STATUS SUMMARY REPORT
SUBSTRATE ENHANCEMENT
SEDIMENT MANAGEMENT PLAN
LAGUNITAS CREEK

Prepared For:

MARIN MUNICIPAL WATER DISTRICT

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1.0 SUMMARY OF SEDIMENT ACCUMULATION-DEPLETION MODELING FOR LAGUNITAS CREEK, MARIN COUNTY

The Marin Municipal Water District has increased the capacity of Kent Lake from 16,000 to 32,000 acre-feet by raising Peters Dam. MMWD plans to operate the enlarged reservoir in a manner resulting in reduced spills from winter storms. Both the number of individual events and the magnitude of the peak flows will decrease. The smaller, less-frequent spills may result in less sediment transport below the dam. Without adequate planning, sediment may accumulate in the channel of Lagunitas Creek downstream from Kent Lake. Sediment accumulation is one of two primary factors identified by biologist Don Kelley as presently constraining habitat values for steelhead and silver salmon, which use Lagunitas Creek and tributary streams for spawning and rearing.

This report summarizes the results of a sediment accumulation-depletion model developed for the reach of Lagunitas Creek extending downstream from Kent Lake to the Tocaloma Bridge. This portion of the stream, designated the "State Park Reach" by Kelley and Dettman (1980), is considered by biologists familiar with the stream to have the greatest importance for spawning, incubation, and rearing. Tributary streams, such as Devils Gulch and San Geronimo Creek, also provide habitat; however, they are not directly affected by operation of Kent Lake, and hence are not specifically assessed in the model. Reaches of Lagunitas Creek downstream from Tocaloma have more limited habitat values; in addition, those values are much less affected by bed sedimentation than by other physical and biological factors. Hence, accumulation and depletion below Tocaloma are not assessed.

The model used in this analysis develops estimates of the relative inflow and outflow of sediment for each day of a representative 30-year sequence of daily streamflows. On days when sediment inflow exceeds sediment outflow, a calculated net accumulation occurs on the bed; depletion is computed when outflows exceed inflows. The model is based on sediment-transport conditions observed during a period of intensive monitoring by our staff, beginning in November 1979 and extending through the summer of 1982. The relationships between streamflow and the rate of coarse-sediment transport observed in the course of about 40 separate storms during this three-year period serve as the bases for the computations. Contributions from erosion of the banks of Lagunitas Creek and from tributary watersheds are included.

This report also relates the findings of the model to a set of streambed indices developed by the project biologists, and which may have correlated with habitat value. In general, habitat quality is known to decrease as sediment accumulates on the bed or infiltrates into the sediments used for spawning and incubation. Embeddedness of cobbles and boulders, and sediment accumulations in pools are both of particular concern to the biologists. The model does not directly predict these values; rather, they are assumed to vary with net accumulation or depletion, based on observations made during our study, and in other Pacific Coast streams.

This study considers only bedload sediment. Bedload is the coarser fraction of the sediment load moved on or near the bed, and supported by the bed. Our work has shown that the bed of Lagunitas Creek is composed almost entirely of sediment of the sizes moved as bedload. The bed of Lagunitas Creek seldom contains more than a few percent of silts and clays, sizes usually transported as suspended sediment While fine sediments may have specific and important effects on habitat values, the finer materials do not appreciably affect overall accumulation or depletion in Lagunitas Creek.

2.0 THE STREAMFLOW MODEL

Direct records of streamflow in Lagunitas Creek and in most West Marin watersheds are limited. The U. S. Geological Survey monitored daily discharge from 1954 through 1960 at a site just upstream from the present Nicasio Dam. The agency has also measured streamflow on Lagunitas Creek below Nicasio Creek since 1975 (site K10, Figure 1), and at the State Park gage (vicinity of K6, Figure 1) since March 1982. HEA and Kleinfelder staff have maintained a daily streamflow gage on lower San Geronimo Creek at Lagunitas Road (K4) since November 1979, and at site K6 from November 1979 through March 1983. All daily records have been developed with the direct support and close cooperation of MMWD. MMWD staff have also maintained daily records of spill rates from both Kent Lake and Nicasio Reservoir since their construction in 1955 and 1962, respectively.

Recognizing that bed conditions and streamflow vary substantially from year to year, MMWD chose to use a longer period of record for analysis of flows, bed conditions, and habitat values. A 30-year synthetic record of daily streamflows was developed by MMWD hydrologists, based on observed daily precipitation readings during the period 1955 through 1984. The model was initially calibrated using the extended record of daily runoff in the Napa River near Napa, and subsequently with data from the State Park gage on Lagunitas Creek. MMWD staff then estimated flows at selected points in the Lagunitas Creek system by correlation to the synthesized flows through the State Park. We then reviewed the preliminary mean daily discharges, and suggested changes in the correlation relations to minimize variance at the highest flows, which are disproportionately significant in transporting bed sediment.

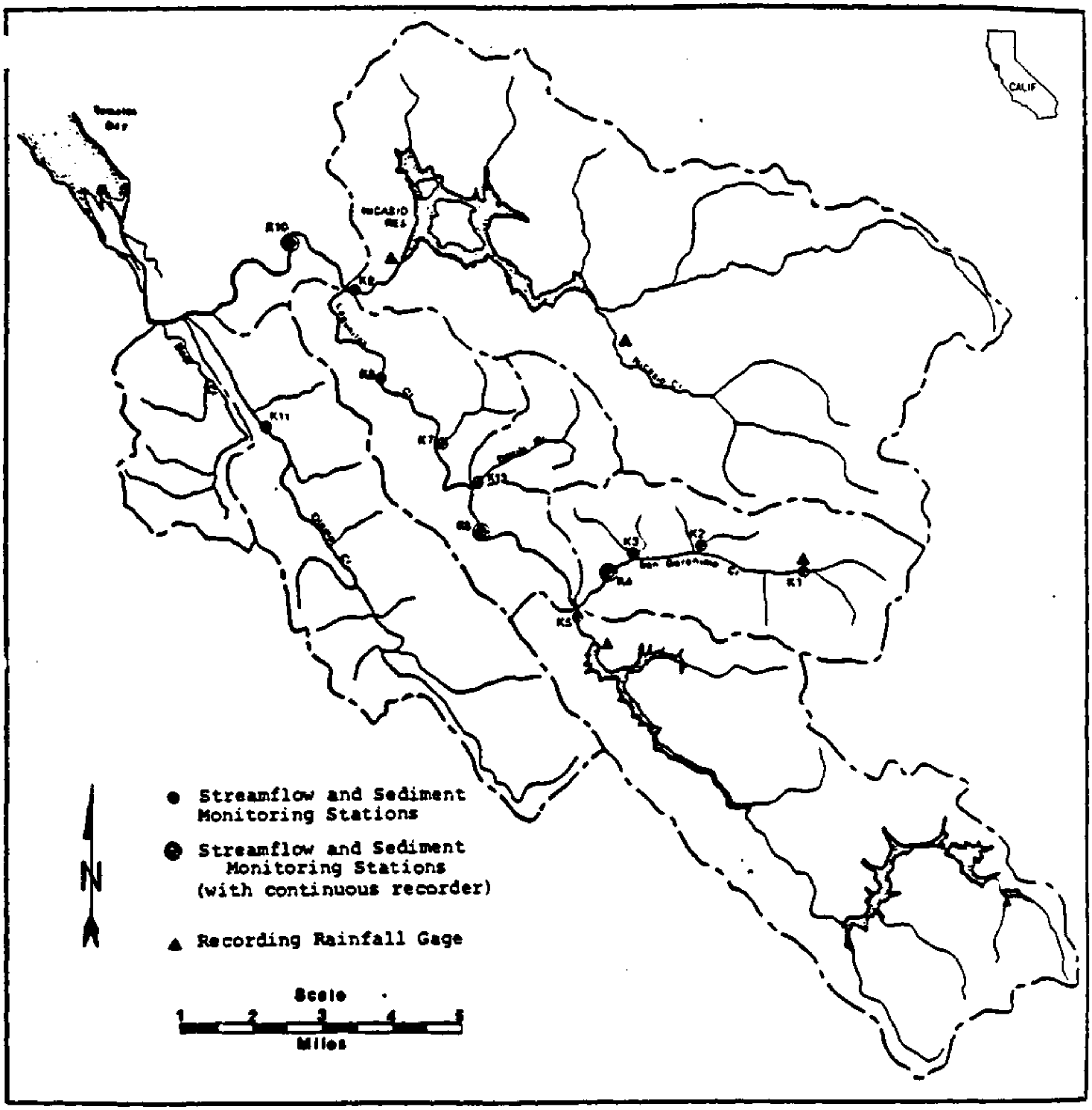

Figure 1. Location of Stream and Recording Rain Gages.

