from a sharp bend in Topanga Creek below the in-stream crossing providing access to house number 815 Topanga Canyon Blvd. and upstream from the landslide that blocked Topanga Creek. The gravel-and-cobble dominated cross-section is adjacent to a lay-by used for vehicle parking and accumulation of road debris by both Caltrans and Los Angeles County Department of Public Works. Approximately 75% canopy cover is provided by mature willows. Understory vegetation is erratically distributed. Cross sections are illustrated in Figure 6-9. Overall, this site experienced a net deposition of sediment during the study.

UTM: 3774362, 352892 Elevation: 253 meters (830')

19 November 2000 – 18 January 2001: Water levels reached 0.63 m, moving slugs of gravel that paused on the crossing through the creek channel, then moved downstream through the narrow channel prior to encountering the reach adjacent to the landslide. This cross section responded to the 8-12 January wet spell with a calculated peak discharge of 2.19 m^3s^{-1}. Suspended sediment yield on 18 January was 72.73 mg l^{-1}. During this interval there was a gain of 0.62 m^2 of sand and gravel in the channel.

18 January – 24 January 2001: This interval experienced modest precipitation. Discharge on 24 January was 0.4034 m^3s^{-1} with a suspended sediment yield of 47.06 mg l^{-1}. There was a 0.44 m^2 accumulation of material along the channel banks.

24 January – 16 February 2001: This interval experienced moderate precipitation with a peak discharge of 0.5932 m^3s^{-1} on 12 February. There was a 0.48 m^2 accumulation of material in the channel.

16 February – 27 February 2001: This period experienced moderate precipitation with a suspended sediment yield of 3650.00 mg l^{-1} measured on 25 February. The suspended sediment was dominated by coarse sand particles. Peak discharge was calculated to be 2.082 m^3s^{-1}. During the interval there was a gain of 1.90 m^2 of material in the channel.

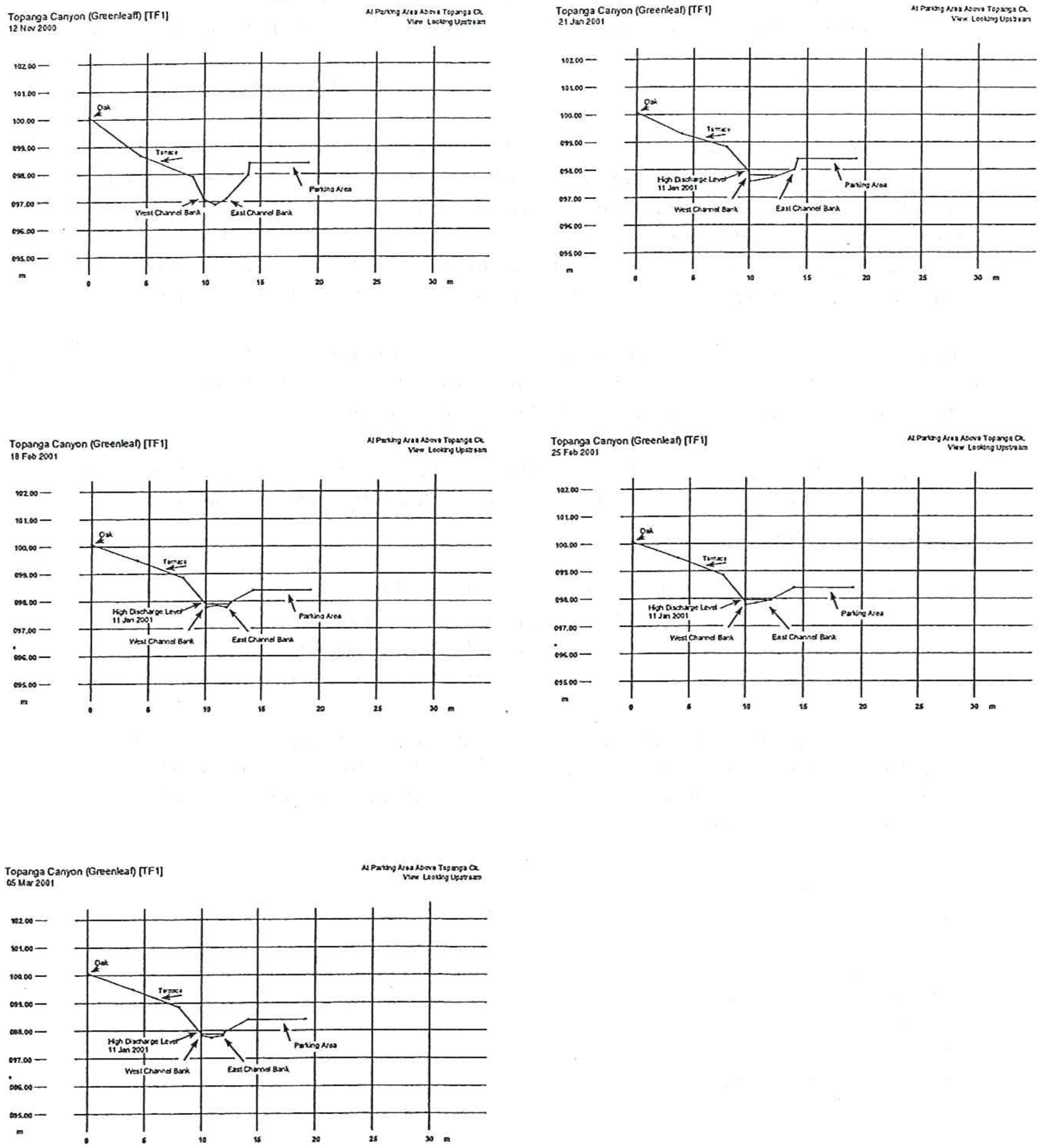
27 February – 5 March 2001: This period experienced a measured peak discharge on 5 March of 0.2863 m^3s^{-1}. Suspended sediment yield was 2320.00 mg l^{-1}. The suspended sediment was dominated by fine-medium sand. During this interval there was a loss of 0.77 m^2 of channel material.

Erosion and Deposition Summary:

18 January	+ 0.62 m^2
24 January	+ 0.44 m^2
16 February	+0.48 m^2
25 February	+1.90 m^2
5 March	-0.77 m^2
Net Change in Channel:	+2.67 m^2

Suspended Sediment Summary:		Measured Discharge:
18 January	72.73 mg l^{-1}	
24 January	47.06 mg l^{-1}	
25 February	3650.00 mg l^{-1}	
5 March	2320.00 mg l^{-1}	0.2863 m^3s^{-1}

Figure 6-10. Greenleaf [TF1] Cross Sections



Greenleaf [TF1]: This narrow, coarse sandy reach was located on Greenleaf Creek upstream of the in-stream crossing on Greenleaf Rd. This location is upstream from the confluence with Topanga Creek, collecting only the drainage from the steep canyon, and adjacent to a small dirt parking area. The reach was bounded on the west by a steep bank with an adjacent vegetation-covered terrace and bounded on the east by a similarly steep oak-dotted bank. The cross-sections are illustrated in Figure 6-10. This site experienced overall deposition of sediment during the course of the study.

UTM: 3773645, 352242	Elevation: 244 meters (800')

12 November 2000 – 21 January 2001: This interval experienced a measured discharge of 0.6827 m^3s^{-1} on 11 January. During this interval 0.07 m^2 of material accumulated in the channel center.

21 January –18 February 2001: A measured discharge of 0.0037 m^3s^{-1} occurred on 24 January, accompanied by a suspended sediment yield of 531.82 m l^{-1}. On 18 February a calculated discharge of 0.5301 m^3s^{-1} occurred with a 50.00 mg l^{-1} suspended sediment yield. During this interval 1.68 m^2 of material accumulated in the channel center.

18 February – 25 February 2001: A calculated discharge of 0.647 m^3s^{-1} occurred on 25 February with 189.53 mg l^{-1} suspended sediment. During the interval 0.10 m^2 of channel material accumulated.

25 February – 5 March 2001: A calculated discharge of 0.2863 m^3s^{-1} occurred on 5 March with 435.71 mg l^{-1} suspended sediment. During this interval 0.14 m^2 of material was lost from the channel bed.

Erosion and Deposition Summary:

11 January	+0.07 m^2
18 February	+1.68 m^2
25 February	+0.10 m^2
5 March	- 0.14 m^2

Net Change in Channel: +1.71 m^2

Suspended Sediment Summary:

11 January	
24 January	531.82 m l^{-1}
18 February	50.00 mg l^{-1}
25 February	189.53 mg l^{-1}
5 March	435.71 mg l^{-1}

Measured Discharge:

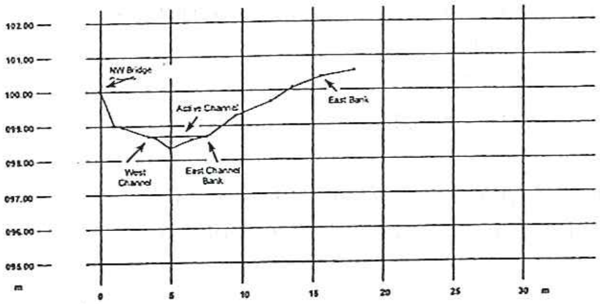
0.6827 m^3s^{-1}

0.0037 m^3s^{-1}

Figure 6-11 Topanga Creek [TF2] Cross Sections

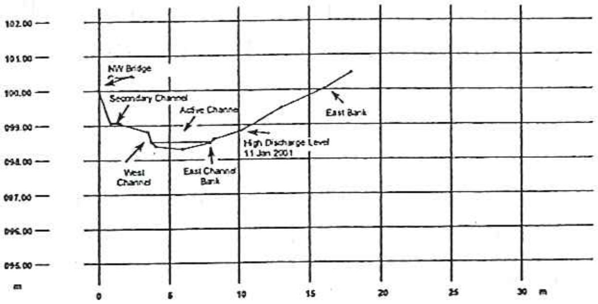
Topanga Canyon (Topanga Creek Greenleaf) [TF2]
12 Nov 2001

Below Confluence with Greenleaf
View Looking Upstream

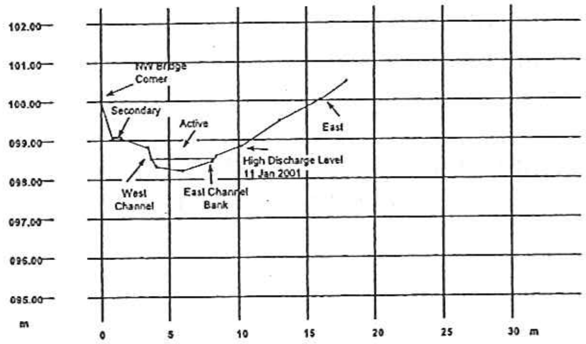


Topanga Canyon (Topanga Creek Greenleaf) [TF2]
21 Jan 2001

Below Confluence with Greenleaf
View Looking Upstream

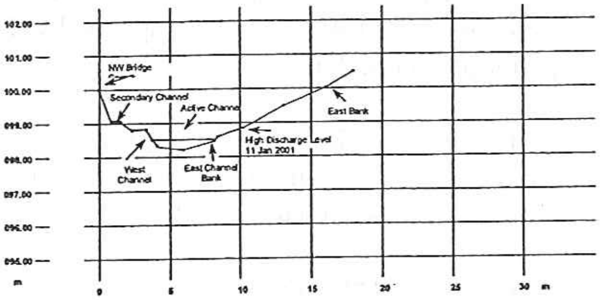


Topanga Canyon (Topanga Creek Greenleaf) [TF2]
18 Feb 2001



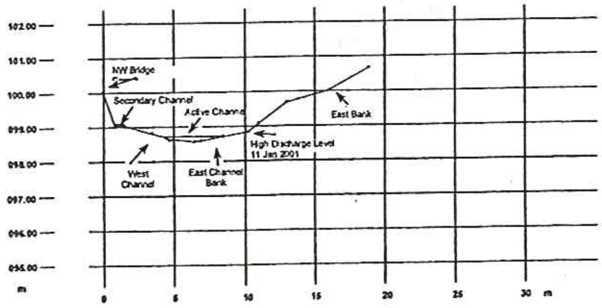
Topanga Canyon (Topanga Creek Greenleaf) [TF2]
25 Feb 2001

Below Confluence with Greenleaf
View Looking Upstream



Topanga Canyon (Topanga Creek Greenleaf) [TF2]
04 Mar 2001

Below Confluence with Greenleaf
View Looking Upstream



Topanga Creek [TF2]: This reach, characterized by boulder, cobble, gravel, and sand accumulation beneath the Greenleaf bridge (County B1896, LA 27-4.9 DOT Caltrans), was located on the main stem of Topanga Creek, downstream from the confluence of Greenleaf Creek. The channel thalweg was confined to a narrow channel adjacent to the central bridge stanchion. Significant accumulation of sand existed between the stanchion and the east bank (Topanga Canyon Boulevard) and bridge abutment. Mature willows provide extensive canopy cover. Cross-section diagrams are illustrated in Figure 6-11. This site also experienced net deposition during the study.

UTM: 3773612, 352313 Elevation: 241 meters (790')

12 November 2000 – 21 January 2001: A calculated discharge of 2.5381 m^3s^{-1} occurred on 11 January with water levels reaching as high as 0.43 m across the 6.5 m wide active channel. During this interval there were 5.01 m^2 material deposited in the channel, largely under the bridge, and a 0.85 m diameter boulder was rotated 40°.

21 January -- 18 February 2001: A measured discharge of 0.0983 m^3s^{-1} occurred on 24 January. Suspended sediment on 18 February was 66.67 mg l^{-1}. During the interval 0.03 m^2 of material was lost from the channel bed.

18 February -- 25 February 2001: A calculated discharge peak of 1.8111 m^3s^{-1} occurred on 25 February in response to a moderate precipitation event. Suspended sediment yield was 350.00 mg l^{-1} characterized by the presence of medium-fine sand. During the interval 0.15 m^2 of material was lost from the channel bed.

25 February - 4 March 2001: A calculated discharge of 0.4959 m^3s^{-1} occurred on 4 March in response to a moderate precipitation event that exploited the antecedent moisture of prior events. Suspended sediment discharge was 94.44 mg l^{-1}. During the interval 0.15 m^2 of material was gained on the channel bed.

Erosion and Deposition Summary:

21 January	+5.01 m^2
18 February	- 0.03 m^2
25 February	-0.15 m^2
4 March	+0.15 m^2

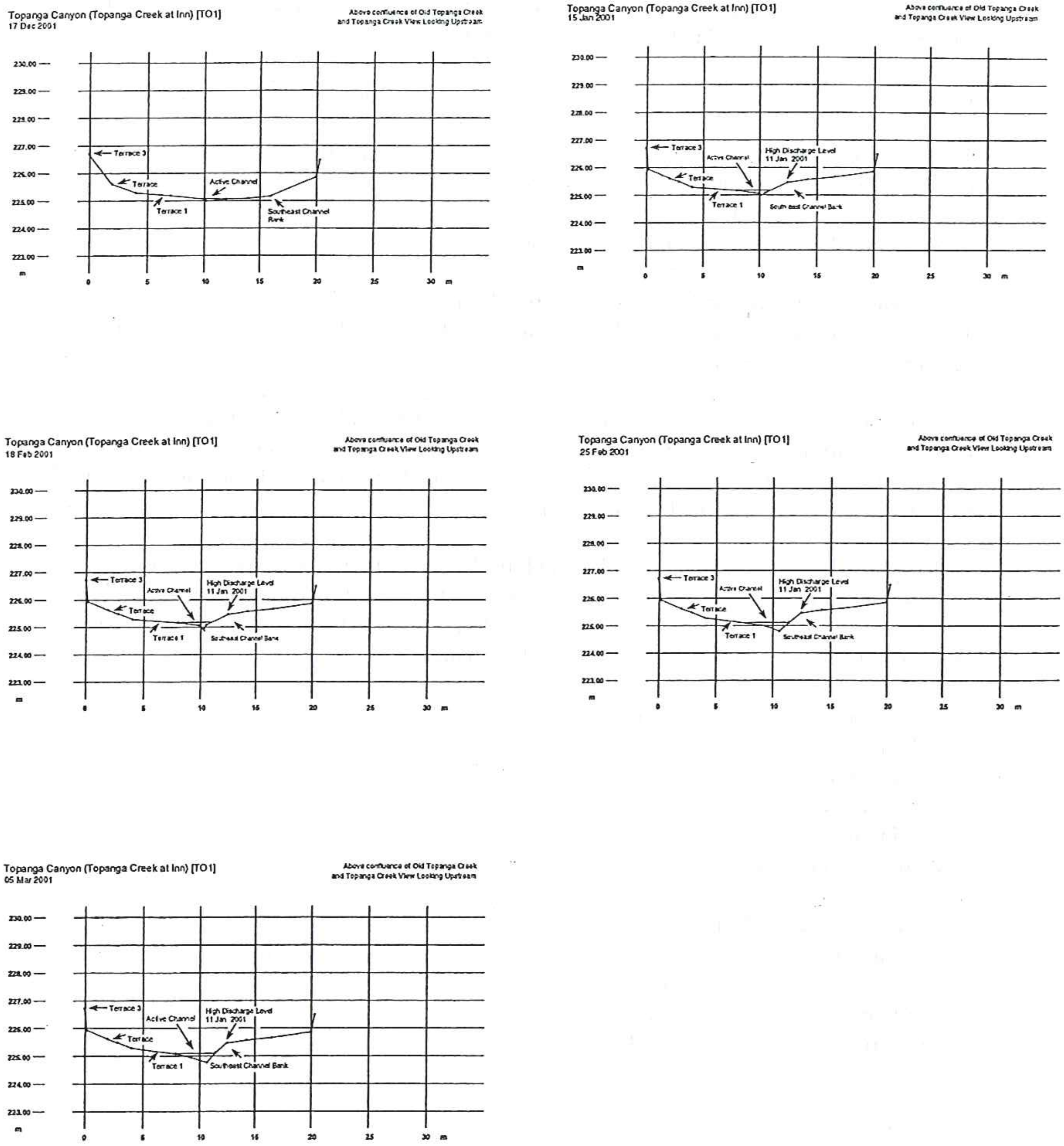
Net Change in Channel: +4.98 m^2

Suspended Sediment Summary:

24 January	
18 February	66.67 mg l^{-1}
25 February	350.00 mg l^{-1}
4 March	94.44 mg l^{-1}

Measured Discharge:
0.0983 m^3s^{-1}

Figure 6-12 Topanga Creek [TO1] Cross Sections


Topanga Canyon (Topanga Creek at Inn) [TO1]
17 Dec 2001

Above confluence of Old Topanga Creek and Topanga Creek View Looking Upstream

Topanga Canyon (Topanga Creek at Inn) [TO1]
15 Jan 2001

Above confluence of Old Topanga Creek and Topanga Creek View Looking Upstream

Topanga Canyon (Topanga Creek at Inn) [TO1]
18 Feb 2001

Above confluence of Old Topanga Creek and Topanga Creek View Looking Upstream

Topanga Canyon (Topanga Creek at Inn) [TO1]
25 Feb 2001

Above confluence of Old Topanga Creek and Topanga Creek View Looking Upstream

Topanga Canyon (Topanga Creek at Inn) [TO1]
05 Mar 2001

Above confluence of Old Topanga Creek and Topanga Creek View Looking Upstream

Topanga Creek [TO1]: This boulder strewn reach was located on the main stem of Topanga Creek, 30 m upstream of the confluence of Topanga Creek and Old Topanga Creek near the Inn of the Seventh Ray. Its northeast bank was characterized by a series of small terraces leading upslope to a small oak-lined trail. The southwest bank was bounded by a steep hillslope leading upwards to Topanga Canyon Boulevard, which also supports scattered oaks. Cross-sections are illustrated in Figure 6-12. This site experienced net deposition of sediment during the study.

UTM: 3773343, 352033 Elevation: 246 meters (807')

17 December 2000 – 15 January 2001: A calculated discharge of 1.3472 m^{3}s^{-1} occurred on 11 January. Suspended sediment yield on 15 January was 277.78 mg l^{-1}. During the interval 2.80 m^2 of material accumulated in the channel and likely was derived from contributions provided by the adjacent hillslope.

15 January – 18 February 2001: During the interval a modest 0.05 m^2 of material were lost from the channel bed. A calculated peak discharge of 0.0587 m^{3}s^{-1} occurred on 13 February.

18 February – 25 February 2001: A calculated discharge of 0.1120 m^{3}s^{-1} occurred on 25 February in response to a moderate precipitation event. During the interval 0.62 m^2 of material accumulated in the channel.

25 February – 5 March 2001: A calculated discharge of 0.5831 m^{3}s^{-1} occurred on 5 March in response to intense rainfall that same day. During the interval, 0.05 m^2 of material were lost from the channel, largely the result of bank collapse.

Erosion and Deposition Summary:

15 January	+2.80 m^2
18 February	-0.05 m^2
25 February	+ 0.62 m^2
5 March	-0.05 m^2

Net Change in Channel: +3.32 m^2

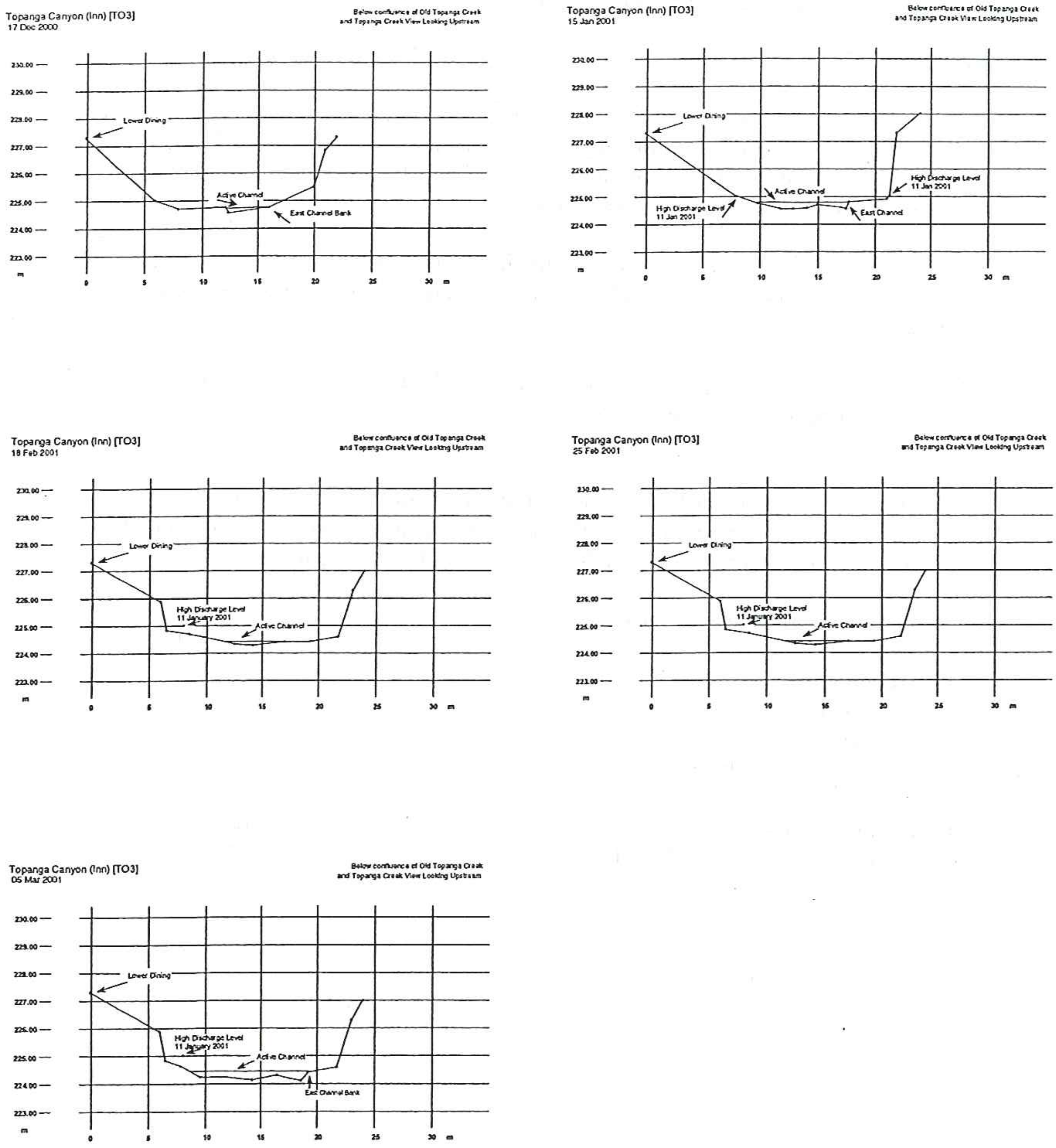
Suspended Sediment Summary:

15 January	277.78 mg l^{-1}

Measured Discharge

No data collected.

Figure 6-13 Topanga Creek [TO3] Cross Sections



Topanga Canyon (Inn) [TO3]
17 Dec 2000

Below confluence of Old Topanga Creek
and Topanga Creek View Looking Upstream

Topanga Canyon (Inn) [TO3]
15 Jan 2001

Below confluence of Old Topanga Creek
and Topanga Creek View Looking Upstream

Topanga Canyon (Inn) [TO3]
18 Feb 2001

Below confluence of Old Topanga Creek
and Topanga Creek View Looking Upstream

Topanga Canyon (Inn) [TO3]
25 Feb 2001

Below confluence of Old Topanga Creek
and Topanga Creek View Looking Upstream

Topanga Canyon (Inn) [TO3]
05 Mar 2001

Below confluence of Old Topanga Creek
and Topanga Creek View Looking Upstream

Topanga Creek [TO3]: This sand and gravel-dominated cross section was located on the main stem of Topanga Creek, downstream from the confluence of Old Topanga Creek and Topanga Creek, adjacent to the lower dining area of the Inn of the Seventh Ray. A mixed canopy composed of willows, oaks and sycamores overlies this site. Cross-sections are illustrated in Figure 6-13. Although both the nearby upstream sites (TO1 and TO2) experienced deposition, this location experienced a significant net erosion during the course of the study. Placement of an additional stream gauge at this location has been proposed to Los Angeles County authorities.

UTM: 3773131, 352050	Elevation: 222 meters (730')

17 December 2000 – 15 January 2001: A measured discharge of 0.078 m^3s^{-1} occurred on 17 December with a suspended sediment yield of < 0.01 mg l^{-1}. A calculated discharge of 5.282 m^3s^{-1} occurred on 11 January. A suspended sediment yield of 39.22 mg l^{-1} was measured on 15 January. During this interval there was a loss of 0.1 m^2 of sediment from the channel.

15 January – 18 February 2001: A calculated discharge of 0.0591 m^3s^{-1} occurred on 18 February. During this interval there was a significant loss of 4.80 m^2 of material from the cross-section owing to severe undercutting of the west bank adjacent to the lower dining area of the Inn.

18 February – 25 February 2001: A calculated discharge of 2.143 m^3s^{-1} occurred on 25 February, together with a suspended sediment yield of 3183.33 mg l^{-1}. The suspended sediment contained ample coarse sand. During this interval there was a loss of 6.20 m^2 of material from the channel, again the result of bed scour and bank erosion.

25 February – 05 March 2001: A calculated discharge of 0.5905 m^3s^{-1} occurred on 05 March. During this interval there was a loss of 4.30 m^2 of material on the channel bed.

Erosion and Deposition Summary:

15 January	-0.1 m^2
18 February	-4.80 m^2
25 February	- 6.20 m^2
5 March	-4.30 m^2

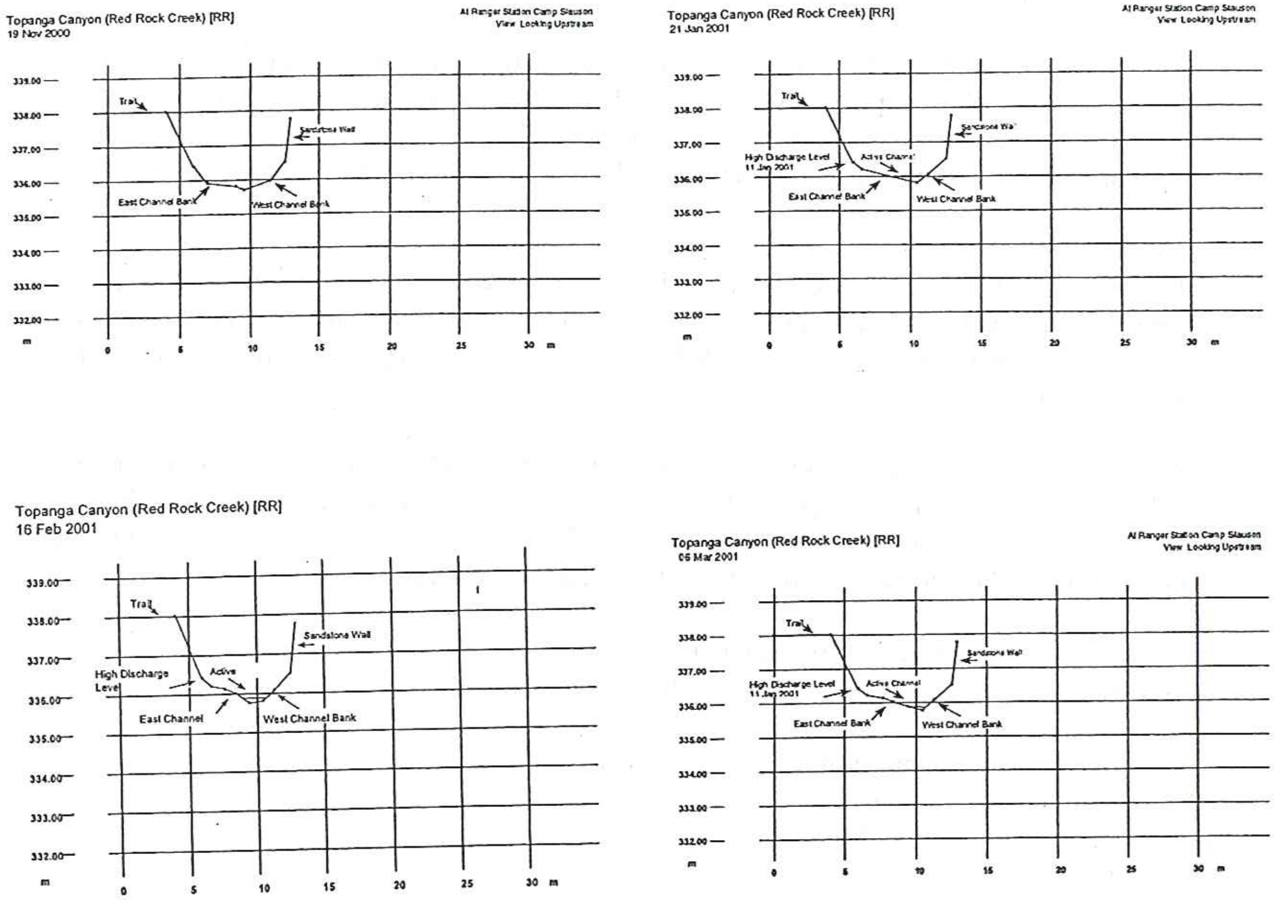
Net Change in Channel: -15.40 m^2

Suspended Sediment Summary:

17 December 00	< 0.01 mg l^{-1}
15 January 01	39.22 mg l^{-1}
25 February	3183.33 mg l^{-1}

Measured Discharge:
0.078 m^3s^{-1}

Figure 6-14 Red Rock [RR] Cross Sections



Red Rock [RR]: This narrow sand and gravel reach was located in Red Rock Creek, downstream from the confluence of a small, steep tributary with its source area high in Red Rock Canyon. The reach was on the southwest side of the Ranger Station parking area and was bounded on the south by a short but steep bank leading to the Red Rock trail and on the north by a vertical sandstone wall. Cross sections are illustrated in Figure 6-14. This location was a site of slight net deposition during the study.

UTM: 3774851, 349012 Elevation: 302 meters (990')

19 November 2000 – 21 January 2001: A calculated peak discharge of 2.0256 m^3s^{-1} with a maximum water depth of 0.55 m occurred on 11 January. During the interval, 0.74 m^2 of material accumulated in the channel, largely in the form of very coarse sand, gravel, and small cobbles.

21 January – 18 February 2001: A calculated peak discharge of 0.1340 m^3s^{-1} occurred on 13 February. Suspended sediment yield on 18 February was 47.06 mg l^{-1}. The suspended sediment was dominated by fine, red sand derived from the Sespe Formation. During this interval 0.21 m^2 of material were lost from the channel bed.

18 February – 6 March 2001: During this interval 0.12 m^2 of material accumulated on the channel bed. A calculated peak discharge of 0.0412 m^3s^{-1} occurred on 5 March.

