Lagunitas Creek Sediment and Riparian Management Plan, Marin County, California:

Streambed Monitoring Report, 1995-2007

Report prepared for:

Marin Municipal Water District

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1. INTRODUCTION

1.1 Background

In 1995, the State Water Resources Control Board issued Order WR 95-17, calling for a Sediment Management Plan and a Riparian Management Plan as a component of the Marin Municipal Water District (MMWD) exercising its water rights within the Lagunitas Creek watershed. Order 95-17 states that:

> "*[MMWD] shall prepare a Sediment Management Plan that describes measures that should be taken to reduce sediment and to provide an appreciable improvement in the fishery habitat within the Lagunitas Creek watershed.*"

The Sediment and Riparian Management Plan (prepared by Prunuske Chatham and others, 1997, for MMWD) identified two goals to shape management of the stream:

- Reduce sedimentation and, further, provide an appreciable improvement in the fishery habitat within the Lagunitas Creek watershed, and

- Improve the riparian vegetation and woody debris within the Lagunitas Creek watershed in order to improve habitat for fishery resources.

An appreciable improvement is interpreted to be one that can be noticed, measured, or estimated (Gregory Andrew, pers. comm.). Long-term trends toward improvement can be established by collecting and evaluating data. Whether or not appreciable improvement has occurred can be assessed by comparing recent data to those collected in previous years, and interpreting the results in light of watershed events (such as floods or landslides) or conditions (such as the collapse of the gallery of mature alders, described below) affecting the channel corridor.

The goals and structure of the plan were based in large part on findings of aquatic biologists that sedimentation of the bed is perhaps the primary constraint affecting salmon and steelhead habitat in Lagunitas Creek, as well as limiting both winter and summer habitat for the

California freshwater shrimp (*Syncaris pacifica*), an endangered species also living in the stream.[1] Geomorphic studies by Balance Hydrologics staff during 1979 through 1982 documented bed conditions, the sources and sizes of sediment, and evaluated how and when the sediment is transported in the channel. The geomorphic field investigations found that the San Geronimo Valley is the primary source of the habitat-impairing sediment between Peters Dam (which impounds Kent Lake) and Tocaloma Bridge, principally fine gravels and coarse or medium sands, usually transported as bedload. Subsequent modeling results (Hecht and Woyshner, 1988) concluded that reducing the bedload-sediment delivery to Lagunitas Creek by 10 to 20 percent (estimated at the time to be a reduction of about 400 to 800 tons per year) would maintain bed conditions similar to those found during the early 1980s. Further reductions in sediment entering the channel system, in combination with establishing riparian vegetation and adding large woody debris, would lead to further improvements in fishery habitat within the watershed (c.f., Ettlinger and others, 2000)[2].

Through 2004, the Sediment Management Plan was being implemented in part through the Marin County Resource Conservation District (MCRCD) as part of the joint MMWD/MCRCD San Geronimo Bedload Reduction Program[3], a multi-year plan for erosion control, sediment reduction, maintenance and annual monitoring. The sediment-monitoring element of the sediment management plan commenced in 1995 and ended in 2004. Work was being conducted by Prunuske Chatham, Inc. ("PCI") and Balance Hydrologics, Inc. ("Balance") under contract to the MCRCD. An interim analysis of data through 2000 (and, for most parameters, 2001) was developed in 2001 and finalized in 2002 (Hecht and Glasner, 2002). O'Connor Environmental conducted an investigation of fine sediment during 2004 and 2005 under contract to MMWD (O'Connor and Rosser, 2006).

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[1] See State Water Resources Control Board (SWRCB) Order WR95-17; also Kelley and Dettman (1980), Eng, (1981), Li (1981), Bratovich and Kelley (1988), Dettman and Kelley, (1988), Serpa (1992,1995), among others, in addition to the MMWD staff and consultants who developed the 1997 plan.

[2] This 2000 assessment also included addition of spawning gravels to streams, a measure which never implemented and probably not presently meriting consideration.

[3]The sediment reduction program includes removal of sediment from six retention locations annually and repair of actively eroding sites. Many of these sites are in the tributaries draining the Flanders, Dickson and Spirit Rock holdings, which drain to the mainstem of San Geronimo Creek upstream of Railroad Avenue and San Geronimo Water Treatment Plant, When filled, the six sites have a sediment-removal capacity of about 1025 tons per-year; additional bedload reduction is achieved by source-site repair and channel maintenance. If successfully implemented, the Program will help reduce bed sedimentation in Lagunitas Creek, and is expected to improve substrate conditions for salmon and steelhead.

This report summarizes the findings of a 13-year monitoring effort beginning in 1995. MMWD resumed bed-conditions monitoring in 2006[4], reflecting ongoing obligations in sustaining improvements in bed conditions. This report also considers data collected during 2006 and 2007, with occasional mention of 2008 conditions. It also includes (a) observations associated with the major storm event of Dec. 31, 2005, (b) measurements of scour undertaken during water year 2002 (WY2002) to WY2006, (c) discussion of channel adjustment and response to several major sediment-delivery episodes at the Big Bend site in lower Samuel P. Taylor State Park (SPTSP) during the late 1990s, and (d) analysis of rock-type counts identifying origins of fine gravels – a dominant habitat-impairing size class of sediment found throughout Lagunitas Creek.

1.2 Annual Monitoring for the Sediment Management Plan

The Plan includes a substantial annual monitoring program, including:

- streambed monitoring,
- stream flow monitoring,
- monitoring of performance of individual sediment-control projects,
- habitat typing, and
- evaluating riparian revegetation and woody-debris projects.

Streambed monitoring is one of the largest of these monitoring elements. The purpose of the monitoring program is to describe processes and events affecting bed conditions in the monitored reach, and to measure the effectiveness of the Sediment Reduction Program. The design of the streambed monitoring program is based largely on methods, sites, and findings from a series of field studies conducted between 1979 and 1982[5], supplemented by a reconnaissance of the entire monitored reach and several other measures. The program is presented in greater detail in Sec. 1.3, and the full text describing the bed-monitoring program is

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[4] Bedload-sediment transport measurements at the lower San Geronimo Creek were continued, and suspended-sediment transport measurements were added during 2005.

[5] Hecht and Enkeboll, 1980; Hecht, Enkeboll and Muehleck, 1981; Hecht, 1983a; 1983b; 1992; Hecht and Woyshner, 1988. This work was peer-reviewed by the John Muir Institute (1982) under contract to the State Water Resources Control Board. The review found the overall monitoring program and its individual elements to be wholly acceptable, with minor additional narrative description of methods. The SWRCB incorporated this monitoring program as a condition of D95-17___

included as Appendix A to this report. Data collection under the revised monitoring program has been conducted in 1995 through 2004 and then resumed in 2006, after trial or test runs in 1991[6] and 1993[7].

MMWD has encouraged broadening the monitoring of sedimentologic conditions beyond the established program as questions and opportunities to explore central issues arose. In 2000, we were asked to evaluate the V* ("V-star") technique[8] of describing bed geometries and fine-grained sedimentation at the request of the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB). Under the minimal-sedimentation conditions then prevalent (see below) with very little sand in the pools, V* was difficult to apply, since with little sand in the pools, a distinction between fine sediment and the fine-gravel bed could not be made sedimentologically or recognized physically[9]. Balance staff have monitored bedload transport in San Geronimo Creek near its mouth whenever possible as an adjunct to gaging streamflow sponsored by MMWD. O'Connor Environmental (O'Connor and Rosser, 2006) used V* and related methods under the very different conditions prevailing in 2004 (see below) to also assess bed conditions. MMWD biologists completed a habitat typing survey report (Ettlinger and others, 2008) which compiled and compared habitat typing data collected between 1992 and 2006.

MMWD formed the Lagunitas Creek Technical Advisory Committee (TAC) to advise MMWD's Board of Directors on implementing the Lagunitas Creek Sediment and Riparian Management Plan. The TAC expressed an interest in developing measurable success criteria, above and beyond the overall goals described above. The TAC formed a Sediment Subcommittee to recommend success criteria that can be incorporated in existing monitoring programs. It is anticipated this analysis will assist the TAC in developing success criteria. It is not within this

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[6] The bed was monitored at four sites in 1991 at the request of MMWD in large part to assess whether the conditions and monitoring program in 1980-1982 were still useful in preparing technical analyses for the forthcoming Lagunitas Creek water rights hearings

[7] The bed was monitored in 1993 to prepare the program for the water-rights hearings and proposed 10-year monitoring, by establishing a new baseline for bed conditions, replacing and surveying monuments to NGVD, and to assess effects of the first major storms in 1993 following the drought of 1987 – 1992.

[8] See Hilton and Lisle,(1993); Lisle and Hilton, (1992; 1999)

[9] Documented in a 2000 letter report to MMWD; see Lisle and Hilton, 1999, discussion of this frequently-encountered condition and how it limits use of V* in monomodal gravel-bedded channels.

scope of this assessment to develop success criteria or to evaluate if the habitat enhancement work being performed under the Lagunitas or San Geronimo Plans is meeting success criteria.

1.3 Purposes

This report is an analysis of streambed monitoring data that has been collected in the Lagunitas Creek watershed, mainly between Shafter and Tocaloma Bridges, and also including hydrologic, sediment-transport and lithologic data from the San Geronimo Valley. The primary purposes of the analyses are to:

(a). identify trends in streambed conditions relevant to anadromous salmonids and *Syncaris pacifica*, with due consideration of anomalous events, and

(b). explore whether there has been a reduction in streambed sedimentation and an appreciable improvement in the fishery habitat within the portion of Lagunitas Creek identified in the monitoring plan.

This report focuses on the streambed monitoring conducted from 1995 through 2007. We found it essential to include data from earlier periods, because:

- Bed conditions were substantially sandier during 1979 and 1980, transitioning to the fine-gravel dominated bed prevalent at present during the early 1980s,
- Rainfall and streamflow during 1995 through 1999 were significantly above average,
- A series of events, conditions, and changes in management practices that occurred during the study period, and especially its second half, described below, make it very difficult to identify a baseline of 'normal' or 'typical' conditions against which trends can be assessed.

Additionally, we recognize that the downstream portion of the channel has become heavily sedimented throughout the period of study by two major channel changes (1995, 1997) and large debris flows (1996, 1997, 2006) at Big Bend, plus related influxes of coarse sediment caused by the related die-off of alders triggered by the Big Bend events (see Hecht and Glasner, Figure 12), plus ongoing incision of the cutoff meander at Big Bend (see Appendix C). In most cases, we have separately considered the results for the Big Bend site plus affected locations downstream from the four sites upstream of Big Bend. The four upstream sites include all of

Lagunitas Creek upstream from Devils Gulch10, a geomorphic unit used in Marin County's forthcoming species conservation planning for the San Geronimo Valley (Stillwater Sciences, 2007); we hope this distinction can also aid in that assessment.

The report also considers the results of stream gaging sponsored by MMWD on San Geronimo Creek at Lagunitas Road in community of Lagunitas. The stream gaging effort is not an integral element of Sediment and Riparian Management Program, but is a vital adjunct to it. MMWD has supported the gaging continuously since October 1979. Over the same period, bedload and suspended-sediment monitoring has been conducted intermittently. Information provided by the sediment-monitoring program is also partly integrated into this document, and has been reported in a number recent papers and presentations (Hecht and Owens, 2006; Hecht and others, 2008).

1.4 Overview of the Bed Monitoring Program

Streambed conditions are surveyed annually, at seven or eight (beginning in 2002) established monitoring sites on Lagunitas Creek, from Shafter Bridge to Tocaloma, where changes in bed conditions are measured. Samples of gravels are also drawn from two sites on San Geronimo Creek, where their rock-type compositions are measured to infer how sediment sources are changing over time; we have also analyzed the rock-type compositions of gravels at the downstream-most site, Kelley's Tocaloma, and (in recent years) several intervening sites. The monitoring program is described in detail as submitted to and subsequently endorsed for use by the State Water Resources Control Board (in 1993), and by the RWQCB (in 1997) as part of the monitoring program for the Riparian and Sediment Management Plan (Appendix A). As noted below, special and supplemental studies have been added to the basic program to address questions and issues arising during the study.

1.4.1 Monitoring elements

The monitoring program each year begins with a walk of the full length of the monitored reach, and preparation of a qualitative assessment of how conditions in the stream may have changed or are being influenced by events in the watershed. This **'subjective reconnaissance'** also

[10] Throughout this report, Devils Gulch and Deadmans Creek are spelled without the apostrophe, consistent with the nomenclature standard of the U.S. Bureau of Geographical Names.

addresses whether and where flows of the previous winter have changed the bed, whether the conditions at each established bed-monitoring site are likely to reflect the channel upstream and downstream of that site, and which sites merit monitoring. If a standard monitoring site is affected by a logjam, fallen trees, or other localized condition, a recommendation is made as to whether to monitor at the usual site, to extend the monitoring upstream or downstream, or (in one instance) move to a different site.

The main components of the bed-monitoring program are quantitative, and include:

- Annual re-surveys of the bed configuration;
- Annual census of bed conditions affecting coho, steelhead, *Syncaris pacifica*, and other aquatic biota;
- Sampling of sediment immediately beneath the bed surface, which affect future bed conditions as well as fish and their food web; and
- Inferring likely sources of the sediment by evaluating the proportion various rock types in the bed gravels.

Ideally, this monitoring effort contributes to a body of knowledge that forms the foundation for concurrent and future ecosystem, riparian, and invertebrate studies.

1.4.2 Environmental background

Lagunitas Creek drains the Mount Tamalpais watershed area, flowing through Lake Lagunitas, Bon Tempe Reservoir, Alpine Reservoir, and Kent Lake, below which it flows freely past Point Reyes Station and into Tomales Bay. Major tributaries downstream of Kent Lake and upstream of Tocaloma include San Geronimo Creek (9.3 square miles) and Devils Gulch (2.7 square miles); Nicasio and Olema Creeks are tributaries that drain much larger watersheds further downstream. The 'unregulated' (e.g., coarse-sediment producing) portions of the watershed upstream of Tocaloma Bridge constitute about 18.0 square miles, inclusive of San Geronimo and Devils Gulch. Lagunitas Creek is presently gaged by USGS at a site just upstream from Deadmans Creek and Devils Gulch, where the total watershed area is 34.3 square miles of which about 12.5 square miles produce coarse sediment. According to USGS staff, Mean annual rainfall averages approximately 35 inches per year in the downstream tributaries, about 43 inches per year in San Geronimo Valley, and about 48 inches in Lagunitas Creek upstream from Kent Lake (Rantz, 1971). Significant runoff occurs in almost all years. Flood and runoff patterns are further discussed in Chapter 2.

Most salmonid spawning habitat in the mainstem of Lagunitas Creek lies between Shafter and Tocaloma Bridges (Kelley and Dettman, 1980; Ettlinger and others, 2000[11]). We have previously recognized two major reaches between the two bridges, a division also made by others:

- State Park Reach: A steep and narrow reach, where the underlying metavolcanic or greywacke or metashale bedrock is seldom many feet below the channel; banks are lined mainly with conifers, often old and majestic, and which generally are holding the banks in place. Until recently, very little sustained bank erosion along the main stem of Lagunitas Creek has been evident, and current loci of bank retreat are mainly of limited extent and likely transient, related to a pulse of sedimentation affecting reaches downstream from Big Bend (Milepost 18.5). Limited volumes of sediment are stored as alluvium. The channel gradient increases gradually from about 0.0025 to 0.005, with limited sediment storage and frequent bedrock-controlled sections (Hecht, 1983). Adjacent hillslopes frequently are steep, and support mixed conifer or conifer/bay forests. Sites KB, KH, KC, KJ and KD are in this reach; however, site KD is often considered in this report with sites KL and KF due to the events described above.

- Tocaloma Reach: A wider reach, with bedrock seldom visible in the bed; banks are lined primarily with alders and willows, with occasional ash, sycamores, and conifers. The valley is typically two to five times, the width of the bankfull channels, with moderate volumes of sediment storage. The gradient is typically 0.0015 to 0.0025. Adjacent hillslopes are moderate to steep, and support mixed hardwoods or grasslands. Sites KL and KF are in this reach, and should generally also be considered with site KD due to conditions resulting from the events described above. Virtually all *Syncaris pacifica* are currently found in the Tocaloma Reach, with their populations extending also downstream below the confluence of Nicasio Creek (Serpa, 2004, 2006).[12]

The division between the two reaches is usually taken as just upstream of Jewell. The State Park Reach is primarily within Samuel P. Taylor State Park; the Tocaloma Reach is primarily within the Golden Gate National Recreation Area.

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[11] Also consistent with subsequent habitat-typing efforts by MMWD staff in 2003 and 2006. Our interpretations generally emphasize the 2000 habitat typing due to the specific anomalous conditions prevailing during those two years (see Sec. 5.2)

[12] During initial years of the monitoring program, *Syncaris* were also reported from the State Park Reach (c.f, Li, 1981; Eng, 1981; Serpa, 1992)

Upstream of Shafter Bridge is a short, steep reach of Lagunitas Creek 'flushed' clean of most gravels by high-energy flows over Peters Dam, and with minimal sediment storage above bedrock. Because only very limited management can occur in this reach, and because the reach is free of sedimentation, it is not monitored.[13] Downstream of Tocaloma Bridge, habitat is governed largely by the distribution of logjams and riparian woodland. It is an arboreally-controlled reach, where conventional physical geomorphic analysis is largely irrelevant for evaluating aquatic habitat values. Depth of pools, the proportion of sand and fines on the bed, the extent of scour and fill, and even whether or not glides are present are governed far more by size and location of logjams (see section 5.2) rather than by sediment supply or gravel recruitment from upstream, or virtually any management practice higher in the watershed. Reaches downstream from Tocaloma Bridge are no longer geomorphically monitored.[14] The term "monitored reach" of Lagunitas Creek hence is restricted to the portions of the stream between Shafter and Tocaloma Bridges.

1.4.3 Site selection

Each ***site*** consists of three ***segments*** -- a pool, a glide or run, and a riffle. The mean length of each site averages about 80 meters; hence, we estimate that the sites occupy about 8 percent of the length of Lagunitas Creek between the two bridges.

Monitoring occurs at eight sites between Shafter and Tocaloma Bridges (Appendix E). One site occurs within each 1000 meters of the seven-kilometer monitoring reach. We chose to retain sites originally selected during the 1979 to 1982 baseline period. These were chosen randomly within each kilometer, applying a random-number table to the road-mile paddles on Sir Francis Drake Highway, which parallels the creek. We excluded only sites where the bed is largely underlain or influenced by bedrock, or sites immediately downstream of the confluences of large tributaries. To document conditions immediately downstream of the tributaries, we originally monitored an additional site ("KG, At Shafter"), immediately downstream of Shafter Bridge; this site was lost to widening of the bridge and highway in 1983, and we made no

[13] Attempts to monitor this reach using a virtually-identical monitoring program were made in 1980 and 1981 (see Hecht and others, 1981), and then abandoned.
[14] The reach from Tocaloma Bridge to Platform Bridge (mouth of Nicasio Creek) was monitored, with some difficulty, during 1980 – 1982 (see Hecht, 1983) and in 1991.

attempt to replace it at the time. Some of the differences characteristic of tributary-confluence sites are discussed in Hecht, 1990; 2008.