3.0 THE SEDIMENT ACCUMULATION/DEPLETION MODEL

The bed sediment accumulation/depletion model used is conceptually a numerical budget of inflows to and outflows from the State Park reach of Lagunitas Creek. Sediment enters the reach at Shafter, at the mouths of tributaries, and from bank erosion; it leaves by transport past the Tocaloma Bridge. Sediment entering and leaving the reach is computed for each day, using quantitative relations of bedload discharge to streamflow established from field measurements of sediment transport in Lagunitas Creek and its tributaries. Accumulation is computed when inflows exceed outflows; depletion occurs when outflows are larger than inflows.

3.1 GENERAL APPROACH

Accumulation or depletion of sediment in the State Park Reach was computed by comparing the amount entering the reach and the amount leaving the reach. Sediment was assumed to enter the reach from three separate sources:

1. San Geronimo Creek
2. Devils Gulch and smaller tributaries
3. Bank erosion along Lagunitas Creek

Sediment was assumed to leave the reach only by transport past Tocaloma. Results represent sediment accumulated on, or depleted from, approximately 1,300,000 square feet of bed between Shafter and Tocaloma. A uniform depth of accumulation or depletion over the entire bed was assumed for computational purposes, even though actual accumulation would not be uniform.

The change in storage (expressed in tons) was converted to net accumulation or depletion using a sediment density of 2600 lbs per cubic yard (96.3 lbs per cubic foot), a value developed by MMWD field staff from experience at Nicasio. Coarse sediment inflows and outflows were computed for each day of the thirty-year period of record. Each daily inflow and outflow of sediment was calculated based upon the simulated mean daily streamflow (computed by the MMWD model), and the most probable rate of daily bedload-sediment transport based on the observed relations for the three monitored years. Inflow from Devils Gulch and all smaller tributaries was set equal to a total of 1.01 times the sediment delivery from San Geronimo Creek, based on average observed contributions during the period of study. The contribution from erosion of the banks of Lagunitas Creek within the State Park Reach was set at a constant rate of 140 tons per year, of which 40 tons are thought to originate upstream from the State Park gage, and 100 tons downstream.

3.2 MODEL STRUCTURE AND ASSUMPTIONS

The model is functionally divided into individual programs, progressing through a series of steps to compute estimated annual sediment accumulation or depletion (figure 2). Initial model inputs of daily mean streamflow applied to empirically-derived functions, known as bedload-transport rating curves, to calculate daily mean bedload transport at each station. Within the assumptions of this study, the bedload-transport curves are generally thought to represent those prevalent during normal bed and watershed conditions. The curves upon which this routine is based are shown in Figure 3. We apply an adjustment factor (Figures 4 and 5) to the mean daily streamflow in computing bedload delivery, as using the mean daily values may result in a considerable underestimate of actual transport; the adjustment has the effect of approximating computation of sediment transport based on hourly data. The adjustment factor varies with mean daily streamflow, and is based on empirical data from approximately 100 storm days over the three-year period of intensive monitoring on Lagunitas Creek.

Once daily mean bedload sediment transport at each station is computed, a budgeting routine is applied to compute sediment accumulation and/or depletion between stations. Tributary watershed contributions are included based on observed proportions to sediment delivery from the San Geronimo Creek. The constant annual rate of bank erosion is equally divided into daily contributions. The model is capable of treating either tributary or bank contributions as adjustable parameters. The program systematically computes between-station differences in bedload transport for each day and adds the tributary and bank contributions for each subreach. Net change in storage is totaled and printed as daily, monthly, or annual summaries, expressed as tons. A conversion to mean sediment accumulation or depletion (expressed in feet) by sub-reach may also be printed.

3.3 RUNS CONDUCTED

Several computer runs have been conducted to explore various patterns of spills and releases in Lagunitas Creek (Appendix 1). Two sets of streamflow data representing hydrologic conditions of the old and enlarged dam heights at Kent Lake have been synthesized by Marin Municipal Water District staff.

Simulated streamflows at the following stations were used in the sediment modeling, for both the pre- and post-project conditions:

- K1 San Geronimo Creek at San Geronimo Water Treatment Plant
- K4 San Geronimo Creek at Lagunitas Road, near mouth
- K6 Lagunitas Creek at the State Park gaging station
- K8 Lagunitas Creek at Tocaloma Bridge

We developed synthetic streamflows for the station at Tocaloma Bridge by correlation to station K6, using 20 paired discharge measurements we performed during 1980 and 1981. The