Erosion and Deposition Summary:

21 January	+0.74 m^2
18 February	-0.21 m^2
6 March	+0.12 m^2

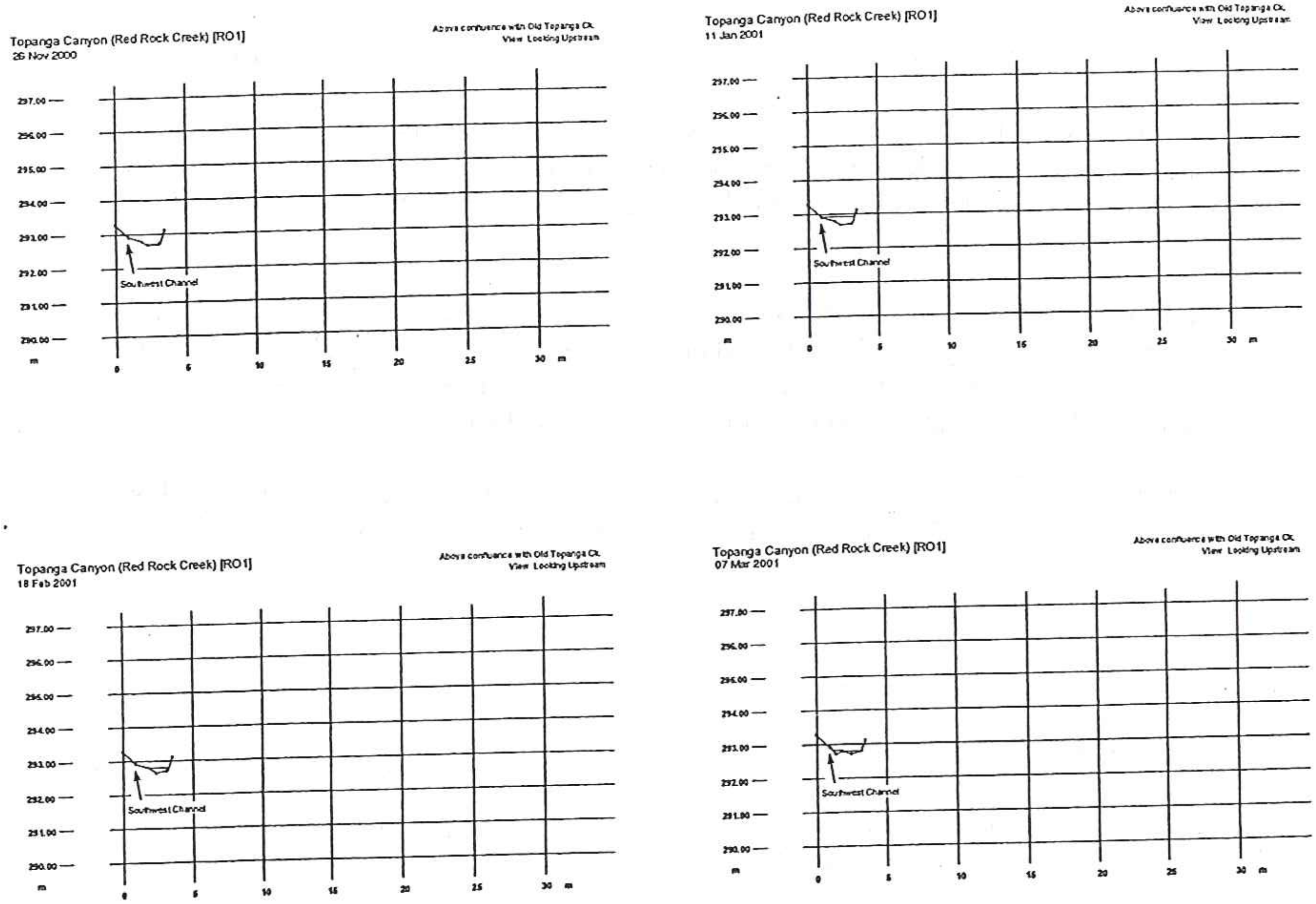
Net Change in Channel: +0.65 m^2

Suspended Sediment Summary:

18 February	47.06 mg l^{-1}

Measured Discharge:
No data collected.

Figure 6-15 Old Topanga Creek [RO1] Cross Sections



Old Topanga Creek [RO1]: This reach was located on Old Topanga Creek, immediately upstream from the confluence of Old Topanga Creek and Red Rock Creek. The channel was narrow, rocky, and disrupted by small channel-width concrete berms that functioned as pseudo-check dams. A concrete wall defined the north bank of the channel and the south bank of the channel was defined by gabions. Mature trees provide almost total canopy cover. Cross-sections are illustrated in Figure 6-15. Slight net deposition occurred at this location during the study.

UTM: 3774593, 349796 Elevation: 282 meters (925')

19 November 2000 – 11 January 2001: A calculated peak discharge of 0.6424 occurred on 11 January with a suspended sediment yield of 50.00 mg l^{-1}. During the interval there was no net change in channel geometry in the reach.

11 January – 18 February 2001: A peak discharge of 0.19709 m^{3}s^{-1} was calculated for 18 February. During this interval there were 0.3 m^2 of material gained on the channel bed.

18 February – 7 March 2001: A peak discharge of 0.2892 m^{3}s^{-1} was calculated for 5 March. During this interval, there was a loss of 0.02 m^2 of material from the channel bed.

Erosion and Deposition Summary:

11 January	0.0
18 February	+0.3 m^2
7 March	-0.02 m^2

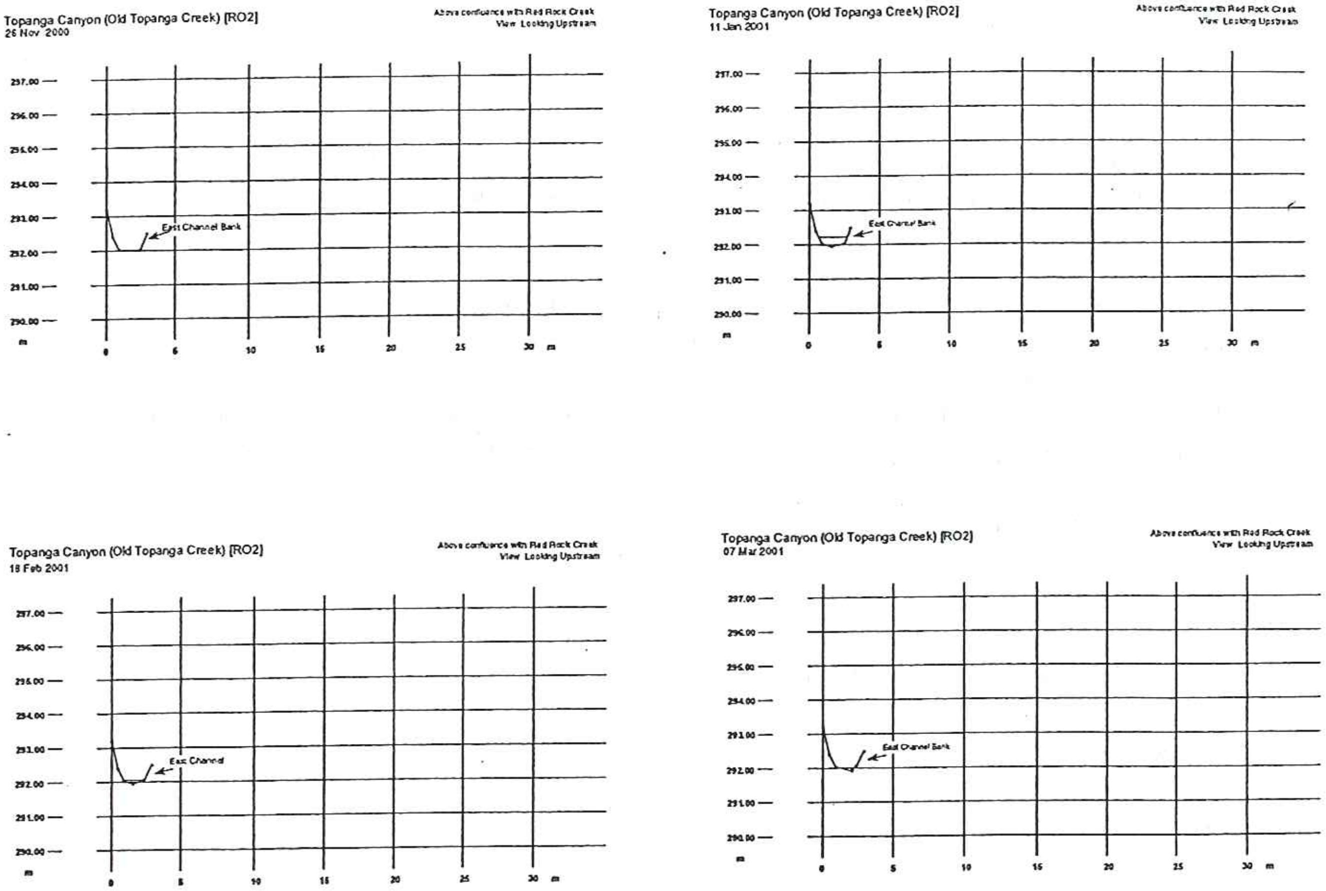
Net Change in Channel: +0.01 m^2

Suspended Sediment Summary:

11 January	50.00 mg l^{-1}

Measured Discharge:
No data collected.

Figure 6-16 Red Rock at Old Topanga Creek [RO2] Cross Sections



Red Rock at Old Topanga Creek [RO2]: This cross section was located on Red Rock Creek, upstream from the confluence of Old Topanga Creek and Red Rock Creek. A vertical concrete wall on the west bank and a low concrete wall overgrown with vegetation on the east bank defined the channel. Mature trees provide significant canopy cover. Cross-sections are illustrated in Figure 6-16. This reach experienced minimal net deposition during the study.

UTM: 3774990, 349787 Elevation: 303 meters (994')

26 November – 11 January 2001: A calculated discharge of 0.562 m^3s^{-1} occurred on 11 January in response to the 07 – 12 January precipitation event. During the interval there was no net change in channel geometry in the reach.

11 January – 18 February 2001: With only modest precipitation recorded in this period, there was a calculated discharge on 18 February of 0.0201 m^3s^{-1}. During the interval there was a modest gain of 0.04 m^2 of material in the channel.

18 February – 07 March 2001: A calculated peak discharge of 0.0105 m^3s^{-1} occurred on 5 March. During the interval, which experienced several precipitation events, there was a modest loss of 0.02 m^2 of channel material.

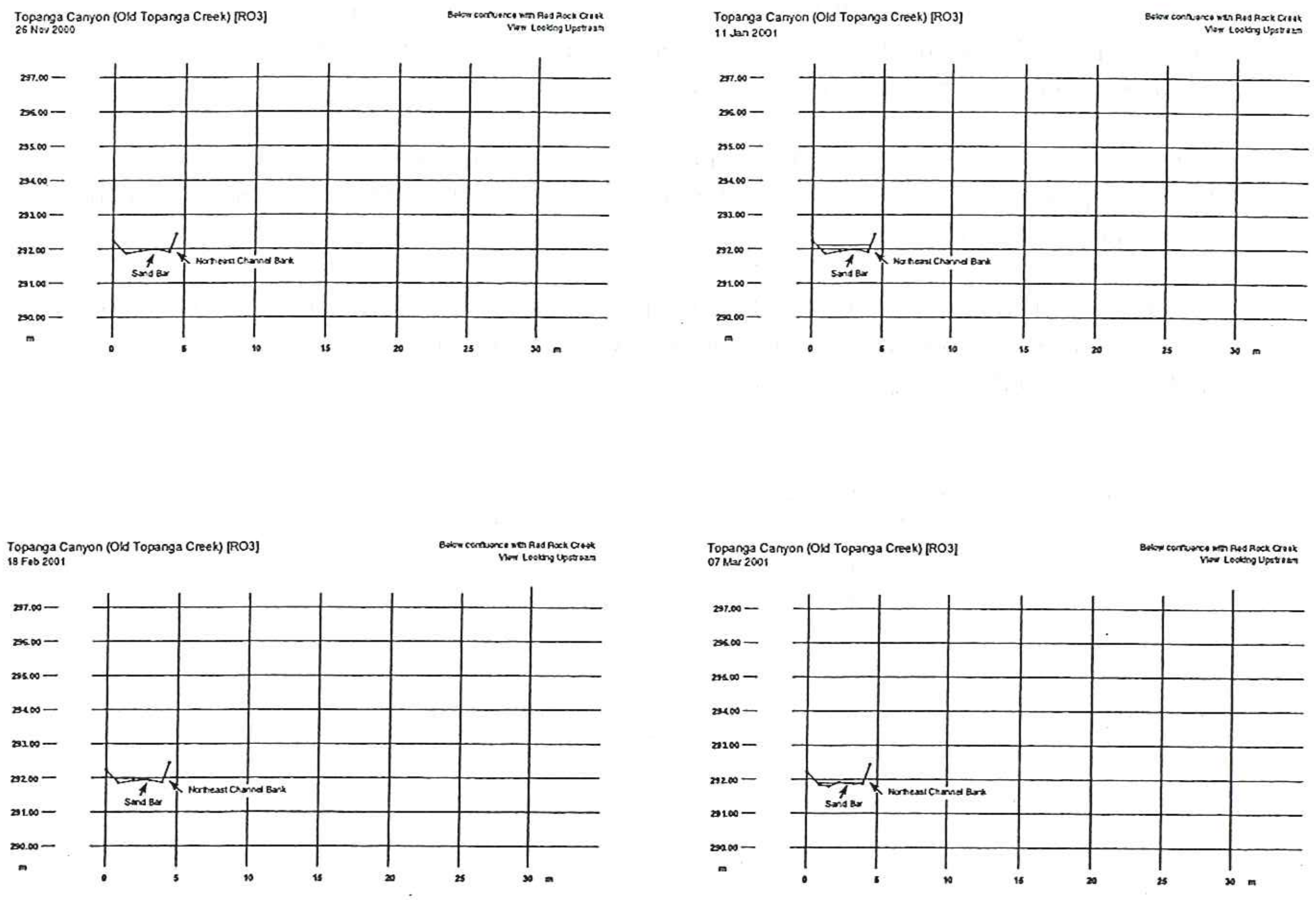
Erosion and Deposition Summary:

11 January	0.0
18 February	+0.04 m^2
7 March	-0.02 m^2

Net Change in Channel: +0.02 m^2

Suspended Sediment Summary:	Measured Discharge:
No data collected.	No data collected.

Figure 6-17 Old Topanga Creek [RO3] Cross Sections



Topanga Canyon (Old Topanga Creek) [RO3]
26 Nov 2000

Below confluence with Red Rock Creek
View Looking Upstream

Topanga Canyon (Old Topanga Creek) [RO3]
11 Jan 2001

Below confluence with Red Rock Creek
View Looking Upstream

Topanga Canyon (Old Topanga Creek) [RO3]
18 Feb 2001

Below confluence with Red Rock Creek
View Looking Upstream

Topanga Canyon (Old Topanga Creek) [RO3]
07 Mar 2001

Below confluence with Red Rock Creek
View Looking Upstream

Old Topanga Creek [RO3]: This cross-section was located on Old Topanga Creek, downstream from the confluence of Red Rock Creek and Old Topanga Creek. The reach was delimited by a half-wall and gabions on both banks. Mature trees provide significant canopy cover. Cross-sections are illustrated in Figure 6-17. A slight overall erosion was noted at this site, which is downstream from the nearby contributing channels, both of which had a very slight deposition.

UTM: 3774966, 349796 Elevation: 264 meters (866')

26 November 2000 – 11 January 2001: A calculated discharge of 1.346 m^3s^{-1} occurred on 11 January. During the interval there was no net change in sediment in the reach.

11 January – 18 February 2001: A calculated discharge of 0.1663 m^3s^{-1} occurred on 18 February. During the interval there was a loss of 0.07 m^2 of sediment from the channel bed.

18 February – 7 March 2001: A calculated peak discharge of 0.0989 m^3s^{-1} occurred on 5 March. During the interval there was a loss of 0.02 m^2 of sediment from the channel bed.

Erosion and Deposition Summary:

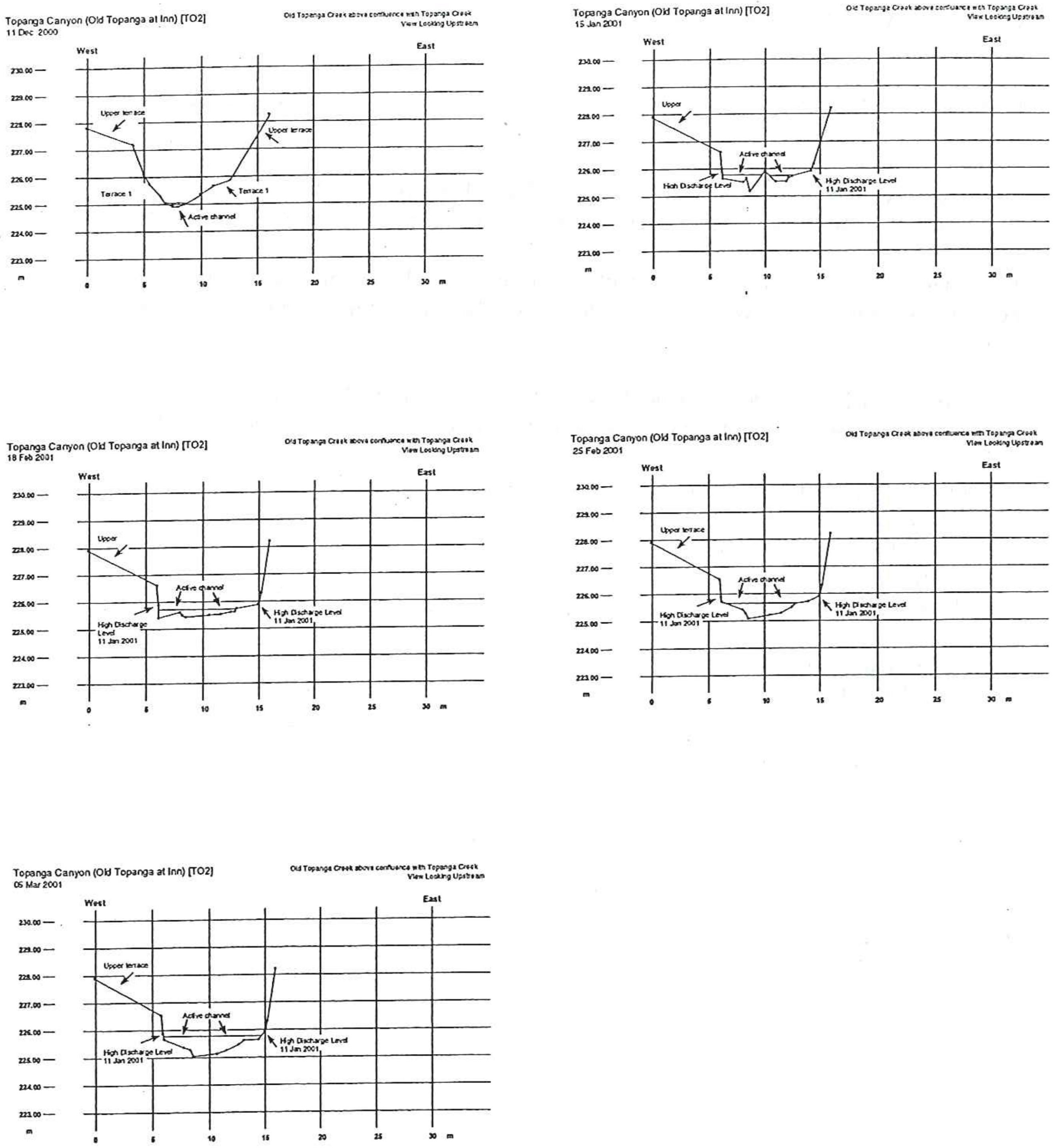
11 January	0.0
18 February	-0.07 m^2
7 March	-0.02 m^2

Net Change in Channel: -0.09 m^2

Suspended Sediment Summary:
No data collected.

Measured Discharge:
No data collected.

Figure 6-18 Old Topanga Creek [TO2] Cross Sections



Old Topanga Creek [TO2]: This sand, gravel, and cobble-dominated cross-section was located on Old Topanga Creek, upstream from the confluence of Old Topanga Creek and Topanga Creek. The channel was situated along the eastern perimeter of the upper dining area of the Inn of the Seventh Ray. Almost total canopy cover is provided by mature sycamores and oaks. Cross-sections are illustrated in Figure 6-18. This site experienced net deposition of sediment during the study.

UTM: 3773158, 352095 Elevation: 288 meters (944')

11 December 2000 – 15 January 2001: A measured discharge of 0.0171 m^3s^{-1} occurred on 11 December 2000 with a suspended sediment yield of 66.67 mg l^{-1}. A calculated discharge of 2.3712 m^3s^{-1}occured on 11 January. Suspended sediment yield on 15 January was 50.00 mg l^{-1}. During this interval 1.80 m^2 of sediment accumulated on the channel bed.

15 January – 18 February 2001: A measured discharge of 0.0201 m^3s^{-1} occurred on 18 February with a suspended sediment yield of 30.77 mg l^{-1}. A calculated peak discharge of 1.3704 m^3s^{-1} occurred on 18 February. During this interval 1.40 m^2 of sediment accumulated on the channel bed.

18 February – 25 February 2001: A calculated discharge of 2.5156 m^3s^{-1} occurred on 25 February with a suspended sediment yield of 18,270 mg l^{-1}. The suspended sediment was dominated by very coarse sand, together with medium-fine sand. During this interval there was a loss of 1.11 m^2 of sediment from the channel owing to bed scour.

25 February – 6 March 2001: A calculated discharge of 1.652 m^3s^{-1} occurred on 5 March in response to the moisture introduced during the 23 – 28 February rainfall event, antecedent to the event of 4 – 6 March. During this interval there was a loss of 0.82 m^2 of sediment from the channel, again owing to bed scour and bank retreat.

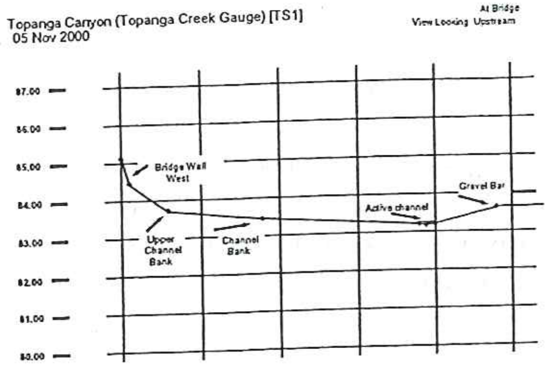
Erosion and Deposition Summary:

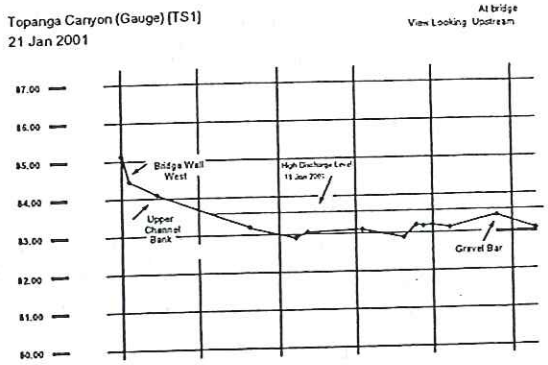
15 January	+1.80 m^2
18 February	+1.40 m^2
25 February	-1.11 m^2
6 March	- 0.82 m^2

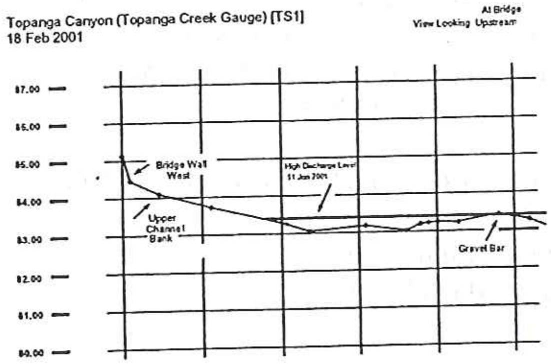
Net Change in Channel: +1.27 m^2

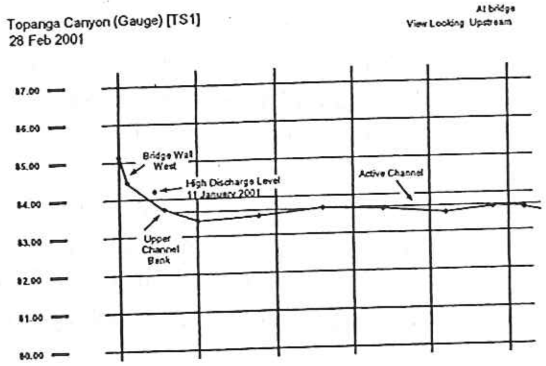
Suspended Sediment Summary:		Measured Discharge:
11 December 00	66.67 mg l^{-1}	0.0171 m^3s^{-1}
15 January 01	50.00 mg l^{-1}	
18 February	30.77 mg l^{-1}	0.0201 m^3s^{-1}
25 February	18,270.00 mg l^{-1}	

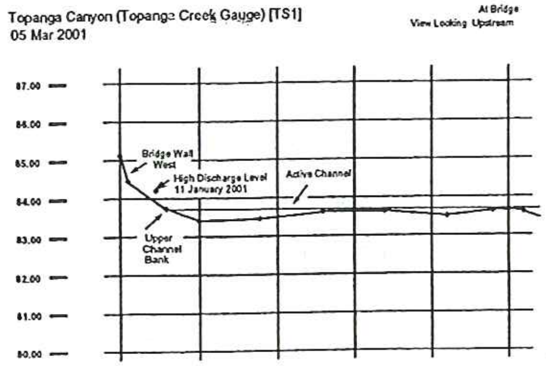
Figure 6-19 Topanga Creek [TS1] Cross Sections


Topanga Canyon (Topanga Creek Gauge) [TS1]
05 Nov 2000


Topanga Canyon (Gauge) [TS1]
21 Jan 2001


Topanga Canyon (Topanga Creek Gauge) [TS1]
18 Feb 2001


Topanga Canyon (Gauge) [TS1]
28 Feb 2001


Topanga Canyon (Topanga Creek Gauge) [TS1]
05 Mar 2001

Topanga Creek [TS1]: This broad cross-section was located at the downstream end of Topanga Canyon Blvd. Bridge 53-143 (Caltrans) that spans Topanga Creek near the LA County Department of Public Works stage gauge F54B-R. The reach was dominated by sands and gravels with the thalweg diverted toward the south bridge abutment. Cross-sections are illustrated in Figure 6-19. The banks have almost 100% cover of willow, mulefat and Arundo, with clusters of cattails forming in the creek channel wherever possible. The site experienced net deposition during the study.

UTM: 3770224, 353619 Elevation: 104 meters (340')

5 November 2000 – 21 January 2001: A measured discharge of 0.0085 m^3s^{-1} was recorded on 5 November. A calculated discharge of 7.3918 m^3s^{-1} occurred on 11 January. During this interval there was a 5.60 m^2 loss of material from the channel bed and as the result of channel incision near the south bridge abutment.

21 January – 18 February 2001: A calculated discharge of 1.9405 m^3s^{-1} occurred on 18 February. During the interval there were 2.42 m^2 of material gained on the channel bed as a slug of sand moved away from the bridge wall and into the channel.

18 February – 25 February 2001: A calculated discharge of 1.0268 m^3s^{-1} occurred on 25 February with a suspended sediment discharge of 300.00 mg l^{-1}. During this interval there was a 5.66 m^2 gain of material across the channel bed as another slug of sand moved into the cross-section from upstream.

25 February – 5 March 2001: A calculated discharge of 1.0559 m^3s^{-1} occurred on 4 March. Suspended sediment yield on 5 March was 23.53 mg l^{-1}. During the interval there was a modest loss of 0.29 m^2 of material from the channel.

Erosion and Deposition Summary:

21 January	-5.6.0 m^2
18 February	+2.42 m^2
25 February	+5.66 m^2
5 March	-0.29 m^2

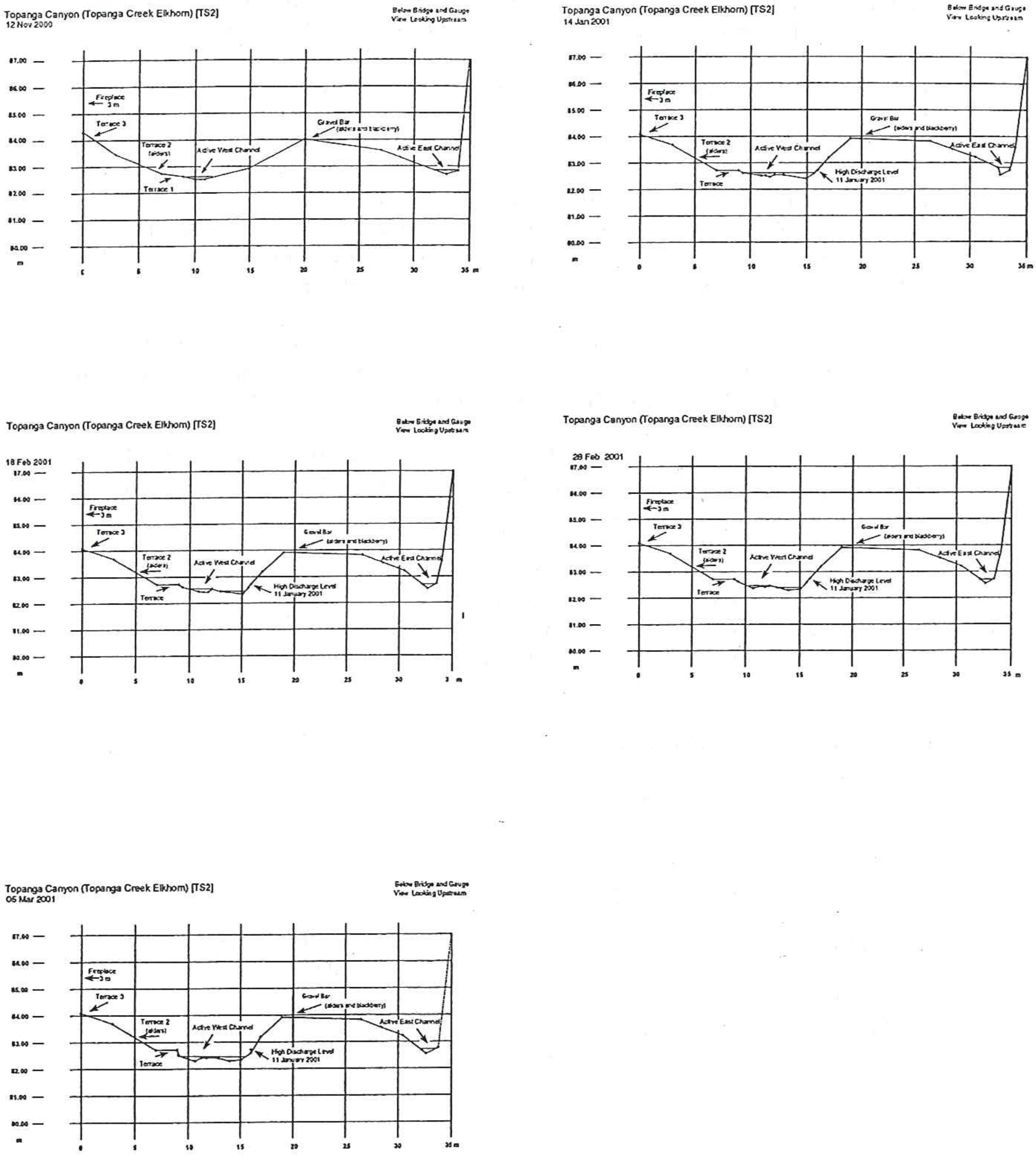
Net Change in Channel: +2.19 m^2

Suspended Sediment Summary:

5 November 00	
25 February 01	300.00 mg l^{-1}
5 March	23.53 mg l^{-1}

Measured Discharge:
0.0085 m^3s^{-1}

Figure 6-20 Topanga Creek [TS2] Cross Sections



Topanga Creek [TS2]: This cross section was located farther downstream and around a meander in Topanga Creek from Bridge 53-143. Characterized by several gravel bars, boulders, and cobbles, this deeply incised reach is bounded on the west by a "fireplace" remnant from the early 20th century "Camp Elkhorn" and on the east by Topanga Canyon Blvd. The entire reach of the creek has 100% canopy cover from alders that became established following the 1980 flood. Several small landslides occur around the outside bend of the meander. Cross-sections are illustrated in Figure 6-20. This location experienced slight net erosion during the study.

UTM: 3770096, 353679 Elevation: 85 meters (280')

5 November 2000 – 14 January 2001: A calculated discharge of 5.7248 m^3s^{-1} occurred on 11 January. Suspended sediment yield on 14 January was 76.92 mg l^{-1}, with a calculated discharge of 0.9316 m^3s^{-1}. During this interval there was a 1.38 m^2 loss of material from the channel bed.

14 January – 18 February 2001: A calculated discharge of 0.3780 m^3s^{-1} occurred on February 18. During this interval there was a gain of 0.18 m^2 of material on the channel bed.

18 February – 28 February 2001: A calculated discharge of 3.0006 m^3s^{-1} occurred on 26 February. During this interval there was a loss of 0.23 m^2 of material from the channel bed.

28 February – 5 March 2001: A calculated discharge of 0.9404 m^3s^{-1} occurred on 5 March. During this interval, there was a loss of 0.41 m^2 of material from the channel bed.

Erosion and Deposition Summary:

14 January	-1.38 m^2
18 February	+0.18 m^2
28 February	-0.23 m^2
5 March	- 0.41 m^2

Net Change in Channel: -1.84 m^2

Suspended Sediment Summary:

14 January	76.92 mg l^{-1}

Measured Discharge:
No data collected.

6.3.2 Analysis of Reach Behavior

As expected, individual reaches responded to inputs of precipitation by episodic increased discharge. Suspended sediment yield generally increased with each precipitation-related event, but did not necessarily mirror the magnitude of each discharge episode (Table. 6-3). Similarly, the greatest amount of channel change in many reaches did not occur in association with the largest rainfall event. Rather, the geomorphic character of each reach—its ability to store sediment for brief periods and then to dispose of sediment later in the same flow event or during a succeeding event, was of paramount importance to the explanation of the nature and magnitude of debris mobilization throughout the watershed. The net change (erosion vs. sedimentation) for each reach investigated is summarized in Table 6.2.