1.4.4 Years analyzed

One specific charge of this report is to assess data collected since inception of the bed-monitoring program in 1995 under Decision 95-17 through completion of the monitoring results conducted during WY2007. Results from an earlier monitoring in 1993 are generally included in our analysis, as well as an update round of samples collected at four sites in 1991, monitored to prepare for the 1992 water-rights hearings, to evaluate whether the conditions had changed since an earlier round of bed-condition monitoring concluded in 1982. We were also able to include most bed-census results from the 1979 to 1982 period, although we were not able to bring the bed-configuration surveys up to date from this earlier period.[15] Finally, this report does include limited mention of monitoring results from 2008 when we deemed it necessary to shed light on several issues. Monitoring pursuant to this program was conducted through 2009, then concluded.

1.4.5 Acknowledgments

No useful long-term monitoring program continues without the sustained dedication of its staff and cooperators[16]. Several individuals have worked over many years to build, develop and apply this program.

Gregory Andrew, as well as Eric Ettlinger and Dana Roxon, all of the MMWD staff, have technically supported the project, with regular updates on their own observations, free sharing

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[15] The 1979 to 1982 cross sections were level-surveyed to a local datum at each site; in 1993, all sites and the pins at the ends of each cross sections were surveyed to NGVD by total station. Slightly pre-dating the age of the personal computer, calculations were conducted by hand, with area computations made with compensating polar planimeters. Additionally, approximately one-third of the pins were replaced in 1991 and 1993 by Balance to make them accessible for survey by total station and to replace spikes in trees or other non-permanent monuments. With some effort, it proved feasible to include some of the data from the earlier period, including the important 1982 storm responses, in this 13-year concluding report. We did not have either the time or budget to do so fully in the interim study.

[16] Review by agency staff through various venues has been consistent and beneficial to the program. Additionally, among non-agency personnel, geomorphologist Laurel Collins and Richard Plant have both contributed ideas for many years as part of the sediment technical advisory committee convened by MMWD.

of their ideas regarding bed conditions and discussions of events in the watershed. Their contributions in framing, sustaining, and adjusting this work as conditions have evolved have reflected their attention and dedication..

Eric Austensen, presently principal of Streamline Engineering, has conducted the cross-sectional surveys and the computation of mean bed elevations since 1997. A number of key observations and concepts have been contributed by Mr. Austensen, who has been accompanying Mr. Hecht on the annual subjective reconnaissances since 1998. A number of his observations are mentioned throughout this report and in Appendix B. Kim Cordell helped develop the format and structure of the subjective reconnaissances in 1995 through 1997. Both Mr. Austensen and Ms. Cordell were originally staffers at Prunuske-Chatham (PCI), the firm that led development of the Riparian and Sediment Management Plan, assisted by Entrix, Trihey & Associates as well as Balance. PCI staff also administered and contributed summaries to annual reports from 1995 through 2004.

Beyond the authors, this work could not have been accomplished without other Balance Hydrologics staff as well their ideas and dedication. Dr. Carla Grandy conducted some of the more recent lithologic analyses, helping to broaden this effort to additional sites; she also worked with Mr. Hecht in interpreting the results. David Shaw, Jonathan Owens, Bonnie (Mallory) de Berry, Gustavo Porras and Mark Woyshner have assisted in various aspects of the field and flow-monitoring program for all, or nearly all, of the period of monitoring since 1995 or earlier; their observations, suggestions, and analyses have been fundamental to this program, which has genuinely benefited from their continuing and consistent work year after year, and their dedication to the quality of data and context.

2. HYDROLOGIC AND GEOMORPHIC INFLUENCES, 1995-2007

Conditions affecting the bed are discussed in this chapter. They include the history of flows, spills and what is known about sediment transport during the study period; our analysis of the stunning episodic sediment influxes at the Big Bend location; measurement of scour during the latter part of the study period; and effects of the introduction of woody debris (both natural recruitment and structures) affecting the bed. These are all important influences generally affecting bed conditions on a reach-wide basis, and also affect the changes in bed conditions and habitat value over time. Events with more localized effects, also intrinsically an important element of the evolving Lagunitas Creek bed, are tabulated by year in Appendix B.

2.1 Flows, Spills and Sediment Transport

Bed conditions are affected by both the peak flows during storms and the total volume of flow in the creek for the year. Within the monitored reach of Lagunitas Creek, bed conditions are also influenced by contributions from (a) spills and releases from Kent Lake below Peters Dam (which receives drainage from 21.5 square miles), and from (b) San Geronimo Creek, a fundamentally unregulated 9.3 square-mile catchment. Once the watershed is saturated, San Geronimo Creek delivers up to 70 percent of the peak flow volume recorded at the USGS stream flow gage at Samuel P. Taylor State Park (USGS gage #11460400) when Kent Lake is not spilling, and a variably smaller proportion during spills. Sediment supplied by San Geronimo Creek also represents a particularly important source of potential bed-condition change in the monitored reach because of its sediment supply. Upstream of the monitoring reach, sediments in the upper Lagunitas Creek watershed are trapped behind a series of water-supply impoundments, making tributary contributions below Peters Dam particularly important. San Geronimo Creek is the largest tributary affecting the monitored reach, and enters Lagunitas Creek above the monitoring sites.

Peak flows for each year during the 1980 to 2007 water years are shown as an historical sequence along with a continuous sequence of mean daily flows in Figures 3 through 6. Figure 3 plots Lagunitas Creek flows measured at Samuel P. Taylor State Park[17]; Figure 4 shows flows

[17] This figure combines the records for the former HEA continuous-recording gage (K6) at the SPTSP Campground Bridge for water years 1980 through 1982 (Hecht, 2003), and the current USGS gaging station #11460400 for Lagunitas Creek at Samuel P. Taylor State Park (December 1983 through present).

for the USGS gaging station (#11460600) on Lagunitas Creek at the gage near Point Reyes Station[18], downstream of the monitoring sites; and Figure 5 plots flows on lowermost San Geronimo Creek at the Lagunitas Road bridge[19]. We juxtapose the annual flows for Lagunitas (at SPTSP) and San Geronimo Creeks in Figure 6. Figures 3 through 6 generally illustrate the especially severe drought conditions which prevailed from mid-1975 through 1977, followed by intense storms and high annual yield in water years 1982 and 1983. During drought water years of 1976 and 1977, peak flows of only 277 and 246 cubic feet per second (cfs), respectively, were recorded at the Pt. Reyes Station., respectively, while peak flows in 1982 reached 6950 cfs at the SPTSP Campground Bridge, 22,100 cfs at the 'near Pt. Reyes Station' gage, and 3810 cfs on San Geronimo Creek. Annual flows at the STPSP gage during 1982 were just below 80,000 acre-feet. Gradual drying and drought occurred through the mid- to late 1980's leading into the early 1990's, followed by relatively wetter conditions through the mid- to late-1990's. Annual flow volume for the latter half of the 1990's was generally at or above 50,000 acre-feet at SPTSP, with peak flows reaching 5830 and 12,200 cfs at the SPTSP and near Point Reyes Station gages, respectively, during the February 1998 event. Rainfall and stream flow again declined to generally drier conditions during the early to mid 2000's, when annual flows rarely exceeded 40,000 acre-feet. Water year 2006 was exceptionally wet, with annual stream flow in Lagunitas Creek of approximately 80,000 acre-feet and large peak flows at both Lagunitas Creek gages. San Geronimo Creek recorded its highest peak flow on record on December 31, 2005 (WY2006), with an instantaneous peak of about 3940 cfs, slightly greater than during the storm of January 4, 1982. Water year 2007 was an exceptionally dry year, with annual flow barely reaching above 16,000 acre-feet. Hence the 13-year period considered in this report began with a substantially wetter than normal period, and ended with more normal, or slightly drier, flows.

Spills and releases from Kent Lake are important influences on bed conditions in Lagunitas Creek because they can transport accumulated bed sediment downstream. Observed flows are outlined in Table 1 and shown graphically in Figure 7. Information regarding reservoir releases was reviewed for water years 1980, 1982, 1993, 1995-2004, and 2006-2007. Table 1 presents estimates of the number of days in each of these years when the average daily releases and spills from Kent Lake exceeded 300 and 600 cfs, respectively. Releases and spills usually occur following a significant storm. They can modify the bed, transporting some of the sediment

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[18] USGS gaging station #11460600
[19] Balance Hydrologics gage K4

which may have been delivered by tributaries during the storm. Thresholds of 300 and 600 cfs have been used to describe the spills because (a) significant sediment movement starts at about 300 cfs during most years, and (b) scouring of many Lagunitas Creek pools seems to begin at about 600 to 800 cfs (c.f., Hecht, 1981). Two days of mean daily spills exceeding 1400 cfs (approximately the morphologic bankfull flow in Lagunitas Creek through the State Park Reach) were reported during the 10-year+ monitoring period - on January 2, 1997 (1564 cfs) and December 31, 2005 (2627 cfs). Spills and releases were generally high in the early 1980's and the mid to late 1990's from the intense and frequent storms in those water years. Dry conditions in the early 2000's are echoed in the reduced number of releases from Kent Lake during this period, when no spills or releases exceeded 600 cfs and the number of spills or releases exceeding 300 cfs rarely rose above 5 during any one year. No spills or high-flow releases were made in water years 2001 and 2002. More recently, wet conditions in water year 2006 led to significant spills or releases, four of which were above 600 cfs and 12 of which exceeded 300 cfs. Two of the spills above 600 cfs during WY2006 were sustained at about 900 cfs, whereas most spills above 600 cfs in prior years rarely exceed 700 cfs. Although it produced one significant peak flow, water year 2007 was an exceptionally dry year throughout the Bay Area, with no spills or peak-flow releases made from Kent Lake.

Sediment contributions from San Geronimo Creek, as measured at the lower gage beneath Lagunitas Road, have been calculated and measured only during the most recent years of data collection. Suspended-sediment transport data are available for water years 2005-07, while bedload transport has been monitored intermittently since late 1979, and regularly calculated since 2000. San Geronimo sediment data are based on discrete measurements used to ascertain sediment-transport rating curves and general trends in bed sedimentation over time. Suspended-sediment transport during 2005 reached 2,452 tons, while the intense storms of 2006 coupled with prolonged March and April rains transported much more suspended sediment, about 26,400 tons. During the dry winter of 2007, we calculated that only 433 tons of suspended sediment were transported past the lower San Geronimo Creek stream gage.

In terms of bedload contributions, transport rates were relatively low in 2000 and 2001, with 423 and 71 tons, respectively. Bedload transport increased to higher calculated rates of 3,348, 1,174, 1,612, and 851 tons during the time span of 2002-2005, a period which began with a sudden upsurge of bedload transport (see Figures 10a and 31). The wet winter of 2006 yielded 6,874 tons of bedload contribution from San Geronimo Creek, while the dry 2007 winter only yielded 229 tons of coarse material (e.g., bedload) to Lagunitas Creek above the bed-monitoring sites.

For the purposes of this report, we believe that the long-term monitoring period (1980-2007) was reasonably representative for rainfall, including three noteworthy floods (January 4, 1982; February 3, 1998; and December 31, 2005) and one extended drought (1987-1992). A short, especially severe drought (1976 and 1977) immediately preceded the monitoring period, which possibly may have altered bed conditions at the time our initial measurements were made. The most recent sampling characterizes the response to an exceptionally wet winter (2006) followed by an exceptionally dry one (2007). The 13 years of the monitoring program under Decision 95-17 began wetter than usual and include an atypical number of high flows, while the latter portion of the 10-year monitoring period included both dry years (e.g., 2000 and 2001) and years collectively within the range of normal (2002-2005). Water year 2006 stands out as a particularly important year, with a very major storm creating disturbances which persisted through dry year 2007. Both 2002 and 2006 (along with 1998 - see also Figure 31) stand out in terms of sediment contributions from San Geronimo Creek. Other localized events have affected bed conditions as much or more than the magnitude and occurrence of high flows.

A number of episodic events occurred during 1980 through 2007, including floods, droughts and debris flows. The 1980 through 2007 period did not include two types of episodic events now recognized as intrinsic to sediment-supply and transport variability – large wildfires, or seismic events (c.f., Hecht, 1983, p. 130). The 13-year period of study considered in this report (1995 through 2007) did not include a drought, but did include one very major flood event and one very dry year. Other localized events have affected bed conditions as much or more than the magnitude and occurrence of high flows. These are discussed below, and are tabulated by year as part of Appendix B.

2.2 Changes in Land Use and Water Management

Land-use changes were limited in kind and scale during the 13 years considered in this study. Minor increases in land-use density through residential infill and the construction of one small subdivision (in Forest Knolls) occurred during the monitoring period. No major public works projects triggering runoff or erosion were in constructed in the San Geronimo Valley or in Samuel P. Taylor State Park. Highway improvement within the San Geronimo watershed was limited to significant partial reconstruction of the White's Hill segment of Sir Francis Drake – the preponderance draining to Corte Madera Creek -- and localized repairs and structural

reconstructions in the western San Geronimo Valley.[20] Roys Dam on San Geronimo Creek in the town of San Geronimo was reconstructed during the first half of the study period. The County Department of Public Works reconstructed and restored several stream crossings, principally near Woodacre, to abet fish passage. Periodic removal and re-use of gravels from behind the grade control on the north fork of San Geronimo County is reported to have continued. MMWD constructed the bike path from Tocaloma to Shafter during the 1980s, and has removed sediment from behind the path on several instances. Other measures described in the 1997 Riparian and Sediment Management Plan were built or put into effect.

Noteworthy restoration and changes in channel management appear to have affected sediment supply and bed configurations both in San Geronimo Valley and downstream in Lagunitas Creek. Beginning in the late 1980s, much of the channel network in upper San Geronimo Valley -- upstream of the MMWD water-treatment plant -- has been successfully stabilized, particularly in the North and Woodacre forks and in the Spirit Rock tributaries. Measures to limit sediment delivery from fire roads were proposed (Stetson Engineers, 2002) and enacted. Other repair efforts elsewhere in the watershed are chronicled in prior reports (PCI and others, 1997; Stetson Engineers, 2002; Stillwater Sciences, 2007). Marin County has repaired the lower reaches of several tributaries to San Geronimo Creek to enable fish passage, which has stabilized incising reaches. The fish ladder at Roys Dam on San Geronimo Creek at the western end of the golf course was replaced, at the same spill level, to preclude release of sediment. Sediment is now removed periodically from an impoundment at Dickson Ranch, and (on at least one occasion) from a basin on Wildcat Creek in the Samuel P. Taylor State Park impounded by the bike trail. Wood entering Lagunitas Creek within the State Park is no longer removed, and an appreciable fraction of larger wood entering Kent Lake is now moved past Peters Dam or incorporated into woody debris structures recently constructed between the dam and Jewell.

[20] A detailed review including analysis changes in land use, drainage and general water management in the San Geronimo Valley sponsored by the County of Marin has recently been issued for public comment.. The County's Existing Conditions report provides expanded discussion of recent changes in land and water use.

2.3 Big Bend Episodes as Channel Influences

Big Bend[21] has experienced a dynamic set of geomorphic changes over the ten-year monitoring period which dwarfs many other sediment-supply influences. Much of the coarse sediment entering Lagunitas Creek during the period of study has been supplied to the channel at Big Bend. The changes have been of such a magnitude so as to induce secondary responses to downstream reaches, likely as far as the Kelley's Tocaloma monitoring site, and perhaps further downstream to Nicasio Creek and beyond. This section presents a summary chronology and description of the channel changes observed at Big Bend, providing the episodic context for discussion of changes seen at downstream monitoring sites.

As early as the 1980 monitoring season the Big Bend subreach was identified as one of the more dynamic portions of Lagunitas Creek. During the high flows in January 1995, a 14-foot-high log jam filled the then-occupied northern alternate channel, diverting flows into a former channel along the southern edge of the valley. This change re-initiated flow along the left bank immediately below the pool downstream of the bridge and extending into the upper portion of the monitoring site, resulting in the release of about 1,000 to 1,500 tons of coarse sediment and the felling of two large alders (inducing further scour within the pool). A small amount of additional coarse sediment was introduced to the reach by a debris flow emanating from a left-bank tributary near the downstream end of the monitoring site (cross section KD-8).

Further channel change occurred in 1996 downstream of the Green Bridge. Approximately 3,000 to 5,000 tons of sediment entered the channel from a large debris flow in the upstream tributary (at cross section KD-4), and continued delivery of (debris flow) sediment from the downstream left-bank tributary, which fully filled the channel temporarily. Remnants of the debris flow are visible along the now abandoned left-bank channel at section KD-7 and additional debris flow inputs from another left-bank tributary upstream of the first.

A major channel shift occurred in early January 1997, when a high and wide wood jam formed in the debris-flow narrowed main channel near the present section KD-8, diverting the creek

[21] Big Bend refers (a) to a portion of Lagunitas Creek from the Green Bridge at the downstream end of Samuel P. Taylor State Park (not to be confused with the Green Bridge in Point Reyes Station) approximately 500 yards downstream to where a new channel rejoins the pre-1995 channel which flowed around the outside of a long, nearly 180-degree bend, and (b) bed monitoring site KD (see figures 2 and 7) which is a much shorter length of stream at the approximate midpoint of (a).

into a new channel on the inside of the bend, cutting off much of the Big Bend. Erosion of this new channel released approximately 3,000 cubic yards of mainly coarse sediment into the creek during 1997 and 1998. Additional coarse sediment from the same source continued to be delivered during and following major storms as the cutoff channel fully incises. This process continues at present, but was especially noteworthy in 2000 and 2003. Fundamental re-alignment of the main channel on the inside of the bend left a portion of the remnant terrace deposits as an 'island' between the old and new channels. The new channel has continued to incise and widen in subsequent years, and cut new channels through the island. Although the cutoff channel is gradually stabilizing, we believe that 1,000 to 2,000 tons of alluvial gravels were introduced into Lagunitas Creek from the downstream end of Big Bend during the December 31, 2005 event and subsequent storms of WY2006. Events of that year at Big Bend, including limited renewed mudflow activity, are further described in Appendix C.

2.4 Analysis of Scour

Beginning in water year 2002 and continuing through water year 2006, Balance conducted a scour-monitoring program to track maximum scour depths at selected potential spawning sites near the glide-riffle transition. Our objective was to identify whether scour could result to depths at which substantial egg loss might occur. We proposed to MMWD that we begin this work in late 2002, a year in which we had observed substantial influx of bed sediment, reasoning that the bed might be 'softer' than usual because of greater amounts of fresh sand and fine gravel that had entered Lagunitas Creek from San Geronimo Creek and other tributaries (see below). The work was quickly authorized, with installations completed in September and October, prior to observed coho spawning activity, at cross sections and spots along the sections where we had previously observed redds or active spawning. We monitored maximum scour for the year using scour chains, and compared this to annual net scour (obtained through survey cross sections). We installed a total of 29 scour chains along cross sections at the transition between glides and riffles -- in each case at locations at five different sites along Lagunitas Creek: KB, KJ, KD, KL, and KF. Our monitoring continued through the major storms of WY2006, with the highest water levels recorded during the past 30+ years. At that point, we believed that sufficient data had been collected to assess the role of scour[22]. A more complete

[22] Stillwater Sciences (2007) conducted a parallel scour survey during WY2006 as part of work conducted for the Marin County RCD, with results that we consider similar to those reported below.

description of the monitoring program, the methods used and detailed findings can be found in Appendix F.

The results of the scour study showed that, on a site-by-site basis, maximum scour at likely spawning sites near the glide-riffle transition did not correlate closely with annual peak flow, although three of the five sites did experience the greatest scour during WY2006. In general, maximum scour recorded by the scour chains was of similar magnitude to annual net scour and deposition, though they were not necessarily the same at a given station on the cross section. In other words, the range of maximum scour throughout the five monitoring sites was similar to the net annual scour as measured using cross sections (considerably less than one-foot in most cases). However, an individual scour chain sometimes recorded significant scour where the cross section survey showed that the bed elevation did not change from one summer's survey to the next. This process was especially prominent at the KJ (Big Rock) site, where the left-bank bar appeared to scour at higher flows, but generally re-formed in a similar configuration during the falling limb of the event, or during subsequent, smaller events later in the season.[23]

Figure 9 shows the distribution of scour recorded over the full four-year monitoring period. Of most importance is the fact that even though the monitoring period spanned a very large event (in water year 2006), only one chain recorded more than a foot of scour, and only five chains recorded more than 0.5 feet of scour[24].