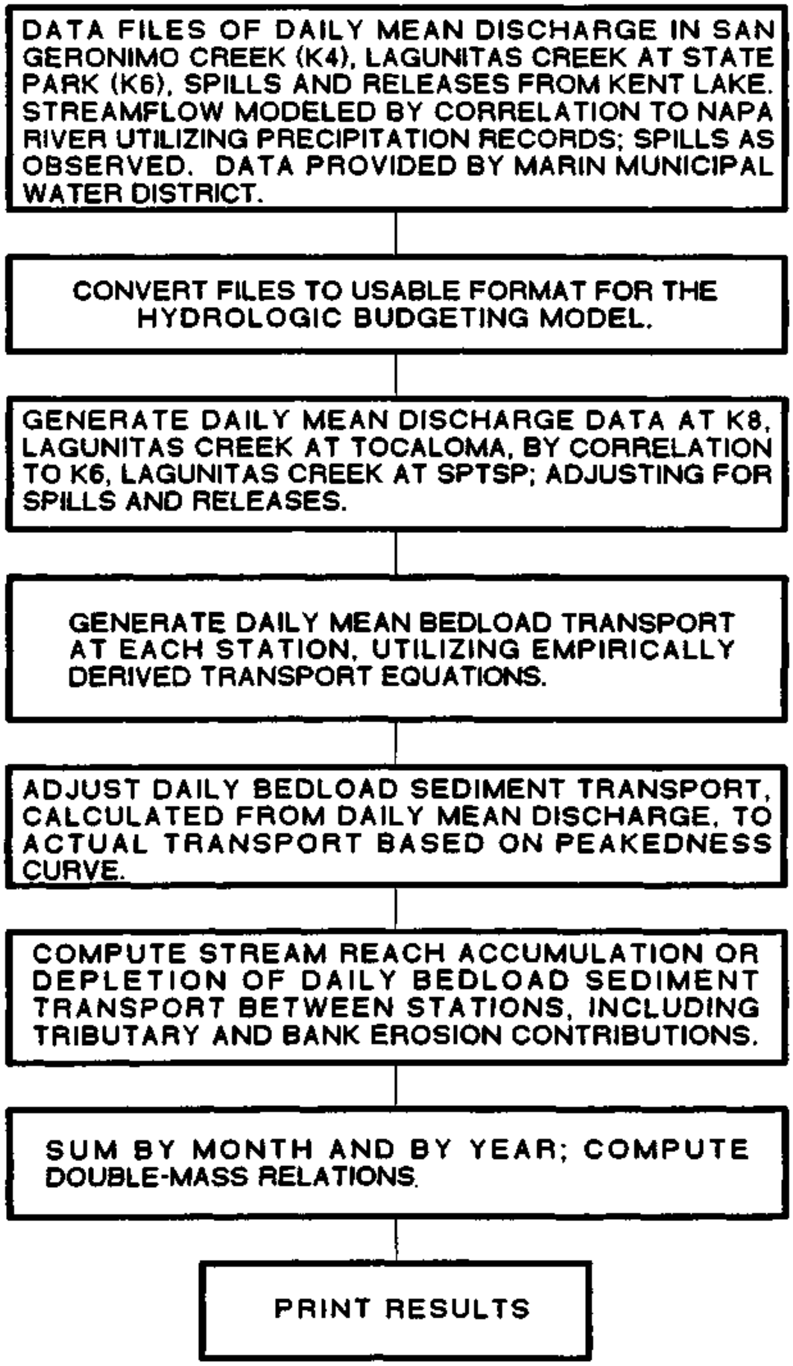

FIGURE 2. DESCRIPTIVE SCHEMATIC OF THE ACCUMULATION/DEPLETION MODEL

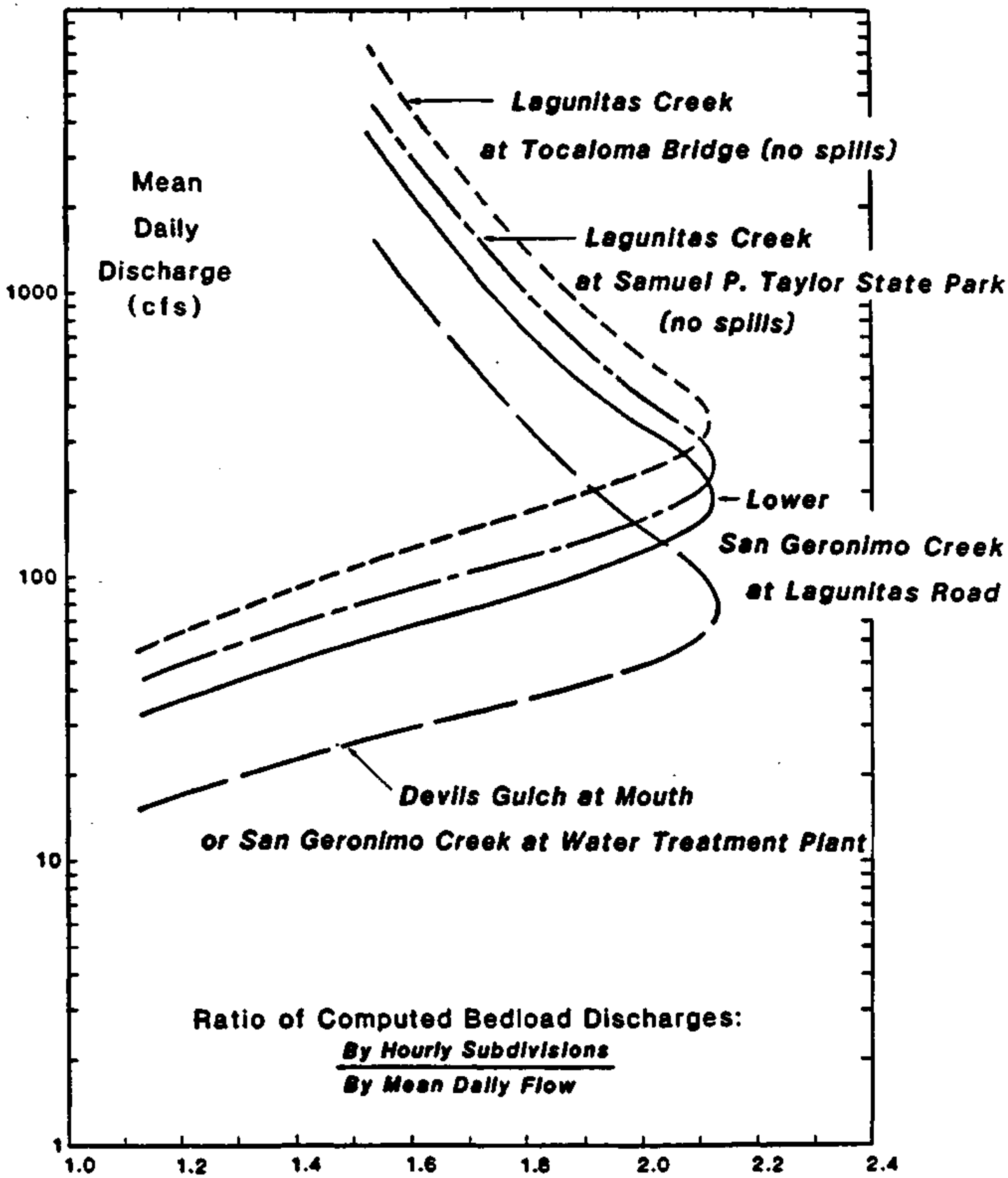

Figure 3. Ratio of Bedload Discharges Computed From Mean Hourly or Mean Daily Streamflow Data.
Computations based on hourly data, used throughout this study, are especially important for storms of intermediate size. Curves are based upon computed ratios from approximately 40 storms during the 1980-1982 seasons for which complete data sets are available.

regression equation:

$$K8 = 2.09\ K6\ 0.92$$

has a computed correlation coefficient (r2) of 0.994.

Bedload-rating curves determined from field measurements were used in the model. The relations used and the data upon which they are based are shown in Figures 4 and 5, for San Geronimo Creek (K4) and Tocaloma (K8), respectively. It should be noted that these are exponential functions, plotted on log-log paper, hence, nearly all transport occurs at the highest flows, corresponding to the 20 to 25 percent of each relation nearest the right-hand margin.

At the Tocaloma Station, K8, available data were collected exclusively during water years 1980 and 1981, generally considered representative of normal transport conditions. The relations developed from these measurements were applied uniformly throughout the modeled period. Bedload unfortunately was not collected at this station during the transient and episodic conditions following the January 1982 storm event. Upstream, at the State Park gage, (K6: figure 1) bedload-sediment transport at a given flow increased many-fold following the January 1982 event Because sediment-rating curves appropriate to normal streambed and watershed conditions were used at K8, sediment transport is assumed to be understated.

Simulations were compared with observed variations in accumulation and depletion to afford some context by which the model's validity and precision may be assessed. Results, presented in Table 1, indicate that model usably predicts net accumulation and depletion under the conditions prevailing during the period of field observations, provided that a sufficient number of stations are monitored. Higher rates of bedload transport through the State Park reach are anticipated under severely-sedimented conditions, when sediment is finer, more available, and