Although there were eight wet spells in the Topanga Creek watershed during the 2000-2001 water year, only six, between 8 January and 6 March, provided enough driving energy to initiate channel change and sediment movement.

Table 6.2 Erosion and Deposition Summary by Drainage

Location	Drainage Area hectares	Net Erosion m^2	Net Deposition m^2
Upper Topanga Creek			
UT1	114		+0.23
UT2			+0.12
GP1	733	-6.05	
GP2		-1.11	
GP3		-4.15	
TG1	1388		+3.49
Middle Topanga Creek			
TL	1800		+2.67
TF1	2100		+1.71
TF2			+4.98
TO1	3647		+3.32
TO3		-15.40	
Old Topanga Creek			
RR	91		+0.65
RO1	658		+0.01
RO2			+0.02
RO3		-0.09	
TO2			+1.27
Lower Topanga Creek			
TS1	4729		+2.19
TS2		-1.84	

Table 6.3 Summary of Suspended Sediment Data

Suspended Sediments
(total in mg/l)

Location	Dates												
	19-Nov-00	10-Dec-00	18-Dec-00	11-Jan-01	12-Jan-01	14-Jan-01	15-Jan-01	18-Jan-01	24-Jan-01	18-Feb-01	25-Feb-01	04-Mar-01	05-Mar-01
UT1					30.77								600
Ut2					37.88								
GP1				145.24									
Gp2				100									
GP3				139.89									
TG1				142.11						700			1295.24
TL	100							72.73	47.06	800	3650	24.39	2320
TF1									531.82	50	189.53		435.71
TF2										66.67	350		94.44
TO1							50			30.77	18270		
TO2		66.67	116.67				44.44				277.78		
TO3			0				39.22				3183.33		
RR										47.06			
RO!													
RO2													
RO3													
TS1											300		
TS2						76.92							
Top Beach				466.67		142.11							
RR at OTC				50									
Upper Top tributary					18800								364.29
Garapito/rourke										26.67			
SM/rourke										30.77			

8-12 January 2001: A total of 194.06 mm of precipitation fell at Topanga during this event, while 162.31 mm fell in Malibu. The greatest intensities were experienced between 2000 and 2400 hours on January 10. The resulting rapid rise in the stream hydrograph was reflected throughout the watershed. Previously dry reaches in the upper watershed (Upper Topanga, Santa Maria, Garapito, and Red Rock) responded with measurable discharge, though the magnitude of flow was quite variable. Upper Topanga above Garapito Creek produced the least volume of flow owing to its small drainage area and infiltration into the deeper soils that characterize that portion of the watershed. Garapito Creek [GP2, GP3] produced the most discharge, likely owing to a greater contributing watershed area. Red Rock Creek produced limited discharge owing to the porous nature of the underlying bedrock.

This event produced an overall pattern of channel erosion in the upper watershed, likely owing to the mobilization of material during peak flow stages immediately following the 0000 hour on 11 January. The only reach that experienced accumulation was Old Topanga Creek [TO2] immediately upstream from the confluence with Topanga Creek. The gain of material, which was characterized by significant amounts of Sespe-type clastics, was the product of sediment that had accumulated in Old Topanga Creek downstream from the confluence of Red Rock Creek and Old Topanga Creek prior to the 2000-2001 water year. Suspended sediment yield was high in the upper watershed basins, with the Upper Topanga tributary contributing 18,800 mg l^{-1}.This is explained by the presence of a significant volume of fine organic debris that was locally derived from a small oak woodland as well as an accumulation of heavy minerals eroded from isolated volcanic materials. The Santa Maria and Garapito drainages also yielded suspended debris in excess of 100 mg l^{-1}, most likely resulting from the mobilization of fines derived from the marine sediments found in these basins.

The middle portion of the watershed responded with higher discharges in general, especially at the Garapito Creek reach immediately downstream from the Garapito (Cheney) Bridge [TG1]. This reach received additional water to the channel as a result of runoff from Topanga Canyon Boulevard that was funneled through one 0.61 m and one 0.30 m diameter drain. These additional inputs to the channel encouraged erosion on the hillslope immediately below the drains and near the channel. Lake Topanga [TL], Greenleaf Creek [TF1], and Topanga Creek-Greenleaf [TF2] all experienced higher discharges than the reaches in the upper watershed. This is likely owing to the greater contributing watershed area, the steepness of the Greenleaf drainage, and increased runoff from Topanga Canyon Boulevard.

Overall, this event produced a pattern of sediment accumulation in the middle watershed. The significant slug of material at Garapito Creek (immediately upstream from the confluence with Topanga Creek) was derived from sediments that were present at the start of the study (5 November 2000) beneath the Garapito (Cheney) Bridge. These sediments were the product of materials shed from the Santa Maria and Garapito basins. A second slug of sediments, recorded at Topanga Creek (Greenleaf), reflected the accumulation of material beneath Greenleaf Bridge. A third slug of material, found in Topanga Creek upstream from the confluence of Old Topanga Creek, appeared to reflect the slight decrease in slope associated with position of the reach downstream from a broad meander. Suspended sediment yield in the middle watershed was modest with the exception of Garapito Creek below the Garapito (Cheney) Bridge. This is not surprising, given the contributions from upstream Santa Maria and Garapito Creeks.

The lower watershed Topanga Creek [TS1], [TS2]) responded with higher discharges as evidenced from field and gauge data. The highest discharge recorded was found at Topanga Creek (Gauge) [TS1] owing to the large contributing watershed area. This site is also located at the lower end of a steep gradient change that reaches over 2000 meters downstream from the confluence of Topanga Creek and Dix Canyon (Figure 6-1).

This event produced a pattern of channel scour in the lower watershed. Most significantly, the channel bed at the gauge reach experienced the highest loss of material. This appears to be related to the caliber of sediment (easily entrained sand-size particles) and an increase in slope through this and the immediate upstream section of Topanga Creek. The loss of material farther downstream at Topanga Creek-Elkhorn [TS2] was more modest in nature, owing to the thalweg location in bedrock. Suspended sediment yield was limited in this portion of the watershed owing to sediment storage in the middle watershed. Further downstream, from the Brookside confluence to the sea, under-capacity discharge flushing from the lower canyon entrained large quantities of alluvial sediment in the floodplain to yield high suspended sediment values at the river mouth.

<u>24-26 January 2001</u>: This small precipitation event yielded a total 36.58 mm at Topanga and 38.10 mm at Malibu, with minimal resulting discharge and minimal channel change. Suspended sediment samples were only taken at Lake Topanga and Greenleaf for this event. The high suspended sediment yield found in Greenleaf Creek where over 500 mg l^{-1} possibly resulted from the dewatering and disintegration of a fairly thick slug of sediment that was mobilized during the 8-12 January event, although no samples at this location were taken for that event. Given the fairly steep and narrow nature of this watershed underlain by the friable Modelo and Topanga Formations, it is not surprising to expect fluidized flows.

<u>7–14 February 2001</u>: A total 113.79 mm of precipitation fell at Topanga during this event , and 107.95 mm at Malibu, with the bulk falling between 10-13 February. Discharge, channel change, and suspended sediment yield were remarkably diverse during this interval, and, in fact, began to demonstrate some of the asynchronous behavior that characterizes the Topanga Creek watershed.

The upper watershed showed quite diverse reactions to the rainfall event. Upper Topanga produced modest accumulations of sediments in the channels, while the Santa Maria and Garapito reaches exhibited scour. Suspended sediment yields in the Santa Maria, Garapito, and Old Topanga drainages were all less than 50 mg l^{-1} and, with light transmission, were clear. By sharp contrast, suspended sediment yield at Garapito Creek downstream from the Garapito (Cheney) Bridge was 700.00 mg l^{-1}.It was clear that the disintegration of a sediment slug that had been deposited upstream and within the reach was moving through this portion of the watershed.

The middle watershed showed significant variability in its discharge magnitude, channel behavior, and suspended sediment yield. Garapito Creek [TG1] experienced some scour, while Lake Topanga [TL] and Greenleaf [TF1] experienced accumulation. The amount of accumulation in the Greenleaf reach was significantly greater than that found in other reaches. It can be surmised that this drainage, though narrow and small, mobilizes slugs of material that move in discrete slugs down canyon in response to small perturbations in the discharge profile. Suspended sediment in the Lake Topanga reach was measured at 800.00 mg l^{-1}. This remarkable volume of fine material likely reflected the disembodiment of a sediment slug that had moved through the system during an earlier rainfall event.

In the Old Topanga Creek sub-drainage, Red Rock [RR] scoured its bed under low discharge conditions, while Red Rock and Old Topanga Creek upstream from the confluence with Red Rock accumulated small volumes of material. Downstream from the confluence there was bed scour. By contrast, Old Topanga Creek [TO2] upstream from its confluence with Topanga Creek [TO3] accumulated nearly 78% of the total sediment it accumulated during greater discharge conditions associated with the 7-12 January event. It is reasonable to assume that this pattern reflects the continued and sometimes largely unnoticed dewatering and disintegration of slugs of material deposited during more viscous flow regimes.

The lower watershed exhibited remarkable contrasts in reach behavior. Topanga Creek [TO3] downstream from the confluence with Old Topanga Creek [TO2] lost significant channel bed and bank material. This was readily explainable by the persistent loss of saturated bank sediments that receive direct flow impact from Topanga Creek [TO2] as it enters the confluence of Old Topanga Creek at the Inn of the Seventh Ray. By contrast, new volumes of material accumulated at reach TS1 beneath the Topanga Creek Bridge at the gauge. With a limited discharge event, this area seems prone to deposition of sediments that have moved through the steep canyon segment upstream with its many constrictions in bedrock.

<u>18-20 February 2001</u>: This small precipitation event (28.45 mm) at Topanga produced minimal changes in discharge and channel configuration.

<u>23-28 February 2001</u>: This 108.72 mm precipitation event at Topanga, though spread over nine days, experienced one brief period of moderate rain between 25 and 26 February. While discharge increased throughout the watershed as a whole in response to this input of rain, certain reaches, notably Lake Topanga [TL] and Topanga Creek [TO2] in the middle portion of the basin experienced relatively significant discharge. In the Old Topanga Creek drainage, Old Topanga Creek [TO2] experienced a loss of material, largely the result of bank collapse and subsequent removal of sediment.

The upper watershed of Topanga Creek [UT1-2, GP1-3, TG1] experienced limited channel changes. No suspended sediment data were collected at these locations.

The middle watershed responded to this event with rather interesting variability. Lake Topanga [TL] experienced channel accumulation as well as a very high suspended sediment yield (3650.00 mg l^{-1}). This can be explained by the progradation of a measurable sediment slug that entered the reach during the afternoon of 25 February. Greenleaf Creek [TF1], Topanga (Greenleaf) Creek [TF2], and Topanga Creek [TO1] [TO3] experienced significant rises in suspended sediment yield that exceeded the 11 January event. Suspended sediment yield at [TO1] was significant (18,270.00 mg l^{-1}), reflecting the mobilization of upstream channel materials that were of medium sand size, with coarser fragments present. These sediments reflected the contributions from Red Rock Creek. Below the confluence, Topanga Creek [TO3] yielded a volume of suspended sediment of 3183.33 mgl^{-1} that, upon microscope investigation, revealed significant coarse sand and orthoclase feldspars derived from Red Rock Creek [RR]. These increased volumes can be explained by the re-mobilization of discrete sediment slugs that had previously moved through the system. These in turn reflect the increased antecedent moisture present in the channels and the re-ignition of discharge throughout the watershed.

The lower watershed also responded with significant sediment accumulation within the Topanga Creek (Gauge) [TS1] reach. A suspended sediment level of 300 mg l^{-1} was recorded. With this moderate rainfall event, sands were deposited along the bridge abutments and on the channel bar, especially as the thalweg was diverted toward the gauge-side of the bridge during the waning stages of the event.

4-6 March 2001: This precipitation event (89.41 mm) at Topanga built on the 23-28 February event, producing significant, though sometimes erratic responses throughout the watershed.

Discharge rose again throughout the watershed, with modest flows in the upper watershed. Garapito Creek [TG1] downstream from the Garapito (Cheney) Bridge experienced discharge that was second in magnitude to the 11 January peak. In the upper watershed, there were limited channel changes but there was much variability. This portion of the watershed behaved erratically, with some reaches experiencing deposition, others experiencing erosion. Suspended sediment yields were equally erratic: exceptionally high volumes emanated from Upper Topanga [UT1] under low flow conditions, with near chocolate-colored debris in transit.

The middle watershed had a wide range of changes: significant channel accumulation at Garapito Creek [TG1], more modest sedimentation at Lake Topanga [TL] and Topanga-Greenleaf Creek [TF2]. Suspended sediment yields at Lake Topanga reflected significant sand contributions (2320.00 mg l^{-1}), while Greenleaf Creek clearly was ridding itself of yet another slug of material (435.71 mg l^{-1}).

There was significant loss of channel material at Topanga Creek [TO3] of –4.30 m^2 below the confluence with Old Topanga Creek.

The lower watershed behaved much more passively during the March event, with measurable discharge similar to the early and late February events, though it was significantly less than the 11 January event. However, the magnitude of channel change, though reflecting scour, was modest.

Diminished flows after March 6, including one small peak in April, produced no significant changes in channel geometry or sediment characteristics. This situation persisted to the close of the water year.

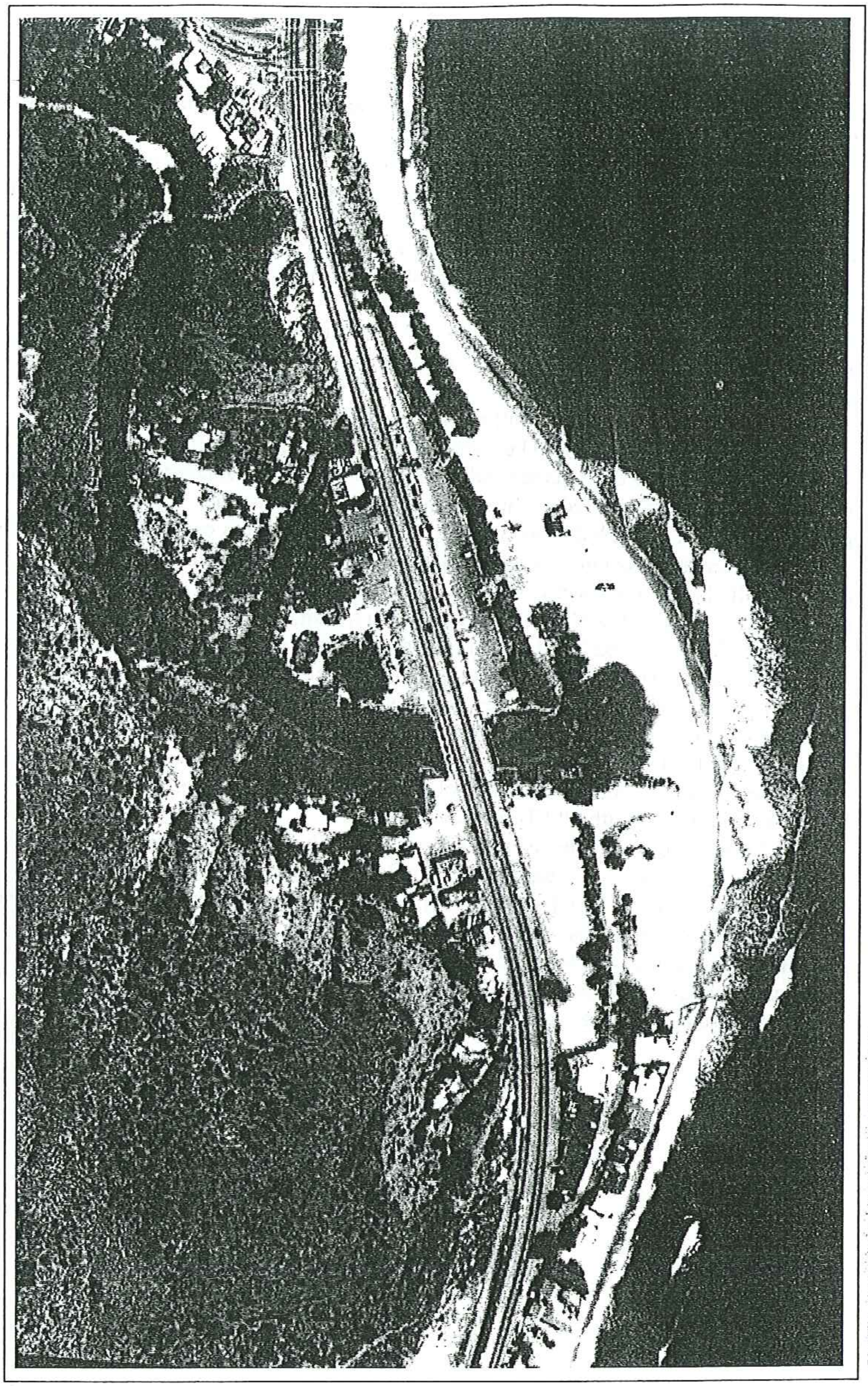


Fig. 7-1. Aerial View of Topanga Lagoon (1997)

7. The River Mouth

7.1 Hydrodynamic Environment

The principle variables influencing the river-mouth environment are stream discharge from Topanga Creek, and wave climate and tidal regime within Santa Monica Bay. Stream discharge is episodically significant during the winter months, but otherwise the river mouth is wave-dominated throughout the year, while tidal forcing plays a minor role. Overall, as with discharge, the wave climate and tidal regime for the 2000-2001 water year were unexceptional. Appendix B contains documentation of wave and tidal conditions. There was no prolonged storm forcing of the wave climate, nor any ocean-atmosphere forcing related to El Nino conditions, nor any unusual astronomical or atmospheric forcing of water levels. In short, observed conditions were about average for the period of record.

The wave climate of the California coast is influenced primarily by ocean-atmosphere interaction over the North Pacific Ocean and modified by nearshore shoaling and refraction. Clockwise atmospheric circulation around the Hawaiian high pressure cell and anticlockwise flow around east-moving low pressure cells generate most of the swell and wind waves that approach the coast from the west quadrant (225-315^0). Wind waves and swells also approach from the southwest quadrant (180-270^0), the former driven by winter cyclonic cells passing along more southerly tracks, the latter either by late summer, tropical cyclones off western Mexico, or by extratropical winter storms in the South Pacific and Southern Oceans. Owing to the orientation of the Southern California Bight and the presence of offshore islands, 90% of all swells approach Santa Monica Bay from the southwest quadrant, through two major windows – 180-220^0 between San Clemente and San Nicholas Islands, and 225-265^0 between San Nicholas and Santa Cruz Islands (Orme, 1985; 2000). Short-period wind waves from 160-180^0 may be generated ahead of approaching cyclones within the Bight.

With predominant wave approach from between south and west, wave-induced longshore currents inevitably set eastward. Littoral drift from the Topanga plume and farther west is thus towards the east, but transport rates are reduced by wave refraction induced by the Topanga fan delta.

Based on water level data recorded at Santa Monica Pier, 8 km to the southeast, ocean tides at Topanga beach are mixed mesotidal with a maximum observed range of 3.22 m (from +2.43 m MLLW on 28 January 1983, to –0.79 MLLW on 11 December 1933). Maximum observed range between extreme high water and extreme low water during the 2000-2001 water year was 2.72 m on 11 January 2001, related in part to modest atmospheric forcing (Appendix B). Because higher high water precedes lower low water, a significant seaward gradient develops between the lagoon and the ocean during the larger semidiurnal ebb tides, a feature of importance to lagoon flushing.

Based on the 69-year record (1933-2001), a high water level of +2.42m MLLW has a recurrence interval of 100 years whereas a high value of +2.31m MLLW recurs every 7 years. The highest observed water level during the 2000-2001 water year was +2.28m MLLW (9 and 11 January 2001), near the annual recurrence interval (Appendix B). For management purposes, it is reasonable to plan for a predicted high water level of +2.50 m MLLW and a range of 3.50 m, to which should be added the relative apparent secular rise of sea level of 1.8 mm yr^{-1} and a value for tsunami forcing.

7.2 Sedimentary Environment

Sediment derived from hillslopes by overland flow erosion or debris flows may eventually reach tributary and stream channels where, subject to episodic transport and storage, it passes downstream. In general terms, any sediment delivered by stream flow to the head of the main canyon near Fernwood is likely to make its way to the estuarine runout section, the narrow floodplain segment that begins 1.8 km above the mouth. Here, depending on stream competence, the coarse fraction (>1.00 mm) of the sediment load will begin to be deposited but, during major floods, a significant portion of this load will reach the sea and contribute to, or replace, deposits in the existing coarse clastic fan delta. The medium fraction (1.00-0.063 mm) will form the bulk of sediment available for beach nourishment but this soon moves eastward. Owing to erratic beach starvation updrift (Orme, 2000), the medium fraction is barely replaced by comparable sediment from father afield, leading to problems for beach maintenance. The fine fraction (<0.063 mm) forms the Topanga plume, modest at best, whose materials settle within Santa Monica Bay, and contribute little to local beaches.

7.3 River Mouth Morphodynamics

7.3.1 General Observations

The mouth of Topanga Creek has been severely altered from its original condition when first mapped by the U.S. Coast Survey and Geodetic in 1876. At that time, the seasonal and tidally flooded wetland/lagoon extended from the base of the west hillslope to the base of the eastern knoll, inland to the first prominent meander, covering approximately 12 hectares. The original highway connecting Santa Monica to Malibu was a dirt road that crossed Topanga Creek on a bridge located inland behind what is now Topanga Ranch Motel. When Pacific Coast Highway was constructed in 1924, a new bridge of over 73 meter spanned the lagoon. The abutments of that bridge are currently exposed on the west bank buried under 10 meters of fill. The alignment of the first PCH is currently used to access the LA County Lifeguard Headquarters at Topanga Beach. In 1933, Caltrans again realigned PCH, moving it inland. At this time, over 600,000 cubic meters of material were cut from surrounding hillslopes and placed into the former lagoon, raising the elevation of the highway approximately 10 meters above Mean Sea Level. The present 25 meter long box bridge with a soft bottom and the vertical fill walls that constrain the lagoon were installed at that time. Today, the beach parking lot sits on the fill to the southeast, an unimproved dirt parking lot fills the southwest section, both are managed by Los Angeles County Department of Beaches and Harbors.

The filled areas on the north side of PCH have recently been acquired by California Department of Parks and Recreation. Numerous commercial and residential structures and parking areas are located on this filled area. The net effect of these modifications has been to reduce the lagoon footprint to less than 0.8 hectares southward of the PCH bridge, with the majority of the area flanked by vertical fill walls that create a narrow floodway. The Los Angeles County Lifeguard Headquarters was built in 1977. Its placement, while providing good visibility for the lifeguards, is in the eastward path of the outflow channel that sometimes forms in response to appropriate marine and discharge conditions.

An additional impact to the river mouth system was the installation of a concrete covered levee located approximately 400 m upstream of the PCH bridge. Reaching a height of almost 8 m above the channel bed, and extending for over 65 m through the floodplain, the levee was constructed by tenants of the structures in the floodplain following the 1980 flood. Due to the limited access to this site during the course of the study (private property), the effects of this berm were not incorporated into the evaluation of the sediment delivery impacts. However, significant deposition of sediment occurs in this reach as a result of altered flow patterns.

River mouth scenarios in Mediterranean-type environments are complex because they respond to fluvial forcing during the rainy season and to marine forcing throughout the year. The relative efficacy of these forces and the properties of the sediment involved determine river mouth morphodynamics. Recognizing a range of possible scenarios, the mouth of Topanga Creek seaward of the Pacific Coast Highway Bridge was surveyed at frequent intervals during the 2000-2001 water year. Timing of these surveys was designed to characterize the changing state of the river mouth as it responded to the hydrodynamic and sedimentary variables described above. Surveys were conducted as near as possible to lower low water during daylight hours in order to capture the effects of the preceding tidal cycle. The following discussion, related to mapped time capsules (Figures 7 –1 to 7-13), is designed to assist the future management of the system.

In simple terms, the Topanga river mouth presented three distinct phases during the water year. First, the barrier-lagoon system inherited from summer 2000 persisted until 11 January 2001. During this time, the barrier was occasionally subject to wave overwash and, from both overwash and higher lagoon levels, breached briefly and then resealed. Second, from 11 January to 29 March 2001, as a result of variable storm-forced stream discharge, the barrier was breached. The open river mouth soon became a friction-dominated estuary impeded by wave-formed bars (Wright, 1977; Orme, 1990, 2000). Thirdly, from 29 March to the close of the water year, a barrier-lagoon system was reestablished by wave forcing, subject to bidirectional seepage, occasional overwash, and rare but brief breaches when lagoon waters spilled across the berm crest.

This triad of barrier-beach construction, destruction and reconstruction is normal at the mouths of small drainage basins on wave-dominated coasts affected by seasonal stream discharge. The details, however, vary from basin to basin, as shown at the mouth of Topanga Creek.

The barrier-lagoon system was frequently disrupted during the study period by mechanical grooming and human impacts on actual or potential lagoon outlets. Such disruptions, reflected in successive surveys, were most frequent during the summer months.

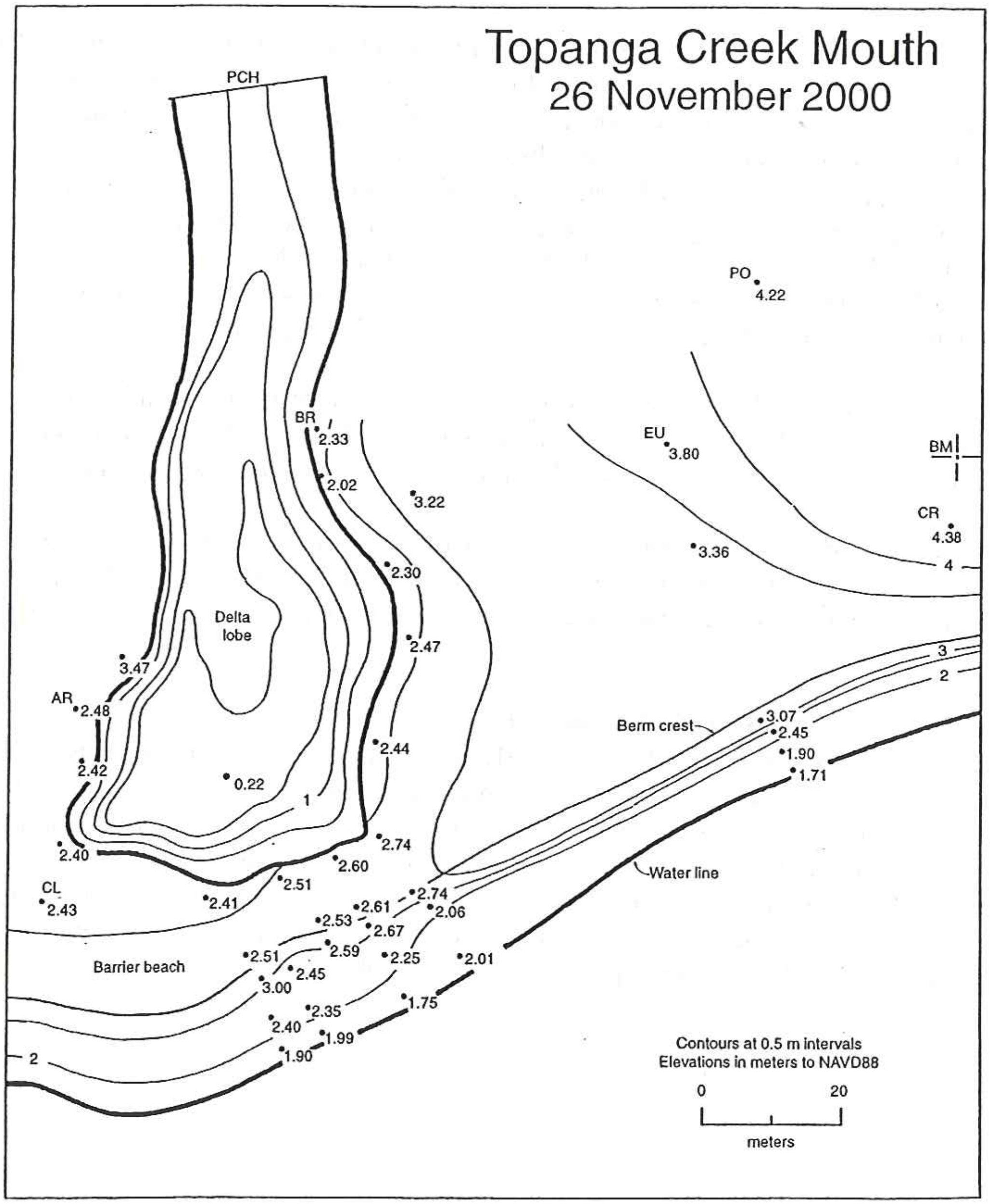
7.3.2 Analysis of Specific Morphodynamic States

From 1 October 2002 to 11 January 2001, the mouth of Topanga Creek existed in its barrier-lagoon state. However, the system was subject to continuing change, as reflected in the first four surveys discussed. The following seven surveys, from 17 January to 11 March, reveal a quite different morphodynamic system in which a friction-dominated river mouth predominates. The last two surveys of 29 March and 26 September bracket the re-establishment of a barrier-lagoon system that lasted, more or less, and despite brief occasional spills and human interference, until the end of the study period on 30 September 2001.

26 November 2000:

On 26 November, the river mouth essentially retained its late summer form as shown in Figure 7-2. This comprised a continuous barrier, mostly above 3 m (NAVD88), and a 20 m wide lagoon with a water level of 2.02m and a maximum depth of 1.8 m. The lagoon bottom reflected scour prior to the study, augmented by a sandy delta lobe introduced by brief storm discharge during 26-29 October. Since 1 October, the beach had been fashioned in part by long period, southwesterly swells (190-210^0) generated by tropical cyclones off southwest Mexico (Appendix B). On breaking, these swells occasionally drove overwash into the lagoon. After 18 November, a pattern of westerly swells (240-290^0) more typical of winter conditions prevailed.

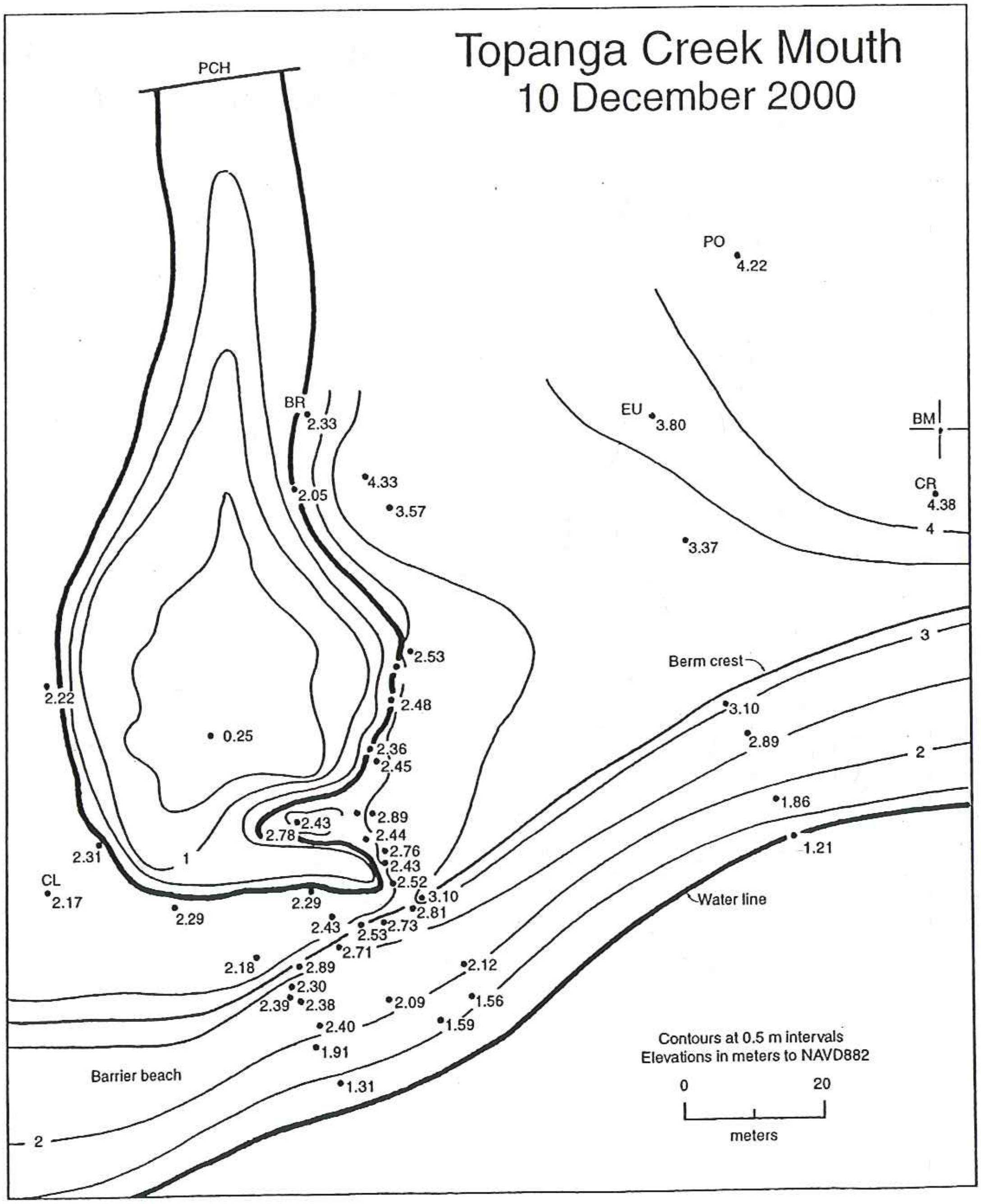
Figure 7-2



10 December 2000:

The transition to the winter wave climate noted above resulted during early December in substantial accretion to the barrier foreshore as shown in Figure 7-3. Deep-water wave heights approached 2 m and, on shoaling and refraction, pushed overwash and sediment into the lagoon. The barrier weakened, lagoon waters spilled briefly, and the barrier then sealed as wave heights diminished and refraction expended most remaining energy. These events are reflected in the survey, which shows an intact barrier, lagoon waters at 2.05 m and a maximum depth of 1.8 m.