Stillwater Sciences (2008) conducted an exploratory study of redd scour over a single (approximately bankfull) event in WY2005 (late December, 2004), and two subsequent, significantly smaller storms. They installed up to four scour chains at nine different redds within Lagunitas Creek, and found that of the 32 chains installed, only one experienced scour approaching the egg burial depth (~0.5 feet), and scour was less than two inches for the majority of the redds monitored. Our 2005 data show similar results, with about 90 percent of chains recording less than 0.4 feet of scour. It might be noted, however, that WY2005 had the

[23] Two of the factors contributing to a more mobile bed at this cross section were (a) pulses of coarse sediment originating from the "Group Camp Tributary", which enters Lagunitas Creek from the left bank at Section KJ-4, and (b) continual shedding of limbs from copses of bay trees on the left bank just downstream from Big Rock itself.

[24] Four chains were lost due to scour; however, depending on the anchor depth the scour may not have been over 0.5 feet. Even assuming that scour was very high at these locations, there were still relatively few sites that experienced over 0.5 feet of scour.

lowest peak flow and the least amount of recorded scour, over the 4-year duration of our scour monitoring program (see Table 2 in Appendix F). Though the late-December 2004 event was estimated to be a bankfull event, it may not have been representative of a "typical" peak annual flow.

While the conventional wisdom is that scour is proportional to shear stress (which is a function of the depth of flow), it is possible – and, in our belief, likely – that scour in Lagunitas Creek is also effected as woody debris moves through a riffle during storms of varying sizes. It might be noted that our field notes[25] recorded evidence of large amounts of wood in the channel during 2003 and 2004, and especially during the latter year where two notable windstorms brought numerous treefalls and fallen limbs into the riparian corridor. The presence of abundant woody debris may be one of the reasons for the seemingly scattered scour data recorded at several of the monitoring sites.

2.5 Woody Debris Structures and Other Wood Loading Affecting Bed Conditions

Relative to the conditions prevailing in the early 1980s, when characterization of bed conditions commenced, the amount of sediment seems to have decreased, while there has been a substantial increase in the amount of large wood in the channel and on the Lagunitas Creek floodplain. One result has been a proportionate increase in the role of wood in influencing bed conditions. The effects of a natural or built log structure is often at the scale of a given pool and glide. Hence one or two additional logjams, where they affect bed monitoring sites, can substantially affect the results of a monitoring program based in part on representative sites.

In this section of the report, we consider why wood is accumulating and where additional large wood is affecting bed conditions.

2.5.1 Factors resulting in additional large wood

A great amount of large wood entered the study reaches of Lagunitas Creek during the period of 1995 through 2007, because:

[25] See subjective reconnaissance reports for these two years. While neither bed monitoring nor subjective reconnaissance work were done in 2005, substantial wood also entered the stream system during the storms and heavy spring rains of WY2006.

1) *Large wood is no longer removed from the floodplain and riparian zone,* an element of the Riparian and Sediment Management Plan. This is a fundamental change, and, quantitative data notwithstanding, seems to be a particularly important source of large wood.

2) *Large wood is being recovered from Kent Lake, and moved downstream of Peters Dam*, for various objectives. Re-use of the snags and trunks removed from Kent Lake is a recent practice.

3) *MMWD is adding large wood through construction of woody debris structures (WDSs).* See below for a discussion of the 38 existing structures, some of which replace or augment structures which have yielded large wood to the stream.

4) *Upland tree growth was more rapid than usual*. The years 1993 through 2006 were a wet period relative to others recorded in central coastal California. Growth of oaks, bays, tanoaks, douglas fir and other upland plants was more rapid than usual (c.f., Herwitz and others, 2000). Of perhaps equal importance, only 2001 was a very dry year, with no multi-year drought to slow growth. More growth leads to more falling limbs or fallen trees.

5) *Sudden oak death (SOD)* entered the San Geronimo and Lagunitas watersheds during the monitoring period, adding discernible increases in the volume of oak, bay and tanoak trunks and branches in the stream.

6) *Collapse of the mature alder canopy*. Through our subjective reconnaissance surveys, we have noted that well over half of the large mature alders which once lined the banks of Lagunitas Creek have fallen since 1995, and are being replaced by mainly small- to mid-sized Oregon ashes. Much or most of this fundamental, once-in-a-(human) lifetime change has occurred from Big Bend downstream. In our 5-year report (Hecht and Glasner, 2000), we attributed the die-off to mortality induced by the 1- to 2-foot increases in summer water levels caused by sedimentation downstream from the release of large volumes of coarse sediment at Big Bend. Because alder mortality is now increasingly manifest upstream of Big Bend (e.g., at site KJ and near the mouth of Deadmans Creek), it might be more appropriate to regard the bed-sedimentation/alder-drowning sequence as accelerating senescence of a gallery of mature alders that are approaching the ends of their life spans. The number of recently-fallen alders is considerable; since the late 1970s, large alders have always been an important component of major logjams, but their current prevalence is notable.

7) *Several windstorms may have added to the volume of large-diameter wood available for delivery to the stream corridor.* In addition to the 2004 event described above, we (or others) noted some of the very strong winds in the area on December 10, 1996, in early January 1997, February 2 and 3, 1998, and January 4, 2008. The first and last storms, in particular, resulted in noticeable windfall especially on the slopes between Shafter and Campground Bridges. Landon Waggoner, long-time chief ranger at Samuel P. Taylor State Park told us that the five or six years before he retired (2003) were discernibly windier than in the past. While we do not know of wind data for the central Lagunitas watershed, our impressions and anecdotal evidence suggests more windfall than usual.

8) *Wood accumulations on the floodplain and lower slopes due to an absence of antecedent high water:* Prior to the January 1995 events, the last major floods were recorded in February 1986. Hence, the high water of 1995-1998 floods could mobilize an additional nine years' accumulation of large wood.

For these eight reasons – and perhaps others -- we believe that considerably more large wood entered the channel than had been the case in previous years, and possibly more than is likely to enter the channel during most 10-year periods in the future. This observation strongly shapes the interpretation of data presented in this report. In many cases, large wood creates pockets of scour and microhabitat critically important for salmonids; nonetheless, it creates conditions which allow sediment to accumulate and for finer sediment to settle over larger areas upstream of naturally-formed woody debris accumulations or of WDSs.

2.5.2 Constructed woody debris structures

In Chapter 4, we will note that all four of the original bed monitoring sites upstream from Big Bend have experienced some aggradation and fining of the bed observably in response to the construction and/or natural development of woody debris structures (WDSs). In this section, we describe the nature and location of the constructed WDSs, for which information is best available. The wood structures, both constructed and natural, are an important new aspect of the geomorphology of Lagunitas Creek, particularly since 2000. As will be seen below, it should not be surprising that all four sites have been affected by the structures.

MMWD has provided us with the locations where large woody debris structures (WDS) were emplaced downstream of Peters Dam (Figure 10), and the dates of their completion. Large woody debris (commonly abbreviated as LWD in geomorphic parlance) in small mountainous

catchments, like Lagunitas Creek, are at least as important as the statistical properties of flow history in controlling the morphology of the bed and channel. LWD can create localized scour and/or deposition through their influence on flow patterns within a stream channel, and can encourage flows to take alternate paths if their presence alters energy gradients in a given reach. LWD also can create backwater effects that alter bed conditions upstream of WDSs or natural logjams. Scour may expose different bed and/or bedrock lithologies to erosive flows and induce lithologic changes in bed condition in downstream reaches. Significant flows can also rearrange, destroy, or transport and re-deposit LWD, enhancing the complexity in flow conditions and sediment transport that these structures afford through time and space. In Lagunitas Creek, movement or destruction of WDSs are discouraged through the manner of construction: cables, lag bolts, fixatives (epoxy) and bracing between large trees are often used to attach logs to one another and to keep structures in position. At certain WDSs, boulders were emplaced with the logs to fortify and anchor the structure. Even with these efforts, however, some WDSs have still been transported during high-flow events.

Forty-three WDSs were created by MMWD and placed downstream of Kent Lake and upstream of Jewell between 1998 and 2006 (Figure 10). Seven structures were set in 1998, one in 1999, seven in 2000, twelve in 2001, seven in 2002, nine in 2003, and two in 2006. Structures in 1998 were all placed on MMWD lands upstream of Shafter Bridge, while the one structure developed in 1999 was placed at monitoring site KJ ("Big Rock"). In 2000, WDSs were placed in various locations throughout the monitoring reach: two below site KB, one below site KX, one between sites KC and KJ, two just above site KD, and one between sites KD and KL. In 2001, LWD structures were placed above, at, and below KX, while in 2002 structures were placed just above and below site KH and at and above site KB. WDSs emplaced in 2003 were at various locations between sites KX and KD, while in 2006 one structure each was placed above sites KC and KJ. Three of the year-1998 structures were replaced in 2006; four of the year-2000 structures were replaced (two in 2006 and two in 2008); eight of the year-2001 structures were replaced (six in 2007 and two in 2008); one of the year-2002 structures was replaced in 2008; three of the year-2003 structures were replaced in 2006; and one of the year-2006 structures was replaced in that same year. Mobility and form of the WDSs probably approaches that of the natural wood accumulations which develop in Lagunitas Creek. Their effects are not permanent, and will evolve over time.

The structures are intended to create diverse microhabitats, including scour pools and other scour features. By their nature, the WDSs introduce bed sediment into Lagunitas Creek at locations where the sediment will likely be mobile and mobilized. Scour induced by the WDSs

is monitored regularly by MMWD staff (Ettlinger and Andrew, 2008). In Chapter 4, we conclude that scour around the 45 structures adds (very roughly) about 100 to 200 tons of bed sediment per year (or about 5% to 10% of the current bed sediment inflow from San Geronimo Creek) for the first few years following emplacement. Hence, the WDSs result in a new source of bed sediment that may in large part be temporary, but probably has moderately affected bed conditions during the years of initial emplacement – corresponding to the years since 2000 covered for the first time by this report-- and diminishing thereafter.

2.6 Sediment Delivery to Lagunitas Creek

Sediment delivery to Lagunitas Creek from each tributary varies from year to year, an important influence of bed conditions during the years since 1995. The volume and rate of flow are clearly major influences; sediment availability is another. Figure 10a shows the estimated amount of runoff and bedload sediment transport in San Geronimo Creek (c.f., Owens and others, 2007). Since 2002, the amount of bedload sediment entering Lagunitas Creek appears to have increased relative to the volume of runoff. In fact, bedload delivery from San Geronimo Creek may have varied from about 4000 tons per year during the early 1980s (Hecht, 1983), to about half this value during the years since a marked increase in sediment yield in 2002. Prior to that increase, sediment yields were lower yet, perhaps half or less of those prevailing since 2002.[26] Our observations during the annual subjective reconnaissance also show considerable variability in the yields from each major tributary entering Lagunitas Creek within the study reach, based on the conditions in their lower reaches and the size of the deltaic apron deposited in Lagunitas Creek at the confluence. Generally, the other tributaries also exhibited lower yields during the years prior to 2001, and show evidence of increased sediment contributions to Lagunitas Creek since that time, although not to the degree observed in San Geronimo Creek.

The increase in sediment transport rates during WY2002 was immediately reflected in bed conditions in Lagunitas Creek (Hecht and others, 2008a), considered in greater detail in Chapter 4. Sediment yields from the tributaries – and San Geronimo Creek in particular -- directly and appreciably affect bed conditions in Lagunitas Creek between Shafter and Tocaloma Bridges.

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[26] Data for the early 1980s is based on a full gaging and sediment-transport monitoring program, including both suspended and bedload sediment. Data for 1997 through present is based on full gaging and a reconnaissance-level sediment-transport program limited to bedload. Yields not computed for 1997 and 1999. Bedload monitoring was added to the MMWD monitoring program in late 2001; previous data are based on the personal research work of Balance scientists.

3. NATURE OF THE DATA COLLECTED

In this chapter, we discuss why, where, and how observations are made.

3.1 General Technical Approach

The overall structure of monitoring, outlined in Chapter 1 and detailed in Appendix A, includes four separate components:

- Subjective reconnaissance
- Site surveys, including monumented cross-sectional and high-water mark surveys
- Bed monitoring
- Rock-type censuses to help identify the origin(s) of impairing sediment

Most individual metrics are measured as part of the site surveys or the bed monitoring. These are described below. These two components share in common that they are measured at fixed sites, each of which is a *sequence* of pool, glide and riffle *segments* taken to be representative of a 1000-meter portion of Lagunitas Creek. Each of the sites upstream of Devils Gulch is also the site of a woody debris structure constructed by MMWD generally midway during the 12-year monitoring period (see Figure 10). MMWD chose to construct the structures within the sites knowing that over the short term, it might perhaps impair the capacity of the monitoring program to discern long-term trends; however, over the longer term, the monitoring program would be able to measure the presumably positive changes resulting from the WDS construction.

All measurements of bed conditions are made using the Wentworth scale, in widespread geologic use (Figure 11). One special accommodation has been made for Lagunitas Creek at the request of the first fisheries biologists – for this study, 'cobbles' are defined as 45 to 256 mm, rather than 64 to 256 mm, which is the norm.

The layout of a representative site (here, site KH) is shown in Figure 12. The spacing of the cross sections, their assignment to segments, and the arrangement of tapes when the site is censused are shown.

3.2 Bed Configuration

3.2.1 Mean bed elevations

Lagunitas Creek, between Shafter and Tocaloma bridges, tends to change relatively little over time. The banks are generally stable. It is the elevation of the bed that can change over time as sediment accumulates or is depleted. Hence, it is the bed elevation that we have chosen to measure. This metric is one of the most useful descriptors of bed conditions in Lagunitas Creek.

Mean bed elevation is a measure of whether the stream bed is accumulating or depleting sediment. While it is possible for the bed to accumulate sediment while retaining its habitat value, experience has shown that accumulation ('aggradation') is generally associated with a bed that is becoming finer, more prone to scour, and with less bed relief, all of which indicate conditions typical of loss of habitat value. Conversely, an alluvial bed maintaining its bed elevation or very gradually decreasing is one which is typically coarsening and firming, and offers more relief, all of which favor salmonid use (providing deeper pools and better cover).

At each cross section, approximately 15 to 25 points on the bed and banks are surveyed to the nearest 0.01 feet. The mean bed elevation between the base of the banks is then computed for each cross section. Mean bed elevations (MBEs) are then averaged for each pool, glide, and riffle, then compared with prior surveys to quantify how these have changed over time. A mean MBE can also be computed for the entire site[27].

3.3 Bed-surface Conditions

The bed surface affords most of the rearing habitat available during summer in Lagunitas Creek, and influences both spawning and migration of anadromous salmonids. The bed surface is coarser and more evenly sorted than the bulk bed material lying beneath it.

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[27] Mean bed elevations may be computed and plotted longitudinally for each cross section. This is a more rigorous, less subjective alternative to thalweg surveys, and one amenable to use in calculating the net accumulation or depletion of sediment in a defined reach of channel.

We sample the bed surface by establishing a grid of stretched tape reels over the entire surface of a pool, glide or riffle. The census results in a stratified random sampling drawn in equal probability from all parts of the segment. Each of the 80 to 150 sampled points is classed as (a) cobble or boulders (>45 mm), (b) sand (<4 mm), (c) gravel, (d) bedrock, or branches or limbs large enough to provide cover for a young rearing salmonid. The size of each particle sampled is measured, and if larger than 16 mm, its embeddedness is estimated. Further details of sampling are discussed in the annual monitoring reports (Hecht and others, 2008b and 2008c).

The distribution of particle sizes on the bed is one of the most important influences on habitat usability especially by anadromous salmonids. The distribution, or 'grading', also strongly affects channel hydraulics and sediment transport during storm runoff. The sizes of particles on the bed of Lagunitas Creek are commonly two to three times coarser than in the 'bulk bed' or 'pool fill' sediment beneath the surface layer. Similar ratios are reported from other streams with unarmored gravel beds.

3.3.1 Particle-size distribution

Percentiles of the particle-size distribution are computed from the field measurements. As is common, we use the median size (D_{50}) and the 84th and 16th percentiles (D_{84}, D_{16}) for analysis. Details are presented in the annual monitoring reports.

3.3.2 Percent of the bed covered by cobbles or coarser material

The bed census provides a percentage of the bed occupied by cobbles or coarser material. A large number of cobbles implies a bed minimally affected by fine sediment, especially when the percent of bed area covered by sand is low; beds with heavy accumulations of fine sediment have fewer cobbles at the surface.

3.3.3 Bedrock as a proportion of the bed surface

Similarly, the percentage of the bed occupied by bedrock can be calculated from the bed census. Over time, a higher bedrock percentage – up to a moderate level -- generally means that bed is relatively depleted of sediment, and conditions are likely to be more favorable for salmonids.

3.3.4 Sand as a proportion of the bed surface

We also measure the proportion of the bed surface occupied by 'sand' as part of the bed census.[28] Sand is recognized when a firm-feeling fine-sediment bed is found beneath the point selected by the sampler; it does not include the algae and clay scum which sometimes develops on the bed over the course of the summer. An increasing proportion of sand often means that sediment has accumulated at the site; bed conditions are likely deteriorating, since a sand bed has little habitat value in this setting.

3.3.5 Embeddedness of cobbles

Embeddedness is visually estimated as the proportion a cobble's or boulder's depth embedded in finer material. In Lagunitas Creek, the embedding sediment is typically sand or very fine gravel, generally finer than 4mm. We estimate embeddedness to the nearest 10 percent of a particle's depth. Kelley and Dettman (1979) established a strong, inverse correlation between the mean embeddedness of cobbles and use of a segment by juvenile steelhead. Bjornn and his colleagues (1977) and man subsequent observers have reported similar relations for salmon. Embeddedness is therefore widely considered to be an important direct predictor of use by rearing salmon and steelhead. High embeddedness means that the cobble is buried in sand or fine gravel, and not available to provide cover and shelter during rearing life stages.

3.5 Sub-Surface ("Pool Fill") Bed Material Particle Sizes

In Lagunitas Creek, the bed-surface layer is mobilized and re-forms with each major storm, probably several times per year in seasons of normal and wetter rainfall. Nonetheless, it is coarser than – and probably formed from -- the "bulk bed" material beneath it, as is true of most gravel-bed rivers (c.f., Parker and Klingeman, 1982, among many others) and virtually all streams supporting salmonids.

The samples that we collect are drawn from the transition from each pool to the glide immediately downstream. This position is perhaps more sensitive to changes in accumulation

[28] Samplers designate the point as "less than 4 mm.", as suggested by Leopold (1965), which technically includes granules (2 to 4 mm.; see figure 4), and silts and clays. Sand constitutes more than 85 to 90 percent of the points on the bed surface found to be less than 4 mm in size; the remainder are silts and clays found in the lees of major obstructions.

of sandy sediment than other positions within a sequence (c.f., Hecht, 1983; Lisle and Hilton, 1999). The particle-size distributions of these samples are helpful indicators of whether the accumulated bed material is fining or coarsening. They likely are partial predictors of future bed-surface material sizes. The bed cores are ***not*** intended to assess properties of spawning gravels or the infiltration of suspended particulates into spawning gravels.