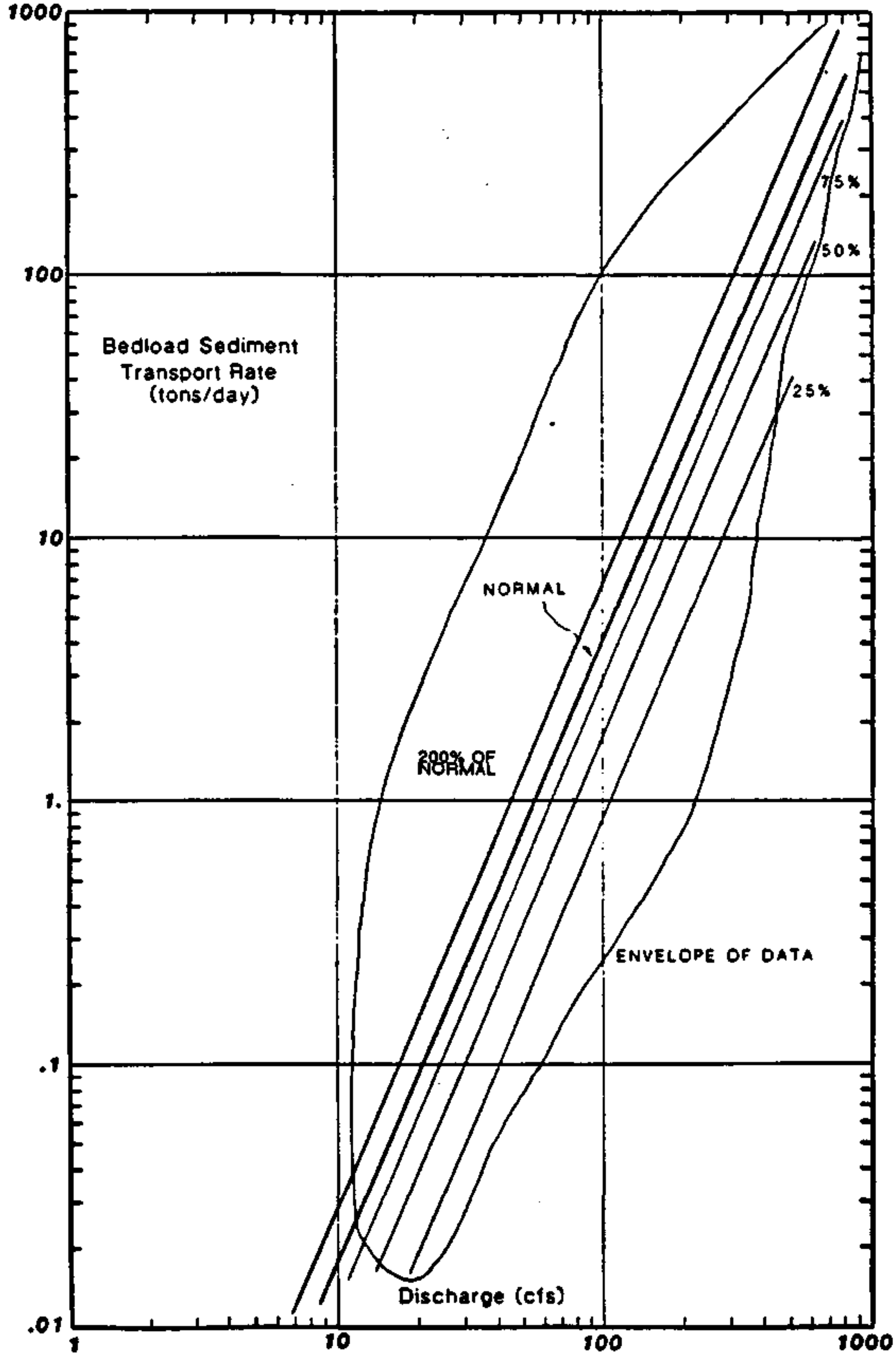

Figure 4. Bedload Sediment Transport Rating Curves for San Geronimo Creek and Lagunitas Road (K4).
Sediment transport can vary with watershed practices; the proportion of "normal" transport rates assumed in sediment control scenarios are shown. Observations made in WY1980, 1981, 1982, and 1986 serve as the bases for the data envelopes.

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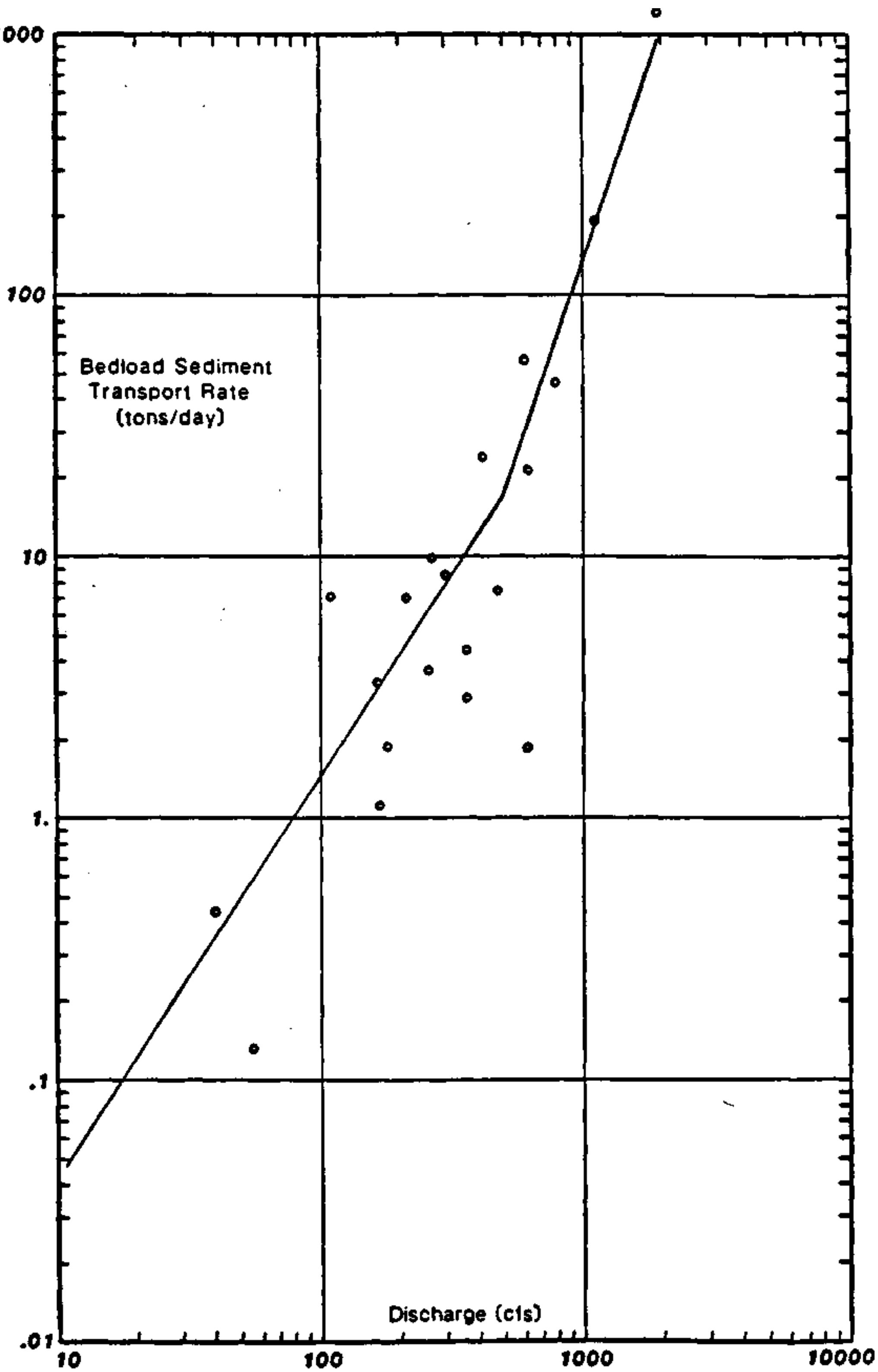


Figure 5. Bedload Sediment Transport Rating Curve for Lagunitas Creek at Tocalomas Bridge, WY1980 and WY1981 Data.
Virtually all sediment is transported at the high flow for which the steeper limb of the transport curve applies.

Table 1

Comparison of Modeled and Observed
Accumulation or Depletion of Sediment
Within the State Park Reach, Lagunitas Creek

Period Bracketed by Survey		Average Sediment Accumulation or Depletion	
Initial Survey	Final Survey	Simulated [a] (ft)	Observed [b] (ft)
Feb. 1980	July 1980 [c]	+ 0.031	- 0.083
July or Nov. 1980 [a]	Feb. 1980 [d]	+ 0.003	+ 0.0060
Feb. 1981 [d]	Summer 1981 [d]	+ 0.001	+ 0.0056
Summer 1981 [e]	Summer 1982 [d e]	+ 0.18	+ 0.24

[a] Normal bedload sediment transport at K4 and K8 is assumed.

[b] From Table 12 of Phase IIIb report.

[c] Three bed-monitoring sites.