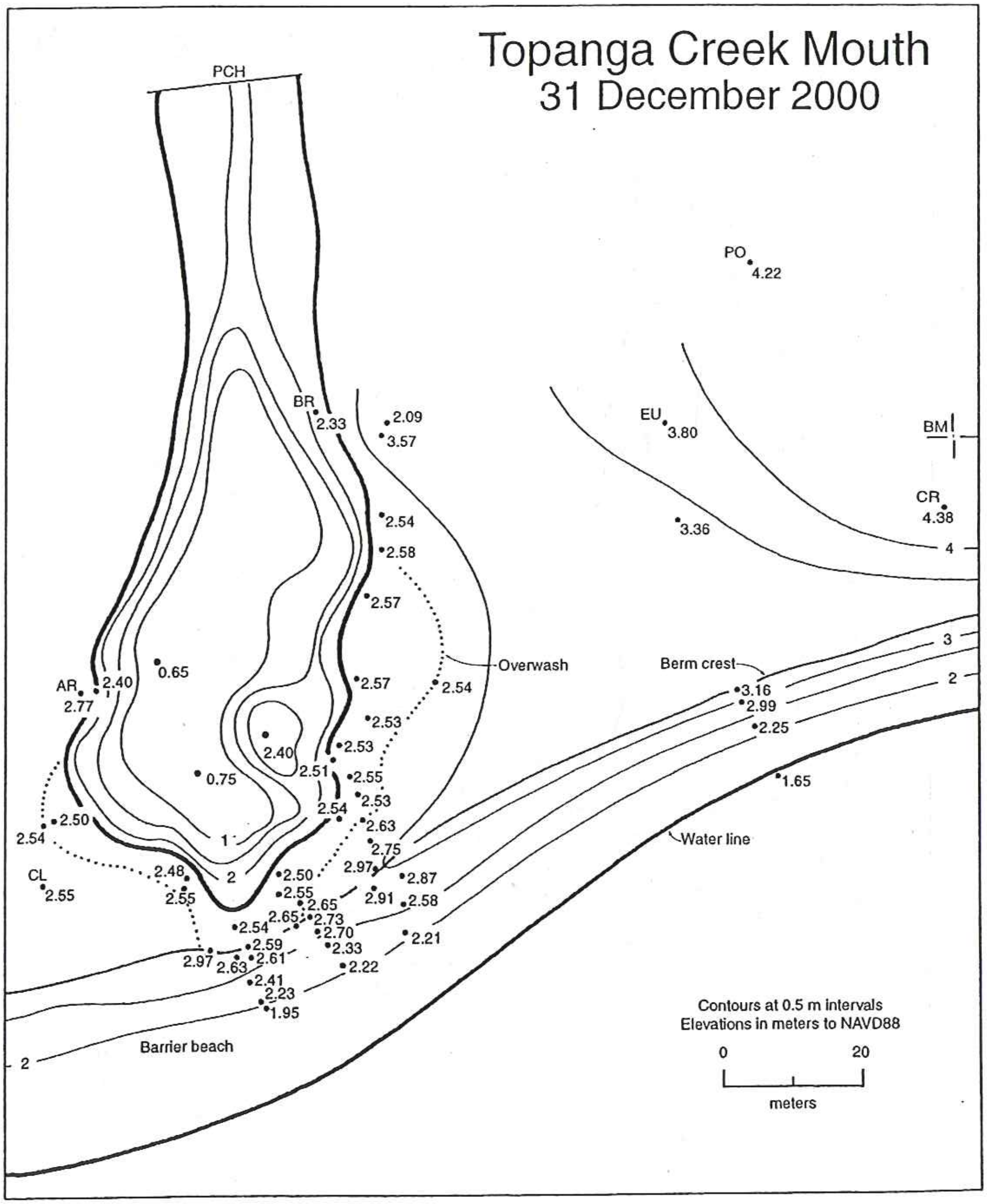
Figure 4-3



31 December 2000:

On 13 December, the barrier was breached briefly by marine forcing related to deep-water wave heights exceeding 2.5 m superimposed on lunar high tides. This occurred during a period of low streamflow, so the barrier reformed as the wave heights and tidal range diminished, and by 18 December the lagoon was again isolated. A return of vigorous wave action on 23-26 December caused further overwash during high water, in several instances pushing sea water 50 m into the lagoon, whose level had risen to 2.4 m by 31 December (Figure 7-4). However, the barrier remained relatively intact because stream discharge continued to be minimal.

Figure 7-4

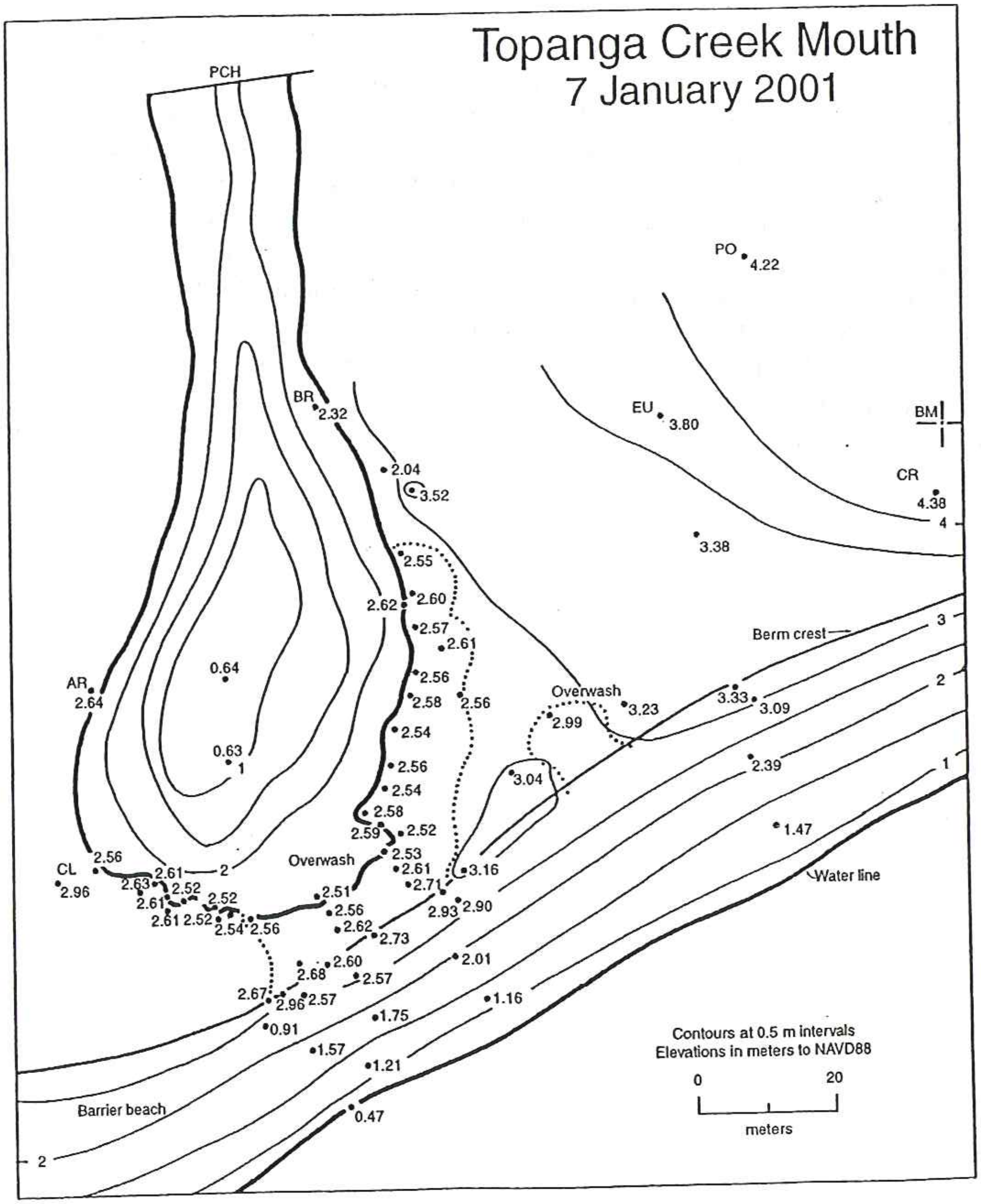


7 January 2001:

A storm series predicted for the next few days occasioned the 7 January survey, at which time hydrodynamic and morphological conditions were similar to those found on 31 Dec 00. Augmented by overwash which penetrated 50 m northward along the eastern margin, lagoon waters rose to 2.6 m, washing across the barrier crest, but not causing a breach (Figure 7-5). The barrier foreshore and crest were being continuously modified by constructive wash and overwash.

Two measurements of discharge in Topanga lagoon were recorded immediately south of the bridge associated with the following 8-12 January storm event. During the waning stages of flow on 11 January at 1430 hours, a 1.1324 m^3s^{-1} discharge was recorded. On 14 January at 1400 hours, a 0.1415 m^3s^{-1} discharge was recorded.

Figure 7-5



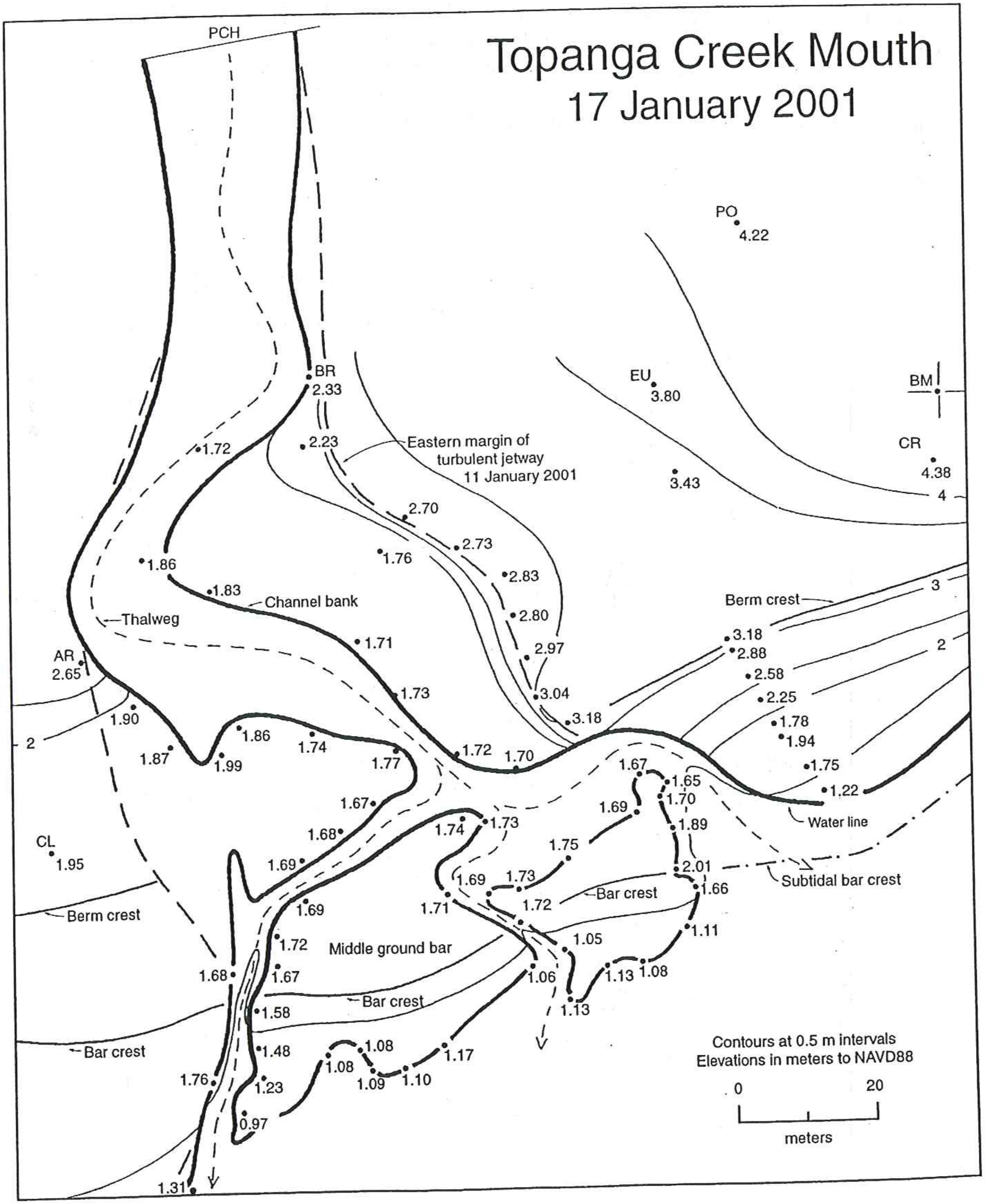
17 January 2001:

The barrier-lagoon system of October 2000 persisted, more or less, until the rainfall event of 10-12 January 2001. These rains, the most intense of the study period, led to a rapid increase in stream discharge which peaked on 11 January at 7.278 m^3s^{-1} at the Topanga gauging station and then recessed over the next several days (see Ch 3 and 6). At the river mouth, the effect was dramatic. The barrier was breached late on 10 January and swept way across a 75 m^{-1} wide front on 11 January. The lagoon ceased to exist.

Residual bedforms observed on 17 January indicate that the initial forcing of the barrier was due to a fully turbulent jet that passed at high velocity (F>>1) through the Pacific Coast Highway Bridge and constraining abutments. On reaching the ocean, this jet diffused laterally and decelerated. Thereafter, flow velocities between the bridge and the ocean were reduced by pronounced bed shear and flows began to expand beyond the 11 January jet way. Flow velocities subsided and the turbulent jetway was transformed into a friction-dominated river mouth with appreciable deposition of bedload occurring both at the mouth and upstream. The 8-11 January storm series generated deep-water waves around 3 m high, augmented on 11 January by short period wind waves generated from the southerly quadrant (140-225^0).

Under these conditions, a complex middle ground bar emerged as medium and coarse clastic sediment was reworked first into an offshore bar, and then this bar migrated into the river mouth. At first the bar was subtidal during high tidal stages but accretion caused it to rise erratically over the ensuing days, even as it welded onto a nascent foreshore (Figure 7-6). This middle ground bar, and a similar successor after February 16, controlled the morphodynamics of the river mouth over the next two months, leading to a pattern in which stream discharge bifurcated into two main distributaries, one to the west and one to the east, as well as several smaller intervening distributaries depending on wave action and tidal stage. The main western distributary was remarkably persistent over the next two months, while the main eastern distributary was often pushed against the berm by migrating bars, only to relax seaward during low stages.

Figure 7-6

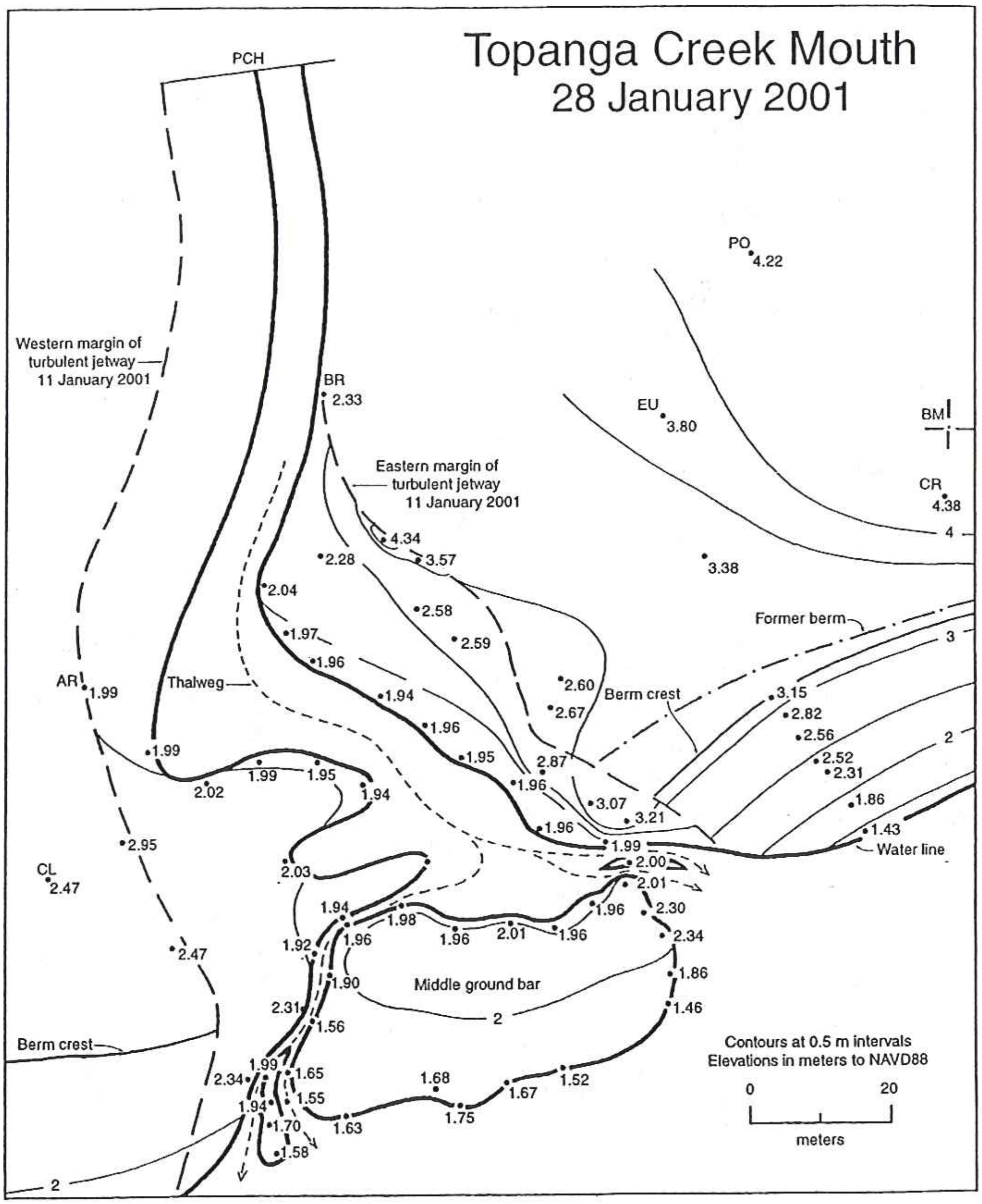


Topanga Creek Mouth
17 January 2001
PCH
PO
4.22
BR
2.33
EU
3.80
BM
2.23
Eastern margin of
turbulent jetway
11 January 2001
CR
4.38
3.43
4
1.72
2.70
2.73
1.86
1.76
2.83
1.83
Channel bank
Berm crest
3
Thalweg
2.80
3.18
1.71
2.97
2.88
2
AR
2.65
2.58
1.73
3.04
2.25
3.18
2
1.90
1.78
1.86
1.94
1.87
1.74
1.72
1.70
1.99
1.77
1.67
1.75
1.65
1.22
1.67
1.70
1.69
Water line
CL
1.95
1.74
1.73
1.89
1.68
1.75
2.01
Subtidal bar crest
1.69
1.69
1.73
1.66
1.71
1.72
Bar crest
Berm crest
1.69
1.11
1.05
1.72
Middle ground bar
1.68
1.67
1.06
1.13
1.08
1.13
Bar crest
1.58
Bar crest
1.48
1.08
1.17
Contours at 0.5 m intervals
Elevations in meters to NAVD88
1.08
1.76
1.09
1.10
0
20
1.23
0.97
meters
1.31

28 January 2001:

After 17 January, westerly wave trains diminished in height and period and, on refraction, favored accretion (Figure 7-7). By 28 January, the middle ground bar was firmly set across the river mouth, having risen to above 2 m in elevation such that, even at high water, the outflowing creek was increasingly constrained by coarse clastic debris. Foreshore accretion and bar welding had also caused the berm crest to shift seaward. The river mouth behind the bar was subject to frequent change from wave action penetrating inshore during the high tidal stages. Runoff from the limited 24-26 January wet spell had no distinguishable impact on the river mouth.

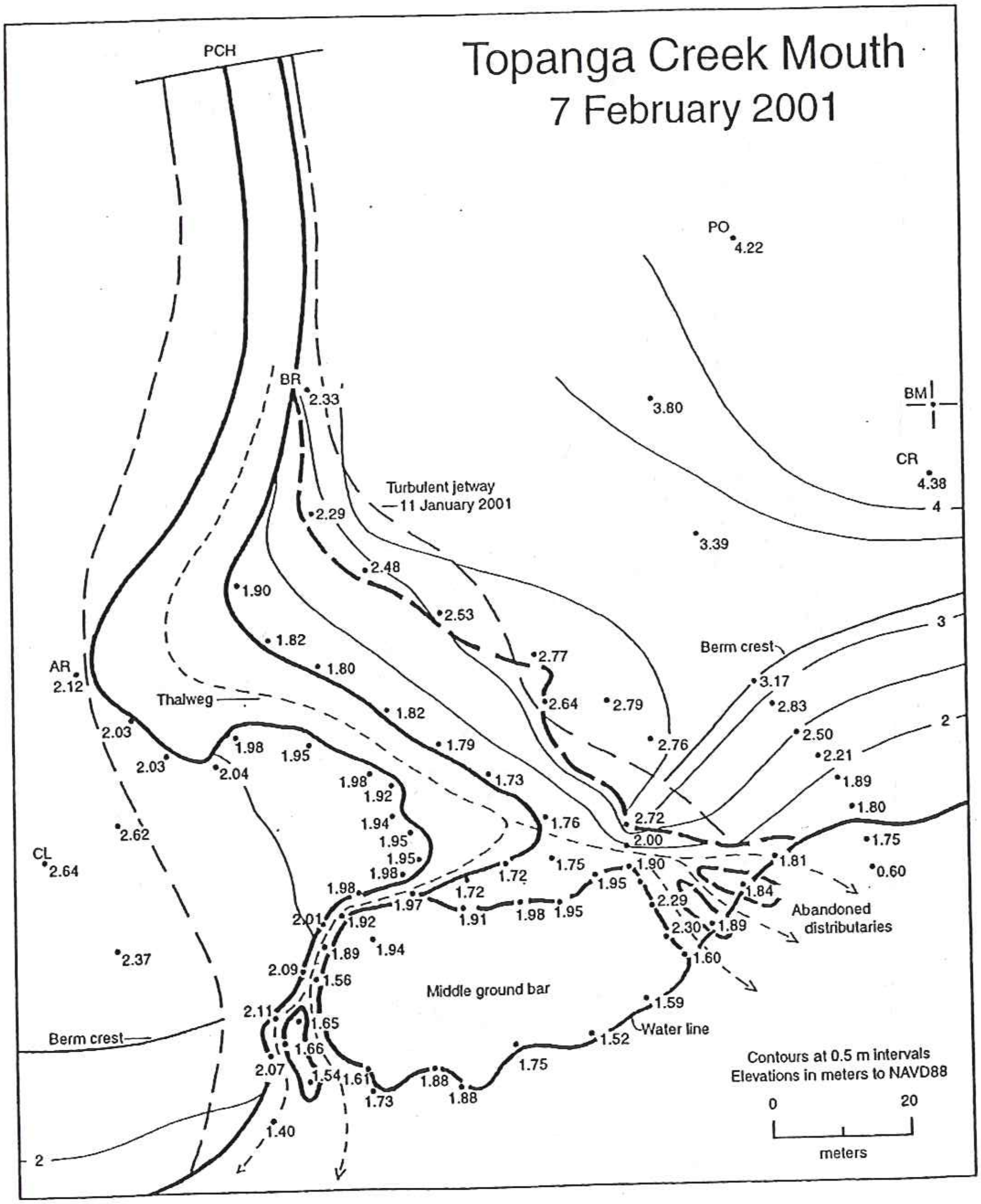
Figure 7-7



7 February 2001:

The survey of 7 February was conducted immediately before predicted storm series of 8-14 February and thus characterizes the river mouth four weeks after the initial breaching on 11 January (Figure 7-8). This was a relatively dry interval during which the river mouth responded mainly to wave action, with stream discharge being just sufficient to maintain an outlet to the sea. By 7 February, the middle ground bar was well established, though both it and the flood channel just inland were washed by the highest tides since 11 January. Immediately after high water, the complex eastern distributary was abandoned and outflow became concentrated in the western distributary.

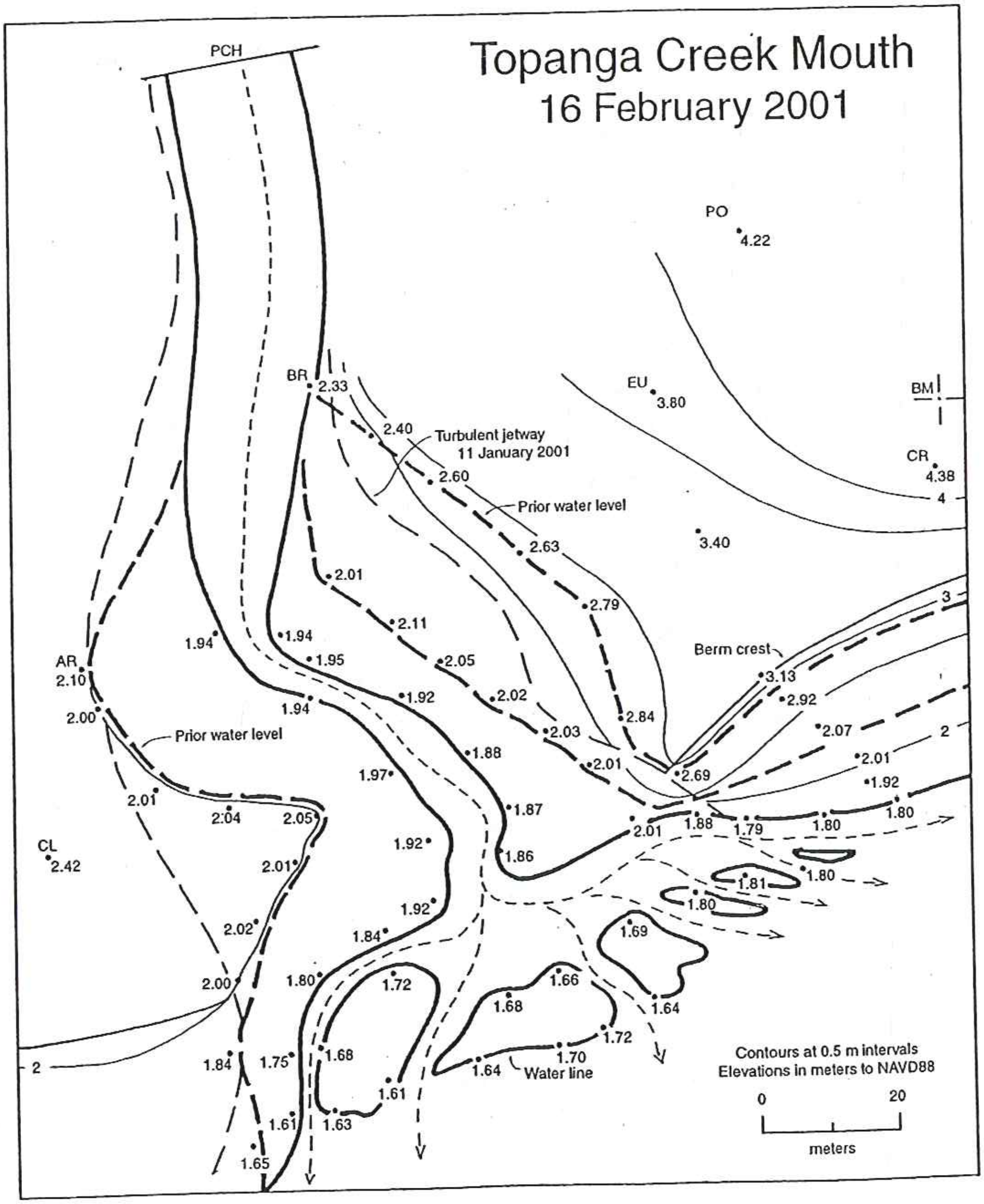
Figure 7-8



16 February 2001:

This survey was conducted immediately after the 8-14 February wet spell, the second largest of the study period after the 8-12 January event. Discharge at the Topanga gauging station rose to 4.560 m^3s^{-1} on 13 February and, augmented by further wet spells, remained significant throughout late February and March. Discharge from this event flushed away the former middle ground bar. Strong refracting wave action, most notably related to 4 m deep-water westerly waves of 6-8 second period on 13-14 February, reworked existing and fresh sediment into a new fledgling bar system comprising thixotropic ("quicksand") lenses broken by numerous, poorly defined distributaries (Figure 7-9). There was also much mobility landward of this new bar system, with frequent channel switching by supercritical flows, but the main thalweg was rarely more than 0.3 m deep.

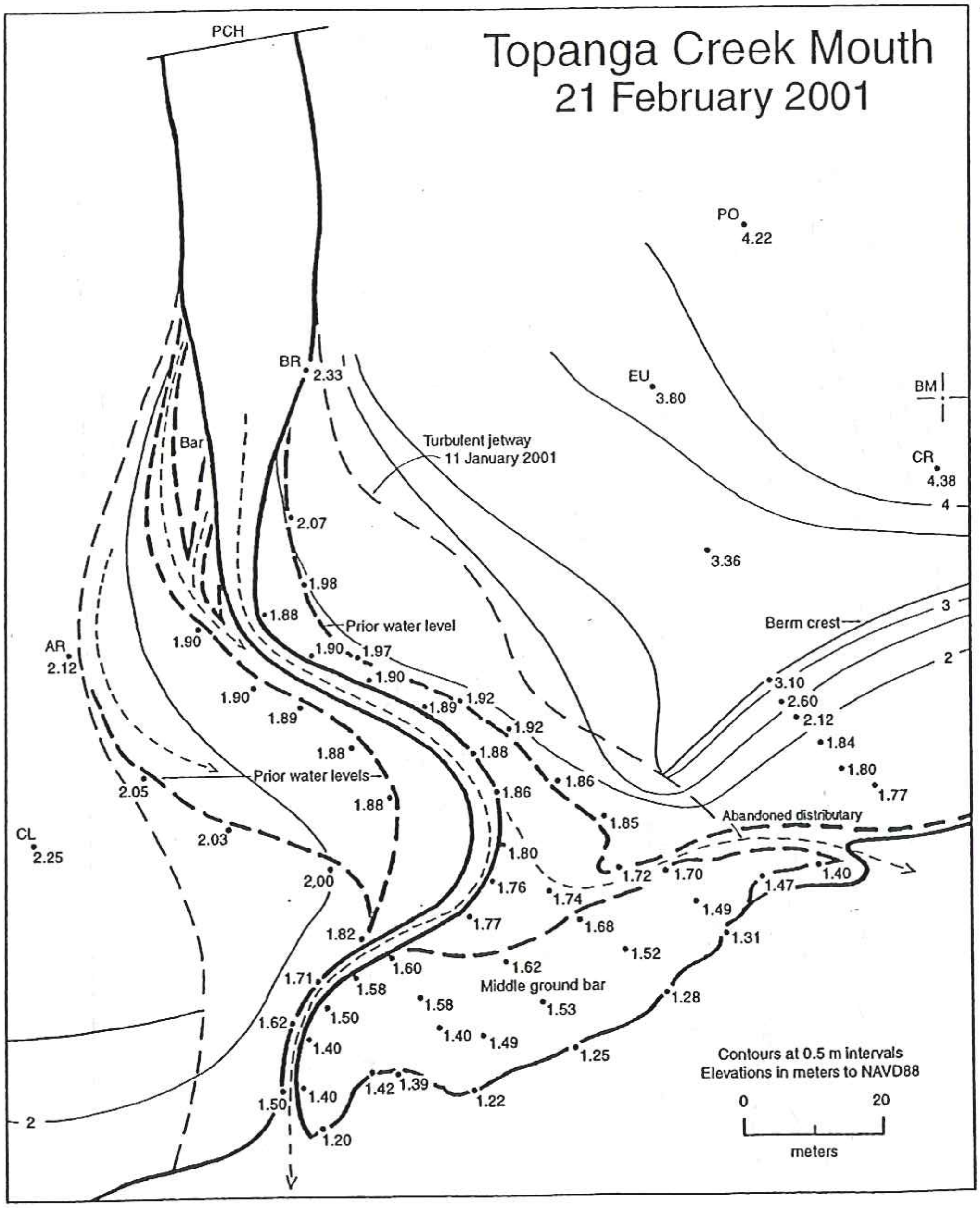
Figure 7-9



21 February 2001:

Continuing westerly waves, augmented by storm waves on 19-21 February, consolidated the fledgling bar system into a continuous middle ground bar flanked by eastern and western distributary channel, recreating conditions analogous to those of late January (Figure 7-10). The eastern distributary dried during the survey as outflow became confined to a single narrow meandering channel through the western distributary. The area inland of the middle ground bar remained highly dynamic, invaded by ocean water during high tidal stages but narrowing to single or multiple-thread channels at lower stages.