We collect samples of bed material by first scraping away the bed-surface layer, and then driving a 15-cm (6-inch) thin-walled cylinder into the gravels. A flexible steel plate (often, an industrial dustpan) is driven under the cylinder, forming a seal while the sample is extracted from the bed. The sample is poured into a basin, then gradually decanted before being placed in a doubled zip-top bag for transport to the sediment laboratory, where they are weighed, dried at 105 deg C, and then re-weighed prior to sieving. Samples are labeled with permanent marker on the inside of the two bags, as well as on a business card placed between the bags. The card stays with the sample during drying and sieving. Sieving is done with a RoTap™ shaker, using 8-inch sieves of 64, 45, 31.5, 22.3, 16, 11.2, 8, 5.6, and 4 mm, and then with brass sand-sized sieves of 2, 1, 0,5, 0.25, 0.125, and 0.0625 mm. Results are expressed in weight percent, with percentiles ("D-sizes") computed. Additional details are presented in the annual monitoring reports (c.f, Hecht and others, 2008b, Appendix D).

3.6 Rock-type Source Analysis ('Lithology')

Sediment supply is a major factor affecting bed-habitat conditions; many geomorphologists believe that in watersheds of this size, sources are the dominant influence. Further, sediment sources in the Coast Ranges evolve over time, both at the local and watershed scale. Although often overlooked in habitat studies, these changes can be very substantial, especially when triggered by episodic events or by changes in land use resulting in coarse sediment entering the stream. By monitoring changes in sediment sources, the watershed can managed in ways that protect important aquatic resources. Sediment sources can be assessed using five approaches: inventorying and mapping; measuring sediment transport in the stream network; modeling; historical evidence combined with aerial photograph interpretation, and tracing sediment to its source based on the rock types ('lithology') of the sands and gravels. Because we had earlier found lithologic tracing to be useful in the Lagunitas system (Hecht and Enkeboll, 1979, Appendix A), we proposed using this approach to describe and monitor changes in the sediment supply throughout the watershed. One of the reasons we focused on lithology was the early 1980s Skye Ranch residential-development proposal, an abandoned project which

would have subdivided much of the southern uplands of the San Geronimo Valley, an area underlain in large part by serpentinites, a distinctive rock type that is readily traceable.

The original bed monitoring program called for lithology analyses at two sites in the San Geronimo Valley. We subsequently added a site at the lower end of the study reach, at the Kelley's Tocaloma (KF) site, in 1995, largely in response to the initial disturbances at Big Bend. For each of the last ten consecutive years (except 2005), we sampled bed sediments and classified them based on rock type, or 'lithology'. Bed core samples were collected at each of three sites along Lagunitas and San Geronimo Creeks between 1993 and 2004. In later years, we also analyzed samples from Devils Gulch and Lagunitas Creek above Devils Gulch, at the Big Rock site (KJ) to better understand sediment sources and sinks. Our sampling methods included first removing the top layer of armor sediment and then carefully extracting a 15-mm (6-inch) core sample from the bed. Bed core samples were then returned to the lab to be sorted by grain size and classified based on lithology.

We analyzed the lithology of fine gravels because they are a primary habitat-impairing influence in the Lagunitas Creek system. Since lithology can vary significantly with the size class of gravels and cobbles, we chose a single size class of 8 to 16 mm for analysis – just large enough to identify by rock type, yet small enough to be indicative of the fine gravel fraction that fills pools and fines spawning riffles. We sorted the bed cores by sieving, drawing our samples from gravels retained on 8 mm sieve, but passing the 16 mm sieve after shaking on a Rotap™ machine for 5 to 10 minutes. Sieved samples were drawn by splitting samples using the method of alternate quartering. Sometimes, multiple quartering needed, or occasionally, few enough clasts of 8-16 mm size were sampled such that the entire sample was utilized.

Once quartered, all of the gravel particles in a quartered sample were classified (hence variability in the number of rocks identified). By fully identifying lithologies of all rocks in each quarter, we assure that no preference be given to (a) rocks near the center of each quartering (which tend to be slightly smaller) or (b) those which can easily be identified. Lithologic identification of most samples took 60 to 90 minutes per sample.

4. ANALYSIS

In this chapter, we examine the data collected and explore validity, representativeness, trends and whether data suggest an appreciable improvement in bed conditions. We explore a number of metrics illustrated in Figures 13 through 29. In certain cases, we also draw upon observations recorded in Chapter 2. Results are summarized in Table 7.

Because of the number of disturbances or anomalous conditions during the 13 years, it is often not appropriate to examine trends using regression or hypothesis testing. Essential assumptions, such as drawing upon a single population or independence of one observation from another, cannot be met. Rather, we emphasize examining the data, using what we can, and seeking trends deemed meaningful between a start and end point. Depending on the data, various start and end points may be used:

a) 1993 or 1995 data compared to 2007 data;
b) 1995 data compared with 2004 data (excludes episodic effects of WY2006)[29];
c) 1980 and 1981 data with 2003 and 2004 data (both periods just prior to a major flood);
d) Summer 1982 with summer 2006 data (immediately following major floods);
e) Other time periods specific to a given site due to conditions at the site.

4.1 Mean Bed Elevation

4.1.1 Upstream of Big Bend

Results of the mean bed elevation monitoring are shown in Figure 13a. Site KB is anomalous in that our 1993 data include only the upstream most 8 cross sections, skewing the results. At KH, MBEs declined as habitat improved from the 1980s until 2002, at which time the combination of the sediment influx from San Geronimo Creek and construction of a new WDS resulted in 0.6 feet of aggradation, which has continued as the WDS has rotated and acquired a coating of logs and woody debris during the WY2006 storms. A parallel decline was observed at Campground bridge, with subsequent rise in mean bed elevation as new log structures were built or washed away. At KJ, the mean bed elevation declined through 2004, then rose sharply in 2006 due to backwater effects from a very large logjam about 300 feet downstream.

[29] No bed sampling was conducted during WY2005

Between 1993 and 2004, pools deepened relative to riffles at the first two sites downstream from Shafter, probably because the accumulated sediment from the 1987-1991 drought had been washed downstream. Other sites upstream of Big Bend showed changes best explained by local conditions (Figure 13b[30]).

4.1.2 Downstream of Big Bend.

All three sites have aggraded, with MBE increases of 0.5 to 2 feet. At Cheda Ranch (KL) and Kelley's Tocaloma (KF), the MBE increased sharply during the 1998 water year, probably reflecting the arrival of the sediment pulse from the Big Bend events. The sawtooth profile of the Cheda Ranch site reflects effects of large wood moving into and out of the site, probably the large riparian-gallery alders which once grew in the half mile upstream.

The Big Bend sediment pulse overwhelmed the two sites downstream, leaving little distinction by segment type (pool, glide or riffle; Figure 13b).

4.2 Bed-Surface Material

4.2.1 Particle-size distribution

Particle sizes diminished slightly at all stations between the early 1980s and 2007 (Figure 20). Noteworthy is that the decline was evident in all segments. Declines in particle size at a given percentile are also evident at all stations in 2004, just prior to the episodic events of the winter of 2006. The decline appears to be associated primarily with the influx of San Geronimo sediment during 2002. Particle sizes did increase during the four years (1995 through 1998) of large spills from Kent Lake.

4.2.2 Cobbles as a proportion of bed area

Figure 19a and 24a show that the proportion of cobbles diminished at all sites from Big Bend upstream during the study period. The decline is most evident beginning in 2002, although most sites show a peak in cobble abundance following the 1998 storms. The decline is most evident in pools and secondarily glides, suggesting that an influx of sands and gravels from an upstream source – most logically, the San Geronimo Valley -- may be one possible cause.

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[30] We chose to compare 1993 with 2007, since neither are years of extreme change in bed conditions.

At Big Bend, cobble percentages dropped from 1994 to 1999, corresponding to the period of debris flows and channel changes, then returned to prior levels, but have diminished since 2000.

Further downstream, the proportion of cobbles remained relatively unchanged during passage of the pulse of sediment emanating from Big Bend, although the proportion of the bed surface comprised of sand appears to have increased sharply. In the pool at site KF, the increase in sand seems to have replaced or covered some of the gravels.

The decline in cobble percentage (most notably upstream of Big Bend) may be attributable to a number of causes, one of which appears to be the increase in bedload sediment during the 2002 water year. It is also possible that the additional large wood in the channel is mixing the bed in a way that results in a finer bed.

4.2.3 Sand as a proportion of bed area

The increase in the proportion of sand following the wet period of the mid-1990s is notable in each segment type. Figure 24b shows an increase in sand for all of the riffles from Big Bend upstream to Shafter, beginning in 2002. A similar pattern is evident for glides (Figure 26a); however, large proportions of sand on the beds of glides also occurred at earlier dates. Pools (figure 25a) show a high percentage of sand on the bed beginning in 1997. Comparisons in sand abundance between 1980/1981 and 2003/2004 show a clear increase in sand percentage. Because very little decrease is evident associated with the protracted 2006 spills, it is reasonable to hypothesize that there is an ongoing source of supply to support this evolving pattern.

4.2.4 Embeddedness

Embeddedness data are shown in Figure 20, emphasizing its distribution by segment. At Big Bend and each station downstream, an embeddedness peak was observed during passage of the sediment pulse from Big Bend. The embedding sediment – probably sands and silt – seems to have arrived a year sooner than the coarser bed material that affected the sub-surface grain sizes.

At all stations, embeddedness rose in the riffles and pools following the major storms of 2006, in many cases to levels exceeding those noted during the early 1980s. It is noteworthy, however, that at nearly all stations, embeddedness fell below 0.30 during 2004 – just before the storms of 2006--a decrease from values observed during the early 1980s. The decrease is significant in its magnitude, and is consistent among segment types (pool, riffle, glide) supporting its validity.

Sites KH and KF are sometimes exceptions. At site KH, the peaks in the glide and pool are probably attributable to water slowing behind the MMWD WDS at the downstream end of the glide. At site KF, embeddedness can be measured on only 2 to 5 cobbles, too few to give meaningful results.

4.3. Sub-surface Bed-Material Particle Sizes

Trends in the size of sediment beneath the bed surface are shown in Figures 14, 15, and 16 for D_{16}, D_{50} and D_{84}, respectively. The primary changes were increases in particle sizes at Big Bend and the two sites downstream. Peaks in all three size metrics occurred during the same years, adding validity to the data. We believe that the pulse of sediment from Big Bend was of larger sizes than what previously prevailed at these sites; here, the increase in the size of subsurface material does not necessarily translate to better habitat.

Little change is discernible at other sites, although mean particle sizes generally increased during the period of best habitat prior to arrival of the 2002 sediment wave.

Little or no change in particle sizes from those prevailing during the early 1980s could be noted.

4.3.1 Ratio of surface to subsurface particles

Figures 17 and 18 illustrate the ratio of surface to subsurface particles. Since the subsurface sample is taken at the pool-glide boundary, it may be compared to either of the two distributions. Figure 17 is based on the median size of material on the bed surface in pools; Figure 18 presents the ratio of the bed surface material in glides to the subsurface size distribution. Since typical ratios are often in the range of 2 to 3, and values below 2 are not common, the low values for Lagunitas Creek, shown on Figures 17 and 18, are somewhat surprising.

Both ratios show a clear set of lower values beginning in 2000. One possible explanation is that the addition of large wood (both naturally recruited and associated with WDS construction) were beginning to mix the bed, diminishing the differences between the surface layer and the subsurface. An alternate explanation is that sediment was accumulating on the bed during years of unremarkable rainfall. Certainly, the ratio increased following major spills in 1995, 1998 and 2006. The ratio did not fall however, during the protracted 1987-1991 drought, and high flows did occur during nearly all years following 2000. The role of large wood appears to be a more reasonable explanation, pending further inquiry.

4.4 Rock-Type Analysis

Figures 29a, b, and c show the distribution of major rock types at the three primary lithology monitoring sites:

- San Geronimo Creek at the MMWD Water Treatment Plant near Woodacre
- San Geronimo Creek at Lagunitas Road
- Lagunitas Creek at Kelley's Tocaloma

Data are also presented in Table 6. The lithology is noticeably consistent from year to year, an indication of a steady supply, such as might be obtained from erosion of its banks. A slight decrease in metavolcanics at the Water Treatment Plant may reflect a smaller contribution from Woodacre Creek, the only location in eastern San Geronimo Valley where metavolcanics are mapped. With little change in lithology over the years, lithology would suggest neither an improvement nor deterioration of bed conditions affected by sediment sources.

In recent years, we have been collecting lithology samples at sites along Lagunitas Creek between Shafter and Tocaloma. Samples collected at site KJ (Big Rock) show a large percentage of metavolcanic rocks, which predominate as bedrock between the lower San Geronimo Creek gage and Devils Gulch. This high proportion suggests that considerable sediment is entering Lagunitas Creek at some point downstream from the lower San Geronimo Creek gage. It is possible (and we believe likely) that the predominant source is the bed itself. We conjecture that the source of the dramatic increase in metavolcanics is reworking of the alluvial materials beneath the bed as more scour is induced by the growing amount of large wood placed in the stream. Some of the implications of this finding are discussed in Chapter 5.

5. DISCUSSION

5.1 Substantial Response to Influx of Sediment

5.1.1 Shafter Bridge to Big Bend

Observations during water years 1999 through 2005 show the effects of introducing large amounts of sediment into the Lagunitas channel from San Geronimo Creek during a period reasonably free of episodic disturbance. For those stations upstream of Big Bend, observations from 1999, 2000 and 2001[31] characterize a relatively 'clean' bed, a period:

- during which sediment delivery from San Geronimo Creek was low,
- when wood loading (both natural and placement of WDSs) was low, and
- following several consecutive years with spills from Kent Lake.

Following an order-of-magnitude increase in the rate of bedload-sediment delivery (measured as the amount of sediment transported at a given flow during storms; see Figure 31) the bed metrics show a cycle of sedimentation. While the source(s) within the San Geronimo Valley for the increased coarse-sediment yield have not been pinpointed, the bed upstream from Big Bend responded by becoming finer, aggrading at some locations, and increasing in embeddedness. Further observations and variables are described in the O'Connor Environmental (2006) report which effectively describes the highly sedimented conditions which prevailed beginning in the summer of 2002.

Results underscore the importance of concurrent measurements of sediment transport and bed conditions. Without the clear record of elevated bedload-sediment transport shown by the reconnaissance transport monitoring, factors contributing to the increased bed sedimentation could have been mis-assigned or conditions might have been interpreted as chronic.

The results also strongly suggest that a very real improvement in bed conditions can be realized if sediment yields from the San Geronimo Valley can be reduced or controlled to constrain the 'reach-wide spiking' in Lagunitas Creek shown during WY2002 and early WY2003. Recent

[31] Our last measurements during WY2001 were also elevated, hinting that at least some of the additional sediment delivery to San Geronimo Creek may have commenced during this relatively dry year.

measurements (Owens and others, 2008) show that, while diminished from the 2002 maxima, yields from the San Geronimo Valley remain substantially elevated above those recorded prior to 2002 (Figure 31).

The record of bed conditions needs to be considered in light of the ongoing accumulation of large wood in the channel resulting from the internal addition of woody debris structures and the concurrent cessation of the State Park's long-term program of clearing large wood from the channel (see Sec. 5.2, below).

5.1.2 Big Bend to Tocaloma

Three major channel-shifting episodes at Big Bend in 1995, 1996, and 1997 delivered large volumes of coarse sediment, particularly large particles stored in basal alluvial deposits, which progressively moved downstream to and through Tocaloma. Collectively, these can be considered a major set of episodic events which introduced the equivalent of 5 to 10 years of expected bedload sediment delivery – and probably several decades of the larger, matrix-forming particles critical to bed habitat. We believe it highly likely that the extensive 1- to 2-foot aggradation observed at most points downstream induced reach-scale sudden collapse of the mature riparian alder gallery, causing further localized bank erosion, formation of numerous transient logjams and a slight general widening of the channel, Given the magnitude and duration of these events, we do not recommend -- without very substantial qualification -- using the data collected at Big Bend and stations or reaches downstreamin assessing whether there is "appreciable improvement" in bed conditions, as the episodic disturbances over the monitoring period likely overwhelm any other factors that might be considered.

The effects of these events are continuing, albeit at a diminishing scale, as the central alluvial terrace at Big Bend is being progressively downcut and dissected, mobilizing stored alluvium accumulated over many years into the lower portion of the study reach. We believe that the aggradational pulse generated by these events induced waterlogging and collapse of the mature riparian gallery of alders, introducing additional coarse sediment into Lagunitas Creek.[32] The channel at Big Bend and points downstream has been gradually downcutting from the maximum sediment accumulation recorded in 2002 or 2003, but remains episodically

[32] As well as its transient storage or sequestration behind a large number of relatively short-term logjams formed of alder.

sedimented. Measurements made at and downstream from Big Bend reflect this sequence of events. They are an important description of the effects of episodes on Lagunitas Creek. They do not describe the 'normal' or chronic conditions expected in this reach. Similarly, they should not be compared with the conditions recorded in earlier reports (e.g., Li, 1983; Dettman and Kelley, 1980; Hecht, 1983) prevailing prior to 1995 without due consideration of these events. Reports by others (e.g., Stillwater Sciences, 2008a; O'Connor and Rossi, 2006) should also be read carefully and evaluated in light of the effects of these events.

We believe it plausible that the progressive downstream shift in *Syncaris* populations (Serpa 2004, 2006) may reflect in large part the pulse of sedimentation that has affected the lower portion of the study reach, and urge biologists to consider this among other potential explanations and contribution factors to the re-distribution of the shrimp.

5.2 Definition of the Geomorphic System Studied

The analysis shows that the monitoring network was at times robust, and at times was overwhelmed, mainly associated with events or circumstances that went beyond the limits envisioned for the original program. Understanding where (and when) we were and were not able to effectively describe responses shapes the context and boundaries within which to evaluate "appreciable improvement" or the identification of outliers and trends.

5.2.1 Limits to discernment

The monitoring program was able to withstand and quantify the response of the bed to major storm events, including the two outstanding, truly episodic events of January 4, 1982 and December 31, 2005. While not all parameters, cross sections or segments could be monitored following the events, the vast preponderance of metrics could be enumerated and used with a considerable degree of confidence. The fixed cross sections and the general stability of the pool, glide and riffle positions helped greatly in the resiliency of the monitoring program to these and other major floods. Similarly, the program has benefited from being conducted by essentially the same veteran professionals year after year, such that consistent field decisions could usually be made.

The program has proven less effective in quantifying or fully describing:

- the effects of the large-scale channel changes at Big Bend,

- the collapse (literally) of the gallery of mature alders lining the banks from Big Bend to Tocaloma into the channel, and
- the changes associated with upheaval of deep bed material caused by the introduction of large wood in the State Park reach between Shafter and Big Bend, including both increased natural recruitment[33] and placement of the woody debris structures.

In these cases, the subjective reconnaissance narratives (Hecht and others, 2008b and 2008c, Appendix B) have proven central in identifying the key events and in qualitatively describing the channel response.

The main differences between the two classes of conditions or events may be that, in general, the major storms transported sediment *over* the bed, while the disturbances less-successfully quantified are ones where the bed is disturbed *to considerable depths*.