[d] Eight bed-monitoring sites.

[e] Includes effects of January 4, 1982 storm and 16000 acre-foot flush of January 4- 19. 1982.

more mobile; the model is expected to significantly over-estimate accumulation during such periods, as no related adjustment in outflow has been incorporated.

Coarse-sediment delivery to Lagunitas Creek from San Geronimo Creek was conceptually treated as an independent variable in the model. Five bedload-transport conditions at this station were simulated — normal, 200% normal, 75% normal, 50% normal, and 25% normal ~ to best represent existing transport conditions, increased transport effects from a watershed disturbance, and the effects of watershed practices, such as bank protection or sediment retention. The effects of various rates of sediment delivery on the two subreaches of the State Park reach are shown in Table 2. Mean accumulation and depletion within the entire reach at the end of each of the 30 years of simulated record are shown in Table 3, for the five sets of bedload-delivery assumptions used in the model. A reduction of 10 to 20 percent in coarse-sediment delivery from San Geronimo Creek is expected to roughly offset the diminished flushing capacity of the proposed operating regime. Enhanced bed conditions are likely to prevail with further reductions. Monitoring of bed conditions is warranted to verify, calibrate and adjust these projections.

Table 2

Cumulative Average Accumulation/Depletion in Lagunitas Creek
For a Thirty Year Period, 1955 Through 1984
Enlarged Kent Lake Conditions

Percent of Normal [a] Sediment Delivery	State Park Reach K4 K8 (ft)	Upper Sub Reach [c] K4 K6 (ft)	Lower Sub Reach [d] K6 K8 (ft)
200% (worst case) [b]	+3.7	+6.6	+1.4
Normal 100% (normal)	+0.4	-0.5	+1.1
75%	-0.4	-1.6	+1.1
50%	-1.3	-2.6	+1.1
25%	-2.1	-3.7	+1.1

[a] Sediment outflows at Tocaloma (K8) is constant for all five modeling runs, assumed normal transport conditions; sediment transport from San Geronimo (K4) is treated as an independent variable.

[b] Increased sediment transport at K6, resulting in the distribution of more sediment downstream of the State Park gage. Other runs use normal transport curves at K6.

[c] Upper Sub Reach is from Shafter Bridge to the SP. Taylor State Park stream gage.

[d] Lower Sub Reach is from S.P. Taylor State Park stream gage to Tocaloma.

Table 3

Annual Average Accumulation or Depletion of Bed Sediment
Within the State Park Reach, Lagunitas Creek (feet)

Year	Bedload Sediment Delivery From San Geronimo Creek				
	Twice Normal	Normal	75% Normal	50% Normal	25% Normal
1955	0. feet	0. feet	0. feet	0. feet	0. feet
1956	+.4	+.1	+.1	0	-.1
1957	0	0	0	0	0
1958	-.1	-.3	-.3	-3	-.4
1959	0	0	0	0	0
1960	+.1	0	0	0	0
1961	0	0	0	0	0
1962	+.1	0	0	0	0
1963	+.2	+.1	0	0	0
1964	0	0	0	0	0
1965	+.1	0	0	0	0
1966	+.1	+.1	0	0	0
1967	+.8	+.1	0	-.2	-.4
1968	0	0	0	0	0
1969	+.1	0	0	0	0
1970	+.5	0	-.1	-.2	-.3
1971	+.1	0	0	0	0
1972	0	0	0	0	0
1973	+.6	+.1	0	-.1	-.2
1974	-.1	-.2	-.2	-.2	-.2
1975	+.1	0	0	0	0
1976	0	0	0	0	0
1977	0	0	0	0	0
1978	0	0	0	0	0
1979	0	0	0	0	0
1980	+.1	0	0	0	0
1981	0	0	0	0	0
1982	+.5	+.2	+.1	0	-.1
1983	0	-.2	-.2	-.3	-.3
1984	+.1	0	0	0	0
TOTAL	+3.7	+0.4	-0.4	-1.3	-2.1

Note: Only one significant figure presented for clarity; for quarter detail, see Appendix 4.

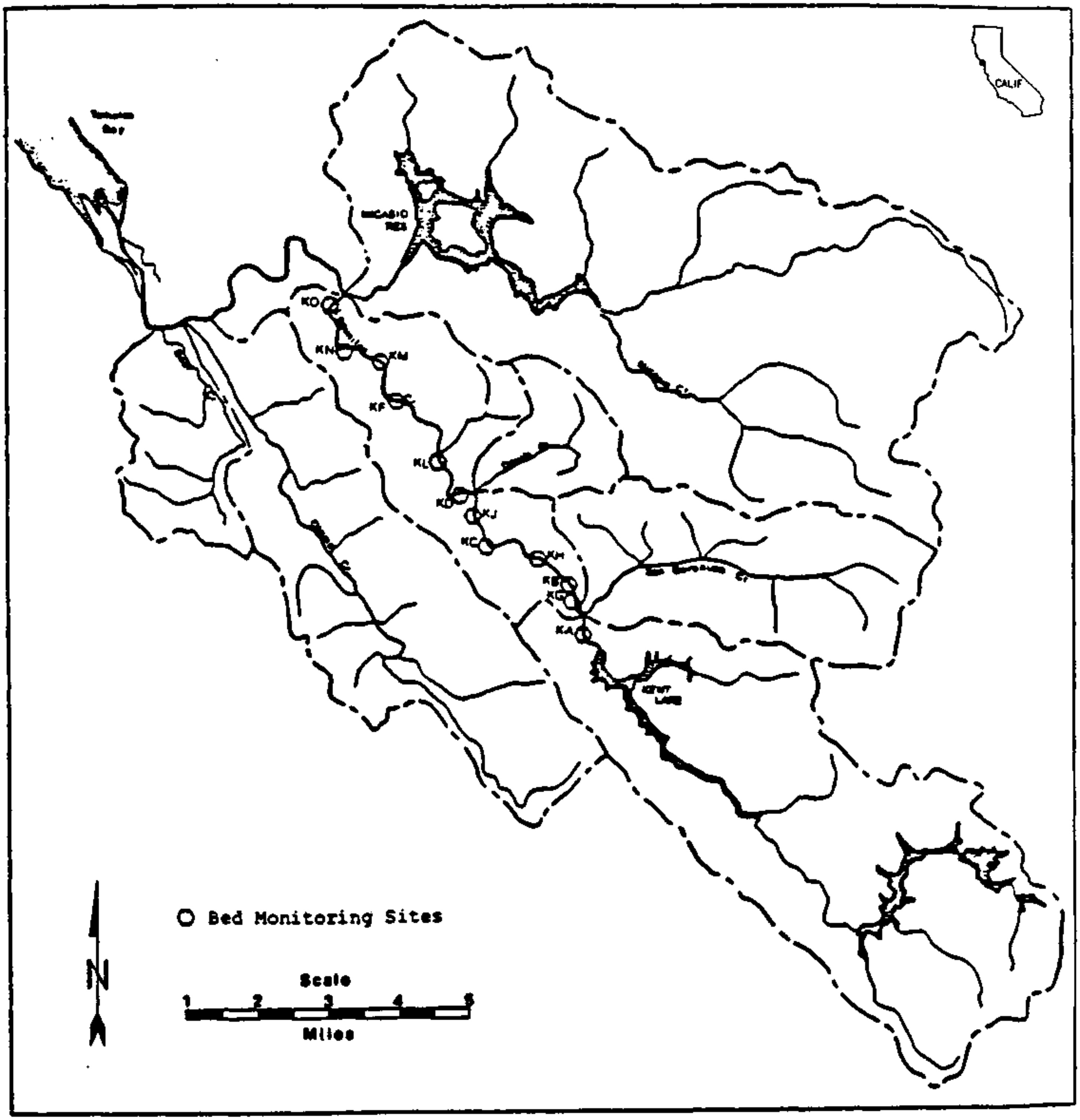
4.0 SEDIMENT ACCUMULATION AND STREAMBED STANDARDS

One of the tasks initially outlined in the agreement of October 1979 was to relate bed sedimentation to specific habitat value indices, preferably in a manner as quantitative as possible. It was recognized at that time that virtually no previous work along these lines had been conducted in coastal streams. While biologists and resource managers knew that sediment impaired habitat values, usable means of measuring bed sedimentation and relating these to habitat indices had yet to be developed, particularly for the rearing stage of the salmonid life cycle. Measures of this type were deemed needed to provide a baseline against which the effects of operating a larger Kent Lake might be assessed, and to provide criteria for evaluating the success of sediment-management measures.