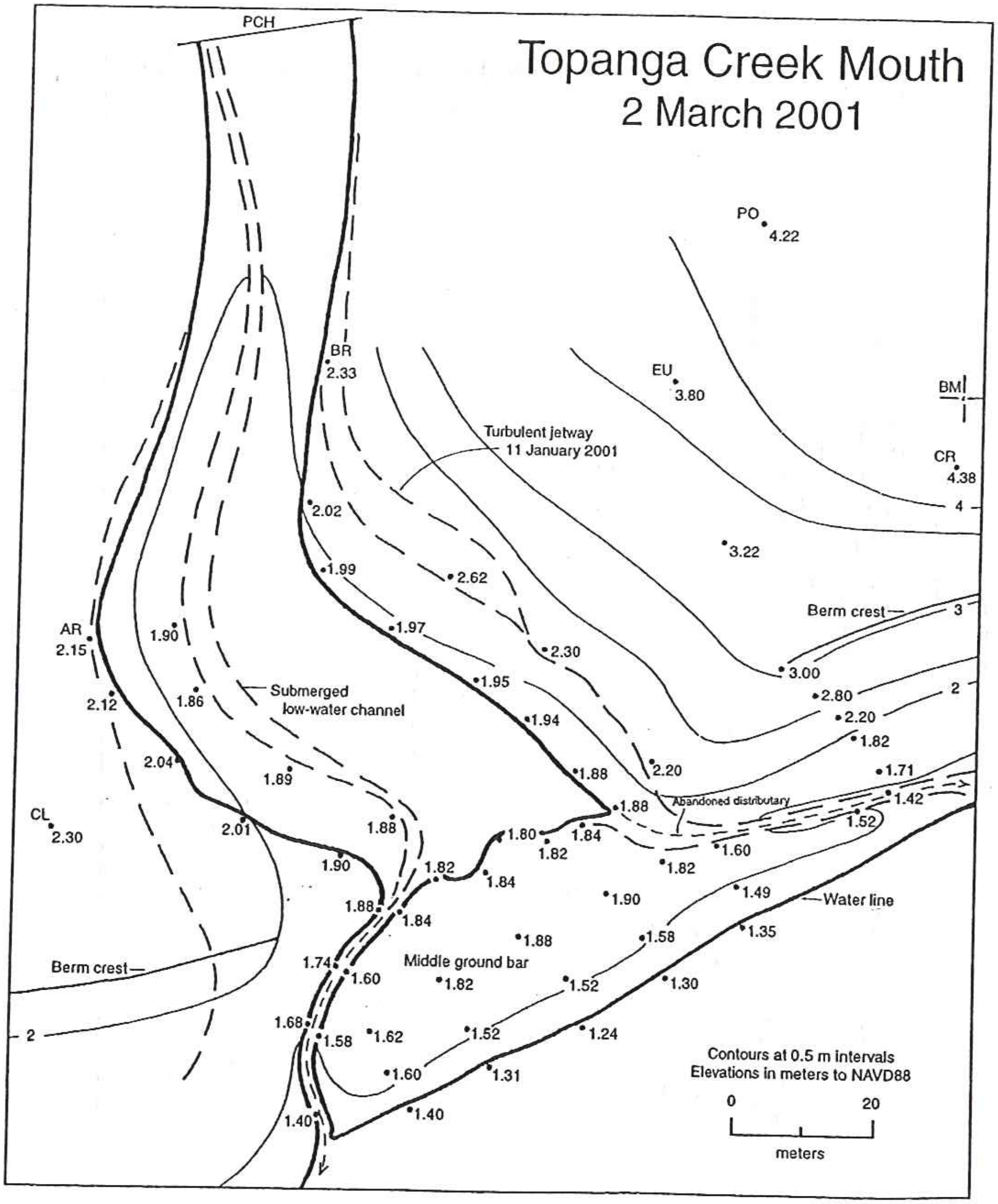
Figure 7-10



2 March 2001:

Preceding this survey, marine conditions dominated by low, long period waves from 210-270^0 favored nearshore sedimentation which the runoff event of 25-26 February did little to disrupt. By now, the eastern distributary had become a narrow abandoned swale and outflow at all tidal stages was confined to the western distributary (Figure 7-11). The middle ground bar was now a continuous feature more or less welded onto the eastern beach. This impeded outflow and formed a brackish lagoon, 20 m wide but <0.3 m deep at high water, which eventually drained into a 2-5 m wide channel at low water.

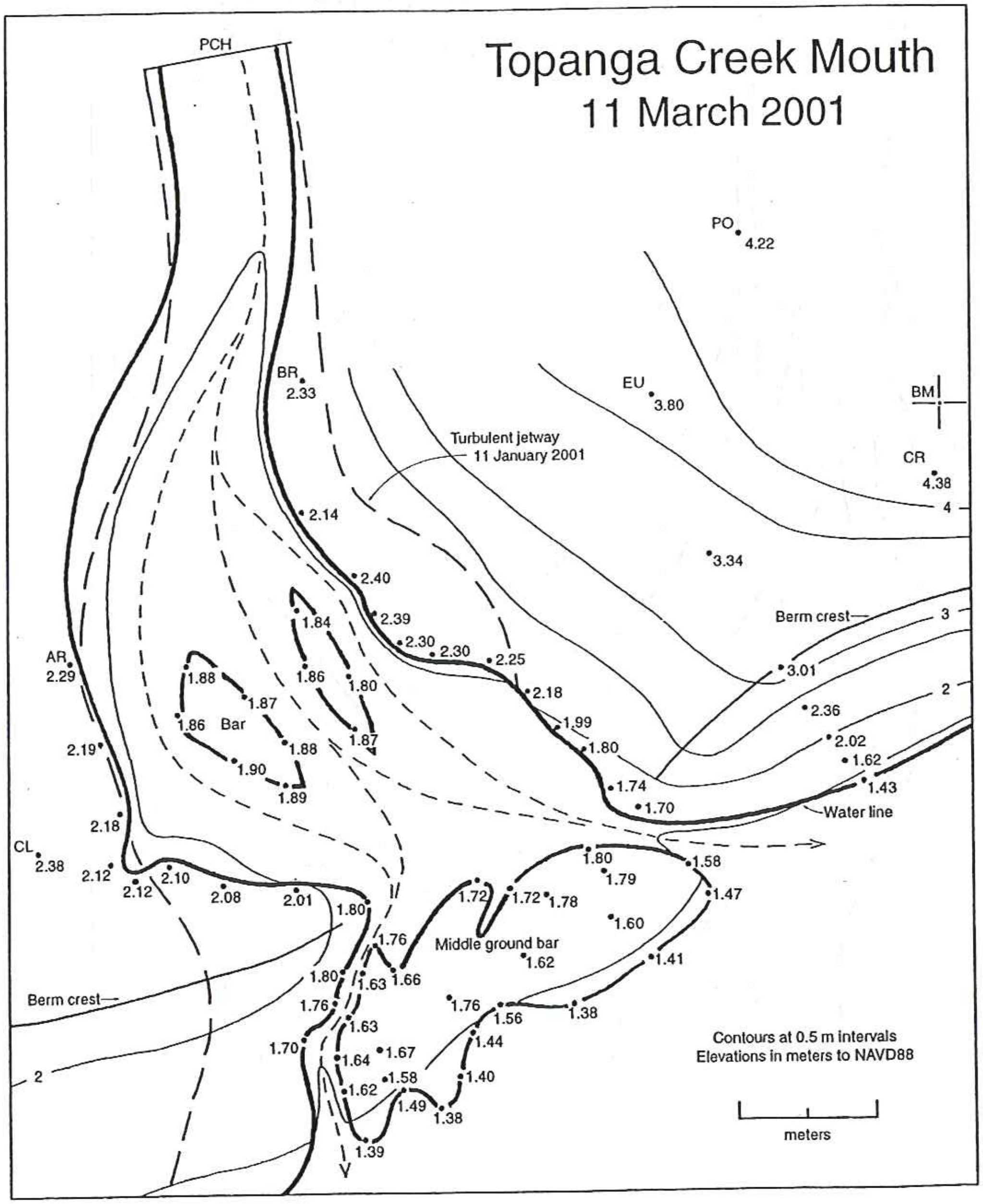
Figure 7-11



11 March 2001:

Following upon modest storm runoff that had peaked at 5.296 m^3s^{-1} on 6 March, short period, 3 m high, deep-water waves, superimposed on lunar high tides, refracted onshore from due west on 10-11 March. These events supplied additional medium clastic sediment to the lagoon and reconfigured both the middle ground bar and distributary system. By 11 March, two longitudinal bars had emerged within the lagoon and the eastern distributary had reopened to accommodate the increased discharge and tidal prism.

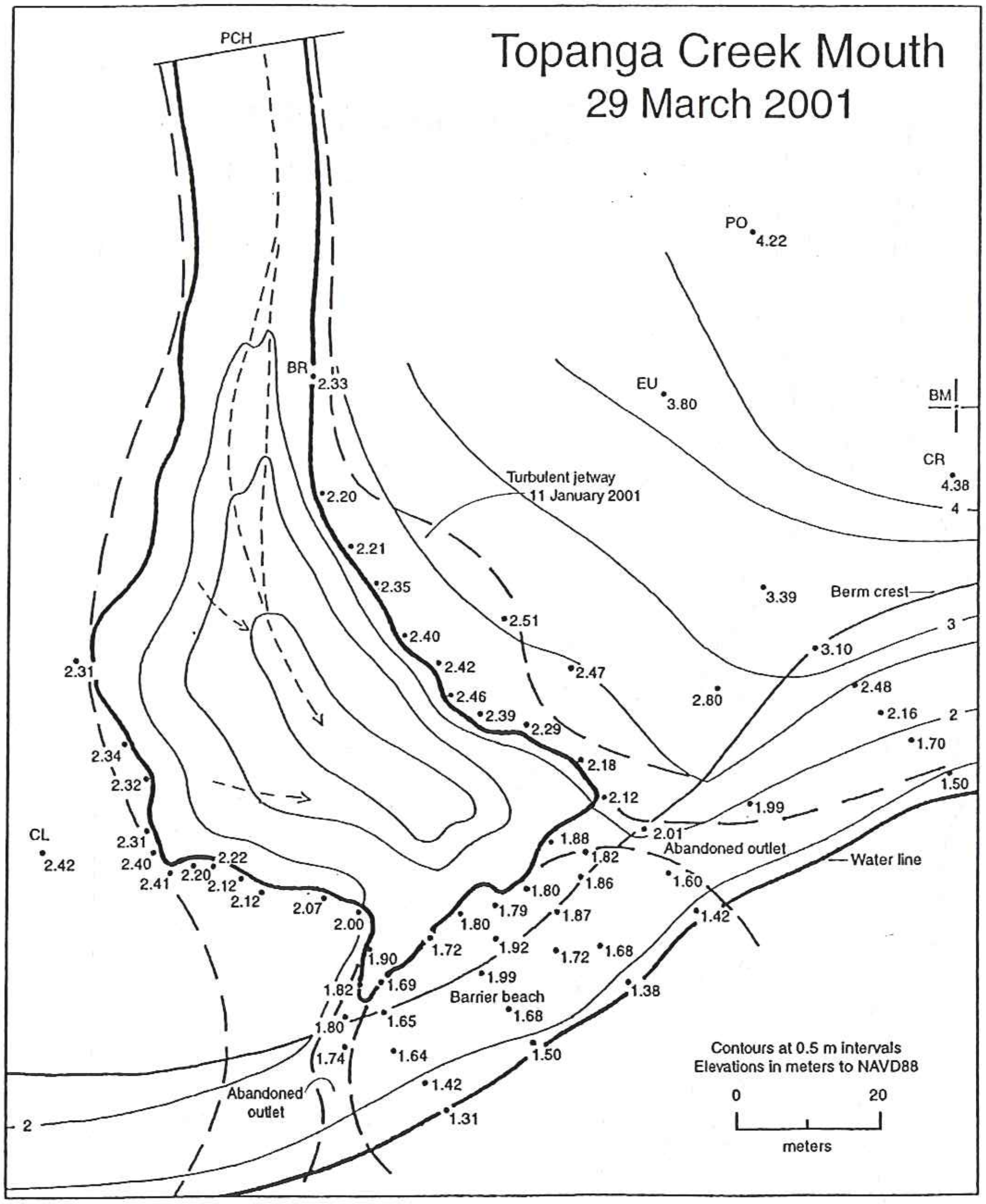
Figure 7-12.



29 March 2001:

Following the above events, no further rain fell in the basin during March and wave action was variable but muted. The foreshore changed little but, in the absence of fluvial forcing, both the eastern and western distributaries eventually closed on 29 March (Figure 7-13). The lagoon now reformed and its water level reached 2 m. Bedforms within the lagoon had been masked by fine clastic fluvial sediment and also reworked by overwash during wave action superimposed on high tides on 26-28 March. The barrier-lagoon system, destroyed by events of 10-11 January, had now reformed.

Figure 7-13

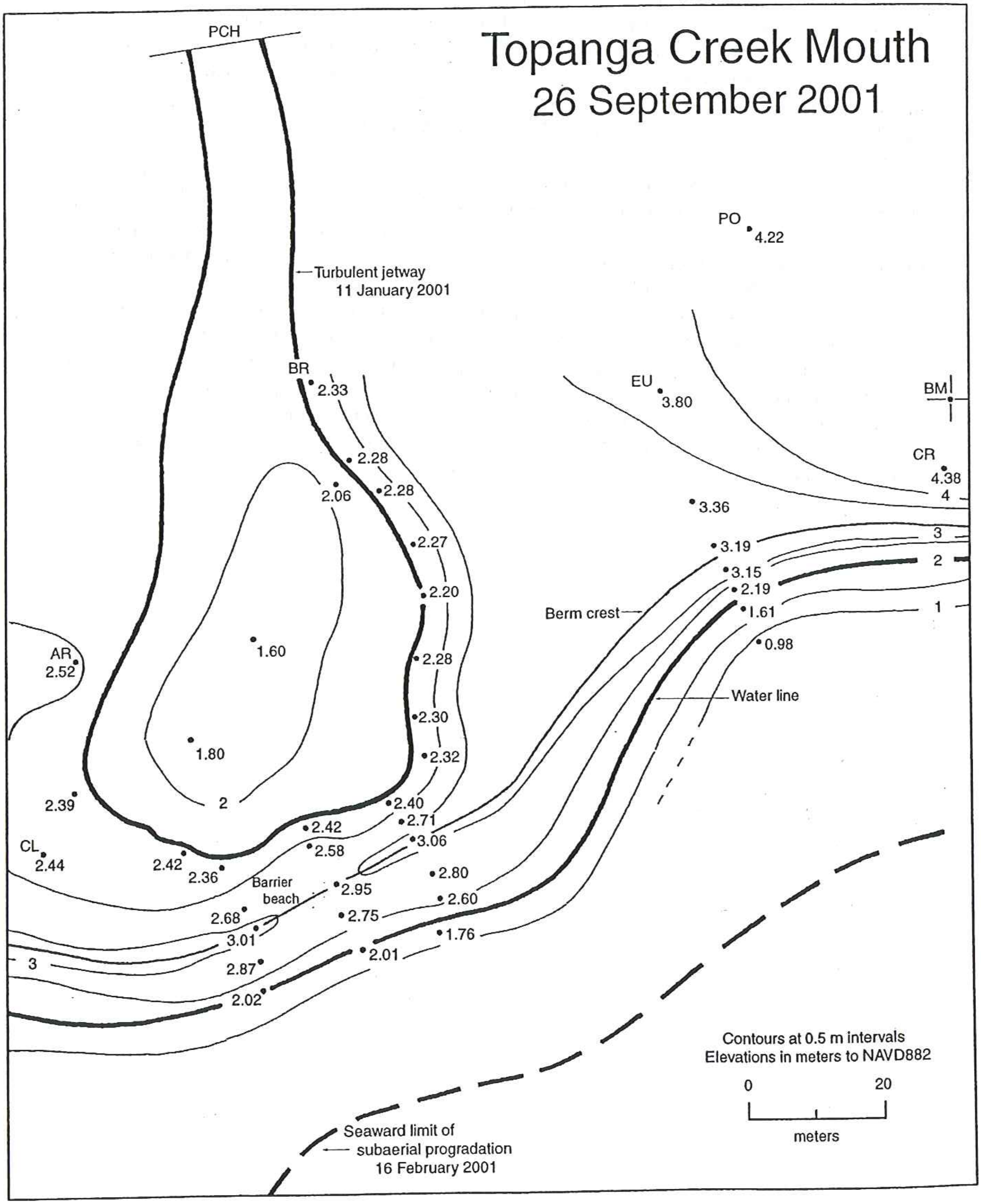


26 September 2001:

With the closure of the distributary outlets on 29 March, the reconstructed barrier-lagoon system entered its summer phase and this persisted to the close of the study period (Figure 7-14). After mid-April, deep-water wave heights subsided to 1 m or below, and, following refraction and shoaling, made little impact on the barrier except during higher high water when overwash sometimes occurred. Southern Hemisphere swell trains approached the coast at frequent intervals, often crossing westerly swells to form broken water, but these had little impact on the barrier.

The barrier-lagoon system was monitored during this time, revealing occasional overwash of ocean waters into the lagoon during high tides, and occasional seaward spillage of lagoon waters as they reached the barrier threshold. Most seaward flow occurred as seepage through the coarse clastic materials forming the barrier, notably at lower low water when a difference of as much as 2 m existed between the lagoon level and ocean level. During these summer months, the barrier crest retreated inland by between 10 –20 m, the beach face steepened in the summer wave climate and the mean low water line moved landward by 20 m off the lagoon and 40 m off the lifeguard station. On 26 September, the lagoon water level lay at 2.2 m and the lagoon had a maximum depth of 0.6 m. There was much mechanical grooming and other disturbance of the beach and lagoon margins during the summer months. On 30 September, the end of the water year, the barrier remained closed and the lagoon was somewhat eutrophic, with extensive algal blooms in its waters.

Figure 7-14 26 September 2001



7.4 Synthesis

The above sequence of events is representative of years characterized by average runoff and average marine conditions. A barrier-lagoon system inherited from the previous summer survives the autumn until destroyed by winter storm runoff. One or more fully turbulent jets remove the barrier along a broad front, but these jets are usually short-lived, as lateral diffusion and sedimentation impose internal and bed friction respectively. A friction-dominated estuary, with a middle ground bar broken by distributaries, then persists for much of the rainy season, subject to fine-tuning by subsequent storm runoff and marine forcing. Eventually, using the middle ground bar as a foundation, waves form a new barrier, thus enclosing a new lagoon and re-establishing a barrier-lagoon system for the coming summer. This barrier retreats landward in the summer wave climate and the lagoon responds to residual basin runoff, overwash and evaporation, and becomes increasingly eutrophic. The lagoon may spill seaward on rising to the barrier crest but such spillage, under natural conditions, rarely affects the overall integrity of the barrier.

In view of the constraints on the system, there is little reason to suppose that the above scenario will change radically from year to year. There are several reasons why this should be so, among which four natural constraints (1-4) and three human induced constraints (5-7) are discussed.

1. The mouth of Topanga Creek faces south near the northeast corner of the Santa Monica Bay, well removed from the direct effects of deep-water waves associated with westerly wave trains. Shoaling across the inner portions of the bay further reduces wave impacts. Although storm waves associated with unusual atmospheric and tidal forcing may cause local damage, this stretch of coast is among the most protected in the Santa Monica Bay.

2. By way of negative feedback, the Topanga fan delta formed by the basin sediment flux serves as a natural groin, refracting westerly and southwesterly shallow-water waves approaching the shore, and therefore further dampening wave impacts.

3. Under normal predictable conditions, the system is not subject to significant tidal forcing. Wave action thus dominates the coast throughout the year and tidal forcing of wave effects is modest.

4. Stream discharge is predictable within certain limits. Very wet years with numerous rainstorms, as in 1982-83 and 1997-98, may enhance fluvial forcing and prolong the longevity of the friction-dominated estuary at the expense of the barrier-lagoon system. But such fluvial forcing does not abrogate the physical principles involved. Very dry years prolong the barrier-lagoon system at the expense of the open estuary, but also favor wave erosion and shoreline retreat by limiting the influx of fresh sediment.

5. The Pacific Coast Highway bridge, some 150 m inland from the ocean, together with channel adjustments upstream and immediately downstream, initiated in 1933, constrain fluvial forcing by location and intensity. The bridge abutments favor turbulent jet outflows during major storm runoff events. Such jets scour the back-barrier lagoon, often to lower low water level or below, and refresh the physical system. Under natural conditions prior to bridge construction, Topanga Creek probably flushed seaward across a broader front, generating less defined scour paths and

less complete reworking of the lagoon. Today, much of the former lagoon inland from the bridge has been filled with sediment and other waste. Should the bridge abutments be widened, turbulent jet outflows would be less achievable, and without dredging the back-barrier lagoon would become broader, shallower and more eutrophic.

6. The present backshore environment seaward of Pacific Coast Highway has been much modified by fill placement and mechanical grooming, while the barrier has been breached mechanically from time to time. Such actions place constraints on the functioning of the natural system.

7. Finally, owing to ill-advised shoreline construction west of Topanga Creek, an historic reduction in littoral drift has diminished the volume of sand available at the mouth of the creek. The degree to which this has been offset by accelerated erosion within the Topanga Creek watershed is not known, but intuitively, some protection is afforded by increased yields of coarse and medium clastic sediment.

Despite these constraints, the mouth of Topanga Creek is probably near a critical threshold involving the relationship between incident fluvial and marine energy, the sediment budget, and the morphodynamic system. This threshold could be readily crossed by human-induced changes within the watershed, at the river mouth, or farther upcoast. For example, a further slight reduction in littoral drift from the west, or a slight increase in storm-wave activity against the existing beach face, could trigger accelerated erosion at the river mouth and downdrift, the consequences of which could only be offset by increased inputs of fluvial sediment or artificial nourishment.

8. Conclusions and Recommendations

8.1 Scientific Conclusions

The Topanga Creek watershed has been investigated in order to evaluate the nature and magnitude of erosion and sediment yield during the 2000-2001 water year. The foregoing study has focused on three spatial environments, namely hillslopes from which sediment is initially eroded, stream channels which convey delivered sediment downstream, and the river mouth where eroded sediment passes seaward into Santa Monica Bay. Roads as a sediment source have also been observed.

These investigations involved prudent sampling at various temporal and spatial scales. Hillslope erosion and sediment yield were sampled from 40 erosion sites in 6 locations between 10 and 19 times during the water year, yielding 658 sediment samples. Sampling locations and hillslope response to hydrodynamic forcing were stratified by slope declivity, slope aspect, vegetation category, substrate, and, by inference, fire history. Stream-channel reaches were subject to repeat surveys and sampling, focusing on 18 reaches at 9 locations, with special emphasis on the winter months, the period of greatest change in the strongly seasonal hydroclimate. The river mouth was surveyed on 13 occasions throughout the year and the changes recorded on detailed maps. The observed morphodynamics and sediment data from these sites were then assessed against the changing hydrodynamics of the water year. The latter involved the rainfall regime as it influenced hillslope and stream-channel processes, and fluvial discharge, wave climate and water-level regimes as they influence river-mouth processes. The following scientific conclusions may be drawn from the observed data.

8.1.1 Hillslope Erosion and Sediment Yield

As might be predicted in a watershed of variable surface characteristics exposed to a pulsating hydroclimate, hillslope erosion is highly variable. Amid the noise, however, certain conclusions emerge. Hillslope erosion is highest during and immediately after runoff-producing rainfall events, most notably after more persistent and intense rains. The highest erosion rates, ranging from 4 to 14 g m^{-2} d^{-1}, occur on steep, north- and west-facing slopes underlain by coarse clastic sedimentary substrate poorly protected by chaparral and coastal sage owing to relatively recent fires. The lowest erosion rates of 0.03 to 0.3 g m^{-2} d^{-1} occur on gentle, south- and east-facing slopes underlain by fine clastic substrate covered by grassland and oak savanna. Erosion rates were much lower during dry intervals but ravel, especially during post-rain dry spells, was locally important, while animal disturbance occasionally generated large amounts of erodible waste. It appears that between 10-15% of the sediment generated on the hillslopes moved into the creek channel during the study year.

The 2000-2001 water year was unspectacular in terms of hillslope processes. There were no watershed fires, rainfall was near average for the longer term, and persistent and intense rainfall was rarely sufficient to generate debris flows or to reactivate deep-seated landslides. Accordingly, most eroded sediment moved short distances to be stored lower in the slope catena. Nevertheless, owing to often steep slopes and variable substrates, the volume of sediment in episodic transit and storage is large. This allows development of a model in which erosion potential and sediment caliber are related to eight morpholithologic units. This model affords a framework for subsequent watershed planning.

8.1.2 Road Erosion and Sediment Yield

Roads and trails are human artifacts and thus by definition sources of accelerated erosion and sediment yield from cut banks and resulting berms. During rainfall/runoff events, much sediment moves as a slurry to roadside ditches and culverts, and thereby to stream channels. Other sediment, normally that generated by mass movement from cut banks, is removed mechanically or bulldozed into roadside berms. It was impossible to quantify the magnitude of erosion from road sources but an inventory of road margins and their behavior was conducted during the study period.

This inventory revealed that along the 42-km margins of Topanga Canyon Boulevard and Old Topanga Canyon Road, small berms (<1 m^2) comprise 29% of the margin, medium berms (1-3 m^2) 8%, large berms (>3 m^2) 3%, cut banks 46%, and open frontages 14%. Each category of berm stores a similar amount of debris, indicating that large berms, including roadside dumps, in the lower canyon are a potentially large source of sediment. However, it is the cut banks, constituting almost half the road margin, that are the main sources of sediment from surface erosion and mass movement. By definition, they are cut into hillslopes, thereby decreasing slope stability and favoring accelerated surface erosion and mass movement, greater than would be found in undisturbed slopes. Cut banks probably supply at least 80%, locally 100%, of the debris generated by road systems. The disposition of this debris is variable: some is trucked out of the watershed; some is stored in temporary roadside stockpiles and berms; some is reworked into berms; and some is either sidecast into streams or reaches streams via culverts and sheetflow. Beyond the paved roads, dirt roads and hiking trails often reveal serious problems of erosion and sediment yield derived from poor design and inadequate maintenance. While these areas are mainly located near the ridges, the erosion eventually makes its way downslope during larger storm events. Therefore they contribute a potentially significant amount of sediment to the overall system.

8.1.3 Stream-Channel Erosion and Sediment Yield

Fluvial erosion of channel beds and banks is the direct source of sediment to streams. This material is augmented by surface erosion of sediment stored on nearby lower hillslopes and floodplains, and by mass movement which may deliver large quantities of sediment instantaneously into channels. Once entrained, this material transported downstream in direct relation to stream competence and capacity. However, the latter are highly variable during flow events, and much sediment moves only short distances before being again stored in channels and overbank deposits. Scour and fill are thus common to streams in the watershed, and the relative importance of transport or storage depends largely on the kinematic and dynamic properties of the transporting fluid.

During the 2000-2001 water year, fluid flows generated significant erosion and sediment transport on only four occasions - between 10 January and 6 March 2001. During these events, substantial scour and fill were recorded at the 18 reaches observed. In general, scour was more common to the upper and lower reaches of the system, while fill was more characteristic of the middle reaches. Dewatering of debris flows and fluidized flows caused the deposition of several lobes of coarse sediment in these middle reaches. However, no single reach showed net fill throughout the year, and only one reach, below the confluence of Old Topanga Creek with Topanga Creek, showed persistent scour. Brief pulses of sediment movement occurred in late October 2000 and April 2001, but the rest of the year saw little channel activity.

Garapito and Santa Maria creeks were major contributors of suspended and bedload sediment during larger winter flows. Reflecting basin properties, the former conveyed much coarse clastic debris along its cobble-bed channel while the latter transported much fine clastic debris. These materials were mainly responsible for channel changes in middle Topanga Creek between the Garapito and Old Topanga creek confluences. Old Topanga Creek was a far less efficient delivery system during the year which, in view of the high hillslope yields in Red Rock Canyon, presumes that much loose sediment is still stored within this basin and likely to be mobilized in future floods.

The Topanga Creek watershed as a whole appears to have experienced a change in stream regime over the past 30-40 years in that floodplains have become incised and channel banks destabilized. Whereas these changes could be attributed to climate change crossing hydrodynamic thresholds, there is no compelling evidence for this. More likely, this regime change is a response to human impacts, including discharge of imported water, road runoff, vegetation change, including more frequent fire, and other land-use changes.

8.1.4 The River Mouth

The river mouth is wave-dominated throughout the year and only during major floods does it succumb to fluvial dominance. Tides play little role in river-mouth hydrodynamics, other than to establish the narrow range of water levels within which waves, stream flow, and seepage function.

For most of the 2000-2001 water year, the river mouth existed as a wave-dominated barrier-lagoon system. The shallow lagoon behind the barrier berm was replenished by stream flows, influent seepage and wave overwash, and diminished by evaporation, effluent seepage and occasional spillage. Between 10 January and 29 March 2001, however, fluvial forcing of the barrier established an open estuary, initially in response to a fully turbulent jet on 10-11 January and then as a friction-dominated system from 12 January. With the influx and reworking of fluvial sediment, the river mouth was soon invaded by sub-tidal, middle-ground bars that gradually welded onto the foreshore, restricting the diminishing fluvial discharge. The barrier-lagoon system was fully re-established after 29 March and the lagoon became shallower and more eutrophic thereafter. River-mouth hydrodynamics, including lagoon behavior, are also constrained by location, negative feedback imposed by the fan delta, confinement from the Pacific Coastal Highway bridge, and by frequent beach grooming.

8.2 Management Recommendations

Management of the Topanga Creek Watershed is a challenge owing to the frequent incompatibility of natural processes and human activities. This is reflected in the hillslope system, along roads, in river channels, and at the river mouth. The following recommendations for future management identify these incompatibilities and offer possible solutions from an earthscience and hydrodynamic perspective.

8.2.1 Hillslope Management

By their very nature, hillslopes are erosional systems in which materials eroded by surface flows, dry ravel and mass movement move downslope toward streams, but may be stored for periods of time en route. Erosion and sediment delivery are conditioned by gravity, the slope environment, and hydrodynamic processes. While initially independent, hydrodynamic variables are influenced by a range of natural and artificial filters, of which vegetation is the most susceptible to change. Vegetation cover and root systems are readily disturbed by fire and human activities, thus forcing hillslopes to adjust. Such disturbance and subsequent attempts at fire management present major incompatibilities with the natural system.

Recommendations

1. Hillslopes should be managed to minimize erosion and sediment yield above natural levels. This implies maintaining good vegetation cover and vegetative root systems, preferably of closely spaced native shrubs and trees.

2. Hillslopes exceeding 20° should be managed with special care and, if possible, left untouched. The field data indicate that an erosion threshold is crossed between 20° and 30° whereafter erosion increases at an exponential rate.

3. Hillslopes underlain by poorly consolidated substrate, most notably among the coarse clastic members of the Sespe Formation and on landslide terrain, should be managed to avoid exposing erodible units.

4. Chaparral and coastal sage vegetation, which cover 75% of the watershed, should be managed with great care. Under natural conditions, chaparral and its litter afford excellent protection against erosion, but removal of chaparral by fire or human activity usually promotes rapid erosion in immediate post-disturbance years, as shown in Red Rock Canyon following the 1993 fire.

5. Fire suppression and fire control policies should be re-examined with a view to gauging the best management practices that will ensure protection of hillslopes against erosion and of human population and infrastructure against fire hazards. The mature chaparral cover of upper Garapito Creek, where the fire hazard is now high, should be an immediate focus.

6. Grassland vegetation, especially alien grasses, should be managed in order to minimize the debris-flow hazard. Under light rains, alien grasses offer good hillslope protection, but more intense rains generate soil slippage and debris flows by virtue of the low infiltration capacity of dense root mats. Grassland is not widespread beyond the upper watershed, but wherever alien grasses occur on slopes exceeding 20° the potential for debris flows is enhanced.

8.2.2 Road Management

Roads and trails present some of the least compatible and problematic of environments in the watershed. Roads, especially cut banks, are a major source of sediment, much of which enters stream channels through culverts. Yet roads are human artifacts needed by residents, visitors, commuters, and public services alike. While this need remains, some degree of accelerated erosion must be expected. Such is the incompatibility of road construction and slope stability in lower Topanga Canyon that cliff falls and bank failures will be a continuing problem. The highway authorities are aware of this and usually do their best to maintain the public road system and remove the products of accelerated erosion.

Recommendations

1. Best management practices should be applied to road and trail construction and maintenance by public authorities and private property owners alike. This implies constant vigilance during and shortly after the rainy season designed for both public safety and wise removal of excessive sediment.

2. Cut banks should be managed so as to minimize surface erosion and mass movement. Initially this implies maintaining a compatible vegetation cover to retard movement. In some instances, however, roadside cliffs and deep-seated landslides must be managed by hard engineering solutions.

3. Culverts should be sited at intervals sufficient to cater for runoff and sediment yield from their drainage area. Main roads are mostly well provided for, but this is not so with fire roads and trails. Culverts should also be given long downspouts so as to reduce the potential for slope failure and debris flows during high runoff. Downspout outlets should be splayed to promote flow divergence and infiltration, rather than flow concentration. Once installed, culverts and feeding ditches should be inspected frequently and cleaned as necessary.

4. Road berms should be managed at levels sufficient to control sheet flow off roads but not become so large that they shed excess sediment into streams. Small berms ($<1\ m^2$) are sufficient. Large berms ($>3\ m^2$) should be removed.