Disturbance to depth means that a relatively large number of larger bed particles are mobilized. The large particles tend to remain within or near the riffle-pool-glide sequence in which they are brought to the surface. In the field, we can often recognize these particles by their angularity, depth of weathering, or rock type. Where the 'bed overturn' is localized – such as downstream from the 4-foot fir which fell in 1998 at KB-4 or downstream from individual logs or WDSs that have furrowed the bed as they are moved downstream -- we typically notice local bed contributions in the riffle downstream, or in the next riffle downstream. The cutoff channel and subsequent dissection of the main bar at Big Bend (as the channel has been deflected by sequential woodjams) have also introduced large volumes of relatively coarse material, some of which remains in place and some of which gradually moves downstream, almost in discrete waves following each major downcut or channel-change event.[34]

Large particles may be loosely defined for this study as those which comprise the framework of the bed. In Lagunitas Creek, many of these particles are in the range of 16 to 64 mm (0.6 to 2.5

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[33] Until the late 1990s, large wood was cleared regularly from the bed throughout Samuel P. Taylor State Park. During the study period, the channel was being naturally 'seeded' with large wood, in addition to the wood being placed as part of the woody debris structure program. Given the storminess (wind included) it is possible that more or larger wood was entering the channel from the slopes than might have been expected during a 12-year period; we do not have the data to test this speculation.
[34] See WY2006 monitoring report, Appendix F. for a description of how this bar is being downcut and dissected.

inches), somewhat coarser near Shafter and somewhat finer near Tocaloma. The supply and size of such particles in this range can have a marked influence on bed-condition metrics, affecting the particle-size distribution and comprising all of one metric -- bed particles larger than 45 mm. A small addition of large particles from deep in the local bed can make sharp differences in several bed metrics. Just how small can be seen by comparing the mean annual volume of particles larger than 20 mm from San Geronimo Creek (about 100 tons per year) with the volume of large sediment mobilized as a large tree or WDS plows a short distance downstream (perhaps 20 to 80 tons). Moreover, the local material mobilized from deep in the bed will likely be larger. As a result, mixing a relatively small fraction of deep bed material with the upper foot or so of bed that is often moved by large storms can make a large difference in one or more metrics.

Each major bed-shaping event is an epicycle of disturbance followed by a relaxation or attenuation phase during which the effects diminish, probably asymptotically. For large floods, the epicycle often lasts several years once the source has ceased contributing. The 'upheaval' events which disturb the bed to greater depth probably take somewhat longer to attenuate. When the event itself takes 4 to 6 years or longer – a duration observed with (a) the mature alder collapse, (b) downcutting and dissection of the Big Bend main bar, and (c) placement of the woody debris structures, the disturbance-attenuation epicycle can take a decade or more, in some cases longer than the monitoring period being reported.

In many cases, the bed at a given site is a mixture of two or more very different populations, and ones which can be expected to change over a time period not markedly different from the duration of the monitoring program.[35] There is a limit to discernment imposed by the presence of two or more populations, especially ones changing over time. It becomes very difficult – at present -- to establish trends that are meaningful for either stochastic or management purposes; recognition of outliers should proceed cautiously and with careful use of subjective reconnaissance results,

[35] One of most useful metrics indicative of mixing are the ratios of Dsize percentiles, such as D_{84}/D_{16},, which tend to remain stable over time in most streams, but show considerable variability in Lagunitas Creek.

It is difficult to envision this ongoing magnitude or frequency of multiple disruptive conditions and events continuing into the future. With a longer duration of monitoring, we believe it is likely that the effects of the disturbances can be discerned and more specifically interpreted.

5.2.2 Boundaries of the study reach

The monitoring program was designed to identify changes in bed conditions between Shafter and Tocaloma bridges. We found that data collected within this portion of Lagunitas Creek could be replicated and are helpful in understanding bed conditions. There was and is little need to monitor conditions upstream of Shafter on Lagunitas Creek using the same approaches. Downstream from McIsaac Creek or the Tocaloma Bridge, channel conditions change substantially. The transition reflects a fundamental geologic change to a reach with a channel formed in alluvium[36] deposited following the global rise of sea level at the end of the ice ages. The transition to post-Pleistocene alluvium is reflected in changes in bed conditions in virtually all salmonid streams in coastal California. In Lagunitas Creek, the flatter gradient results in chronic deposition and development of logjams. Locations of pools change with major storms, unlike the almost universal stability of pools, riffles, and glides within the monitored reach over the 30 years of study.[37] The assumption that a given pool-riffle-glide sequence is usually geomorphically connected with other sequences upstream and downstream, and that it is likely to be representative of those sequences, cannot be supported for the downstream reach. The few pools that appear to persist in the same location occur where the channel impinges on the bedrock walls of the valley, not truly typical of this reach. Seemingly significantly, use by the species of concern changes near this transition; virtually all salmonid spawning occurs upstream of Tocaloma Bridge, and the large, stable populations of *Syncaris* are now found downstream of the bridge.

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[36] The most downstream location we have found with bedrock exposed in the bed and extending seemingly beneath the entire bed and valley is just upstream of the "Trifurcation Point", approximately 200 yards downstream of McIsaac Creek and about 50 yards upstream from the McIsaac Ranch barns. This is a location where a downstream-migrant trap was operated during the Limiting Factors study (Stillwater, 2007). We believe that all of Lagunitas Creek downstream of this point is formed within post-Pleistocene deposits.

[37] See Table 10 in the Phase IIIA study (Hecht, 1981). We established and operated three stations downstream of Tocaloma and upstream of Nicasio Creek in 1981 (KM, KN, and KO; see Appendix A of that report for locations), and found that bed mobility as measured by accumulation and depletion of sediment was generally an order of magnitude greater than at the sites upstream of Tocaloma.

Monitoring of bed conditions, if any, might usefully be based on factors relating vegetation (both living riparian and logjams) to bed conditions, and/or to pool and glide metrics such as V* which are not specific to a given pool or glide. Conventional "geomorphic" approaches are not currently suitable downstream of Tocaloma.

5.2.3 Effects of tributaries and confluences

The original monitoring program design purposely excluded monitoring sites within 2 to 3 sequences of major tributary confluences. One exception was made deliberately to test whether this exclusion was warranted -- site KG, which included the second pool below Shafter Bridge[38]. Very different monitoring results were observed at this site than at the other bed-monitoring sites while it was active during water years 1980, 1981 and 1982 (Hecht, 1990).[39] Hence, results of the monitoring apply to the approximately 90 to 92 percent of the length of Lagunitas Creek between the two bridges that is not within 2 sequences of a major confluence.[40] We have no information from the bed-sites monitoring program[41] regarding sequential changes just downstream of the confluences of Devils Gulch, Irving and Cheda Ranch and McIsaac Creeks. By excluding these sites, however, we were able to avoid sampling a mix of populations – the spatial equivalent of the temporal mix that limits the level of discernment of other data.

The riffle and pool at the Campground Bridge (site KC) are just downstream from the confluence of a smaller but significant stream not named on the topographic quadrangle, which is locally known variously at Wildcat, Eagle, and Pioneer Trail Creek. Since construction of the bike path, the stream has been routed through a sedimentation basin, spilling through a large culvert into Lagunitas Creek. The basin filled with sediment during WY2006 (likely during the December 31 storm), introducing coarse sediment into Lagunitas Creek. A smaller amount again entered during the storms of WY2007. The riffle at site KC migrated downstream by

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[38] This site was lost in 1983 to realignment of SFD Highway associated with construction of the new Shafter Bridge

[39] During moderately wet WY1980, the site scoured an average of 0.40 feet compared an average of 0.13 feet at the other sites; it filled to a depth of 0.36 during WY1981, when almost no change was observed on average (and individually) at the other sites; and the riffle and glide filled while the pool scoured during the high flows of 1982 while the other sites filled by an average of about 0.35 feet. (See Appendix A)

[40] For Lagunitas Creek, major confluences might loosely be defined as those named on the 7.5-minute quadrangle map, plus Cheda Ranch, Wildcat, and McIsaac Creeks.

[41] These sites were regularly described with particular attention in the subjective reconnaissances, and numerous were photos taken.

about 10 feet, significantly filling the pool at this site. While there are a number of complicating factors at this site, it suggests that introduction of large gravels and small cobbles can destabilize the pool-riffle configurations on Lagunitas Creek. Site KC is the only the site to show discernible, unidirectional migration of segments during the 28 or 30 years of study.

5.3 Changes in Bed Lithology, 1980 to 2008

Lithologic evidence suggests that the bed currently contains a much larger fraction of locally-derived larger particles than at the start of our investigations in 1979. Our current lithologic counts from Site KJ (Big Rock) -- the site upstream of Devils Gulch -- contains about 40 percent metavolcanic rock, compared to about 10 percent at the Lagunitas Road gage on San Geronimo Creek (see Hecht and others, 2008b, Table 4). About 70 percent of the intervening watershed area is underlain by metavolcanic rocks ('**Jfg**' on Figure 2). Hence it is likely that about 3 to 5 times as much of the larger particles may be derived from the deeper bed – assuming that the deep bed has a lithology similar to the intervening watershed, which our field observations would support. In 1979, we concluded from more detailed lithologic evidence that San Geronimo Creek contributed 85 to 90 percent of the bed sediment at sites upstream from Devils Gulch (Hecht and Enkeboll, 1979, Figure 4). While no 1979 bed data are available from near Big Rock, we used sites upstream and downstream to interpolate that about 18 percent of the bed might have been composed of metavolcanic rock. The comparisons, while not exactly comparable, suggest that more than twice as much of the bed is now composed of metavolcanic particles. In our experience, this is a very, very large difference over a short period of time. Results imply that (a) sediment yields from San Geronimo Creek have diminished, and/or (b) more deep bed material is now in the near-surface bed sediment that we sample. Other data would seemingly rule out (a), so it is reasonable to conclude that the additional wood in the channel (from natural sources and/or MMWD WDSs) is mixing the bed more deeply.

In 1998, we observed the bed material dislodged from a 7-foot plunge pool downstream for a 4-foot douglas fir which fell across Lagunitas Creek near cross section KB-4, within the "Below Shafter site. This materials was distinctly different from the shallow bed material. It was subangular, rather than round, and it was composed of 95% metavolcanic rocks, which make up the walls and bed of the canyon at this location. We noted a very high percentage of metavolcanic rock originating from a smaller scour hole at a mobile WDS which lodged within cross-section KX-3, at Irving Campground. It is our belief that much of bed deeper than 2 to 3 feet is composed of locally-derived metavolcanic rock. The apparently sudden spike in the metavolcanic content of the bed, we believe, is due to re-working of these deep deposits, which

have not been mobilized for many years, due to the influx of very large wood over the past decade.

It should be emphasized that rock-type identification is not likely a source of this difference. Rock-type identification was conducted using a detailed checklist that had been refined over many years (see Appendix D), and was conducted independently by two experienced geologists, one of whom had done virtually all prior lithologic discriminations on Lagunitas Creek. Hence, the results must be given full credence as showing that the bed has been deeply mixed over the past decade in locations that have not seen such mixing in decades or centuries.

It is not clear whether the deep mixing will continue. If it does not, conclusions based on current conditions will not be representative of the long term, and it would be misleading to base an assessment of long-term trends on the current transient conditions.

5.4 Is There Appreciable Improvement in Bed Conditions?

Table 7 catalogs the individual metrics monitored and comments on whether they individually are indicative of appreciable improvement in bed conditions. In a few areas of inquiry, we do see some movement in directions deemed favorable for anadromous salmonids, and/or freshwater shrimp. In many areas, improvement does not clearly appear or there are confounding factors suggesting interpretation is not as simple as originally envisioned.

It is apparent, however, that substantive disturbances or episodes have affected Lagunitas Creek during the 13-year monitoring period, and particularly during its second half. Among these are:

- The recurrent disruptions at Big Bend, including a cycle of bar incision induced by a meander cutoff that is likely to persist for some time;
- An unexpected and sudden surge of sediment from San Geronimo Creek, whose source and cause we do not know, but whose presence is clear.[42] Conceivably, other tributaries may be responding to the same influences.

[42] Until we understand the cause and source, it is reasonable to be alert to the possibility that other tributaries may be yielding accelerated volumes in response to similar influences.

- A large episodic storm event (likely greater than a 20-year storm) during the next-to-last year of the monitoring period, juxtaposed with the absence of such a storm earlier during the monitoring period
- Twin decision to cease clearing woody debris naturally entering the streams –and allowing natural wood to accumulate – with a decision to place large woody debris structures in the monitoring sites, a bold choice that may yield important habitat enhancement in the short- and long-term future, but which disturbed the bed at depth, and will limit our ability to discuss straightforwardly the long-term trends in bed conditions questions until their transient effects have dissipated.

Each of these has introduced a volume of coarse sediment on the order of several to many years 'normal' sediment delivery. In some cases, disturbances beget derivative disturbances, which, in combination are persisting for 5 to 10 years – a duration that is long relative to the envisioned monitoring-and-reporting periods. Under these circumstances, asking the monitoring program for steady-state answers may be unrealistic.

In many respects, these events and their manifestations are exactly what we should all be seeking to learn about – responses of the bed to multiple types and sequences of perturbations in this channel, and watershed. Careful observation, and patience in watching stream response and adjustment, may provide the context and clues to understand this important habitat and channel.

We have tried to direct much of our work leading to this report to that end.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

1. This study is directed to a reporting and interpretation of 13 years of monitoring conducted as a condition of the State Water Resource Control Board's order WR95-17, encompassing 1995 through 2007. The report therefore also addresses 10 years of monitoring specified in the 1997 Sediment and Riparian Management Plan prepared by MMWD and approved by the State Water Resources Control Board. Where helpful, we have included discussion of prior monitoring using similar methods and sites conducted intermittently since 1979. A few qualitative observations made during the 2008 monitoring are mentioned, particularly where conditions have changed. The monitoring program continued using these approaches and methods through the summer of 2009.

2. Runoff during the 1995-2007 period (13 years) included a broad range of wet and dry years and several significant storm events. Mean runoff from San Geronimo Creek was virtually identical to the mean of the preceding 15 years (1980-1994). Runoff in Lagunitas Creek at SPTSP was about 160 percent of the 1980-1994 period; with adjustment for initial filling of the expanded Kent Lake, runoff from upstream of Peters Dam probably approached double the values of the 1980-1994 period. One implication is that the incidence and duration of low to medium spills may have been larger than might have prevailed during the earlier period. Conversely, four or five years between 2000 and 2004 are ones of minimal spills from Kent Lake with significant sediment loads from San Geronimo Creek, creating conditions under which sediment would tend to accumulate. Results should be interpreted in light of this bimodal pattern of flows.

3. Although the 1995 to 2007 period began with four consecutive years of heavy sediment transport associated with above-average rainfall and runoff, the 13 years ended with by a sequence of seven years of near- or below-normal rainfall interrupted only by WY2006. The period ended with two years during which bed conditions appear to reflect the episodic influence of the very major storm on December 31, 2005, plus the much above-average rainfall of the remainder of WY2006. Bed changes from 1995 to 2004 should be interpreted in light of the progressively drier prevailing conditions at the end of that period; comparisons made using endpoints in 1995 and 2007 may reflect the influence of the anomalous WY2006 events.

During the study period, several sequential events at Big Bend in 1995, 1996 and 1997 suddenly introduced large volumes of bed material into Lagunitas Creek at Big Bend ("Big Bend events"). These events, plus ongoing adjustments and further changes during WY2006 are described in Chapter 2 and in Appendix C. The volume of material mobilized at Big Bend is comparable to several years of expected bedload delivery from San Geronimo Creek. In addition to delivery of coarse material from the tributaries, sediment mobilized at Big Bend has raised the bed of Lagunitas Creek downstream to at least Tocaloma. The associated coarse-sediment influx has overwhelmed all other influences on bed conditions. These episodes have led to other events (secondary and tertiary episodic echoes) that continue to affect the lower portion of the study reach. At most locations below Big Bend, aggradation and fining reached a maximum during 21001, 2002 and 2003, with an overall recovery/depletion pattern complicated by ongoing incision of the Big Bend bar, forming and breaching of major logjams and logjam breaches.

Portions of our analysis make critical distinctions between Lagunitas Creek conditions above and below Big Bend. While gradually resuming more normal conditions, the bed at and downstream from Big Bend has been episodically sedimented to varying degrees since 1995. Influxes of coarse sediment from debris flows directly into the creek or from meander cutoff which equal or exceed the volume of bedload transport down Lagunitas Creek was not envisioned in developing WR1573 or in the Sediment and Riparian Management Plan. Given the magnitude and duration of these events, we do not recommend using the data collected at Big Bend and stations or reaches downstream in assessing whether there is "appreciable improvement" in bed conditions.

4. Since sequential episodes of coarse-sediment delivery have dominated bed conditions downstream of Big Bend, the logic of the WR1573 and the Sediment and Riparian Management might be reconsidered to incorporate such events. It is not difficult to anticipate that events of this type recur, at Big Bend or elsewhere. Additionally, Lagunitas Creek has not yet experienced during the monitoring period certain types of episodes that might be expected, including wildfires, severe droughts, and seismic events, each of which have been shown to generate comparably large sediment yields in similar coastal watershed of nearby counties. We may learn from the Big Bend events that management of Lagunitas should reasonably include provisions for the effects of episodic events, and the monitoring plan should explicitly include and anticipate rapid documentation of effects of quantifying recovery.

5. Since late-winter 2001, the bed throughout the study reach – and especially upstream from Big Bend -- appears to have been influenced by an influx of fine sediment, principally from San Geronimo Creek. Evidence for the influx includes both bed descriptors (decreases in the proportion of the bed occupied by cobbles and bedrock, and an increase in the proportion of sand) and an increase in the rate of bedload transport (coarse-sediment discharge) at the lower San Geronimo Creek gage. Initial indicators of increased San Geronimo contributions were first noted during the final storms of 2001, and were sharply manifested during 2002 and 2003, with some decrease in 2004. The 2005 and 2006 storms resulted in further increases in both bedload transport and bed sedimentation, which has continued through 2007 and into 2008 without clear signs of amelioration.

6. With the notable exception of the debris flows and the Big Bend meander cutoff, sediment enters Lagunitas Creek almost exclusively through tributaries and through localized changes in stream course. Under normal circumstances, very little sediment is mobilized from the banks of Lagunitas Creek itself, which in most locations are heavily vegetated or rocky. Tributary banks appear to be one set of primary sources of coarse sediment. In this respect, sediment delivery to Lagunitas Creek is distinctly different from other Marin streams, so markedly different sediment- and channel-management strategies are appropriate in this system.

7. Sediment delivery varies considerably from year to year in all tributaries. Debris flows or related processes, typically delivering several hundred tons of sediment, have been observed to enter Lagunitas Creek from each tributary except for San Geronimo Creek and Devils Gulch. The latter streams have experienced notable pulses of sediment delivery in 2002 to 2003 and 2006 to current (2008) respectively.

8. Since 1998 or 2000, measured bedload-sediment yields from San Geronimo Creek have averaged somewhat less than 2000 tons per year, or about half of the average rates observed during the base study period of water years 1980-1982. Within this new range, transport rates at a given flow have been higher in recent years. The sediment yields during the 1980s base period appear to have been episodically elevated, even prior to the January 4, 1982 flood; we infer that the bank weakening associated with the 1976-1977 drought was a major factor in introducing the predominantly sandy sediment which impaired habitat in the channel during the early 1980s – a benchmark period for this stream, and one which was the basis for many management goals and strategies.

9. Bed conditions respond to coarse-sediment delivery, whether it originates as tributary contributions, debris flows and landslides, re-working of the existing bed by formation and collapse of natural logjams or construction and migration of woody debris structures built as part of the Sediment and Riparian Management Plan, or localized changes in stream course.