We measured a total of ten major types of bed descriptors within four major categories:

1. Bed configuration
2. Composition of the streambed surface
3. Particle-size distribution of sediment stored beneath the surface
4. Embeddedness of cobbles

The descriptors and their relations to habitat values and sediment management are presented in Table 4. Each of the bed descriptors was monitored over a period of two or three years in a pool, glide, and riffle at one site within each of the 11 kilometers of Lagunitas Creek between Shafter and the confluence of Nicasio Creek (Table 4). Cross-sectional surveys of the bed were also taken immediately following the bed-condition measurements, so that net accumulation and depletion of sediment could be related to changes in other habitat indices. The manner in which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Geomorphic Studies WY1981, WY1982 and Their Relation to
Habitat Values and Sediment Management

Bed Condition or Descriptor	Relation to Habitat Values	Relation to Sediment Management
I. <u>Bed Configuration</u>		
A. Net mean scour and fill at a section	Most unequivocal basic measure of sediment accumulation and depletion.	The basic unit for measuring change in amount of sediment stored in the channel (See I.C., below).
B. Wet maximum scour and fill at a section	A minimum value for maximum scour and/or fill over a given period. Large values in sections with spawning activity suggest high risk of egg loss. May also affect lampreys and other organisms.	Not significant except as an indicator of bed instability and its possible causes.
C. Material added or removed from each riffle-pool-glide sequence	Single most important measure of which reaches are affected by sedimentation. Derived from I.A., above.	Identifies the location and amount of sediment accumulation and depletion.
D. Relative segmental relief (Relative extent of development of pools, riffles, glides)	Deeper pools are preferred by juvenile salmon. Riffles probably produce most food, they are principal habitat for young steelhead. Deeper pools and glides probably preferred by <u>Syncaris pacifica</u>.	Accumulating sediment diminishes pool depth, and the relative pool/riffle relief.
II. <u>Particle-Size Distribution of Sediment Stored Beneath the Bed Surface</u>	This is the principal material impairing rearing habitat. It may also approximate bed composition in spawning areas, and may have bearing on any egg emergence problems.	May be one of the most sensitive indicators of relative sediment accumulation and depletion.
III. <u>Composition of the Bed Surface</u>		
A. Coarse sediment size distribution	Coarse sediment provides the cover that is the basis of rearing habitat, quantified as cobble abundance. Affects many other aspects of the aquatic ecology, including food production, bottom-dweller habitat, and species diversity.	Closely related to bed mobilization thresholds. Large pebbles and small cobbles may be more densely packed. Recent research (Parker and Klingeman, 1982; Andrews, in press) suggests that the bed-surface distribution may be largely governed by sizes in storage beneath the bed, a new concept.
B. Percent of bed area covered by sand and silt	Fine material typically covers less than 15 percent of the bed surface in Lagunitas Creek, except locally. Larger percentages may seriously alter the aquatic ecology of the stream.	An index of the amount of sand and finer material on the bed surface.
C. Bedrock percentage of bed area	Unknown. Intuitively, a small percentage of bedrock may indicate a relatively "clean" pool or riffle. In some cases (e.g. site KG) the percentage of bedrock is so large that it probably constrains habitat value.	Limits and describes the extent of scour.
D. Coarse organic elements	Root mats snags, limbs, sawgrass clumps, and similar features provide rearing for salmonids and many other species.	Minimal, as measured for this study. Root mats and snags can strongly alter bed and channel form in coastal streams, especially when these are badly sedimented. In this study, we quantify the relative habitat provided by coarse organic material, and not its stability value.
IV. <u>Embeddedness</u>	Kelley and Dettman have shown a strong inverse relation between embeddedness and the populations of juvenile steelhead. Other species may be similarly affected.	One of the fundamental goals of this study is reducing mean bed embeddedness.

Table 5. Streambed Standards for Salmonids Proposed by Don Kelley.

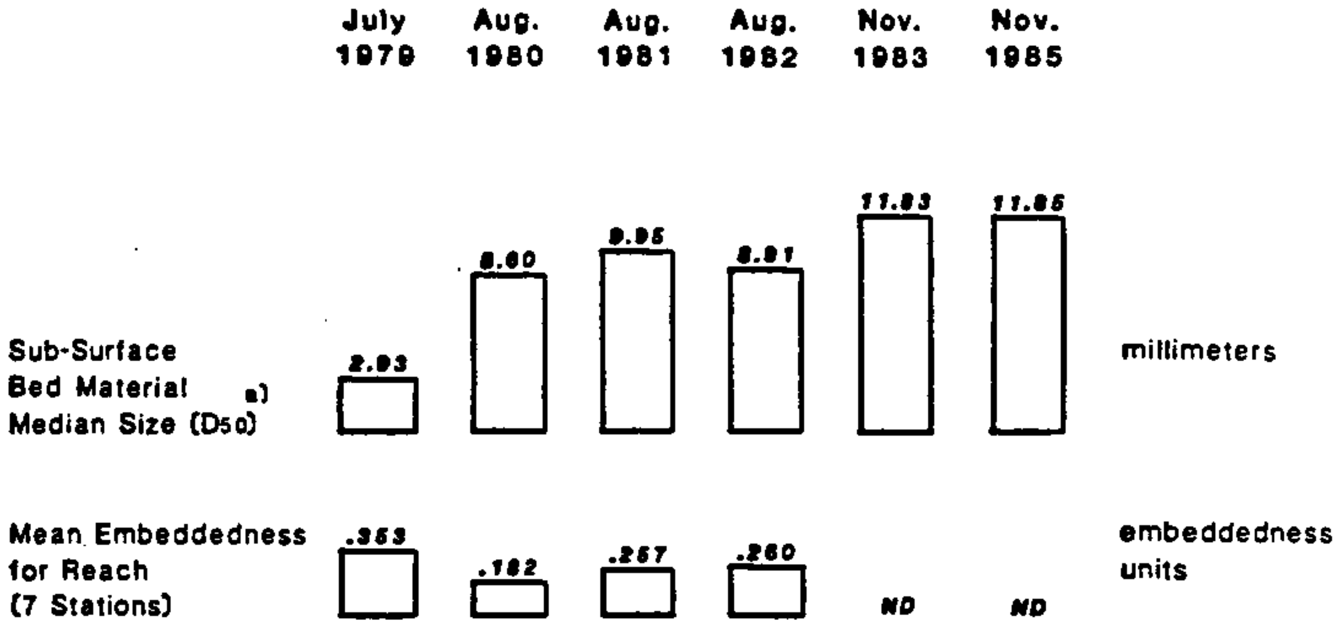
Average Percent Embeddedness of Cobble (>45 mm)[1]			Average Percentage of Streambed Area Covered by Cobble (>45 mm)		Area of Spawning Habitat in Glides (% of amount measured in 1984-1985)	Average Percent of Redd Material that is Sand and Fine Sediment <3 mm at end of incubation
Habitat Type	Maximum Allowable	1981 Level	Minimum Allowable (1981 level)	Goal	Minimum Allowable	Maximum Allowable
RIFFLE	25	22	50[2]	80		
POOL	30	27	232	40		
GLIDE	30	28	192	40	80	10
Flows at which measures should be made.	4-8 cfs		4-8 cfs		10-16 cfs	January - March when flows are low enough to obtain samples.