5. Road widening should not be undertaken if it would cause fill material supporting an outside shoulder to encroach on stream channels, diverting streamflow toward potentially unstable sideslopes and exposing fill to entrainment by constrained and thus swifter flow.

6. The advantages and disadvantages of riprap, for erosion control beneath road shoulders alongside stream channels, should be carefully evaluated. Riprap deflects stream energy and generates further downstream erosional problems on opposing stream banks and also immediately upstream and downstream of such structures.

7. Dirt fire roads and recreational trails should be provided with proper drainage and erosion controls. Existing ruts and gullies should be repaired. Trails should also be closed periodically to permit recovery from compaction.

8.2.3 Stream-Channel Management

Stream channels are paths down which water and sediment flow seaward. They are naturally subject to variable velocity and discharge, to erosion and deposition, thalweg shifts, and flood impacts ranging from annual events to rare high magnitude events which affect much of the valley floor. Human encroachment on these channels is often incompatible with flood routing and some structures pose serious hazards. Every attempt should be made to accommodate predictable high flows within these streams, especially within lower Garapito, middle Topanga, and Old Topanga creeks, so as to minimize related hazards to private property and road infrastructure.

Recommendations

1. As a minimum, stream channels should be reshaped to accommodate a recurrence of the damaging 1980 flood event. This event is well defined by dendroanalysis of trees that have since grown on floodplains and terraces. Reshaping should include revegetation of unstable banks with native riparian species.

2. Existing stream channels and banks should be cleaned of extraneous debris, including large organic debris which poses a major threat because it may dam lesser flows and become mobile in larger floods. A good start has recently been made with the removal of junked vehicles, but much trash remains.

3. Structures that constrict and accelerate stream flow should be removed so as to reduce dangerous pulsing of flows which impact flow types and has serious downstream implications. Landslides and rock falls that impact stream flows should be removed.

4. The efficacy of erosion control devices along the main creeks should be reassessed. This peculiar array of devices, ranging from chicken wire and bedsteads to gabions, riprap and cement pilings, has accumulated willy-nilly to protect properties. Most are unwisely located.

5. Channel and bank segments 200 m upstream and 200 m downstream of the confluence of Old Topanga Creek with Topanga Creek (in the center of the town of Topanga) should be given special attention. The channels here have been tightly constrained by a variety of structures and the reach just below the confluence recorded persistent scour during the 2000-2001 water year. Erosion is likely to continue here.

6. The concept of bankfull discharge as a measure of flood hazard should be abandoned. Mediterranean-type mountain streams rarely have a definable bankfull stage because they flow in pulses of varying type, subject to super-elevation at bends (e.g. below Garapito bridge) and episodic deposition of coarse sediment loads. Instead, the 1980 maximum flood stage, related to a discharge of 390 m^3s^{-1} and an 83 year recurrence interval, should be used as a measure of flood hazard for management purposes. The 1980 flood stage, the largest on record, is still evident in many segments of the main channels and can be reconstructed elsewhere.

8.2.4 The River Mouth

The present river mouth involves hydrodynamic forces seeking to respond naturally in an unnatural situation constrained by bridge abutments and artificial fill. The beach functions within these constraints, prograding with terrestrial sediment during winter flood events, undernourished and retreating during late summer swells. While the present situation prevails, there is little to manage. Unidirectional littoral drift means that sediment introduced to the fan delta and reworked onto Topanga Beach during winter storms has little residence time. It moves downdrift toward Santa Monica and is not replaced by sediment from farther updrift because of net sediment losses in recent decades from beaches farther west (Orme, 1982; Orme, 1991; Orme et al., 2000).

Recommendations

1. Under the present system, management of the river mouth can be restricted to maintaining a safe recreational beach and an appropriate surf break off the existing fan delta.

2. For similar reasons, when the present small lagoon is closed to the ocean, that is for most of the year, it should be managed to minimize eutrophication and maintain a safe recreational experience (see *Lagoon Restoration* below).

8.2.5 Lagoon Restoration

Restoration of the existing lagoon to an earlier state is presently being contemplated by certain agencies. Whereas this is a worthy cause, it will not be easy. Certainly, from the engineering perspective, given sufficient funds, it is possible to widen the Pacific Coast Highway Bridge, remove part or all of existing fill adjacent to the river mouth both north and south of the bridge, and excavate sediment from the former estuary to create a larger lagoon. However, the nature of such a lagoon should be anticipated.

Estuarine lagoons, such as the small original feature at the mouth of Topanga Creek, originate when ocean waters flood existing valleys. For this to occur the rate of sea-level rise or tectonic subsidence must exceed the rate of estuarine sedimentation or tectonic uplift. The former lagoon came into existence towards the close of the Flandrian transgression when the sea-level rise slowed from 20 m ka^{-1} and ocean water flooded perhaps one kilometer upstream, while the rate of tectonic uplift was only 0.3 m ka^{-1}. The precise dimensions of this initial lagoon, presently unknown, are discoverable from borehole or seismic surveys, as recently used at Malibu Lagoon farther west (Orme, 1990; 2000).

However, over the past 4 ka, the rate of sea-level rise has slowed to 1 to 2 m ka^{-1}, and a similar rate for the past 70 years is confirmed from tide-gauge data at Santa Monica Pier. This still exceeds tectonic uplift rates. However, it is clearly less than the rate of sedimentation which has filled most of the initial lagoon. An early map of the historic lagoon, prepared by the United States Coast and Geodetic Survey in 1876, shows the lagoon largely converted to intertidal wetland and supratidal vegetated flats, with just sufficient space for Topanga Creek to reach the sea. Later maps, photographs and paintings from the late 19th and early 20th centuries also show a small lagoon. Since then, the area has been further filled by a variety of rock and other waste, both natural and artificial.

The above evidence confirms that estuarine lagoons are essentially transitory features of the coastal environment, destined with time to see their original accommodation space filled with sediment. Thus, whereas lagoon restoration is feasible, it must be accepted that subsequent sedimentation will necessitate frequent dredging in order to maintain a functional lagoon - and sedimentation has presumably increased from human impacts in recent decades.

Further, to be effective, a restored lagoon needs an adequate circulation system in which ocean water and stream flow cooperate to maintain and flush the system. Thus provision of adequate circulation is a *sine qua non* for effective lagoon restoration, a factor that was ignored when a misguided attempt to restore Malibu Lagoon was implemented in the 1980s (Ambrose and Orme, 2000; Orme, 2000).

Widening of the Pacific Coast Highway bridge over Topanga Creek also poses problems. At present, the river mouth is opened during winter floods by turbulent jets generated by the constriction afforded by the narrow bridge. This effectively flushes out the back-barrier lagoon and over the following weeks prepares refreshed accommodation space for a new lagoon. Widening of bridge abutments would reduce or eliminate these turbulent jets, leaving a less effective friction-dominated system in which the lagoon would quickly reform. Whether or not this is desirable is an important ecological issue. Within the existing range of stream and sediment discharge, for example, a wider outlet would provide for an initially broader lagoon which would accumulate more sediment and thereby shallow, producing a less effective circulation system and increased eutrophication.

8.3 Conclusion

The foregoing study represents a forward step in seeking to evaluate the erosional-depositional cascade of the Topanga Creek watershed. It presents information relevant to the continuing debate regarding management of the watershed. It does not answer all questions that might be raised, essentially because there was no previous information, for example on sediment yield, against which to compare these new data. However, the information presented here provides that baseline.

It is to be hoped that surveys of hillslope and channel erosion and sediment yield will be continued on a regular basis. For such studies to be effective, the watershed needs to be better instrumented permanently, and instruments need to be well sited, regularly calibrated and maintained, An array of 15-minute automatic rain gauges should be installed in the basin - in Red Rock Canyon, upper Topanga Creek, Garapito Creek, Trippet Ranch, Topanga village, the river mouth, and Saddle Peak Road. Regularly calibrated stream gauges should be installed at Garapito Bridge, Old Topanga Canyon at Red Rock Creek, and at the Old Topanga Creek-Topanga Creek confluence. The stage-discharge rating curve for the existing stream gauge should be recalibrated and permanent suspended sediment samplers installed. Other hydroclimatic instrumentation should be added. Daily monitoring of the river mouth should be initiated and recorded.

If the above steps are taken, the momentum developed in the present study can be maintained and the Topanga Creek watershed can come to serve as a model for small basin analysis.

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APPENDIX A

Table 4.1 Hillslope Erosion and Sediment Yields, Topanga Canyon Watershed, 2000-2001 Water Year [Sediment Yield = dry weight x 2/interval]

Table 4.2 Hillslope Erosion and Sediment Yields per Site, 2000-2001 Water Year

Table 4.3 Hillslope Erosion and Sediment Yields, Comparison of Wet and Dry Season Rates, 2000-2001 Water Year

Table 4.1. Hillslope Erosion and Sediment Yields, Topanga Canyon Watershed, 2000-2001 Water Year [Sediment yield = dry weight x 2/interval]

Sample period (month/day)	Interval (days)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)
		UTE 10		**UTE 20**		**UTE 30**	
11/29-12/06	7	0.95/0.95	0.27	0.05/0.05	0.01	1.09/0.05	0.31 sl
12/06-12/14	8	0.05/0.05	0.01	0.05/0.05	0.01	0.42/0.21	0.32 sl
12/14-01/05	22	0.24/0.24	0.02	0.38/0.38	0.03	0.86/0.69	0.08 sl
01/05-01/12	7	0.92/0.92	0.26	0.32/0.03	0.09 sl	2.10/0.21	0.60 c
01/12-01/22	10	1.36/0.14	0.27 sl	0.32/0.16	0.06 sl	0.84/0.08	0.17 sl
01/22-01/30	8	0.42/0.04	0.11 sl	0.82/0.41	0.21 sl	0.32/-	0.08 sl
01/30-02/09	10	0.24/0.02	0.05 sl	0.12/0.06	0.02 sl	0.32/0.16	0.06 sl
02/09-02/15	6	1.18/0.12	0.39 sl	0.36/0.18	0.12 sl	1.27/0.38	0.42 sl
02/15-03/02	15	0.48/0.12	0.06 sl	0.72/0.04	0.10 sl	).56/0/17	0.08 sl
03/02-03/08	6	0.23/0.12	0.08 sl	0.25/0.01	0.08 sl	0.60/0.12	0.20 sl
03/08-03/29	21	0.18/0.09	0.02 sl	0.45/0.02	0.04 sl	0.64/0.06	0.06 sl
03/29-04/19	21	0.25/0.13	0.02 sl	0.32/0.16	0.03 sl	0.30/0.27	0.03 sl
04/19-04/24	5	0.01/0.01	t	0.08/0.08	0.03	0.12/0.11	0.05 sl
04/24-05/25	31	0.01/0.01	t	0.31/0.31	0.02	379.50/-	24.45 c
05/25-06/29	35	0.45/0.45	0.03	0	0	40.40/-	2.31 c
06/29-07/27	29	2.30/2.30	0.16	0.10/0.10	0.01	0	0
07/27-09/05	40	0	0	0	0	0	0
09/05-09/28	23	0	0	0	0	0	0
		UTN 10		**UTN 20**		**UTN 30**	
11/29-12/06	7	0.84/0.42	0.24 sl	0.36/0.02	0.10 fs	1.36/1.36	0.39
12/06-12/14	8	0.10/0.05	0.02 sl	0.70/0.04	0.18 fs	0.21/0.01	0.05 fs
12/14-01/05	22	0.30/0.15	0.03 sl	1.12/0.06	0.10 sl	1.73/0.17	0.16 sl
01/05-01/12	7	4.48/0.45	1.28 sl	1.68/0.08	0.48 g/sl	0.78/0.70	0.22 sl
01/12-01/22	10	3.22/0.32	0.64 sl	1.82/0.18	0.36 sl	0.09/0.81	0.18 sl
01/22-01/30	8	1.48/1.33	0.37 sl	1.42/0.42	0.36 sl	0.94/0.85	0.24 sl
01/30-02/09	10	0.78/0.70	0.18 sl	0.70/0.63	0.14 sl	1.15/1.09	0.23 sl
02/09-02/15	6	0.96/0.48	0.32 sl	0.78/0.04	0.26 sl	0.71/0.67	0.24 sl
02/15-03/02	15	0.84/0.42	0.11 sl	0.21/0.01	0.01 sl	0.72/0.68	0.10 sl
03/02-03/08	6	0.37/-	0.12 sl	0.30/0.02	0.10 sl	0.32/0.30	0.11 sl
03/08-03/29	21	0.92/0.46	0.09 sl	0.28/0.28	0.03	1.08/0.97	0.10 sl
03/29-04/19	21	0.12/0.12	0.01	0.15/0.15	0.01	0.84/0.76	0.08 sl
04/19-04/24	5	0.06/0.06	0.02	0.14/0.01	0.06 sl	0.22/0.20	0.09 sl
04/24-05/25	31	0.36/0.36	0.02	0	0	0.76/0.68	0.05 sl
05/25-06/28	34	0	0	0	0	0	0
06/28-07/27	29	0	0	0	0	0.36/0.36	0.03
07/27-09/05	40	0	0	0	0	0	0
09/05-09/28	23	0	0	0	0	0	0

t = trace, <0.01g. Mineral sediment caliber by modal class: c clod, g gravel, cs coarse sand, ms medium sand, fs fine sand, sl silt, cl clay.

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)
		SMS 10		**SMS 20**		**SMS 30**	
12/13-01/05	23	0.28/0.01	0.02 fs	1.47/0.15	0.13 g	6.25/-	0.54 g/fs
01/05-01/15	10	10.62/0.1	2.12 fs	6.45/0.12	1.29 ms	26.6/0.53	5.32 g/ms
01/15-01/30	15	1.87/0.02	0.25 fs	0.72/-	0.10 sl	2.10/-	0.28 fs
01/30-02/09	10	0.45/t	0.09 fs	1.60/0.08	0.32 sl	0.10/0.01	0.02 fs
02/09-02/15	6	2.52/0.03	0.84 sl	2.20/-	0.73 sl	1.50/0.08	0.50 sl
02/15-03/02	15	2.60/0.03	0.35 sl	0.97/-	0.13 sl	0.63/0.06	0.08 sl
03/02-03/08	6	1.22/0.01	0.41 sl	0.38/-	0.13 sl	0.52/0.03	0.17 sl
03/08-03/29	21	0.59/t	0.06 sl	0.44/-	0.04 sl	0.72/0.07	0.07 sl
03/29-04/19	21	0.46/0.05	0.04 sl	0.34/0.03	0.03 sl	0.26/0.03	0.02 sl
04/19-04/24	5	0.34/-	0.14 sl	0.38/-	0.15 sl	0.10/-	0.04 sl
04/24-05/25	31	0.20/0.02	0.01 sl	0.28/0.28	0.02	0.42/0.22	0.03 fs/sl
05/25-06/29	35	0	0	0	0	0	0
06/29-07/27	28	0	0	0	0	0	0
07/27-09/05	40	0	0	4.70/0.02	0.24 g/sl	0	0
09/05-09/28	23	0	0	3.36/0.17	0.29 g/sl	0	0
		SMW 10		**SMW 20**		**SMW 30**	
12/13-01/05	23	2.49/1.00	0.22 fs	48.14/-	4.19 c	9.52/0.48	0.83 c
01/05-01/15	10	18.42/0.9	3.68 fs	15.64/7.8	3.13 c	16.80/0.8	3.36 sl
01/15-01/30	15	18.12/0.9	2.42 fs	32.85/6.6	4.38 c	4.86/1.46	0.65 sl
01/30-02/09	10	21.18/6.4	4.24 fs	157.1/31	31.42 c	1.92/0.19	0.38 c/sl
02/09-02/15	6	24.38/4.9	8.13 c/sl	28.52/5.7	9.51 c/sl	4.35/0.09	1.45 sl
02/15-03/02	15	61.82/6.2	4.12 c/sl	38.34/27	5.11 c/sl	3.10/1.55	0.41 sl
03/02-03/08	6	10.84/0.6	3.61 c/sl	14.86/3.0	4.95 c/sl	2.28/0.46	0.76 sl
03/08-03/29	21	14.18/1.4	1.35 c/sl	22.88/6.9	2.18 c/sl	3.74/1.12	0.36 g/sl
03/29-04/19	21	17.22/2.6	1.64 c/sl	296.3/45	28.22 c/sl	28.48/2.9	2.71 c/sl
04/19-04/24	5	13.22/4.0	5.29 c/sl	69.94/28	27.98 c/sl	4.58/0.92	1.83 c/sl
04/24-05/25	31	9.14/8.23	0.59 sl	4.20/2.10	0.27 sl	87.32/17	5.63 c/sl
05/25-06/29	35	11.62/5.8	0.66 c/sl	12.18/7.3	0.70 c/sl	36.68/3.7	2.10 c/sl
06/29-07/27	29	6.92/3.46	0.48 g/c	74.48/7.5	5.14 c/sl	61.65/6.2	4.40 c/sl
07/27-09/05	40	7.52/3.76	0.38 g	0	0	55.4/11.1	2.77 c/cl
09/05-09/28	23	0	0	0	0	8.20/0.82	0.71 c/sl

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/ organic (g)	Sediment yield and caliber $(g\ m^{-2}\ d^{-1})$	Total dry weight/ organic (g)	Sediment yield and caliber $(g\ m^{-2}\ d^{-1})$	Total dry weight/ organic (g)	Sediment yield and caliber $(g\ m^{-2}\ d^{-1})$
		GPS 10		**GPS 20**		**GPS 30**	
12/06-01/05	30	32.1/32.1	2.14	7.62/7.62	0.51	5.80/5.80	0.39
01/05-01/15	10	8.06/8.06	1.61	12.7/1.27	2.53 fs	63.5/3.18	12.70 fs
01/15-01/22	7	6.28/3.14	1.79 c	5.38/0.54	1.54 fs	3.92/0.39	1.12 fs
01/22-01/30	8	1.20/1.20	0.3	1.24/t	0.31 fs	15.92/3.2	3.80 fs
01/30-02/09	10	15.9/15.0	3.17 sl	7.68/3.01	1.54 sl	1.26/0.63	0.25 sl
02/09-02/15	6	4.92/4.67	1.64 sl	9.08/1.82	3.03 sl	63.66/6.4	21.22 sl
02/15-03/02	15	2.13/2.02	0.28 sl	2.75/0.55	0.37 fs	28.9/11.6	3.86 sl
03/02-03/08	6	1.16/0.12	0.39 sl	2.21/1.15	0.74 sl	18.0/1.80	6.00 sl
03/08-03/29	21	25.5/24.2	2.43 sl	12.6/10.1	1.20 sl	5.56/1.67	0.53 sl
03/29-04/19	21	14.9/13.4	1.42 sl	6.12/4.90	0.58 sl	15.1/10.5	0.72 sl
04/19-04/24	5	3.31/2.98	1.32 sl	1.20/0.60	0.48 sl	10.3/5.14	4.11 sl
04/24-05/25	31	4.02/4.02	0.26	0.58/0.58	0.04	25.05/5.0	1.62 g/sl
05/25-06/28	34	3.70/3.70	0.22	0.90/0.90	0.05	1.76/1.76	0.1
06/28-07/27	29	2.42/2.42	0.17	0.20/0.20	0.01	1.74/1.74	0.12
07/27-09/05	40	15.2/15.2	0.76	3.38/3.38	0.17	19.3/0.97	0.97 c/g
09/05-09/28	28	0	0	5.00/5.00	0.43	3.06/3.06	0.27
		GPW 10		**GPW 20**		**GPW 30**	
12/06-01/05	30	1.20/1.20	0.08	2.20/2.20	0.15	3.20/0.20	0.21 c
01/05-01/15	10	2.19/0.22	0.44 sl	2.28/0.11	0.46 fs	6.86/-	1.37 sl
01/15-01/22	7	0.40/0.40	0.11	2.70/0.27	0.77 fs	3.40/3.40	0.97
01/22-01/30	8	0.78/0.47	0.20 sl	0.28/0.28	0.07	0.62/-	0.16 sl
01/30-02/09	10	0.15/0.02	0.03 sl	0.12/t	0.02 fs	0.12/0.10	0.02 sl
02/09-02/15	6	0.76/-	0.25 fs	0.24/0.01	0.08 fs	4.24/0.08	1.41 sl
02/15-03/02	15	0.64/0.03	0.09 sl	0	0	0.98/0.05	0.13 sl
03/02-03/08	6	0.55/0.03	0.18 sl	0.45/-	0.15 fs	0.77/-	0.26 sl
03/08-03/29	21	1.10/0.06	0.11 sl	0.58/0.03	0.06 fs	0.42/-	0.04 sl
03/29-04/19	21	0.88/0.09	0.08 sl	0.25/0.13	0.02 fs	0.42/0.02	0.04 sl
04/19-04/24	5	0.36/0.07	0.14 sl	0.16/0.13	0.06 fs	0.23/0.12	0.09 sl
04/24-05/25	31	0	0	0.60/0.60	0.04	0.36/0.32	0.02 sl
05/25-06/28	34	0	0	0.66/0.66	0.04	1.28/1.28	0.08
06/28-07/27	29	0	0	0	0	0	0
07/27-09/05	40	0	0	0.80/0.80	0.04	0	0
09/05-09/28	28	0	0	0	0	0	0

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})
		TRE 10		**TRE 20**		**TRE 30**	
11/20-11/29	9	28.92/1.5	6.43 fs	15.44/0.8	3.43 g	8.19/0.08	1.83 g/cs
11/29-12/06	7	0.26/0.01	0.07 fs	24.76/2.5	7.07 g	10.15/0.2	2.90 g/cs
12/06-12/14	8	0.05/t	0.01 fs	0.05/-	0.01 fs	27.45/0.3	6.86 g/cs
12/14-01/05	22	2.24/2.02	0.20 sl	165.8/1.7	15.07 g	92.73/0.9	8.43 g/cs
01/05-01/12	7	3.20/0.32	0.91 sl	44.60/-	12.74 g/cs	99.28/1.0	28.37 g
01/12-01/22	10	2.52/1.26	0.50 fs	1.48/1.33	0.30 sl	9.40/0.47	1.88 g
01/22-01/30	8	26.3/5.26	6.58 g/fs	13.76/0.1	3.44 g	36.3/0.36	9.08 g
01/30-02/09	10	3.90/1.95	0.78 fs	12.34/0.6	2.47 g	10.82/0.1	2.16 g
02/09-02/15	6	6.98/3.49	2.33 fs	11.44/0.6	3.81 g	44.7/0.89	14.90 g/sl
02/15-03/01	14	2.38/1.19	0.34 fs	22.18/1.1	3.17 g/sl	105.7/2.1	15.10 g/c
03/01-03/08	7	0.12/0.04	0.03 fs	2.64/0.13	0.75 sl	12.26/0.6	3.50 g/c
03/08-03/29	21	18.42/8.7	1.72 g/fs	47.22/-	4.50 g	157.6/23.6	15.01 g/sl
03/29-04/19	21	31.36/21	2.99 sl	6.11/0.61	0.58 g	45.67/2.3	4.35 g/sl
04/19-04/24	5	0.72/0.29	0.29 sl	0.56/0.11	0.22 ms	11.84/1.6	4.74 g/sl
04/24-05/25	31	7.34/6.61	0.47 fs	0.01/0.01	t	7.44/-	0.48 g/sl
05/25-07/02	38	2.58/2.32	0.14 fs	0	0	14.64/0.8	0.77 g
07/02-07/27	25	0	0	0	0	0	0
07/27-09/05	40	5.45/4.91	0.27 sl	0	0	2.54/0.51	0.13 g
09/05-09/28	23	5.72/5.15	0.50 sl	0	0	9.66/1.45	0.84 g
		TRW 10		**TRW 20**		**TRW 30**	
11/20-11/29	9	6.66/0.07	1.48 sl	2.30/0.12	0.51 fs	9.37/0.47	2.08 fs
11/29-12/06	7	0.37/0.02	0.11 sl	0.73/0.07	0.21 fs	1.62/0.08	0.46 fs
12/06-12/14	8	3.66/0.18	0.92 ms	0.84/0.08	0.21 g/fs	2.50/2.00	0.63 ms
12/14-01/05	22	6.28/0.31	0.57 fs	6.66/0.67	0.61 g/ms	11.53/6.9	1.05 fs
01/05-01/12	7	2.58/0.13	0.74 fs	6.19/1.24	1.77 sf	22.50/2.3	6.43 sl
01/12-01/22	10	0.25/0.01	0.05 fs	0.45/0.09	0.09 fs	3.40/0.21	0.68 g
01/22-01/30	8	0.28/0.01	0.07 fs	0.75/0.38	0.19 fs	6.05/1.21	1.51 g/ms
01/30-02/09	10	0.16/t	0.03 fs	0.64/0.32	0.13 fs	3.08/1.54	0.62 fs
02/09-02/15	6	0.22/-	0.07 fs	0.72/0.36	0.24 fs	21.48/4.3	7.16 sl
02/15-03/01	14	0.20/0.10	0.03 g	2.50/1.25	0.36 fs	3.63/1.45	0.52 sl
03/01-03/08	7	0.42/0.21	0.12 g	0.62/0.31	0.18 fs	1.75/0.88	0.50 sl
03/08-03/29	21	1.32/0.26	0.13 sl	2.73/1.64	0.26 fs	7.50/3.35	0.71 fs
03/29-04/19	21	0.80/0.64	0.08 sl	6.26/5.01	0.60 fs	7.24/5.79	0.69 fs
04/19-04/24	5	0.10/0.08	0.04 sl	1.22/0.98	0.49 sl	2.08/1.04	0.83 fs
04/24-05/25	31	1.74/1.74	0.11	1.50/1.35	0.10 sl	4.74/4.27	0.31 sl
05/25-07/02	38	1.78/1.74	0.09	0.05/0.05	t	0.24/0.24	0.01
07/02-07/27	25	0	0	0	0	0.68/0.68	0.05
07/27-09/05	40	0	0	1.50/1.50	0.08	2.52/0.50	0.13 g
09/05-09/28	23	0	0	0	0	0	0

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/ organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)
		RRE 10		**RRE 20**		**RRE 30**	
11/29-12/20	21	1.00/1.00	0.1	3.12/3.12	0.3	1.28/t	0.12 g/cs
12/20-01/12	23	5.80/-	0.50 cs	36.93/0.4	3.21 g/cs	361.50/-	31.43 g/cs
01/12-02/18	37	39.4/-	2.13 cs	77.4/1.55	4.18 g/cs	136.20/-	7.36 g/cs
02/18-02/28	10	8.64/-	1.73 ms	26.66/-	5.33 g/ms	32.84/-	6.57 g/cs
02/28-03/03	3	0.30/-	0.20 ms	0.68/t	0.45 ms	2.65/-	1.77 g/cs
03/03-03/07	4	4.16/-	2.08 ms	12.32/-	6.16 g/ms	12.16/-	6.08 g/cs
03/07-04/05	29	5.36/0.05	0.37 ms	13.96/0.7	0.96 g/ms	21.62/-	1.49 g/cs
04/05-04/22	17	3.10/-	0.36 ms	10.15/-	1.19 g/ms	18.25/-	2.15 g/cs
04/22-05/31	39	2.56/0.13	0.13 ms	6.24/0.31	0.32 ms	16.98/0.2	0.88 g/cs
05/31-09/30	122	3.70/0.19	0.06 ms	22.85/1.1	0.37ms	37.44/0.4	0.61 g/cs
		RRW 10		**RRW 20**		**RRW 30**	
11/29-12/20	21	1.50/-	0.14 ms	6.52/0.33	0.62 ms	7.63/-	0.73 g/cs
12/20-01/12	23	3.56/0.04	0.31 ms	37.6/0.38	3.27 ms	401.61/-	34.92 g/cs
01/12-02/18	37	31.92/-	1.73 g/ms	86.84/0.9	4.69 g/ms	642.52/-	34.73 g/cs
02/18-02/28	10	186.44/-	37.29 g/cs	34.86/-	6.97 g/ms	396.76/-	79.35 g/cs
02/28-03/03	3	12.16/0.1	8.11 ms	1.52/-	1.01 g/ms	28.30/-	18.87 ms
03/03-03/07	4	67.20/-	33.6 ms	28.7/1.4	14.35 g/ms	211.15/-	105.6 g/cs
03/07-04/05	29	115.65/-	7.98 ms	9.24/-	0.64 ms	65.78/-	4.54 cs
04/05-04/22	17	72.10/-	8.48 ms	16.78/-	1.97 g/ms	176.65/-	20.78 g/cs
04/22-05/31	39	42.86/2.1	2.20 ms	3.05/-	0.16 ms	38.46/1.9	1.97 cs
05/31-09/30	122	76.32/-	1.25 ms	12.5/-	0.21 ms	112.62/5.	1.85 g/cs

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})	Total dry weight/organic (g)	Sediment yield and caliber (g m^{-2} d^{-1})
		BTE 20 Ou		**BTE 20 Ol**		**BTE 20 Oo**	
11/08-11/29	21	1.05/1.00	0.10 sl	1.04/1.04	0.1	1.04/1.04	[0.10]
11/29-12/06	7	0.25/0.24	0.07 sl	0.90/0.90	0.26	0.27/0.27	[0.08]
12/06-12/14	8	0.11/0.10	0.03 sl	0.94/0.94	0.24	0.83/0.83	[0.20]
12/14-01/05	22	1.88/1.69	0.17 sl	3.44/2.75	0.31 fs	3.52/0.70	[0.32] sl
01/05-01/12	7	7.85/7.07	2.24 sl	46.2/46.2	13.21	25.1/1.26	[7.17] sl
01/12-01/22	10	1.20/-	0.24 sl	1.34/1.34	0.27	5.68/5.37	[1.14] sl
01/22-01/30	8	4.40/4.40	1.1	1.84/1.66	0.46 sl	7.90/7.11	[1.98] sl
01/30-02/09	10	0.45/0.45	0.09 sl	3.58/3.22	0.72 sl	5.42/3.79	[1.08] sl
02/09-02/15	6	5.72/3.43	1.91 sl	8.14/4.88	2.71 sl	32.9/23.0	[11.0] sl
02/15-03/01	14	1.88/0.94	0.27 sl	7.26/6.53	1.04 sl	36.48/24	[5.21] sl
03/01-03/08	7	1.40/0.70	0.40 sl	3.74/3.18	1.07 sl	15.02/12	[4.29] sl
03/08-03/29	21	1.16/1.04	0.11 sl	10.78/9.7	1.03 sl	6.24/5.62	[0.59] sl
03/29-04/19	21	6.38/5.74	0.61 sl	16.2/14.6	1.54 sl	16.4/14.8	[1.56] sl
04/19-04/24	5	1.50/1.35	0.60 sl	1.98/1.78	0.79 sl	4.22/3.80	[1.69] sl
04/24-05/25	31	2.02/1.92	0.10 sl	2.22/2.00	0.14 sl	2.58/2.45	[0.17] sl
05/25-06/29	35	1.54/1.54	0.09	2.42/2.42	0.14	5.51/5.51	[0.31]
06/29-07/27	28	0.90/0.90	0.06	0.65/0.65	0.05	1.20/1.20	[0.09]
o7/27-09/05	40	0	0	4.96/4.96	0.25	9.58/9.58	[0.48]
09/05-09/28	23	0	0	0	0	0	[0]
		BTE 20 G		**BTE 20 Go**			
11/08-11/29	21	0.11/0.05	0.01 sl	0.81/0.08	[0.08] sl		
11/29-12/06	7	0.01/0.01	t	0.42/0.04	[0.12] sl		
12/06-12/14	8	0.01/0.01	t	0.05/0.05	[t]		
12/14-01/05	22	0.28/0.14	0.03 sl	0.96/0.48	[0.09] fs		
01/05-01/12	7	0.72/0.36	0.21 sl	0.30/0.30	[0.09]		
01/12-01/22	10	0.02/0.02	t	1.38/0.14	[0.28] c		
01/22-01/30	8	0.01/t	t	2.17/0.22	[0.54] c		
01/30-02/09	10	1.62/0.81	0.32 sl	1.20/0.12	[0.24] c		
02/09-02/15	6	0.18/-	0.06 sl	6.04/0.03	[2.01] c		
02/15-03/01	14	0.48/0.43	0.07 sl	1.40/0.07	[0.20] c/sl		
03/01-03/08	7	0.29/0.03	0.08 sl	2.34/0.12	[0.67] sl		
03/08-03/29	21	1.85/0.93	0.18 sl	1.28/0.06	[0.12] sl		
03/29-04/19	21	1.97/0.99	0.19 sl	2.22/1.33	[0.21] sl		
04/19-04/24	5	0.16/0.13	0.06 sl	0.24/-	[0.10] fs		
04/24-05/25	31	0.75/0.75	0.05	1.70/0.85	[0.11] sl		
05/25-06/29	35	1.65/1.65	0.09	1.60/1.60	[0.09]		
06/29-07/27	28	0	0	0	[0]		
o7/27-09/05	40	0.10/0.10	t	0	[0]		
09/05-09/28	23	0	0	0	[0]		

[Sediment yield values for **BTE 20 Oo** and **BTE 20 Go**, which relate to open sites, are for comparison with constrained sites and are not appropriate for further analysis].