10. Lithology analyses show responses to influxes from San Geronimo Creek and the Big Bend events:

    a. We recorded a tripling of the percentage of bed material composed of metavolcanic rocks at sites KC and KJ relative to 1979 measurements. It is possible (and we believe likely) that the predominant source is the bed itself. We conjecture that the source of the dramatic increase in metavolcanics is reworking of the alluvial materials beneath the bed as more scour is induced by the growing amount of large wood placed in the stream. This is one of the major findings of this report. As most readers of this report are likely to be non-geologists, it is important to indicate how large this change is and how rigorous and clear is the rock identification underlying this conclusion.

    b. We observed relatively minor changes in the locations of identifiable sediment sources within the San Geronimo Valley despite the significant increase in sediment production from the San Geronimo watershed during the 13-year monitoring period. One likely interpretation is that the increased yield is being produced from longer-term sediment storage, such as the bed of the channel (incision), its banks (bank retreat), or remobilization of sediment previously stabilized by vegetation.[43]

    c. In samples of bed material collected at the lower end of the study reach at Kelley's Tocaloma, increases in the proportion of certain sedimentary rocks outcropping near Big Bend probably reflect the influx in sediment from the

[43] A study of sediment sources, routing, and management options sponsored by the County of Marin and the RWQCB is currently under way, which may address the source locations.

debris flows at this site and (to a lesser degree) from other tributaries draining similar lithologies of the San Bruno terrane that forms Bolinas Ridge.

The lithologic analyses can be seen as underscoring differences in process between the main channel of Lagunitas Creek and the San Geronimo Valley, and to a lesser degree, other tributaries.

11. The program is evolving effectively, adding analyses as we adapt:

    a. periodic measurements of scour at selected spawning sites where cross-sectional data are also available back to 1980 or 1981;

    b. lithology counts have been added, directed toward discerning effects of remobilizing the bed ("bed turnover") associated with more large wood in the channel, the Big Bend events, and changes in land use in the San Geronimo Valley; and

    c. Describing and assessing the effects of events at Big Bend on the reaches downstream.

12. While mean flow for the 13-year monitoring period approximated normal, other factors were such that an 'appreciable improvement in bed conditions' should not be expected. Most telling is that changes in overall wood management appear to have fundamentally disturbed and 'turned over' portions of the bed. We and others had assumed that disturbing the experiment would not materially change the results, a hypothesis that has proved invalid in the light of hindsight. The fact that the 1995 - 2007 study period commenced with a sequence of wet years and large spills then ended with a sequence of predominantly dry years also affects the results. With respect to bed conditions, order matters. Had this sequence been reversed, bed conditions would likely have been very different, and most probably, much 'cleaner'. Other anomalous events discussed elsewhere in this chapter also merit consideration. We do not consider resumption of high sediment delivery from San Geronimo Creek to be anomalous, but rather recurrent.

13. The inventory of large wood in the Lagunitas Creek channel seems to have increased sharply since the early 1990s as a result of:

a. Changes in woody debris management practices, allowing fallen wood to remain in the channel;

b. Construction of woody debris structures on MMWD and SPTSP lands;

c. Corridor-changing die-off of the gallery of mature alders, followed by their collapse into the Lagunitas Creek channel, especially downstream of Big Bend;

d. Several significant windstorms, reportedly more than typical for a 10- or 12-year period, with resulting windfall loadings to both Lagunitas Creek and its tributaries; and

e. Above-average precipitation during this period, likely resulting in more rapid growth – especially of non-conifers – and a greater tendency for branches and whole trees to fall into the tributary and main channel.

With more wood entering the stream and less being removed, the channel has become distinctly more diverse. Localized accumulation and scour related to dragging large wood,, scour at logjams or structures, or backwaters from accumulation at bridges or bedrock outcrops have become increasingly significant factors in habitat conditions at any given point in the channel. The subjective reconnaissance portion of the monitoring program is becoming increasingly informative and essential to understanding (and chronicling) changes at the bed monitoring sites.

6.2 Recommendations

1. Continue the basic program elements.

2. Continue the evolving tradition of doing special studies as needed.

3. Make several changes in the monitoring:

   a. Systematically quantify additional sediment inputs. The present monitoring effort assumes that San Geronimo Creek is the primary source of sediment, as prevailed during the early 1980s base period. We have established that there are other important and time-varying sources of coarse sediment. These should be quantified systematically and semi-quantitatively, using a combination of field measurements, sketches and photography. Specific elements meriting quantification are:

      - Debris flows and deltas entering from tributaries;

- Major changes in channel course, such as at and below Big Bend, the reach immediately downstream of the Devils Gulch confluence and Trifurcation Point; and

- Exchange of sand and gravel from deeper within the bed than the immediate sub-bed-surface layer may be volumetrically an important element in the sediment budget, as highlighted by the mineralogical evidence from station KJ.

b. The simple rise and fall of the bed, segment by segment at the bed monitoring sites, should be quantified and understood.

c. The long-term role of the scour hole at the base of the Peters Dam spillway as a potential sediment source should be quantified.

d. Add particle-size analysis, and possibly lithologic assessment, to the San Geronimo Valley program.

e. Continue MMWD's program of examining net scour and fill around WDS, and factor in upstream and downstream effects identified by this program, such as the shoaling and fining extending considerably upstream from the natural log jam below site KJ (which is visually discernible as far upstream as KJ-6), or the woody debris structures (each of which have been moved by flows) at sections KH-7, KX-3, or KC-8

4. Recognizing that the USGS gage at SPTSP has a specific low-flow focus, question whether the data provided for peak flows are sufficient for habitat purposes, and inquire into whether the costs of alternate gaging methods or locations are warranted in light of recent biological data and interpretations, which identify other limiting factors (Stillwater Sciences, 2007) or alternative hypotheses (Serpa, 2006). This may be as simple as conducting a standard FISP indirect peak flow measurement at another location on Lagunitas Creek, and using these results to guide the next steps.

5. It may prove helpful to revisit the specific geomorphic and sediment-management goals for *Syncaris pacifica* to emphasize hydraulic and geomorphic factors affecting the distribution of adventitious roots and deep pools, and to recognize that undercut banks seem to be a secondary factor in Lagunitas Creek (although perhaps not in other systems), perhaps as part of a comprehensive re-thinking of *Syncaris* needs in this stream in light of abrupt (below Big Bend) and progressive changes in riparian canopy vegetation.

6. New paradigms integrating multiple processes and dynamics of the Lagunitas watershed -- including vegetation, hydrology, and fluvial geomorphology, and sediment supply -- will be needed to effectively manage this stream. The former mechanistic approach for managing bed conditions of focusing solely on the changes in flushing flows emanating from Kent Lake has proven helpful but is not nearly sufficient to account for year-to-year and site-to-site variability in bed conditions. We have learned that coarse-sediment supply can have an overwhelming influence (below Big Bend, or following the 2002-3 and 2006 supply events from San Geronimo Creek) as can sediment storage (potential role of the Big Bend event on *Syncaris*, the effects of changing large-wood management, and the current storage of fine gravels behind the natural debris jam below KJ), plus the role of the WDS in detaining sediment. Wood in the channel, as well as the status of riparian vegetation, are all critical factors affecting bed conditions. While there is merit to considering the reach globally, local differences often prove to be governing; it may not be adequate or useful to summarily characterize bed conditions as improving or deteriorating throughout the study reach. We have found a global description to mask the important changes – and their causes or drivers -- that we observed during this 13-year period.

7. The core bed-monitoring strategy remains useful, diagnostic, and versatile, including the program at the 8 bed-monitoring sites. Principal recommendations for changes in the bed-monitoring program include:

    a. Perform a longitudinal survey of the channel from Shafter to Tocaloma bridges, including both thalweg and high-water marks (HWMs), and specifically HWMs from the WY2006 event and a near-bankfull event. Stationing for this survey can and should be used to reference the locations of logjams, specific pools, or other measurements, and may also prove useful in the spawner surveys or Syncaris monitoring. The HWMs are a useful integrator of the role of vegetation and physical bed conditions over the long term in shaping Lagunitas Creek – perhaps our greatest long-term challenge.

    b. Continue the practice of incorporating special studies warranted by conditions developing each year, as has been conducted during recent years, when recommended by the project geomorphologists.

    c. Incorporate photographs at each bed monitoring site, and at other locations as indicated by each year's events or conditions, with the captioned and located

photos included as an appendix to the annual report.

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8. ABBREVIATIONS AND ACRONYMS

Abbreviations/Acronyms	Description
AGU	American Geophysical Union
CCCRWQCB	California Central Coast Regional Water Quality Control Board
CDMG	California Division of Mines and Geology (now California Geological Survey)
CNCRWQCB	California North Coast Regional Water Quality Control Board
D16 or D_{16}	16th percentile of size distribution (16 percent of the particles are finer)
D50 or D_{50}	Median particle size (50th percentile of distribution, with 50 percent of the particles being finer)
D84 or D_{84}	84th percentile of size distribution (84 percent of the particles are finer)
D1573	State of California Water Resources Control Board's Decision 1573
DFG	California Department of Fish and Game
FISP	Federal Interagency Sedimentation Program, the guidelines which also govern standard USGS techniques
HWMs	High-water marks
K1, K4, K6	stream gage and/or sediment-transport monitoring site (see Figure 1
KB, KH, KX, KC, KJ, KD, KL, KF	Bed-condition monitoring sites (see Figure 2)
LWD	Large woody debris
MBEs	Mean bed elevations
MCFCWCD	Marin County Flood Control and Water Conservation District
MCRCD	Marin County Resource Conservation District
MMWD	Marin Municipal Water District
NCCC	North-Central California Coast recovery domain: (NOAA-TM- NMFS-SWFSC)
NOAA	National Oceanic and Atmospheric Administration
PCI	Prunuske Chatham, Inc.
RWQCB	Regional Water Quality Control Board, San Francisco Bay Region

SFD Highway	Sir Francis Drake Highway
SOD	Sudden oak death
SPTSP	Samuel P. Taylor State Park
TAC	Lagunitas Creek Technical Advisory Committee
USGS	United States Geological Society
WDS	Woody debris structures
WRR	Water Resources Research

Note: Balance Hydrologics observes the convention of National Board on Geographical Names to not use apostrophes in place names (e.g., Devils Gulch, Deadmans Creek)

TABLES

Table 1. High-Flow Spills and Releases From Kent Lake, Lagunitas Creek
Water Years 1995 to 2009, Also Including 1980, 1981, 1982, and 1993

Water Year[1]	Date of Spill	Mean Daily Spills > 300 (cfs)[2]	Mean Daily Flow @ SPTSP (cfs)[3]
1980	15-Jan	375	533
	16-Jan	373	509
	17-Jan	371	no data
	17-Feb	353	no data
	18-Feb	583	no data
	19-Feb	605	1486
	20-Feb	578	1153
	21-Feb	531	no data
	22-Feb	373	no data
	23-Feb	321	421
#days with spill over 300 cfs		**10**	
#days with spill over 600 cfs		**1**	
1981		**no spills**	
1982	5-Jan	493	1170
	6-Jan	498	740
	7-Jan	474	680
	8-Jan	466	640
	9-Jan	458	610
	10-Jan	450	590
	11-Jan	442	560
	12-Jan	503	618
	13-Jan	601	730
	14-Jan	480	690
	15-Jan	558	650
	16-Jan	537	600
	17-Jan	524	550
	18-Jan	382	401
	16-Feb	432	955
	17-Feb	414	657
	31-Mar	442	1280
	1-Apr	430	740
	2-Apr	405	956
	3-Apr	437	836
	4-Apr	435	640
	5-Apr	302	381
	11-Apr	421	900
	12-Apr	417	680
#days with spill over 300 cfs		**24**	
#days with spill over 600 cfs		**1**	
1993	21-Jan	620	868
	22-Jan	471	618
	23-Jan	318	402
	19-Feb	400	675
	24-Feb	338	420
#days with spill over 300 cfs		**5**	
#days with spill over 600 cfs		**1**	
1995	13-Jan	340	969
	14-Jan	709	1560
	15-Jan	503	893
	23-Jan	833	1590
	24-Jan	419	809
	25-Jan	361	460
	27-Jan	562	1380
	28-Jan	731	1260
	29-Jan	484	737
	9-Mar	886	1790
	10-Mar	886	1430
	11-Mar	572	933
	14-Mar	582	1090
	15-Mar	552	882
	16-Mar	308	457
#days with spill over 300 cfs		**15**	
#days with spill over 600 cfs		**5**	

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Water Year[1]	Date of Spill	Mean Daily Spills > 300 (cfs)[2]	Mean Daily Flow @ SPTSP (cfs)[3]
1996	28-Jan	335	626
	29-Jan	340	395
	31-Jan	305	738
	1-Feb	401	538
	2-Feb	359	349
	4-Feb	568	2000
	5-Feb	798	1540
	6-Feb	569	651
	7-Feb	328	363
	20-Feb	434	865
	21-Feb	501	1030
	22-Feb	537	688
	23-Feb	445	371
#days with spill over 300 cfs		**13**	
#days with spill over 600 cfs		**1**	
1997	30-Dec	308	1280
	31-Dec	532	1130
	1-Jan	428	2600
	2-Jan	1564	1970
	3-Jan	810	935
	23-Jan	401	803
	26-Jan	493	1170
	27-Jan	419	561
#days with spill over 300 cfs		**8**	
#days with spill over 600 cfs		**2**	
1998	18-Jan	484	792
	19-Jan	371	914
	31-Jan	358	387
	1-Feb	562	868
	2-Feb	655	1690
	3-Feb	406	2870
	4-Feb	392	973
	5-Feb	308	973
	6-Feb	737	1310
	7-Feb	709	1490
	8-Feb	392	1030
	14-Feb	300	699
	19-Feb	592	1090
	20-Feb	341	888
	21-Feb	687	1120
	22-Feb	392	948
	23-Feb	333	709
#days with spill over 300 cfs		**17**	
#days with spill over 600 cfs		**4**	
1999	7-Feb	715	1250
	8-Feb	329	1000
	9-Feb	312	987
	16-Feb	451	378
	17-Feb	508	1270
#days with spill over 300 cfs		**5**	
#days with spill over 600 cfs		**1**	
2000	29-Feb	349	501
	1-Mar	388	328
	2-Mar	341	237
#days with spill over 300 cfs		**3**	
#days with spill over 600 cfs		**0**	
2001		**no spills**	
2002	21-Feb	320	342
#days with spill over 300 cfs		**1**	
#days with spill over 600 cfs		**0**	
2003	23-Jan	371	420
	24-Jan	304	360
#days with spill over 300 cfs		**2**	
#days with spill over 600 cfs		**0**	

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Table 1. High-Flow Spills and Releases From Kent Lake, Lagunitas Creek
Water Years 1995 to 2009, Also Including 1980, 1981, 1982, and 1993

Water Year[1]	Date of Spill	Mean Daily Spills > 300 (cfs)[2]	Mean Daily Flow @ SPTSP (cfs)[3]
2004	16-Feb	460	473
	17-Feb	560	660
	25-Feb	454	567
#days with spill over 300 cfs		**3**	
#days with spill over 600 cfs		**0**	
2005	28-Feb	358	419
	1-Mar	328	338
	2-Mar	341	370
	22-Mar	465	1010
	23-Mar	415	909
#days with spill over 300 cfs		**5**	
#days with spill over 600 cfs		**0**	
2006	30-Dec	916	622
	31-Dec	2627	4620
	1-Jan	644	1210
	2-Jan	517	667
	3-Jan	527	561
	4-Jan	498	568
	29-Jan	300	480
	30-Jan	392	489
	25-Mar	493	1150
	11-Apr	362	514
	12-Apr	916	1700
	13-Apr	451	913
#days with spill over 300 cfs		**12**	
#days with spill over 600 cfs		**4**	
2007		**no spills**	

Notes:

1. Data are presented on a water year basis (October 1 to September 30).
2. Spills measured daily at Kent Lake spillway by MMWD staff.
3. Mean daily flow in 1980 and 1982 recorded by H. Esmaili & Associates (HEA) at Samuel P. Taylor State Park campground bridge. See Hecht and Enkeboll (1980), Hecht and others (1981), and Hecht (1983) for daily flows. Mean daily flow in 1983 through 2007 measured at USGS station 11460400 (Lagunitas Creek at Samuel P. Taylor State Park, CA).

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Table 2. Elements, foci, and applications of bed-conditions monitoring program, Lagunitas Creek

Monitoring Task	*What Is Done*	*Reaches*	*Segment(s)*	*Population*	*Main Application*	*Life Stages*	*Remarks*
1. Subjective reconnaissance	Geomorphologist and engineer walk the full length of both reaches and: 1. Describe conditions during prior winter 2. Observe changes in bed and channel conditions 3. Note locations of sediment delivery, esp. tributaries	State Park and Upper Tocaloma			Record discernible geomorphic trends Assess whether data can be collected at standard monitoring sites, and the degree to which the sites are representative of the 1-km sections of creek Identify where sediment is entering or leaving the channel of Lagunitas Cr. Catalog significant disturbances or recovery from disturbances Understand downstream (longitudinal) changes and responses Obtain a general idea of bed conditions likely to affect salmonids and *Syncaris*		An important task, often skipped in other monitoring programs suggested by Dana Roxon, MMWD
2. Bed-surface particle-size distribution	Particles on bed are measured, using intermediate axis, based on bed census	8 sites	P, G, R	Bed surface	Rearing-habitat quality Susceptibility to scour Spawning suitability	Rearing; also spawning, incubation	Stratified random sampling by area to promote equal chance of being sampled
3. Percent area covered by sand, bedrock, organic particulates and elements, and cobbles	Bed census is used to measure the percentage of bed surface occupied	8 sites	P, G, R	Bed surface	Rearing-habitat quality	Rearing	Stratified random sampling by area to quantify percent of bed area occupied
4. Embeddedness	Mean embeddedness is measured for each particle sampled in bed census	8 sites	P, G, R	Bed surface	Rearing-habitat quality Possible Syncaris habitat descriptor	Rearing	We are beginning to question the value of this metric in Lagunitas Creek
5. Bed cores	A sample of bed material from beneath the surface is collected in a 6-inch sampler driven into the bed	8 sites + San Geronimo Cr at Lagunitas Rd and water treatment plant	pool/glide boundary	Beneath surface	Measures the size and type of sediment stored beneath the bed surface, which is likely to affect near-future bed surface See also Gravel lithologies	All stages will be affected	Does **not** measure suitability of material for spawning or incubation; descriptors limited to range of D_5 to D_{95}, so does not measure infiltration of fines.
6. Bed configuration surveys	7 to 12 cross sections are surveyed ~ 1 channel width apart are surveyed at each site. High-water marks are recorded; locations of fallen wood within cross sections is noted	8 sites	P, G, R	Bed and banks	Measures changes in mean bed elevation Residual pool volume Location of net scour and fill Net accumulation or depletion of sediment on the bed Long-term trends in bed configuration Bank retreat or bar growth, if any Characterizes thalweg at each site	Basic data applied in misc. ways	Measurements made between rebar monuments installed at 5-year flood level on each bank. Eric Austensen (PCI) is presently directing the cross-sectional surveys Tapes are pulled to standard tension to abet comparing bed configuration from year to year
7. Gravel lithologies ('gravels source tracing')	Rock types of 8 to 16 mm gravels are identified under magnification	San Geronimo Creek at Lagunitas Rd and WTP Lagunitas Cr nr Tocaloma Since 2006, at other sites	P, G	Beneath surface	Quantifies changes in the sources of coarse sediment in Lagunitas Cr.	n/a	Approximately 120 to 250 particles are identified using a standard 'key' Gravels are from bed cores after sieving 8-16 mm size fraction used for tracing
8. Sediment transport and streamflow (bedload and suspended sediment)	Measured during storms with a Helley-Smith sampler, 0.250 net mesh	San Geronimo Cr at Lagunitas Road bridge	n/a	Material in actual transport	Assessing long- and short-term trends in sediment yields from SG Valley	Basic data affects all stages	Proving very useful in assessing utility of sediment-reduction program and episodicity; Since March 2006, streamflow telemetered to website
		San Geronimo Cr.	n/a	temperature	Evaluating long-term trends; episodes	Summer rearing	Since March 2006, telemetered to website
10. Special studies	As indicated by field findings	Where indicated by field findings			Scour (2002-2006) Big Bend events (1995-7) Sedimentation below Big Bend(2006)	Early life stages All life stages All life stages, *Syncaris*	See report Major and ongoing effects See report