[1] Percent embeddedness is the percent of the cobble's height that is embedded in sand.

[2] Data from Hecht (1983) collected during 1981 to serve as baseline streambed conditions in Lagunitas Creek.

Variation In Mean Observed Streambed Conditions, Lagunitas Creek, 1980-1982 Upper State Park (KH) to Cheda Ranch (KL)

	Fall 1980	Feb. 1981	Summer 1981	Summer 1982
Riffles				
Mean accumulation or depletion (ft.)	-	+0.019	+0.010	+0.232
Mean embeddedness (percent)	27.4	31.1	22.3	28.9
Cobbles abundance (percent of bed area)	54.4	49.1	48.4	48.4
Percent of bed area covered by fines	6	7	5	3
Pools				
Mean accumulation or depletion (ft.)	-	nil	-0.001	+0.206
Mean embeddedness (percent)	28.8	34.2	28.1	23.7
Cobble abundance (percent of bed area)	33.3	26.9	23.1	40.2
Percent of bed area covered by fines	16.0	14.7	11.3	8.2
Glides				
Mean accumulation or depletion (ft.)	-	+0.033	+0.011	+0.107
Mean embeddedness (percent)	34.0	33.3	26.7	32.1
Cobble abundance (percent of bed area)	24.0	22.3	19.4	27.6
Percent of bed area covered by fines	9.5	8.9	6.0	6.6



a) Median size of bed matierial of site 15.80, about 0.4 miles downstream from Shafter Bridge, near Kelley's Upper State Park Station

Figure 7. Inverse Relation of Embeddedness with Sub-Surface Bed Material
Samples of sub-surface bed material are collected to depths of 6 to 10 inches, after removing the bed-surface or "armored" layer. Data shows the small range of bed-condition variations during the 1980-1982 monitoring period relative to those prevailing before and after. We believe that habitat values improve with increasing size of sub-surface bed material, and with decreasing embeddedness.

Table 7.

Summary of Bedload Sediment Discharge
Two Sites on San Geronimo Creek
WY 1980 through WY 1982 [a]

Station No.	K1	K4
Stream	San Geronimo Cr.	San Geronimo Cr.
Station	Water Treatment Plant	Lagunitas Road
Drainage Area	3.3 sq. mi.	8.7 sq. mi.
Bedload-Sediment Discharge [b]		
WY1980	1750-200 tons [c]	4830 tons
WY1981	173 tons	264 tons
WY1982a [d]	3910 tons	6125 tons
WY1982b (Jan 4, 1982 storm) [e]	2260 tons	19800 tons
WY1982c	5830 tons	2960 tons
Subtotal, "Normal" Watershed Conditions (WY1980, WY1981, WY1982a)	6000 tons	11000 tons

[a] Values from Tables 8, 9, 18, Phase IIIb report.

[b] Annual values given as computed using methods described in earlier reports; actual precision is lower than implied by computations. The subtotal values are rounded, better reflecting monitoring precision.

[c] Estimated value, after detailed adjustment for two separate major bank collapses immediately upstream of station; see Phase IIIb, Table 8, footnote d.

[d] Through January 3,1988; by Jan. 3, seasonal runoff was more than twice mean annual runoff.

[e] January 4-6,1988. Estimates for the water treatment plant developed from intensive data collection during most of storm, as we were not able to reach other stations due to closed roads. The estimate of 19,800 tons at site K4 is a most-probable value between possible high and low estimates of 56,000 and 5800 tons, respectively. See Phase IIIb report, Table 9 and associated text for details.

a. Release of 16,000 acre feet from Kent Lake immediately following the January 4,1982 storm event, to conform with dam-safety requirements; this release constituted 15 consecutive days of flows gradually diminishing from 650 to 400 cfs.

b. Spills during mid-April 1982, which continued at flows capable of transporting sediment for 7 to 10 days following the end of sediment delivery from the tributaries.

We found that significant aggradation occurred during the January 1982 storm and flood. The bed, however, was smoothed by the tremendous amounts of water released following the storm, and perhaps re-groomed by the end-of-season flows.

As a result, only poorly-defined relations between the bed descriptors used as streambed standards and the actual sediment accumulation and depletion may be developed from the Lagunitas Creek data (Appendix 5, Tables A, B, C). The observations provide an invaluable quantification of baseline conditions, characterize the response of the bed to varying flows, and establish the downstream changes in bed conditions from Shafter to Tocaloma. They do not, at present, extend over a sufficiently broad range of bed conditions to provide a quantitative basis for projecting the future status of individual streambed-standard indices.

We believe at this time that the sediment-management program for Lagunitas Creek should be based on an operational criterion of non-accumulation. If the stream is managed to prevent accumulation, the streambed standards are most likely to be sustained. Other physical factors noted to be biologically important, such as relative pool depth (Kelley and Dettman 1979; Bjornn and others, 1977) or backwaters and near-bank areas with little flow velocity and suitable cover and water depth (Eng, 1981; Li, 1983), are also likely to be preserved. In this respect, observations in Lagunitas Creek are consistent with those in the literature relating accumulation and depletion to embeddedness, cobble abundance, and percent of bed covered by fine material (e.g., Bjornn and others, 1977; Hecht, 1981; Lisle, 1982; Parker and Klingeman, 1982; Nolan and others, 1983; Hecht and Woyshner, 1984).

If managing Lagunitas Creek to prevent sustained sediment accumulation is taken to be the operating criterion for sustaining the streambed standards, the simulations indicate that a reduction of 10 to 20 percent in coarse sediment contributions from San Geronimo Creek would be needed (Table 3). As the model projects for accumulation or depletion a mean value for the entire State Park reach, a somewhat larger reduction might be sought if protection of certain specific subreaches is deemed particularly critical to habitat maintenance. We believe, based on preliminary field results to be reported elsewhere, that reduced coarse-sediment delivery of this magnitude may be achieved by sediment retention and removal or by increased bank protection along San Geronimo Creek and certain of its tributaries, combined with limited sediment retention.

Potential retention basin sites at the San Geronimo Water Treatment Plant and near Shafter Bridge can be hypothetically considered as representative of upstream and downstream sites. Coarse-sediment delivery by San Geronimo Creek at these two locations can be represented by the 1980 through 1982 monitoring results from the stations at the Water Treatment Plant bridge (Kl) and the Lagunitas Road Bridge (K4), shown in Table 7. While the proportion of San Geronimo Valley's bedload discharge originating upstream of the Water Treatment Plant may be expected to vary from year to year, the three years of record suggest that 50 to 60 percent of the coarse sediment load originates above the Water Treatment Plant during years of normal watershed conditions. Detailed inventory of sediment contributions from eroding bank segments of the main stem and larger tributaries conducted in October 1987 indicate that approximately 40 percent of the coarse sediment entering the channels from eroding banks is contributed upstream of the Water Treatment Plant. For planning purposes, the two independent sets of data indicate that approximately 50 percent of the total coarse-sediment load originates from the upper portion of the watershed, and would be under normal watershed conditions amenable for control by retention or by a combined bank-protection and sediment-removal program sited at or upstream from the Water Treatment Plant. In the appended tables, values computed using 50 percent of the total coarse-sediment load for the valley may be taken to apply to a possible program of this type. Plans for a site at or near Shafter may be based on the monitoring results for the lower San Geronimo Creek station in Lagunitas (K4). Intensive site-specific studies are warranted prior to developing operating plans for a basin at either site.

5.0 SUMMARY AND SEDIMENT-MANAGEMENT PLAN OVERVIEW

1. Streambed sedimentation management is critical to overall management of flows in Lagunitas Creek because bed conditions appear to affect habitat productivity as much as flows. Release of more water will be needed to support or enhance habitat if the bed is highly sedimented; conversely, less water may be released if suitable bed conditions are maintained.