Table 4.1 (continued)

Sample period (month/day)	Interval (days)	Total dry weight/organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)	Total dry weight/organic (g)	Sediment yield and caliber ($g\ m^{-2}\ d^{-1}$)
		BTW	**20 Ou**	**BTW**	**20 Ol**	**BTW 20 Oo**	
11/08-11/29	21	2.18/2.18	0.21	0.93/0.93	0.09	14.6/14.6	[1.39]
11/29-12/06	7	0.24/0.24	0.07	7.26/7.26	2.07	30.0/30.0	[8.58]
12/06-12/14	8	0.47/0.24	0.12 fs	6.80/6.80	1.7	25.5/23.0	[6.38] fs
12/14-01/05	22	1.10/1.00	0.12 fs	6.43/6.43	0.58	6.00/3.00	[0.55] fs
01/05-01/12	7	23.4/22.3	6.69 fs	12.8/12.8	3.66	26.1/23.5	[7.46] sl
01/12-01/22	10	1.26/1.20	0.25 fs	4.28/4.28	0.86	12.5/11.3	[2.51] fs
01/22-01/30	8	2.46/2.21	0.62 sl	5.37/5.37	1.34	7.82/7.82	[1.96]
01/30-02/09	10	0.50/0.05	0.10 sl	6.25/6.25	1.25	6.48/5.83	[1.30] fs
02/09-02/15	6	3.80/1.52	1.27 sl	11.4/11.4	3.81	12.7/11.4	[4.22] fs
02/15-03/01	14	2.70/2.57	0.39 sl	3.70/3.70	0.53	4.48/4.03	[0.64] fs
03/01-03/08	7	1.58/1.50	0.45 sl	1.92/1.92	0.55	2.02/1.82	[0.58] fs
03/08-03/29	21	2.64/2.38	0.25 sl	2.72/2.58	0.26 sl	3.34/3.01	[0.32] fs
03/29-04/19	21	2.72/2.45	0.26 sl	2.70/2.57	0.26 sl	6.62/5.96	[0.63] fs
04/19-04/24	5	0.76/0.68	0.30 sl	1.46/1.31	0.58 sl	3.05/2.90	[1.22] fs
04/24-05/25	31	1.28/1.22	0.08 sl	2.12/2.12	0.14	5.86/5.57	[0.38] fs
05/25-06/29	35	5.15/5.15	0.29	2.82/2.82	0.16	2.20/2.20	[0.13]
06/29-07/27	28	0.20/0.20	0.01	0.70/0.70	0.05	0.48/0.48	[0.03]
07/27-09/05	40	0	0	3.56/3.56	0.18	6.30/6.30	[0.32]
09/05-09/28	23	0	0	5.75/5.75	0.5	0	[0]
		BTW	**20 G**	**BTW**	**20 Go**		
11/08-11/29	21	1.12/1.06	0.11 sl	1.43/0.04	[0.14] sl		
11/29-12/06	7	0.13/0.12	0.04 sl	0.25/0.25	[0.07] sl		
12/06-12/14	8	0.01/t	t sl	0.09/0.09	[0.02] sl		
12/14-01/05	22	1.08/0.97	0.10 fs	0.54/0.54	[0.05] sl		
01/05-01/12	7	1.96/0.20	0.56 sl	1.26/0.63	[0.36] sl		
01/12-01/22	10	0.22/0.20	0.04 fs	0.70/0.35	[0.14] fs		
01/22-01/30	8	1.32/1.19.	0.33 sl	0.50/0.40	[0.13] fs		
01/30-02/09	10	0.36/0.32	0.07 sl	1.92/0.86	[0.38] fs		
02/09-02/15	6	3.37/0.17	1.12 sl	1.62/0.16	[0.54] fs		
02/15-03/01	14	1.36/0.07	0.19 sl	0.50/0.40	[0.07] fs		
03/01-03/08	7	1.04/-	0.30 sl	0.60/0.36	[0.17] fs		
03/08-03/29	21	0.72/0.04	0.07 sl	1.56/0.62	[0.15] fs		
03/29-04/19	21	0.85/0.51	0.08 sl	1.12/0.56	[0.11] fs		
04/19-04/24	5	0.12/0.02	0.05 sl	0.05/t	[0.02] sl		
04/24-05/25	31	0.43/0.39	0.03 sl	0.68/0.68	[0.04]		
05/25-06/29	35	1.92/1.92	0.11 sl	0.90/0.68	[0.05]		
06/29-07/27	28	0	0	0	[0]		
07/27-09/05	40	0	0	0	[0]		
09/05-09/28	23	0	0	0	[0]		

[Sediment yield values for **BTW 20 Oo** and **BTW 20 Go**, which relate to open sites, are for comparison with constrained sites and are not appropriate for further analysis].

Table 4.1 (continued)

Site summary of organic matter as percent of total sediment dry weight, Topanga Creek Watershed, 2000-2001 Water year

Sample Site	Total Dry Weight (g)	Organic Content (%)	Sample Site	Total Dry Weight (g)	Organic Content (%)
UTE 10	9.27	60.41	UTN 10	14.83	35.87
UTE 20	4.65	43.87	UTN 20	9.66	20.08
UTE 30	429.34	0.58	UTN 30	11.27	85.27
SMS 10	21.15	1.28	SMW 10	236.53	21.1
SMS 20	23.29	4.51	SMW 20	815.45	21.76
SMS 30	39.2	2.63	SMW 30	328.88	14.95
GPS 10	140.65	93.96	GPW 10	9.01	28.75
GPS 20	78.55	52.92	GPW 20	11.32	46.11
GPS 30	282.81	22.21	GPW 30	22.9	25.24
TRE 10	148.46	41.69	TRW 10	26.82	20.66
TRE 20	368.44	2.59	TRW 20	35.66	39.2
TRE 30	706.33	5.27	TRW 30	111.91	32.95
RRE 10	74.02	1.85	RRW 10	609.7	0.38
RRE 20	210.31	3.42	RRW 20	237.61	1.27
RRE 30	640.92	0.08	RRW 30	2081.48	0.36
BTE 20 Ou	39.69	47.22	BTW 20 Ou	52.44	89.66
BTE 20 Ol	117.64	92.43	BTW 20 Ol	89.01	99.53
BTE 20 Oo	179.91	67.85	BTW 20 Oo	176.14	92.39
BTE 20 G	10.21	62.78	BTW 20 G	16.01	44.85
BTE 20 Go	24.11	22.77	BTW 20 Go	13.72	49.85

Table 4.2. Hillslope Erosion and Sediment Yields per Site, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
UTE 10	303	9.27	0.03	0.06	22.33
UTE 20	303	4.65	0.02	0.03	11.20
UTE 30	303	429.34	1.42	2.83	1034.38
UTE 30*	238	9.44	0.04	0.08	28.95
UTN 10	303	14.83	0.05	0.10	35.73
UTN 20	303	9.66	0.03	0.06	23.27
UTN 30	303	11.27	0.04	0.07	27.15
SMS 10	289	21.15	0.07	0.15	53.42
SMS 20	288	23.29	0.08	0.16	59.03
SMS 30	288	39.20	0.14	0.27	99.36
SMW 10	288	236.53	0.82	1.64	599.54
SMW 20	288	815.45	2.83	5.66	2066.94
SMW 30	288	328.88	1.14	2.28	833.62
GPS 10	301	140.65	0.47	0.93	341.11
GPS 20	301	78.55	0.26	0.52	190.50
GPS 30	301	282.81	0.94	1.88	685.88
GPW 10	301	9.01	0.03	0.06	21.85
GPW 20	301	11.32	0.04	0.08	27.45
GPW 30	301	22.90	0.08	0.15	55.54
TRE 10	312	148.46	0.48	0.95	347.36
TRE 20	312	368.34	1.18	2.36	861.94
TRE 30	312	706.33	2.26	4.53	1652.63
TRW 10	312	26.82	0.09	0.17	62.75
TRW 20	312	35.66	0.11	0.23	83.44
TRW 30	312	111.91	0.36	0.72	261.84
RRE 10	305	74.02	0.24	0.49	177.16
RRE 20	305	210.31	0.69	1.38	503.36
RRE 30	305	640.92	2.10	4.20	1534.01
RRW 10	305	609.70	2.00	4.00	1459.28
RRW 20	305	237.61	0.78	1.56	568.71
RRW 30	305	2081.48	6.82	13.65	4981.90
BTE 20 Ou	324	39.69	0.12	0.25	89.43
BTE 20 Ol	324	117.64	0.36	0.73	265.05
BTE 20 Oo**	324	179.91	0.56		
BTE 20 G	324	10.21	0.03	0.06	23.00
BTE 20 Go**	324	24.11	0.07		

* Recomputed ignoring gopher effect, 04/24 - 06/28; **open sites for comparison of sediment loading only

Table 4.2 (continued)

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean load per day ($g\ d^{-1}$)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Annual yield 2000-2001 ($t\ km^{-2}\ yr^{-1}$)
BTW 20 Ou	324	52.44	0.16	0.32	118.15
BTW 20 Ol	324	89.01	0.27	0.55	200.55
BTW 20 Oo**	324	176.14	0.54		
BTW 20 G	324	16.01	0.05	0.10	36.07
BTW 20 Go**	324	13.72	0.04		

**Open sites for comparison of sediment loading only

Table 4.3. Hillslope Erosion and Sediment Yields, Comparison of Wet and Dry Season Rates, 2000-2001 Water Year

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean daily yield $(g\ m^{-2}d^{-1})$	Wet season as factor of dry season
UTE 10 dry	194	4.00	0.0412	2.34
UTE 10 wet	109	5.27	0.0967	
UTE 20 dry	194	0.89	0.0092	7.52
UTE 20 wet	109	3.76	0.0690	
UTE 30 dry*	129	2.37	0.0367	3.53
UTE 30 wet	109	7.07	0.1297	
UTN 10 dry	194	1.60	0.0165	14.72
UTN 10 wet	109	13.23	0.2428	
UTN 20 dry	194	2.18	0.0225	6.11
UTN 20 wet	109	7.48	0.1372	
UTN 30 dry	194	4.42	0.0456	2.76
UTN 30 wet	109	6.85	0.1257	
SMS 10 dry	179	0.48	0.0054	70.72
SMS 10 wet	109	20.67	0.3793	
SMS 20 dry	179	9.81	0.1096	2.26
SMS 20 wet	109	13.48	0.2473	
SMS 30 dry	179	6.67	0.0745	8.01
SMS 30 wet	109	32.53	0.5969	
SMW 10 dry	179	37.69	0.4211	8.66
SMW 10 wet	109	198.84	3.6484	
SMW 20 dry	179	139.00	1.5531	7.99
SMW 20 wet	109	676.45	12.4119	
SMW 30 dry	179	258.77	2.8913	0.44
SMW 30 wet	109	70.11	1.2864	
GPS 10 dry	192	57.34	0.5973	2.56
GPS 10 wet	109	83.31	1.5286	
GPS 20 dry	192	17.68	0.1842	6.06
GPS 20 wet	109	60.87	1.1169	

*Recomputed ignoring gopher effect, 04/24 - 06/28

Table 4.3 (continued)

Erosion site	Total days of record (days)	Total dry weight for record (grams)	Mean daily yield (g m^{-2} d^{-1})	Wet season as factor of dry season
GPS 30 dry	192	56.71	0.5907	
GPS 30 wet	109	226.10	4.1486	7.02
GPW 10 dry	192	1.20	0.0125	
GPW 10 wet	109	7.81	0.1433	11.46
GPW 20 dry	192	4.26	0.0444	
GPW 20 wet	109	7.06	0.1295	2.92
GPW 30 dry	192	4.84	0.0504	
GPW 30 wet	109	18.06	0.3314	6.57
TRE 10 dry	203	52.56	0.5178	
TRE 10 wet	109	95.90	1.7596	3.40
TRE 20 dry	203	206.01	2.0297	
TRE 20 wet	109	162.33	2.9785	1.47
TRE 30 dry	203	172.80	1.7025	
TRE 30 wet	109	533.53	9.7895	5.75
TRW 10 dry	203	20.49	0.2019	
TRW 10 wet	109	6.33	0.1161	0.58
TRW 20 dry	203	13.58	0.1338	
TRW 20 wet	109	22.08	0.4051	3.03
TRW 30 dry	203	33.20	0.3271	
TRW 30 wet	109	78.71	1.4442	4.42
RRE 10 dry	182	7.26	0.0798	
RRE 10 wet	123	66.76	1.0855	13.61
RRE 20 dry	182	32.21	0.3540	
RRE 20 wet	123	178.10	2.8959	8.18
RRE 30 dry	182	55.70	0.6121	
RRE 30 wet	123	585.22	9.5158	15.55
RRW 10 dry	182	120.67	1.3260	
RRW 10 wet	123	489.03	7.9517	6.00
RRW 20 dry	182	22.07	0.2425	
RRW 20 wet	123	215.54	3.5047	14.45

Table 4.3 (continued)

Erosion site	Total days of of record (days)	Total dry weight for record (grams)	Mean daily yield ($g\ m^{-2}\ d^{-1}$)	Wet season as factor of dry season
RRW 30 dry	182	158.71	1.7441	
RRW 30 wet	123	1922.77	31.2646	17.93
BTE 20 Ou dry	215	7.75	0.0721	
BTE 20 Ou wet	109	31.94	0.5861	8.13
BTE 20 Ol dry	215	16.57	0.1541	
BTE 20 Ol wet	109	101.07	1.8545	12.03
BTE 20 G dry	215	2.91	0.0271	
BTE 20 G wet	109	7.30	0.1339	4.95
BTW 20 Ou dry	215	10.62	0.0988	
BTW 20 Ou wet	109	41.82	0.7673	7.77
BTW 20 Ol dry	215	36.37	0.3383	
BTW 20 Ol wet	109	52.64	0.9659	2.85
BTW 20 G dry	215	4.69	0.0436	
BTW 20 G wet	109	11.32	0.2077	4.76

APPENDIX B

Wave Climate, Santa Monica Bay Buoy (CDIP 02801), 2000-2001 Water Year

Tidal Regime, Santa Monica Bay, 2000-2001 Water Year
(NOAA/NOS/CO-OPS Verified Hourly Height Water Level Plot 9410840 Santa Monica, CA)