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Table 3. Mean embeddedness by site, segment, and year
Lagunitas Creek bed monitoring program

Year		KB Below Shafter	KH K. Up St Pk	KX Above Irving Br.	KC Cmpgrd Bridge	KJ Big Rock	KD Big Bend	KL Cheda	KF K. Tocaloma	Average, all 7 sites	Average upstream of Big Bend sources
1991	R	0.29	0.12	--	--	0.12	--	0.19	0.20	0.1840	*0.177*
	P	0.18	0.24	--	--	0.21	--	--	0.24	0.2175	*0.210*
	G	--	0.22	--	--	0.24	--	--	0.35	0.2700	*0.230*
	Mean	*0.235*	*0.193*	--	--	*0.190*	--	*0.190*	*0.263*	*0.2143*	*0.206*
1993	R	0.34	0.24	--	0.33	0.16	0.18	0.21	0.18	0.2343	*0.268*
	P	0.31	0.31	--	0.20	0.33	0.25	--	0.53	0.3217	*0.288*
	G	0.47	0.22	--	0.22	0.47	0.30	0.42	0.40	0.3571	*0.345*
	Mean	*0.373*	*0.257*	--	*0.250*	*0.320*	*0.243*	*0.315*	*0.370*	*0.3040*	*0.300*
1995	R	0.37	0.16	--	0.23	0.27	0.14	0.33	0.12	0.2314	*0.258*
	P	0.42	0.27	--	0.21	0.29	0.23		0.38	0.3000	*0.298*
	G	0.62	0.22	--	0.24	0.28	0.22	0.46	0.12	0.3086	*0.340*
	Mean	*0.470*	*0.217*	--	*0.227*	*0.280*	*0.197*	*0.395*	*0.207*	*0.2845*	*0.298*
1996	R	0.37	0.18	--	0.24	0.42	0.37	0.54	0.07	0.3129	*0.303*
	P	0.25	0.3	--	0.18	0.36	--	--	0.52	0.3220	*0.273*
	G	0.32	0.29	--	0.16	0.42	--	--	--	0.2975	*0.298*
	Mean	*0.313*	*0.257*	--	*0.193*	*0.400*	*0.370*	*0.540*	*0.295*	*0.3383*	*0.291*
1997	R	0.28	0.20	--	0.29	0.08	--	0.08	0.14	0.1783	*0.213*
	P	0.33	0.21	--	0.27	0.32	--	--	0.54	0.3340	*0.283*
	G	0.31	0.33	--	0.25	0.24	--	--	0.34	0.2940	*0.283*
	Mean	*0.307*	*0.247*	--	*0.270*	*0.213*	--	*0.080*	*0.340*	*0.2428*	*0.259*
1998	R	0.17	0.20	--	0.29	0.10	0.07	0.14	0.25	0.1743	*0.190*
	P	0.49	0.26	--	0.27	0.18	0.23	--	--	0.2860	*0.300*
	G	0.43	0.33	--	0.21	0.26	0.13	--	--	0.2720	*0.308*
	Mean	*0.363*	*0.263*	--	*0.257*	*0.180*	*0.143*	*0.140*	*0.250*	*0.2281*	*0.266*
1999	R	0.31	0.21	--	0.22	0.13	0.14	--	0.16	0.1946	*0.218*
	P	0.53	0.3	--	0.22	0.19	0.00	--	0.30	0.2567	*0.310*
	G	0.51	0.34	--	0.21	0.21	0.16	--	--	0.2866	*0.318*
	Mean	*0.450*	*0.283*	--	*0.217*	*0.177*	*0.100*	--	*0.231*	*0.2428*	*0.282*
2000	R	0.22	0.31	--	0.17	0.16	0.09	0.17	0.11	0.1751	*0.215*
	P	--	0.35	--	0.19	0.31	0.00	0.00	--	0.1700	*0.283*
	G	0.48	0.28	--	0.23	0.27	0.12	0.06	0.28	0.2460	*0.315*
	Mean	*0.350*	*0.313*	--	*0.197*	*0.247*	*0.069*	*0.076*	*0.196*	*0.2069*	*0.277*
2001	R	0.25	0.14	--	0.21	0.08	0.00	0.06	0.08	0.1181	*0.170*
	R_{minor}	--	--	--	--	--	--	--	0.17	0.1667	--
	P	--	0.23	--	0.23	0.15	0.00	--	--	0.1530	*0.204*
	P_2	--	--	--	--	--	--	0.00	--	0.0000	--
	G	0.44	0.35	--	0.26	0.12	0.00	--	0.35	0.2542	*0.293*
	Mean	*0.345*	*0.241*	--	*0.235*	*0.116*	*0.000*	*0.032*	*0.202*	*0.1670*	*0.234*
2002	R	0.25	0.25	0.17	0.23	0.13	0.23	0.10	0.11	0.1839	*0.206*
	P	0.32	0.28	0.42	0.33	0.21	0.13	--	0.38	0.2939	*0.310*
	G	0.33	--	0.31	0.30	0.30	0.24	--	0.26	0.2894	*0.309*
	Mean	*0.297*	*0.263*	*0.299*	*0.286*	*0.214*	*0.203*	*0.095*	*0.249*	*0.2383*	*0.272*
2003	R	0.29	0.25	0.25	--	--	0.24	0.30	--	0.2665	*0.266*
	$R_{with\ bar}$	--	--	--	--	0.10	--	--	0.18	0.1405	*0.100*
	$R_{without\ bar}$	--	--	--	--	0.10	--	--	0.16	0.1264	*0.096*
	P	0.49	0.47	0.26	0.33	0.43	0.14	--	0.37	0.3533	*0.394*
	G	0.35	0.51	0.17	0.39	0.39	0.43	--	0.37	0.3727	*0.362*
	Mean	*0.376*	*0.410*	*0.228*	*0.358*	*0.254*	*0.269*	*0.296*	*0.268*	*0.3074*	*0.325*
2004	R	0.21	0.21	0.21	--	0.17	0.06	0.27	0.10	0.1767	*0.201*
	$R_{scoured}$	--	--	--	0.36	--	--	--	--	0.3647	*0.365*
	$R_{backwater}$	--	--	--	0.29	--	--	--	--	0.2875	*0.288*
	P	0.42	0.27	0.25	0.27	0.19	0.21	0.27	--	0.2693	*0.280*
	G	0.22	0.59	0.10	0.33	0.35	0.15	--	0.28	0.2893	*0.319*
	Mean	*0.283*	*0.359*	*0.185*	*0.315*	*0.237*	*0.139*	*0.273*	*0.193*	*0.2479*	*0.276*
2006	R	0.20	0.31	0.31	0.22	0.25	0.34	0.24	0.25	0.2640	*0.258*
	P	0.38	0.35	0.41	0.24	--	0.24	--	0.42	0.3403	*0.347*
	G	0.46	0.28	0.28	0.24	--	0.30	--	0.35	0.3174	*0.315*
	Mean	*0.350*	*0.313*	*0.331*	*0.233*	*0.252*	*0.292*	*0.238*	*0.336*	*0.2932*	*0.296*
2007	R	0.33	0.37	0.37	0.27	0.23	0.22	0.25	0.42	0.3081	*0.314*
	P	0.56	0.57	0.26	0.35	0.56	0.43	--	0.64	0.4811	*0.459*
	G	0.66	0.49	0.28	0.38	0.20	0.29	0.00	0.51	0.3516	*0.402*
	Mean	*0.517*	*0.476*	*0.304*	*0.330*	*0.331*	*0.314*	*0.126*	*0.525*	*0.3655*	*0.392*
Mean	R	0.277	0.225	0.262	0.258	0.167	0.173	0.221	0.169	0.2190	*0.238*
	P	0.390	0.315	0.320	0.253	0.286	0.169	0.091	0.431	0.2819	*0.313*
	G	0.431	0.342	0.227	0.262	0.289	0.214	0.235	0.328	0.2911	*0.310*
	Mean	*0.366*	*0.294*	*0.270*	*0.258*	*0.247*	*0.185*	*0.182*	*0.309*	*0.2640*	*0.287*

Notes

Average not computed for a site and year if fewer than two segments are listed; also excluded from segmental, site, and annual means
Exclude segment if less than 5 percent of bed material sampled are cobbles
Exclude segment if bed census moved to a very different site for the year (KD in 1996, 1997)
Site means may deviate slightly from segment means because all years' segments are averaged, even if a site mean is not computed
Underscore designates that a major change occurred at that site between summers shown

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Table 4. Lagunitas Creek Bed Conditions Monitoring: Mean Bed Elevations

SITE KB – BELOW SHAFTER

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KB1	155.50	156.40	155.80	155.20	155.70	155.60	155.90	156.00	156.44	155.55	155.96	155.03	155.23	-0.27	155.72	0.43	R/P
KB2	ND	155.70	155.70	155.50	155.70	155.70	155.90	156.00	156.28	155.80	155.93	155.06	155.20	-0.50	155.71	0.33	P
KB3	157.20	155.90	155.70	155.50	155.60	155.90	155.90	155.90	156.11	155.83	155.84	155.07	155.26	-1.94	155.82	0.50	P
KB4	155.90	155.90	155.60	155.50	155.60	155.70	156.90	155.80	156.20	155.84	155.71	155.03	155.12	-0.78	155.75	0.47	P
KB5	155.60	155.60	155.60	155.50	155.10	154.50	ND	ND	154.89	ND	ND	155.19	155.22	-0.38	155.24	0.38	P/G
KB6	155.80	155.70	155.70	155.50	155.10	154.70	ND	ND	155.08	154.98	155.13	154.98	155.09	-0.71	155.25	0.36	G
KB7	ND	155.50	155.50	155.50	154.80	155.00	155.30	155.40	155.62	155.27	155.62	154.71	154.69	-0.81	155.24	0.35	R
KB8	155.50	155.40	154.80	155.00	154.50	154.40	154.70	154.80	155.13	155.15	155.11	154.53	154.57	-0.93	154.89	0.35	P
KB9	155.50	155.10	154.40	154.80	154.30	154.30	154.70	154.70	154.27	154.83	154.63	154.28	154.27	-1.23	154.62	0.38	P
KB10	155.40	154.90	154.10	154.10	154.00	ND	154.50	154.50	154.41	154.31	154.57	154.00	154.00	-1.40	154.40	0.42	P
KB-11	ND	ND	ND	ND	ND	ND	154.50	154.50	154.86	153.91	154.05	153.94	153.95	-0.55	154.24	0.37	G
KB-12	ND	ND	ND	ND	ND	ND	154.60	154.90	154.72	154.90	154.94	154.63	154.57	-0.03	154.75	0.16	R
KB-13	ND	ND	ND	ND	ND	ND	153.70	153.70	153.63	153.22	153.66	154.14	154.12	0.42	153.74	0.32	R
Mean	*155.80*	*155.61*	*155.29*	*155.21*	*155.04*	*155.09*	*155.15*	*155.11*	*155.20*	*154.97*	*155.10*	*154.66*	*154.71*	-1.09	155.15	0.31	

SITE KH – KELLEY'S UPPER

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KH1	143.10	143.00	142.90	142.90	143.00	143.00	142.90	142.90	143.10	143.06	143.02	143.50	143.54	0.44	143.07	0.21	R
KH2	142.60	142.40	142.30	142.20	142.30	142.40	142.40	142.40	142.60	142.75	142.41	142.98	143.14	0.54	142.53	0.28	R
KH3	142.30	141.90	141.70	141.80	141.80	141.80	141.80	141.90	142.20	142.11	142.06	142.25	142.32	0.02	142.00	0.22	R/P
KH4	142.10	141.50	141.70	141.40	141.20	141.30	141.30	141.40	141.90	141.70	141.74	141.79	141.72	-0.38	141.60	0.27	P
KH5	142.30	141.80	141.80	141.70	141.70	141.60	141.60	141.70	142.10	142.12	142.11	142.11	142.16	-0.14	141.91	0.25	P/G
KH6	142.40	142.10	142.00	142.10	141.90	141.90	141.90	141.90	142.20	142.36	142.22	142.15	142.19	-0.21	142.10	0.17	G
KH7	142.30	142.10	141.80	141.70	141.80	141.80	141.80	141.90	142.20	142.09	142.13	142.31	142.37	0.07	142.02	0.23	G
Mean	*142.44*	*142.11*	*142.03*	*141.97*	*141.96*	*141.97*	*141.96*	*142.01*	*142.33*	*142.31*	*142.24*	*142.44*	*142.49*	0.05	142.17	0.21	

SITE KX – ABOVE IRVING BRIDGE

Section	2002	2003	2004	2006	2007	**overall change 2002-2007**	**Mean MBE 2002-2007**	**Stand.dev**	**Segment type** (R, P, G)
KX1	138.08	138.00	138.74	138.34	138.41	0.24	138.31	0.29	P
KX2	138.34	138.38	138.51	137.56	137.72	-0.45	138.10	0.43	P
KX3	138.11	138.17	138.43	138.09	138.18	0.05	138.20	0.14	G
KX4	137.94	137.91	137.00	137.91	137.99	0.04	137.75	0.42	P/G
KX5	138.54	138.50	137.97	137.47	137.43	-0.80	137.98	0.54	G
KX6	139.00	139.02	138.75	138.04	138.01	-0.71	138.56	0.50	R
KX7	138.69	138.70	138.67	137.43	137.57	-0.81	138.21	0.65	R
KX8	138.16	138.32	138.14	136.95	137.06	-0.80	137.73	0.66	R
KX9	136.77	136.83	136.95	136.68	136.93	0.12	136.83	0.11	R
Mean	*138.18*	*138.20*	*138.13*	*137.61*	*137.70*	-0.35	137.96	0.29	

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Table 4. Lagunitas Creek Bed Conditions Monitoring: Mean Bed Elevations

SITE KC – CAMPGROUND BRIDGE

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KC1	117.80	117.70	117.70	117.60	117.60	117.60	117.60	117.60	117.57	117.57	118.41	117.46	117.76	-0.03	117.69	0.23	R
KC2	117.20	117.20	117.00	116.90	116.80	116.80	116.80	116.80	116.98	116.89	117.03	116.75	117.18	-0.02	116.95	0.16	R
KC3	117.00	116.90	116.70	116.70	116.50	116.50	116.60	116.60	116.85	116.74	117.01	117.18	117.32	0.27	116.82	0.26	P
KC4	116.90	121.50	116.50	116.50	116.50	116.40	116.40	116.50	116.66	116.54	116.88	116.99	117.12	0.19	117.03	1.36	P
KC5	116.80	116.60	116.30	116.20	116.40	116.30	116.40	116.40	116.62	116.51	116.82	116.89	116.99	0.16	116.56	0.25	P
KC6	116.60	116.50	116.30	116.20	116.30	116.30	116.20	116.30	116.57	116.41	116.87	117.04	117.27	0.57	116.53	0.34	G
KC7	117.20	117.00	116.80	116.70	116.70	116.60	116.60	116.80	116.76	116.82	117.19	117.38	117.60	0.34	116.93	0.32	G
KC8	117.00	117.10	116.80	116.70	116.80	116.70	116.70	116.80	116.84	116.86	116.98	117.04	117.27	0.23	116.89	0.17	R
KC9	116.90	116.80	116.80	116.60	116.60	116.40	116.50	116.70	116.65	116.69	116.62	116.43	116.59	-0.27	116.64	0.14	R
KC10	ND	116.80	116.30	116.40	116.40	116.00	116.20	116.30	116.61	116.01	115.59	113.84	113.96	-2.43	115.87	0.97	R
Mean	*117.04*	*117.41*	*116.72*	*116.65*	*116.66*	*116.56*	*116.60*	*116.68*	*116.81*	*116.70*	*116.94*	*116.70*	*116.91*	-0.12	116.80	0.23	

SITE KJ – BIG ROCK

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KJ1	109.90	110.30	109.70	109.50	109.10	109.40	109.00	109.10	109.17	109.38	109.20	110.48	110.62	0.66	109.60	0.56	P
KJ2	109.40	110.50	109.30	109.60	109.30	109.70	109.40	109.30	109.19	109.02	108.93	110.86	111.00	1.46	109.65	0.69	P
KJ3	110.40	110.70	110.00	110.30	109.60	110.10	109.90	110.00	109.64	109.35	107.03	110.74	110.93	0.48	109.90	0.98	P
KJ4	109.90	110.30	debris	109.90	109.80	110.10	110.00	110.10	109.83	109.61	109.46	110.41	110.70	0.73	110.01	0.34	G
KJ5	110.20	110.80	109.80	110.00	110.00	110.30	110.30	110.30	110.45	110.06	109.99	110.68	110.77	0.52	110.28	0.32	G/R
KJ6	109.80	109.90	109.90	108.80	110.00	109.70	109.70	109.60	109.58	110.35	110.01	110.32	110.10	0.27	109.83	0.39	R
KJ7	111.10	110.90	109.90	110.50	109.90	110.30	110.30	110.30	110.42	110.18	110.45	110.73	110.81	-0.26	110.45	0.36	R
KJ8	109.00	108.70	108.20	109.30	108.70	108.80	108.80	108.70	108.92	108.80	108.72	108.77	108.88	-0.11	108.79	0.24	R
Mean	*109.96*	*110.26*	*109.54*	*109.74*	*109.55*	*109.80*	*109.68*	*109.68*	*109.65*	*109.59*	*109.22*	*110.37*	*110.48*	0.47	109.81	0.36	

SITE KD – BIG BEND

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KD1	ND	ND	ND	91.60	90.90	90.50	90.60	90.50	90.27	90.77	90.76	90.36	90.40	-1.31	90.67	0.38	G/R
KD2	90.50	91.00	91.10	90.50	90.60	89.10	90.10	90.00	89.62	90.77	90.31	90.66	90.74	0.27	90.38	0.56	P
KD3	88.80	89.90	88.90	90.90	90.10	89.40	89.60	89.50	89.34	90.02	89.71	91.21	90.98	2.45	89.87	0.76	P
KD4	89.20	89.80	89.10	91.00	90.50	90.40	90.40	90.30	89.94	89.63	89.69	91.48	90.96	1.97	90.18	0.71	P
KD5	90.80	90.10	89.70	90.90	90.70	90.50	90.70	90.70	90.27	90.01	90.16	91.59	91.43	0.69	90.58	0.54	G/R
KD6	89.80	89.90	89.50	90.30	90.50	90.50	90.60	90.50	90.00	89.94	89.62	91.31	91.34	1.71	90.29	0.58	R
KD7	ND	ND	ND	ND	ND	ND	88.20	88.60	88.52	88.62	88.68	90.38	90.17	2.23	89.02	0.87	R
Mean	*89.82*	*90.14*	*89.66*	*90.87*	*90.55*	*90.07*	*90.03*	*90.01*	*89.71*	*89.97*	*89.85*	*91.00*	*90.86*	1.16	90.19	0.46	

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Table 4. Lagunitas Creek Bed Conditions Monitoring: Mean Bed Elevations