2. A bed-sedimentation model was developed which simulates the net accumulation or depletion of sediment on the bed of the critical habitat reach. The model is based on the net change in sediment storage; it compares sediment delivery from San Geronimo Creek, other tributaries, and bank erosion along subreaches of Lagunitas Creek with outflow past Tocaloma. The model was applied to each day of a continuous 11000-day (30-year) record of streamflows for Lagunitas Creek computed by MMWD staff.

3. The model was used:

   a. To compare mean accumulation and depletion of sediment on the bed of the State Park reach under flow patterns prevailing before and after the enlargement of Kent Lake.

   b. To assess the potential effects of various land-use practices and conservation programs in San Geronimo Valley on bed conditions in Lagunitas Creek below the confluence of San Geronimo Creek.

4. We found that the computed sediment accumulation/depletion over the 30-year period was -2.1 feet if the dam were operated as prior to its raising, and 0.4 feet if operated as

proposed by MMWD. The assumptions of the simulation perhaps overstate the extent of accumulation, in that they do not incorporate the greater rate of bedload transport which occurs under severely-sedimented conditions. The simulations do, however, serve as a common basis for comparing expected pre- and post-project conditions, provided that this overstatement is recognized.

5. A reduction of about 10 to 20 percent in the coarse-sediment delivery from San Geronimo Creek would likely offset the diminished flushing capacity of the proposed operating regime; further reductions are likely to enhance bed habitat values under most watershed conditions.

6. Either sediment retention basins or a combined bank-stabilization and sediment-retention program may be used to achieve a reduction of 20 percent, or more, in coarse-sediment delivery.

7. The model closely reconstructed the observed net accumulation and depletion observed at eight bed-monitoring sites over three separate storm periods during 1981 and 1982.

8. We were not able to establish a usable empirical relation between accumulation or depletion of bed sediment and the specific streambed standards recommended by biologist Don Kelley and his colleagues, perhaps because too narrow a range of bed conditions prevailed during the three years of field study. Experience in other coastal streams and elsewhere in the range of salmon and steelhead establishes that habitat deteriorates as sediment is allowed to accumulate on the bed. Accordingly, we recommend a criterion of no net accumulation of sediment in the State Park Reach as being a useful index under which the streambed standards recommended by the biologists are likely to be achieved. We believe that the simulated record of accumulation and

depletion provides a useful means of assessing long-term trends and shorter-term fluctuation in these streambed standards.

9. The criteria of no net accumulation of sediment is also expected to meet habitat needs identified for Syncaris pacifica, an endangered freshwater shrimp populating Lagunitas Creek.

10. Erosion-control, sediment-retention and bed-sedimentologic monitoring plans will be needed to implement the recommended management program. Related work is under way.

6.0 REFERENCES CITED

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J. H. Milligan, R.A. Klamt, C. Chacho, C. Schaye, Transport of Granitic Sediment in Streams and Its Effects On Insects and Fish. College of Forestry, Wildlife and Range Sciences, University of Idaho, Bulletin Number 17. 43 p. September 1977.

Bratovich, P.M. and D. W. Kelley, Instream Row Recommendation For Coho Salmon and Steelhead Trout In Lagunitas Creek, Marin County, California: D. W. Kelley & Associates. Report to the Marin Municipal Water District, 216 p. 1986.

Bratovich, P.M., D.H. Dettmen, and D.W. Kelley, Investigations of Salmon and Steelhead In Lagunitas Creek, Marin County, California, Volume II: Recommendations for Managing Instream Flows and Streambed Characteristics: D.W. Kelley & Associates, Report to the Marin Municipal Water District, 88 p. May 1988.

Chatham, S. Interim Report San Geronimo Creek Streambank, Erosion Control, Marin County, California. Prunuske/Chatham, Report to the Marin Municipal Water District Var. pg. December 1987.

Eng, L.L., Distribution, Life History, and Status of the California Freshwater Shrimp, <u>Syncaris pacifica</u> (Holmes): California Department Fish and Game, Inland Fisheries Branch. Special Publication 81-1. 27 p. February 1981.

Hecht, B., Sequential Changes in Physical Conditions Affecting Aquatic Habitat in the Upper Cannel River, California, Following the Marble-Cone Fire of August, 1977: Proceedings of the California Riparian symposium, September 1981, pp.124-133.

Hecht, B., Substrate Enhancement/Sediment Management Study, Lagunitas Creek, Marin County - Phase ma: Sediment Transport and Bed Conditions, 1980 -1981. H. Esmaili & Associates, Inc. Report prepared for Marin Municipal Water District. 92 p. November, 1981.

Hecht, B., Substrate Enhancement/Sediment Management Study, Lagunitas Creek, Marin County - Phase IIIb: Sediment Transport and Bed Conditions, 1979 -1982. Report to the Marin Municipal Water District. 172 p. April 1983.

Hecht, B. Efficacy of Bank Protection Proposals for Selected Locations in the San Geronimo Valley. Memo to Dana Roxon and Don Kelley. 5 p. March 29,1988.

Hecht, B. and R. Enkeboll, Substrate Enhancement/Sediment Management Study, Lagunitas Creek, Marin County — Phase I: Sediment Control Alternatives, H. Esmaili & Associates, Inc., Report to the Marin Municipal Water District, 44 p. October 1979.

Hecht, B., R. Enkeboll, and G. Muehleck, Substrate Enhancement/Sediment Management Study for Lagunitas Creek, Marin County — Phase II: Sediment Transport and Substrate Conditions, 1979 - 1980. H. Esmaili & Associates, Inc. Report to the Marin Municipal Water District, 91 p. September 1980.

Hecht, B. and M.R. Woyshner, Restoration of Normal Bed Conditions following the Storm of January 4,1982 In Corralitos and Browns Creeks, Santa Cruz County, California: Paper Presented at the 18th Annual Geomorphology "Binghampton" Symposium, Oxford, OH, 1987. In Press.

Kelley, D. W., Proposed Investigations on Lagunitas Creek Relevant to the Enlargement of Kent Reservoir Memorandum to Marin Municipal Water District, 10 p. October 8,1982.

Kelley, D.W. and D.H. Dettman, Relationships Between Streamflow, Rearing Habitat, Substrate Conditions and Juvenile Steelhead Populations in Lagunitas Creek, Marin County, 1979. D. W. Kelley, Aquatic Biologist Report to the Marin Municipal Water District, 23 p. February 1980.

Li, S.K., Survey of the California Freshwater Shrimp, Syncaris pacifica. In Lagunitas Creek, Marin County, California: D.W. Kelley & Associates report to the Marin Municipal Water District, 15 p. August 1981.

Lisle, T. E., Effects of Aggradation and Degradation On Riffle-Pool Morphology In Natural Gravel Channels, Northwestern California: Water Resources Research, v. 18, no. 6, pp. 1643 -1651. December 1982.

Nolan, K.M., D.C. Marron, and L.M. Collins, Stream-Channel Response to the January 3-5, 1982, Storm In the Santa Cruz Mountains, West Central California: U.S. Geological Survey Open-File Report, October 1983 draft, 54 p.

Parker, G. and P.C. Klingeman, On Why Gravel Stream Beds Arc Paved: Water Resources Research, v. 18, no. 5, pp. 1409-1423. October 1982.

Ritter, J.R. and W. M. Brown, EL, Turbidity and Suspended Sediment Transport in the Russian River Basin, California: U.S. Geological Survey Open-File Report, October 1,1971,100 p.

Wolman, M.G., A Method For Sampling Coarse River-Bed Material. Trans. Am. Geophys. Union v. 35, no. 6. pp. 951-956. 1954.

Appendices

1. Description of computer modeling runs to date.

2. Relations of bedload-sediment transport to streamflow used in accumulation/depletion modeling.

3. Annual and cumulative discharge of water and bedload, by station.

4. Annual accumulation/depletion of bedload sediment in State Park Reach, Lagunitas Creek

5. Relation of bed descriptors to observed sediment accumulation and depletion, Lagunitas Creek

   5a. Glides
   5b. Pools
   5c. Riffles