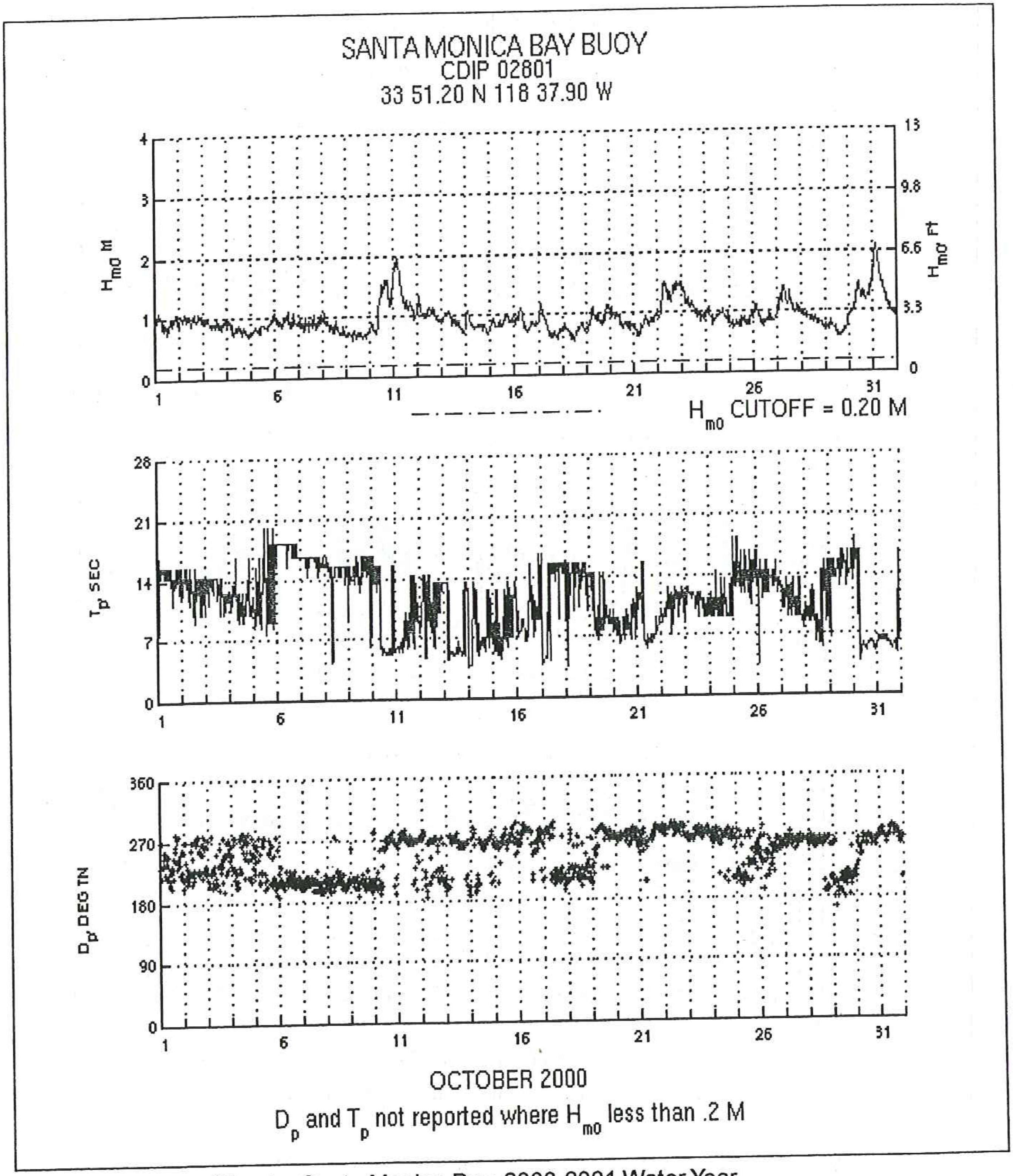

Figure 7-1. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

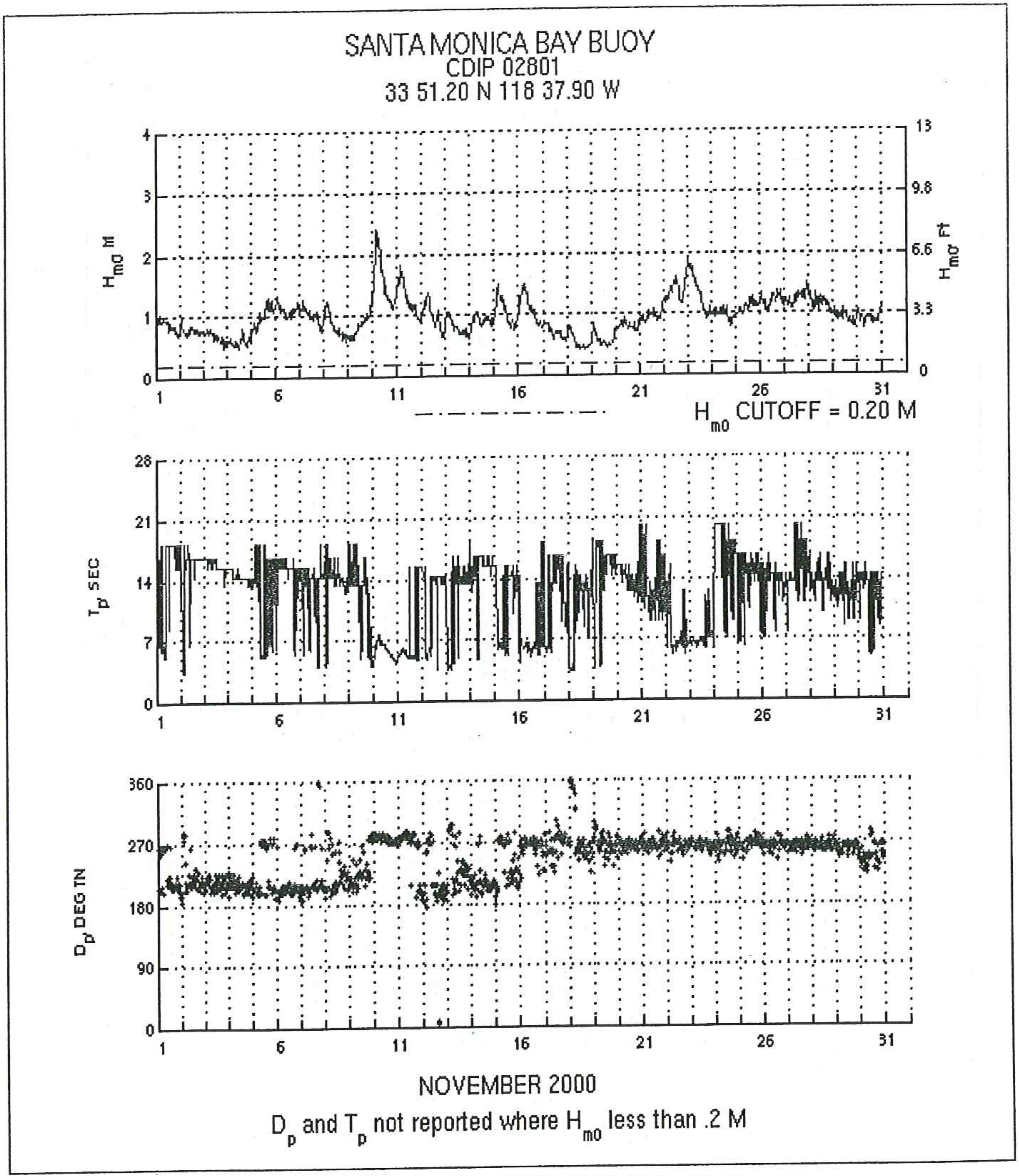

Figure 7-2. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

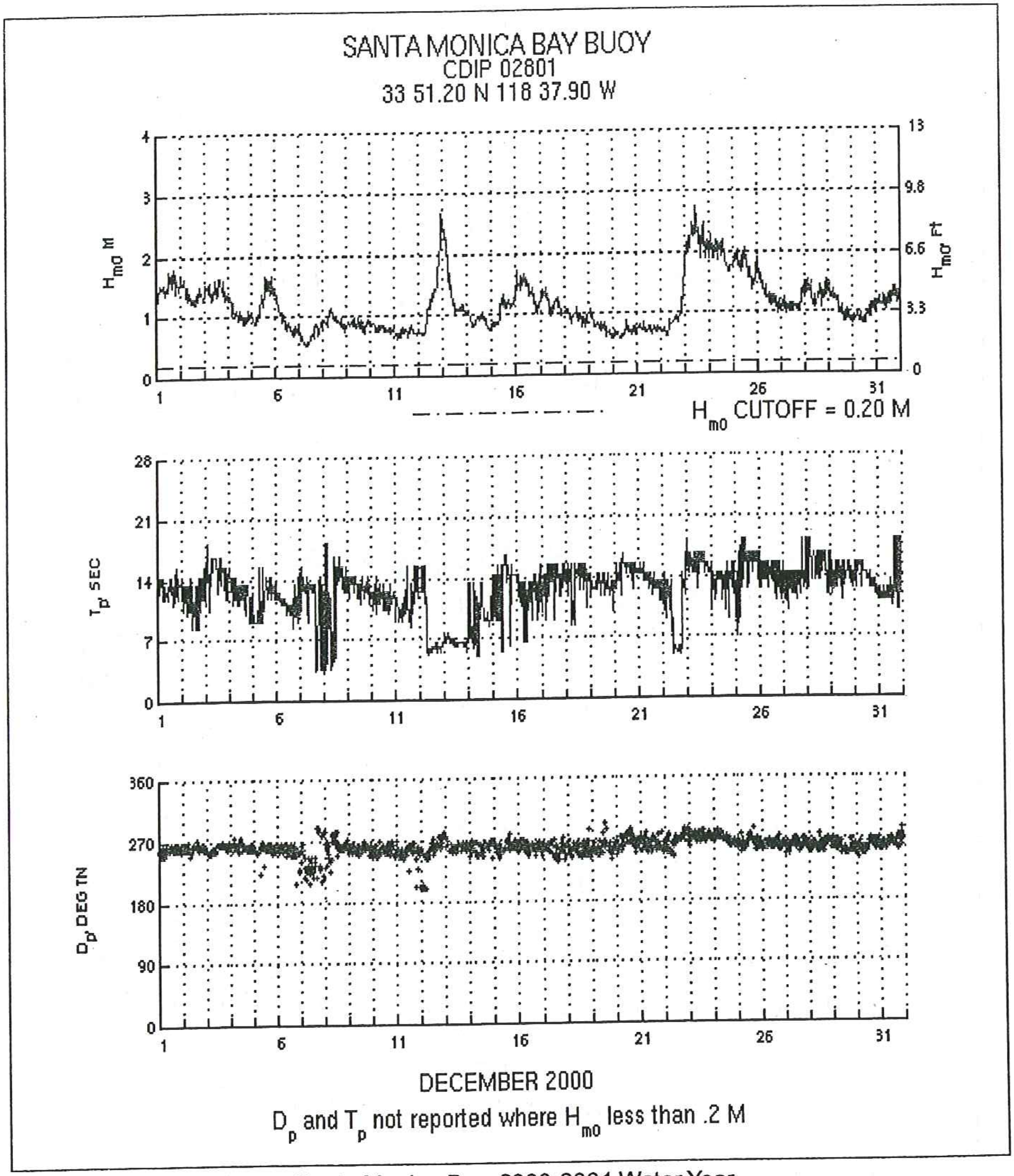

Figure 7-3. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

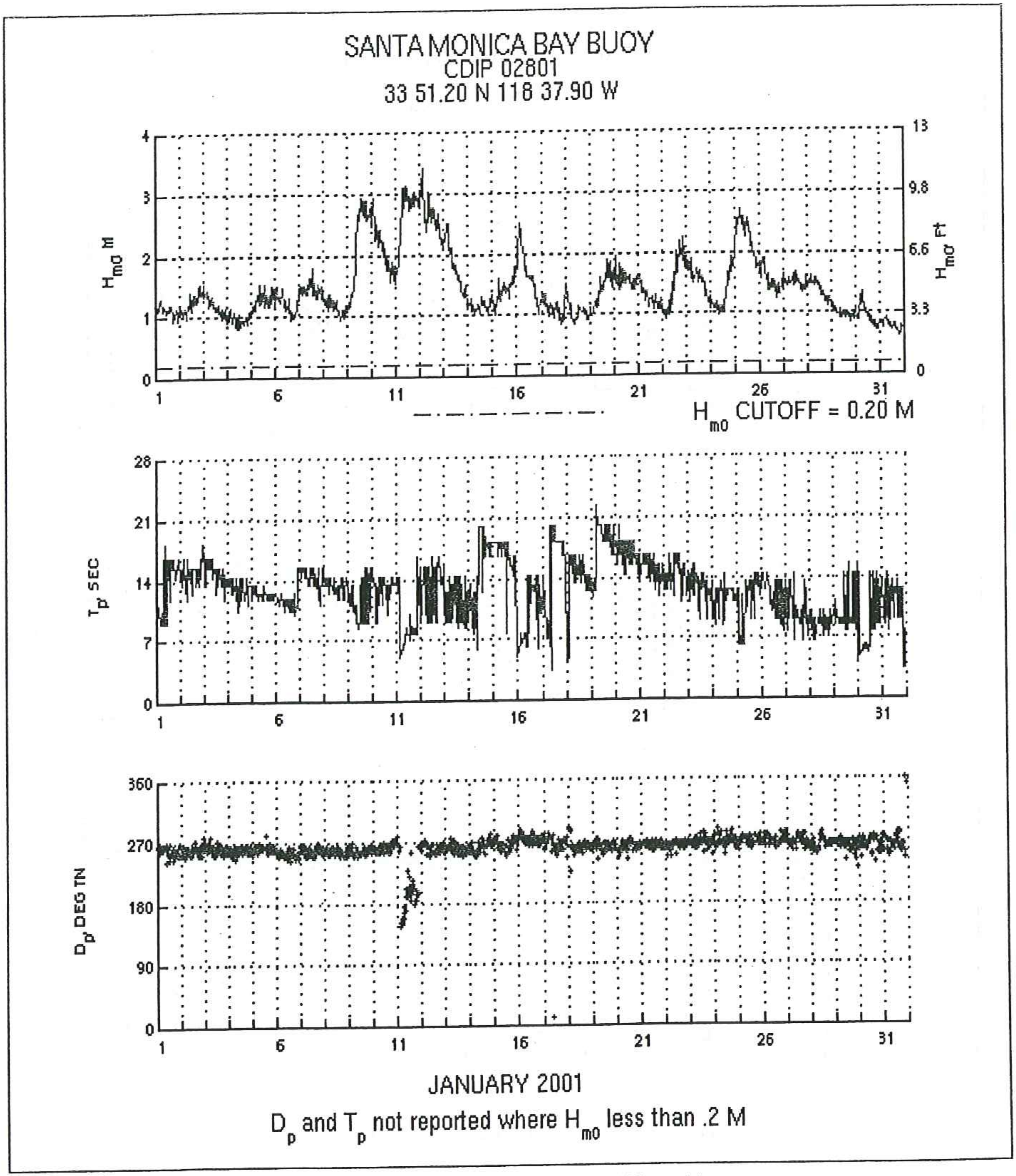

Figure 7-4. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

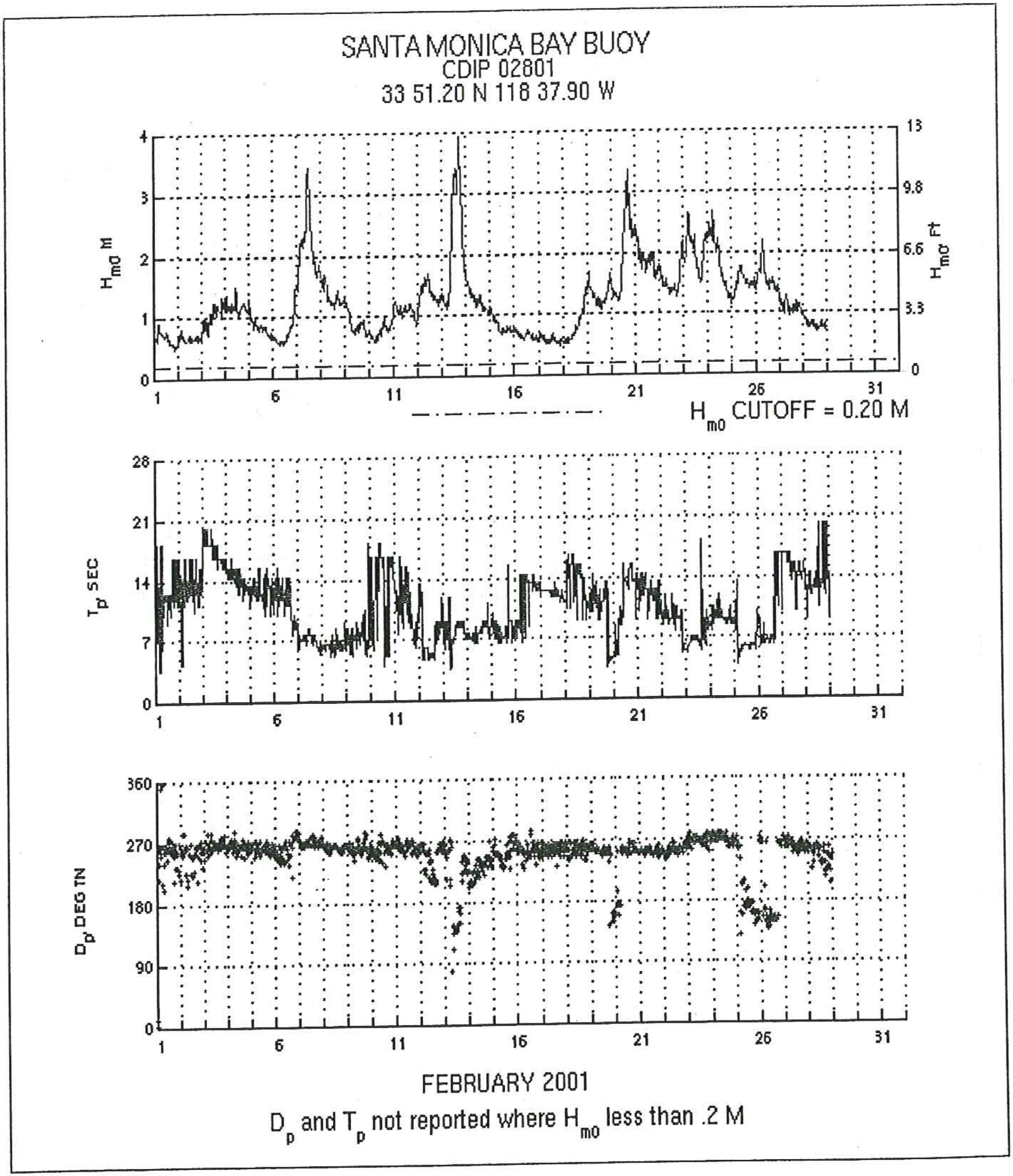

Figure 7-5. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

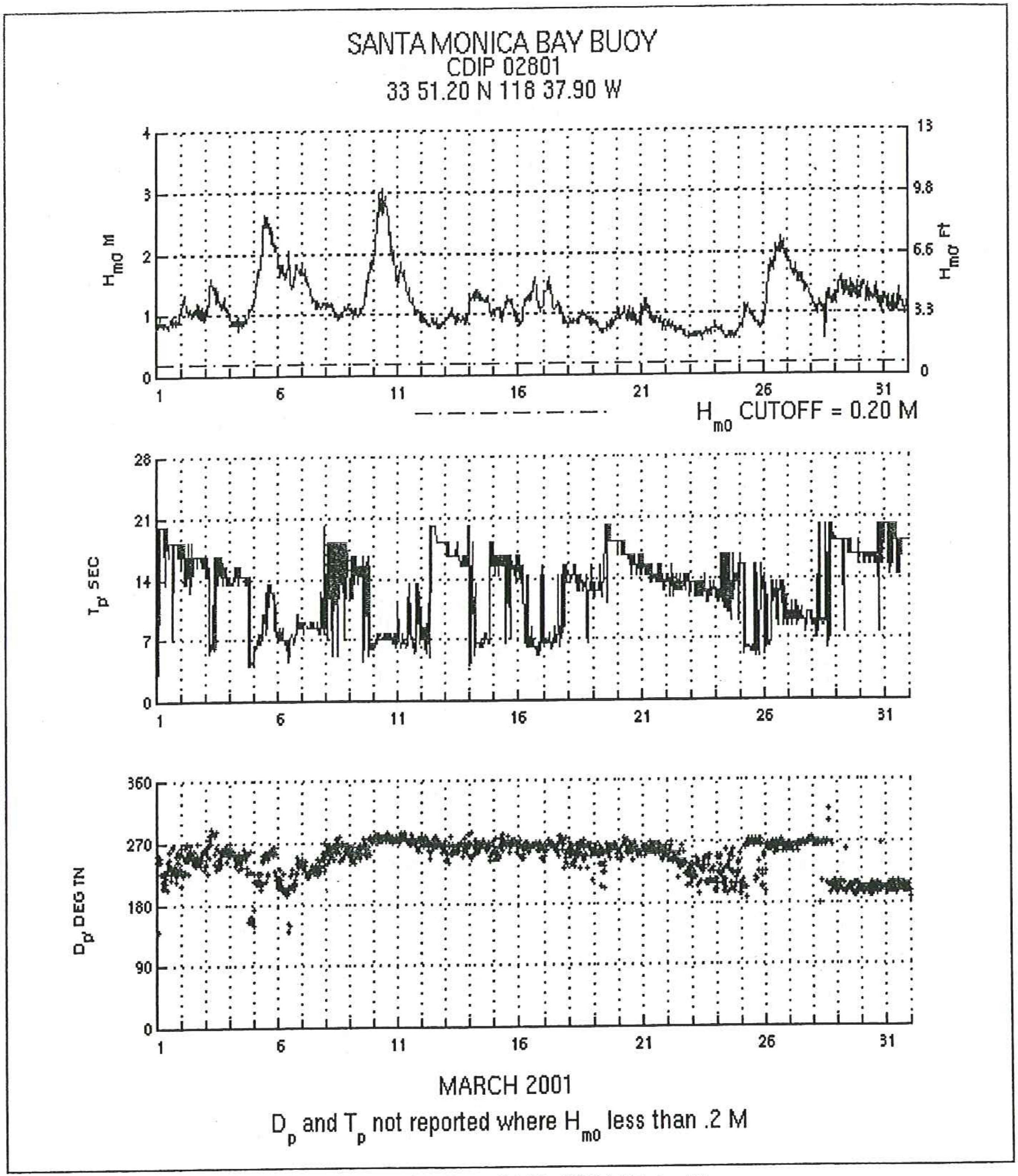

Figure 7-6. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

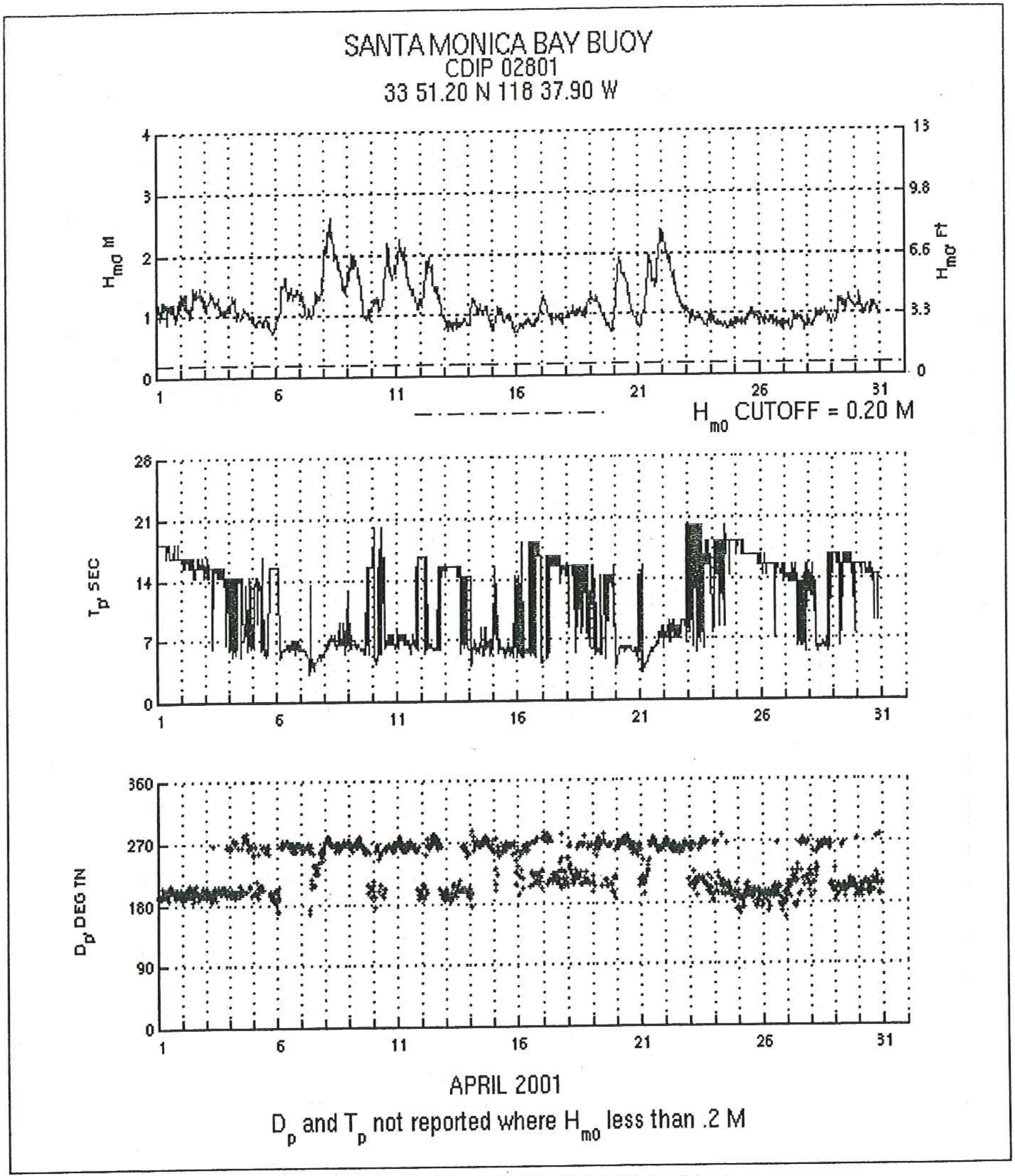

Figure 7-7. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

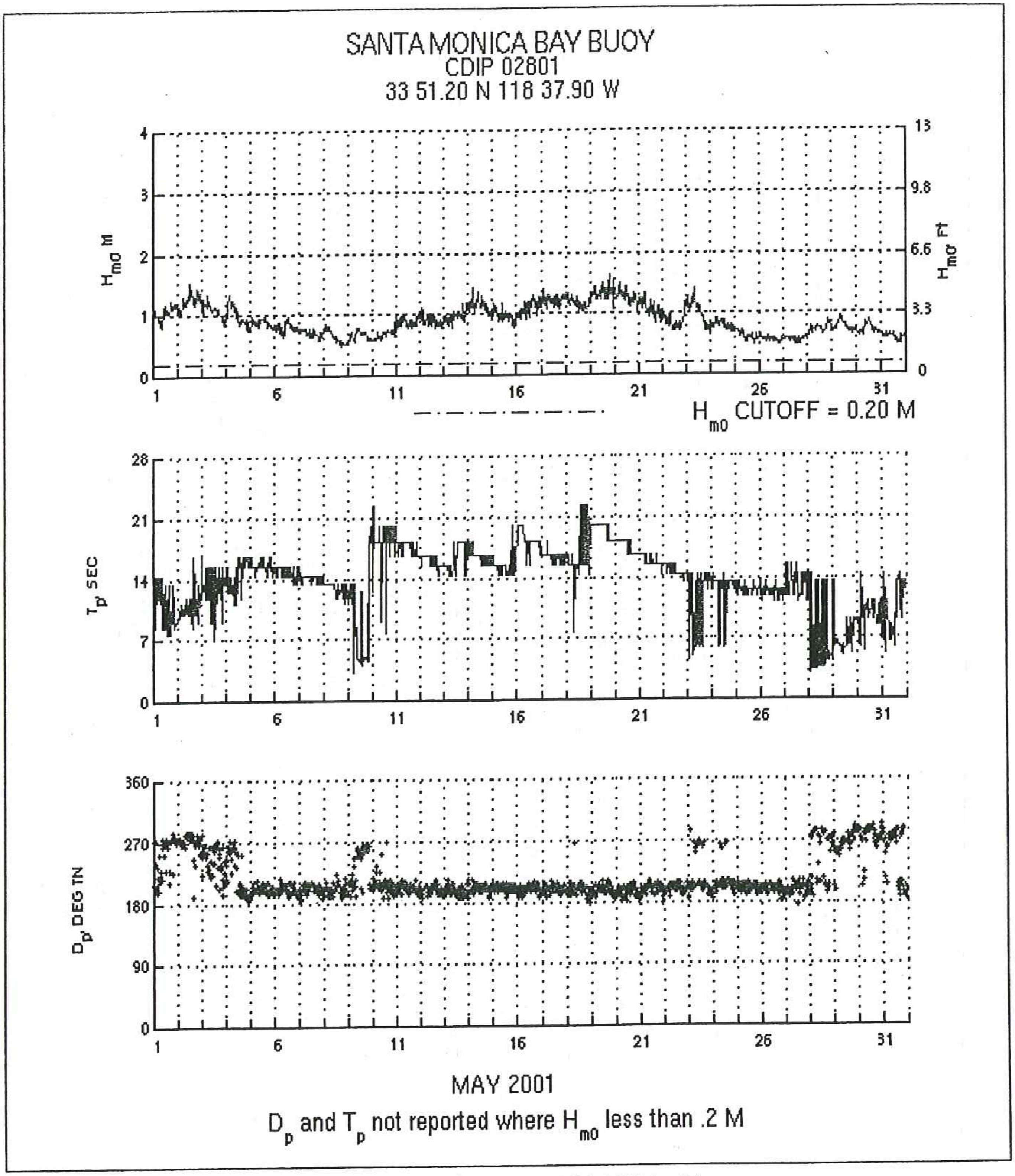

Figure 7-8. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

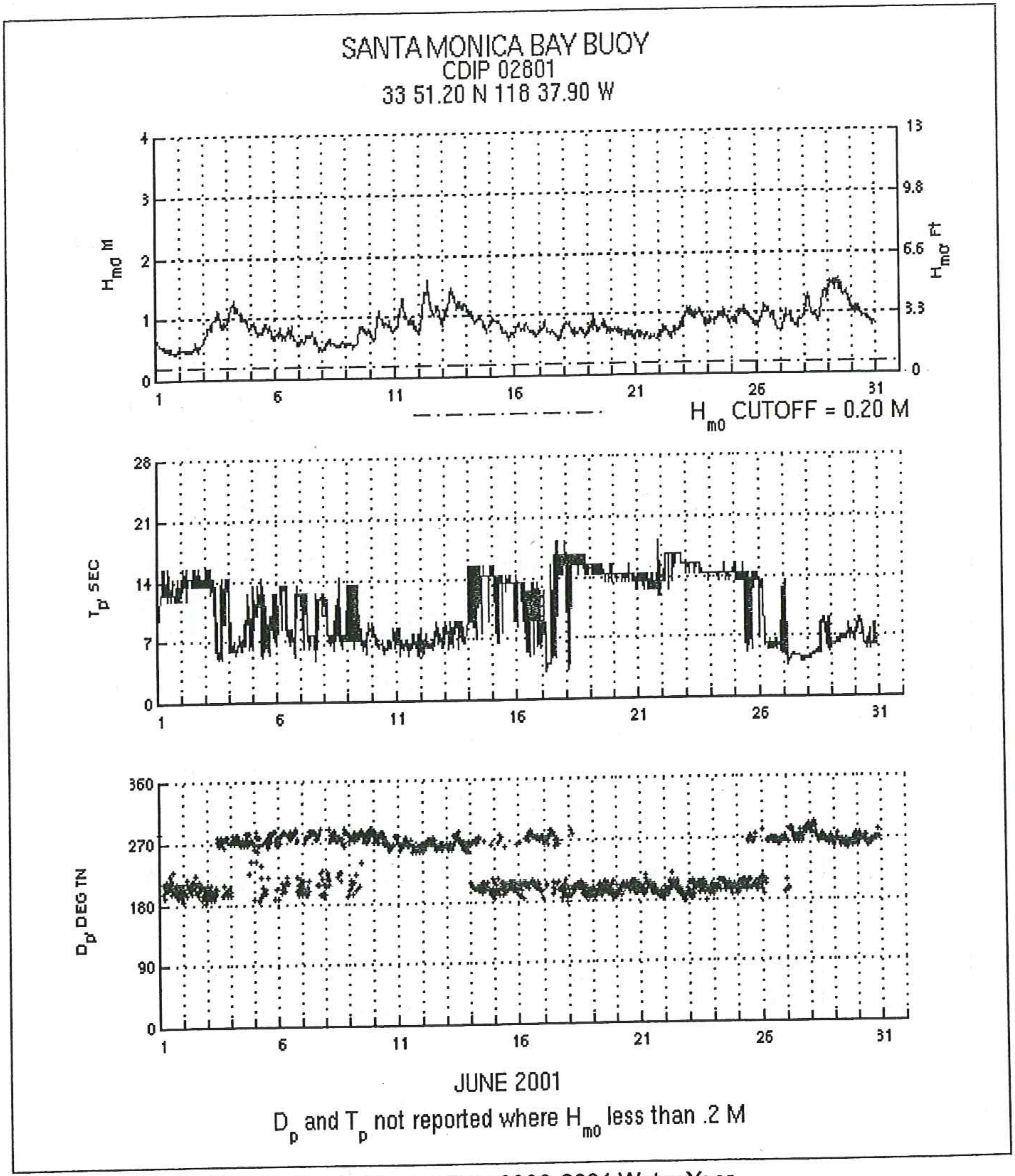

Figure 7-9. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

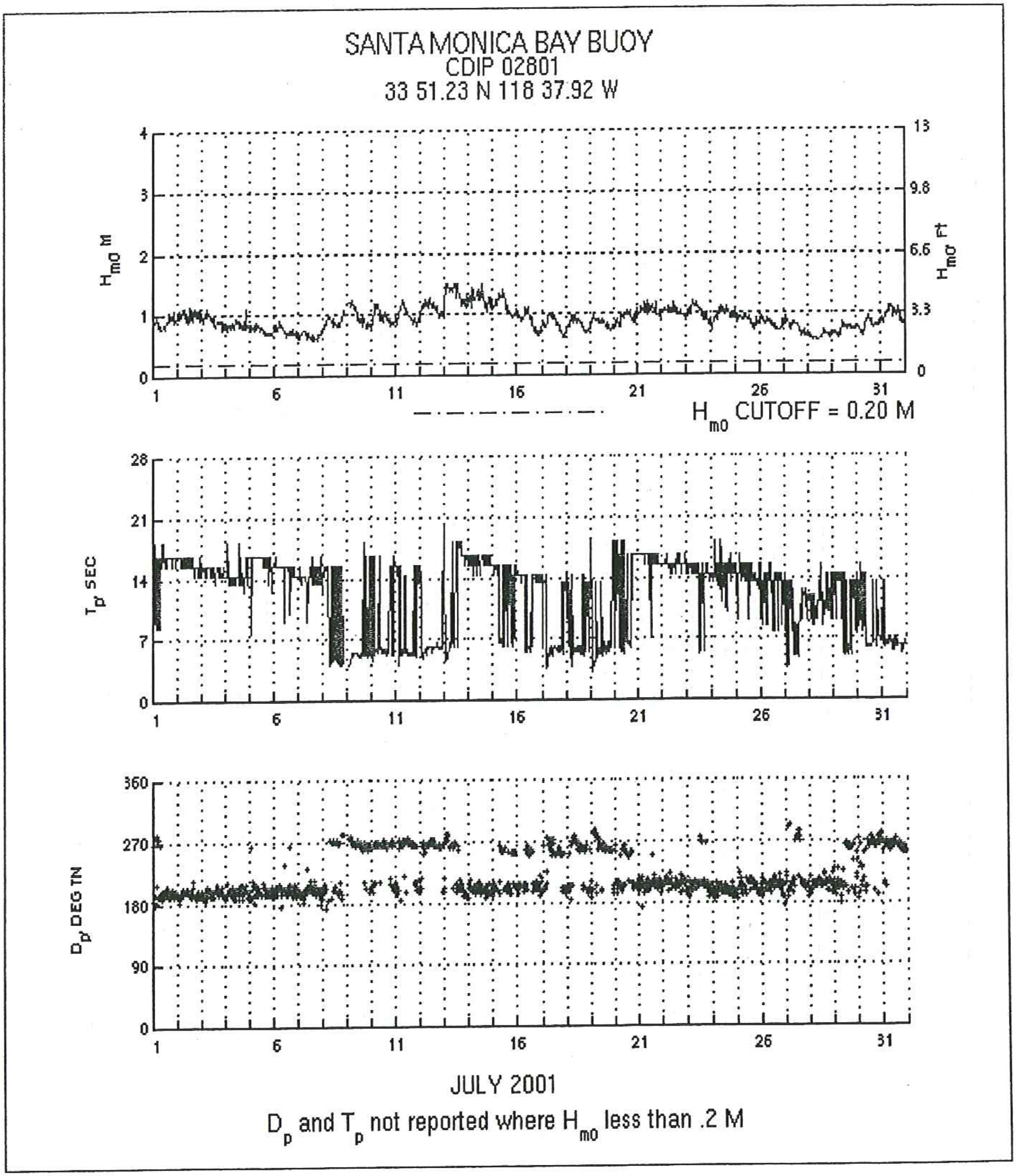

Figure 7-10. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

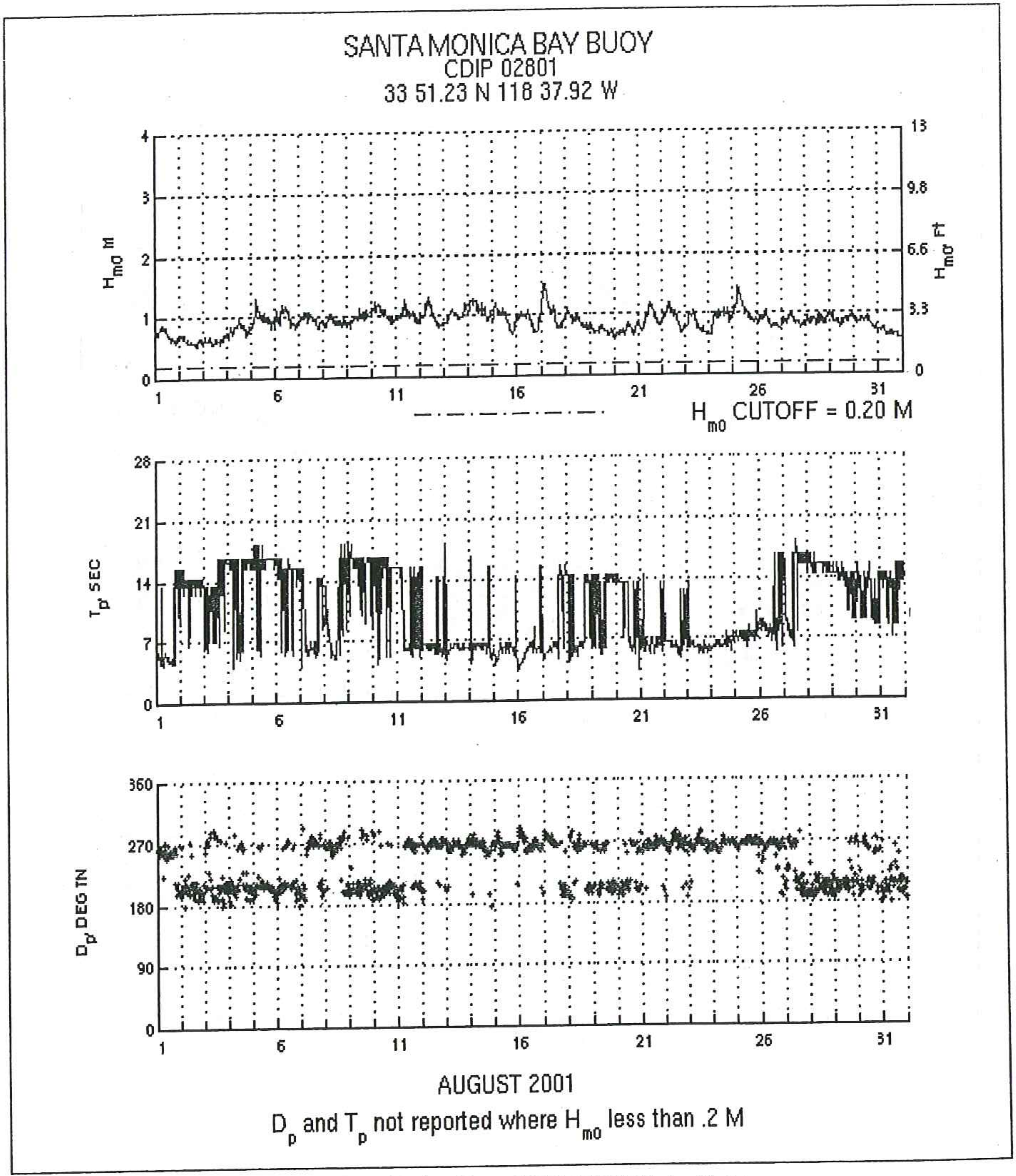

Figure 7-11. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

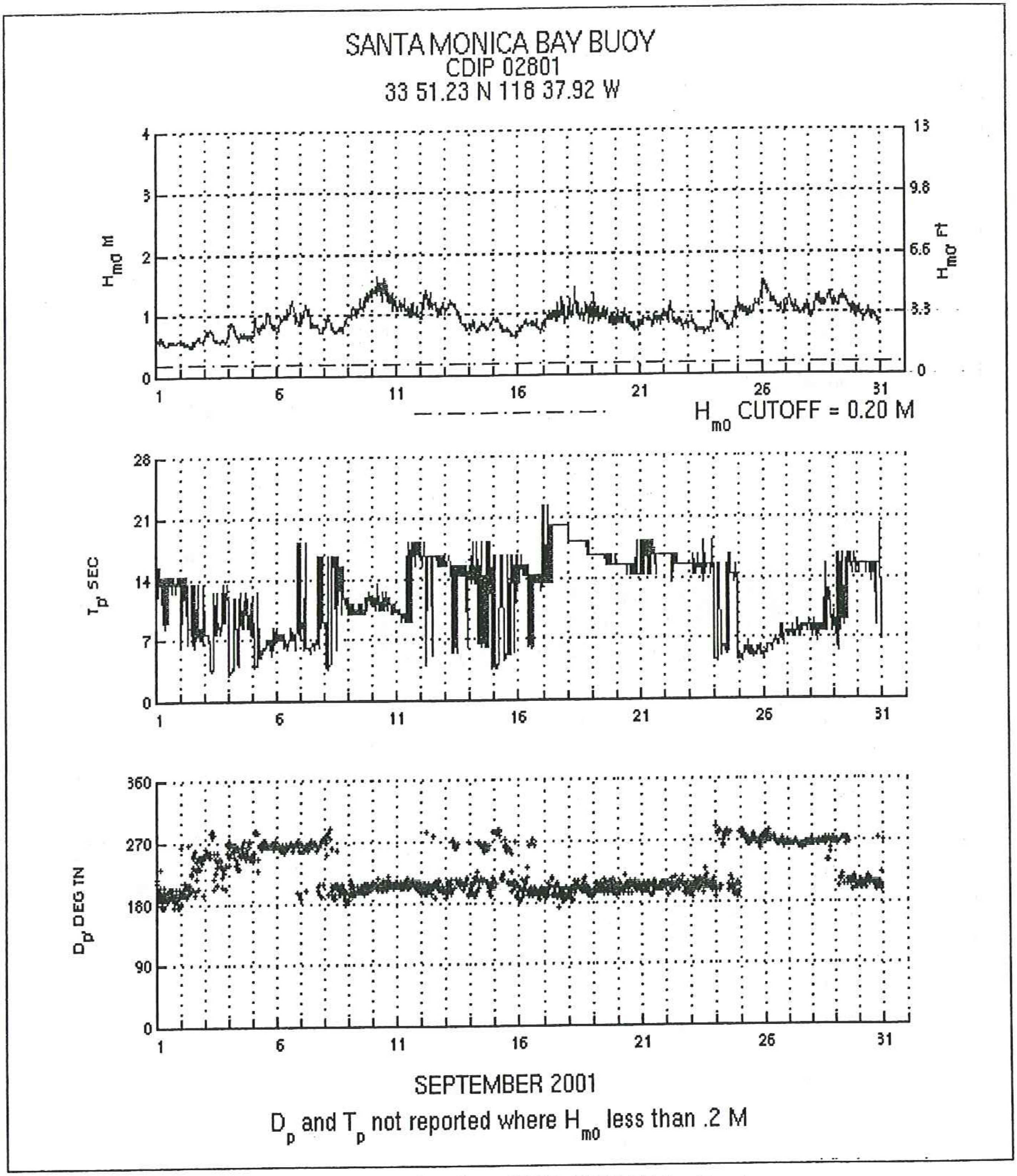

Figure 7-12. Wave Climate, Santa Monica Bay, 2000-2001 Water Year

Source: Coastal Data Information Program (2001)

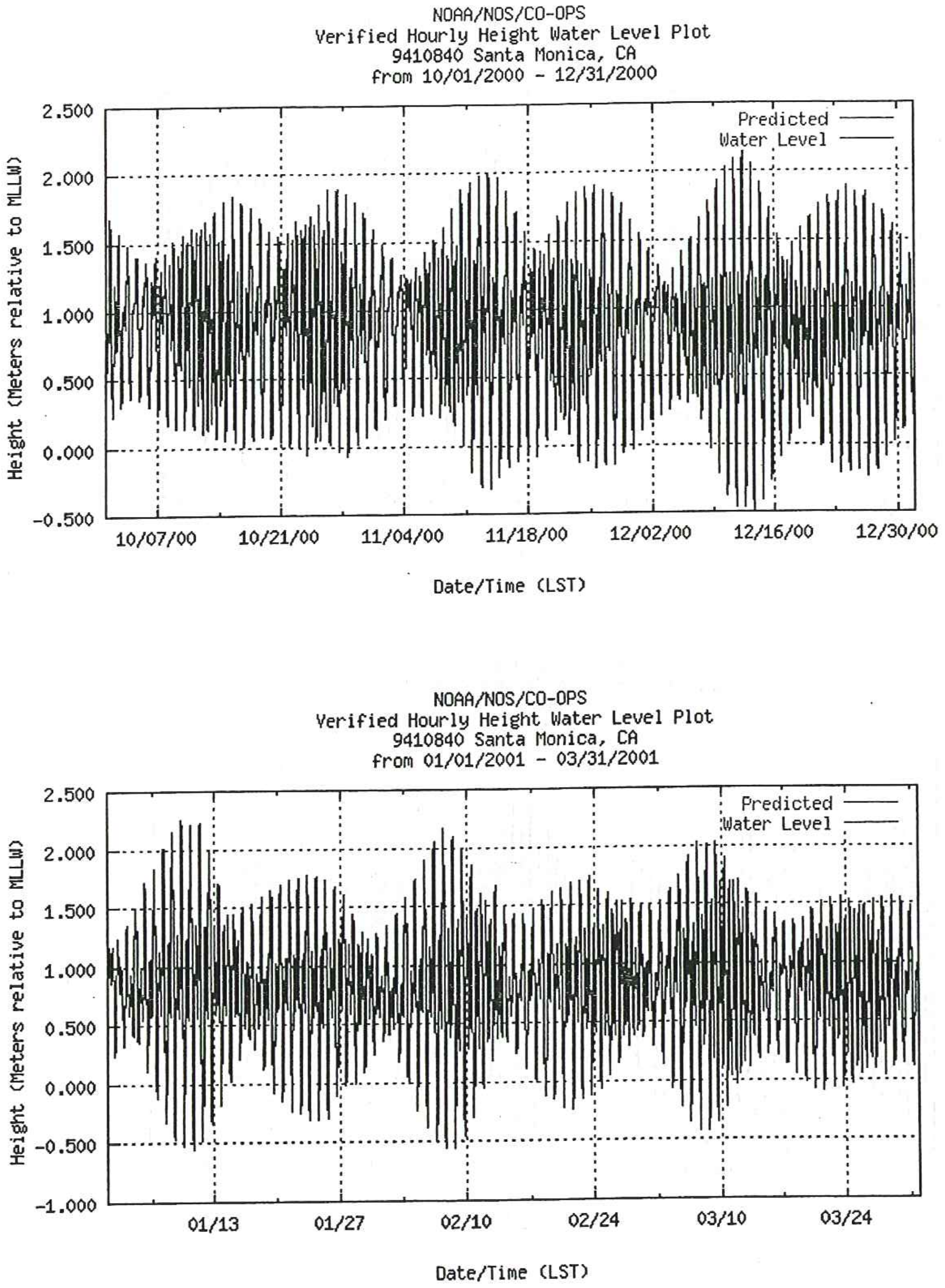

Figure 7-13. Tidal Regime, Santa Monica Bay, 2000-2001 Water Year

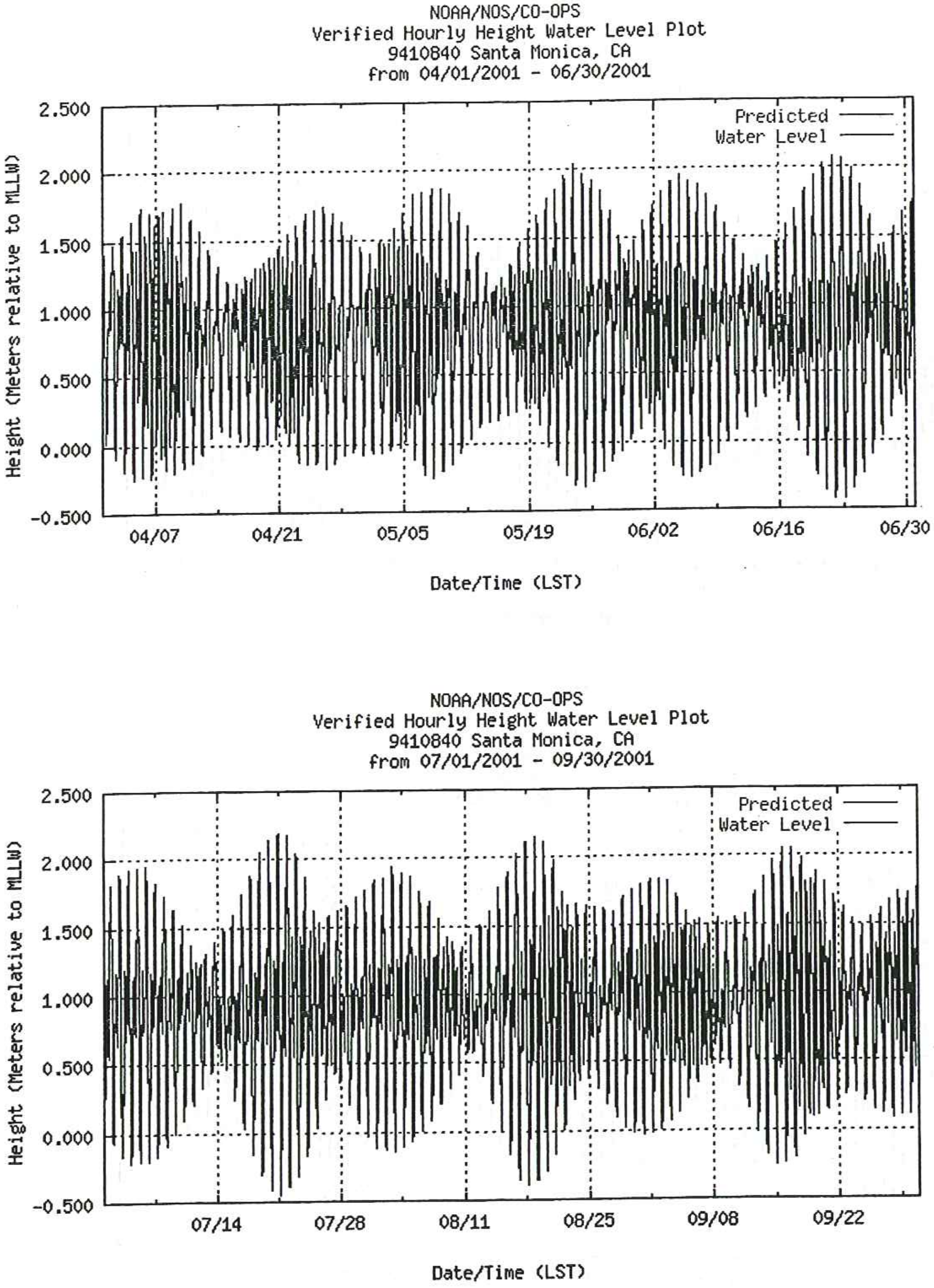

Figure 7-14. Tidal Regime, Santa Monica Bay, 2000-2001 Water Year