SITE KL – CHEDA RANCH ROAD

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KL1	77.20	78.00	77.70	77.10	77.90	77.90	77.90	77.90	78.20	78.06	77.86	77.04	77.16	-0.05	77.69	0.41	R
KL2	ND	78.00	77.60	77.10	77.80	77.50	77.40	77.50	77.90	78.09	77.62	76.97	77.22	-1.00	77.56	0.35	P
KL3	76.60	ND	ND	75.90	76.40	76.30	76.50	76.70	76.55	76.82	76.37	76.18	76.41	-0.25	76.43	0.25	P
KL4	ND	ND	ND	74.90	75.50	75.60	75.90	75.80	75.98	76.47	75.11	75.59	75.59	0.92	75.64	0.44	P
KL5	76.10	ND	75.30	75.60	75.90	76.10	77.40	77.40	76.33	76.83	75.79	76.53	76.79	0.91	76.34	0.67	P/G
KL6	76.00	75.90	76.00	76.00	77.00	77.30	77.50	77.60	77.01	77.87	77.12	77.89	77.69	2.22	76.99	0.76	G/R
KL7	76.00	76.30	76.60	76.50	77.60	77.20	77.30	77.40	77.08	77.55	77.27	76.67	77.05	1.38	76.96	0.50	R
KL8	76.70	76.80	76.80	76.30	77.90	77.00	77.20	77.10	76.78	77.10	76.67	77.01	76.98	0.37	76.95	0.37	R
Mean	*76.43*	*77.00*	*76.67*	*76.18*	*77.00*	*76.86*	*77.14*	*77.18*	*76.98*	*77.35*	*76.73*	*76.74*	*76.86*	0.56	76.85	0.31	

SITE KF – KELLEY'S TOCALOMA

Section	1993	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	**overall change 1993-2007**	**Mean MBE 1993-2007**	**Stand.dev**	**Segment type** (R, P, G)
KF1	64.10	64.00	64.40	64.60	65.00	65.00	65.00	65.00	65.10	64.92	64.88	64.39	64.74	1.00	64.70	0.37	R/P(1)
KF2	64.00	63.80	64.30	64.60	64.80	65.00	64.90	64.90	64.76	64.80	65.04	64.63	65.10	1.72	64.66	0.40	P
KF3	64.00	64.40	64.70	64.80	65.10	65.40	65.30	65.20	65.27	65.32	65.51	64.81	65.17	1.83	65.00	0.44	P
KF4	64.10	64.40	64.60	65.00	65.20	65.40	65.50	65.40	65.48	65.65	65.70	65.12	65.36	1.97	65.15	0.50	P/G
KF5	64.70	64.70	65.10	65.20	65.30	65.50	65.60	65.60	65.56	65.75	65.80	65.70	65.90	1.85	65.42	0.39	G
KF6	64.30	63.50	64.80	65.10	65.50	65.60	65.70	65.70	65.88	65.99	65.77	65.47	65.80	2.33	65.32	0.72	G
KF7	64.50	64.70	64.50	65.10	65.50	65.70	65.60	65.60	65.75	65.90	65.47	65.53	65.56	1.64	65.34	0.48	R
KF8	64.00	64.50	64.40	65.20	64.10	65.70	65.60	65.50	65.57	65.71	65.16	65.73	65.56	2.44	65.13	0.65	R
KF9	ND	ND	ND	ND	ND	64.90	64.50	64.50	64.67	64.76	64.48	65.14	65.06	0.25	64.75	0.26	R
Mean	*64.21*	*64.25*	*64.60*	*64.95*	*65.06*	*65.36*	*65.30*	*65.27*	*65.34*	*65.42*	*65.31*	*65.17*	*65.36*	1.79	65.05	0.42	

Notes:

(1) Cross section began as a riffle in 1979; experienced LWD deposition and debris dam in 1980; 1981 storms removed LWD and scoured reach, forming a pool.

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Table 5. Variations in Embeddedness of the Deep and Shallow Halves of the Pool at Kelley's Upper State Park Site
Lagunitas Creek, Marin County, 1998 to 2009

	Deep Half		Shallow Half		% of bed	Annual	Kent Lake	San Geronimo	Remarks
Water Year	number	mean emb	number	mean emb	>45 mm	Flows	Spills	Yield Rate	
						(% of mean)			
1998	26	0.265	22	0.263	45	222%	large	low rate	Extensive spills and flows after Feb. 3 peak
1999	19	0.279	27	0.312	45	126%	mid-range	low rate	
2000	19	0.367	14	0.364	31	27%	low	low	Large peak flow ( ) relative to annual
2001	32	0.266	16	0.269	42	43%	none	low	
2002	13	0.29	4	0.200	15	90%	low	very high	Construction of woody debris structure
2003	50	0.26	31	0.24	62	83%	low	high	
2004	9	0.37	6	0.13	12	118%	mid-range	mod	
2006	18	0.33	7	0.41	23	220%	large		
2007	15	0.46	11	0.59	22	46%	none		

Notes

Deep half includes passes 1-6 in 1998 and 1999; passes 3-6 in 2000, passes 3-8 in 2001, passes 5-10 in 2002-04, passes 7-10 in 2006, and passes 1-6 in 2007;
shallow half includes passes 7-10, passes 1,2,7-10, passes 1,2,9,10, passes 1-4, passes 1-6, and passes 7-10, respectively.

Note that the deep half includes 60%, 60%, 40%, 60%, 60%, 60%, 60%, 40%, and 60% of the bed area of the pool in the nine years; number of cobbles >45 mm should be interpreted accordingly.

Water Year: Flow at the USGS gage and spills at Kent Lake are for the water year, ending Sept. 30; data from a bed census conducted in early summer of the named year

Number is the sample size of cobbles larger than 45 mm encountered in the deep and shallow halves.

Mean emb is the mean embeddedness of all cobble larger than 45 mm in each 'half' of the channel

% of bed >45 mm is the percentage of the bed for which the sampling encountered particles of 45 mm or larger, excluding woody material

Spills are the estimated volume of spills from Kent Lake

San Geronimo Yield Rate describes the *relative rate* of bedload sediment yield from San Geronimo Creek, measured as the amount of sediment being transported at a given flow, equivalent to the value of 'a' in the equation I_b in the equation $I_b = aQ^j$ (see Owens and Hecht, 2001; Hecht, 2008). Increase occurred during the latter half of the 2000 season.

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Table 6. Lithology counts at selected sites, along San Geronimo and Lagunitas Creeks, 1979 to 2008

Sampling Year	***1979***	***1993***	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2006***	***2007***	***2008***
Rock Types	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***
San Geronimo Creek below Woodacre (MMWD Water Treatment Plant access road--K1)															
Gravels counted	*93*	*425*	*200*	*148*	*186*	*142*	*129*	*103*	*139*	*111*	*128*	*128*	105	187	109
Date sampled	*summer*	*931120*	*951101*	*961004*	*970903*	*980903*	*990730*	*000929*	*010524*	*020604*	*030906*	*040714*	*060516*	*070517*	*080411*
Metabasalts	20.30%	21.90%	18.50%	11.49%	12.90%	4.93%	12.40%	8.74%	5.76%	9.91%	9.38%	10.93%	11.32%	15.51%	12.96%
Diabases	0.00%	1.40%	0.50%	0.68%	0.00%	0.00%	1.55%	0.00%	0.72%	0.00%	0.78%	1.56%	0.00%	0.00%	0.00%
Cherts+quartz	9.70%	9.40%	9.50%	16.89%	8.60%	12.68%	7.75%	6.80%	10.07%	8.11%	5.47%	5.47%	10.38%	9.09%	12.04%
Sandstones	4.30%	12.00%	9.50%	12.16%	6.99%	7.75%	13.96%	14.56%	7.91%	7.21%	6.25%	8.57%	3.77%	3.74%	5.56%
Greywackes	43.00%	35.30%	32.00%	27.03%	37.10%	44.37%	31.01%	31.07%	33.81%	33.33%	34.38%	31.25%	33.96%	27.27%	27.78%
Phyllites+shales	18.30%	11.30%	19.50%	18.24%	31.18%	26.76%	29.46%	37.86%	31.65%	37.84%	39.06%	39.06%	39.62%	40.11%	36.11%
Blueschists	0.00%	0.90%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.72%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ultramafics	3.20%	7.50%	10.50%	12.84%	2.69%	3.52%	3.88%	0.97%	4.32%	4.50%	4.69%	3.13%	0.94%	4.28%	5.56%
Human-made	0.00%	0.00%	0.00%	0.00%	0.54%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Other	1.10%	0.30%	0.00%	0.68%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.93%
San Geronimo Creek at Lagunitas (Lagunitas Road bridge - K4)															
Gravels counted	*657**	*117*	*165*	*146*	*233*	*103*	*88*	*100*	*141*	*125*	*101*	*129*	136	134	103
Date sampled	*summer*	*931120*	*951101*	*961004*	*970903*	*980903*	*990903*	*0009299*	*010524*	*020604*	*030906*	*040714*	*060516*	*070517*	*080411*
Metabasalts	17.0%	10.30%	25.45%	14.38%	10.73%	7.77%	11.36%	9.00%	14.89%	7.20%	9.90%	10.08%	11.19%	9.70%	9.71%
Diabases	0.0%	1.70%	0.61%	0.00%	0.43%	0.00%	0.00%	0.00%	0.71%	0.00%	0.00%	0.00%	1.49%	0.75%	1.94%
Cherts+quartz	10.7%	7.70%	7.27%	8.22%	7.30%	12.62%	6.82%	8.00%	9.93%	7.20%	5.94%	6.98%	5.97%	7.46%	6.80%
Sandstones	14.7%	23.90%	3.03%	4.79%	8.15%	5.83%	18.18%	10.00%	10.64%	14.40%	5.94%	7.76%	6.72%	2.24%	4.85%
Greywackes	26.3%	33.30%	31.52%	39.73%	43.78%	30.10%	35.23%	35.00%	32.62%	35.20%	33.66%	31.78%	33.58%	30.60%	28.16%
Phyllites+shales	22.0%	16.20%	24.85%	25.34%	26.18%	36.89%	27.27%	33.00%	29.78%	32.00%	36.63%	40.31%	40.30%	43.28%	42.70%
Blueschists	0.0%	0.00%	0.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.71%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ultramafics	6.8%	6.80%	6.67%	7.53%	3.00%	5.83%	1.14%	5.00%	0.71%	4.00%	6.93%	2.33%	1.49%	4.48%	6.80%
Human-made	0.0%	0.00%	0.00%	0.00%	0.43%	0.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.78%	0.75%	0.00%	0.00%
Other	0.2%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.99%	0.00%	0.00%	1.49%	0.00%
Campground Bridge (KC)															
Gravels counted															88
Date sampled															*080411*
Metabasalts															25.00%
Diabases															2.27%
Cherts+quartz															5.68%
Sandstones															6.82%
Greywackes															30.68%
Phyllites+shales															30.68%
Blueschists															0.00%
Ultramafics															9.09%
Human-made															1.14%
Other															0.00%
Lagunitas Creek at Big Rock (MP 17.86) (KJ)															
Gravels counted													*113*	*412*	*144*
Date sampled													*060518'*	*070524*	*080505*
Metabasalts													46.02%	41.75%	35.42%
Diabases													1.77%	0.73%	1.39%
Cherts+quartz													5.31%	5.83%	9.03%
Sandstones													2.65%	5.10%	4.17%
Greywackes													15.93%	14.32%	19.44%
Phyllites+shales													23.01%	27.91%	28.47%
Blueschists													0.00%	0.24%	0.00%
Ultramafics													5.31%	4.13%	2.08%
Human-made													0.00%	0.00%	0.00%
Other													0.00%	0.00%	0.00%

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Table 6. Lithology counts at selected sites, along San Geronimo and Lagunitas Creeks, 1979 to 2008

Sampling Year	***1979***	***1993***	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2006***	***2007***	***2008***
Rock Types	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***
Devil's Gulch (30 ft. d/s of SFD)															
Gravel's counted													*106*		
Date Sampled													*060523*		
Metabasalts													44.34%		
Diabases													0.00%		
Cherts+quartz													5.66%		
Sandstones													5.66%		
Greywackes													20.75%		
Phyllites+shales													19.81%		
Blueschists													0.00%		
Ultramafics													3.77%		
Human-made													0.00%		
Other													0.00%		
Lagunitas Creek at Kelley's Tocaloma (KF) (MP 20.03)															
Gravels counted	*671***	*****	*150*	*163*	*170*	*107*	*107*	*104*	*117*	*142*	*104*	*116*	111	101	108
Date sampled	*Sept. 1979*		*951027*	*961031*	*970903*	*980903*	*990901*	*000929*	*010622*	*020604*	*030906*	*040602*	*060516*	*070523*	*080411*
Metabasalts	35.0%		20.00%	12.96%	17.65%	5.61%	14.29%	9.62%	7.69%	11.27%	11.54%	9.48%	10.81%	12.87%	7.41%
Diabases	0.0%		0.00%	0.62%	0.59%	0.00%	1.90%	0.00%	0.00%	0.00%	1.92%	0.00%	0.90%	0.00%	0.93%
Cherts+quartz	5.1%		6.00%	9.88%	4.71%	5.61%	9.52%	3.85%	14.53%	4.93%	7.69%	4.31%	7.21%	3.96%	12.96%
Sandstones	10.6%		8.67%	10.49%	8.82%	15.89%	9.52%	9.62%	8.55%	10.56%	8.65%	6.90%	5.41%	4.95%	3.70%
Greywackes	26.4%		40.67%	36.42%	31.18%	28.04%	29.52%	27.88%	25.64%	35.21%	38.46%	35.35%	24.32%	30.69%	30.56%
Phyllites+shales	18.6%		21.33%	25.93%	34.71%	40.19%	30.48%	47.12%	40.17%	34.51%	29.81%	42.24%	46.85%	44.55%	40.70%
Blueschists	0.0%		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ultramafics	3.3%		3.33%	3.70%	2.35%	4.67%	4.76%	0.96%	3.42%	3.52%	1.92%	0.86%	4.50%	2.97%	4.63%
Human-made	0.0%		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.86%	0.00%	0.00%	0.00%
Other	0.6%		0.00%	0.62%	0.00%	0.00%	0.00%	0.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Analyst	RE+BH	BH	BH	BH	BH	BH	BH	BH	BH	BH	BH	BH	CG + BH	CG + BH	CG + BH

Notes

Analysts: Robert Enkeboll (RE), Barry Hecht (BH), Carla Grandy (CG)

* Mean of 5 subsamples collected at MP15.00, approximately 0.3 miles downstream from Lagunitas Road bridge. Intervening watershed underlain almost solely by metavolcanics. See Phase I report, (Hecht and Enkeboll) p.A-25.

** Mean of 5 subsamples collected across the channel at the identical location along the stream. See Phase I report, page A-25

*** Kelley's Tocaloma is not a part of the approved monitoring program, but was added in 1995 after the initial sediment delivery events at Big Bend; Big Rock added in 2006 to help assess role of ongoing disturbance downstream at Big Bend, comminution, and possible volumes of bed storage and roles of LWD structures. Campground Bridge pool affected by greywackes and other metasediments introduced from tributary immediately upstream at Wildcat Creek.

Certain rock types appear preferentially at various sizes. For example, ultramafics (serpentitinites) are more common as coarse gravels (32-64 mm) than in the 8-16 mm. range. Percentages presented on this table are standardized by size to allow comparisons over time, downstream distance, and position (bed, terraces, bars, etc.), but do not proportionally represent all gravels in the creek.

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Table 7. Long-term trends and assessment of substantial improvement of bed conditions, representative parameters

Shafter to Tocaloma Bridges, Lagunitas Creek, California

Variable	Station or site	Change observed	Comparison interval	Complicating events	Substantial Improvement?	Source	Comments
Bed Configuration							
Mean bed elevation, whole site	Above Big Bend (KB, KH, KC, KJ)	Avg 0.5' decrease in bed elevation	1993 to 2004	Buildup of LWD and WDSs	yes	Figure 13a	Excludes episodic bed aggradation, 2006
Mean bed elevation, whole site	Big Bend and below (KD, KL, KF)	Avg 0.5' increase in bed elevation	1993 to 2004	Big Bend events	no	Figure 13a	Probably mainly sediment pulse from Big Bend
Bed Surface							
D16	Above Big Bend	Increases in most riffles; decreases in most glides and pools	1993 to 2004	2002 sediment , 2006 storm	no	Figure 21c	Differences above and below Big Bend persist through 2004
D16	Big Bend and downstream	Decreases in most pool, glides, riffles	1993 to 2004	Big Bend events, 2002	no	Figure 21c	
D84	Riffles	30 to 160 mm; 45 to 130 mm	1993 to 2004	excludes KX	no	Figure 20	50 to 170 mm in early 1980s
	Pools	38 t0 112 mm ; 20 to 105 mm	1993 to 2004	excludes KX; KB pool	no	Figure 20	25 to 120 mm in early 1980s
	Glides	32 to 80 mm; 18 to 62 mm	1993 to 2004	excludes KX	no	Figure 20	30 to 130 mm in early 1980s
Embeddedness							
	Sites above Big Bend (KB,KH,KC,KJ)	Decreases in most pool, glides, riffles	1993 to 2007	Buildup of LWD and WDSs; 2002 and 2006 events	yes, slight	Figure 21a	Highly variable, 1998 to 2004
	Big Bend and downstream	Increases in all pools, glides, riffles	1993 to 2007	Big Bend events	no	Figure 21a	Most change at KF (Kelley's Tocaloma)
Percent bed area covered by sand	Glides, all sites	Approximate doubling of sand %	1993 to 2007	Excludes KX	no	Figure 26a	Most of the increase in 2002, 2004
covered by cobble (>45 mm)	Riffles, all sites	Cobble % decreases by 40%	1995 to 2007	Eccludes KX	no	Figure 24a	Most decreases during 2002 through 2004
Ratios of bed-surface to in-bed sediments	Gildes, Pool	Former ratios of about 2:1 now 1.5:1	1993-2007	in conjunction with smaller particles	no	Figures 17, 18	Potential for more scour, and greater sediment exchange with deep bed.
Below the Bed Surface							
D16	all	1 to 4 mm; 1 to 10 mm	1993 to 2007	Increase in LWD and WDSs	yes	Figure 14	1 to 5 mm during early 1980s; sharp increase in year-to-year variability after 2000
D50	all	4 to 16 mm; 8 to 23 mm	1991 to 2007	excludes site KD	yes	Figure 15	Early 1980s range is 4 to 23 mm; beginning in 2000, year-to-year variability sharply increases
D84	all	15 to 75 mm; 20 to 80 mm	1993 to 2007	as above; see comment	yes	Figure 16	1991 and 1995 ranges are 15-45 mm and 8-25 mm, respectively
Lithology							
Monitoring at 3 routine sites	K1, K4, Kelley's Tocaloma	very little	1995-2007		n/a		Little variability relative to other streams
Potential new sources of sediments	Big Rock	substantial increase in local rock	1979-2008f	Increase in Lagunitas LWD	n/a	Table 6	Little variability relative to other streams
Scour							
Scour chain monitoring, known spawning sites	KB, KC, KJ, KL, KF	Limited depth of scour, even WY2006	1980s - [2002-2006] period	none	yes	Appendix F	Maximum seasonal scour observed at these sections is less than recorded in 1980, 1981 at KF, KL

Notes

Site KX not included for comparisons older than October 2002, when monitoring began at this site.

Unless otherwise stated, early 1980s (or 1980, 1981) data does not include any 1982 observations, following the major Jan. 4, 1982 event.

2007 used as default endpoint; 2004 used for variables known to be especially affected by episodic sedimentation or where most of the differences appeared agttributable to the WY 2006 events.

See conclusion 12 for context regarding substantial improvement.

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FIGURES

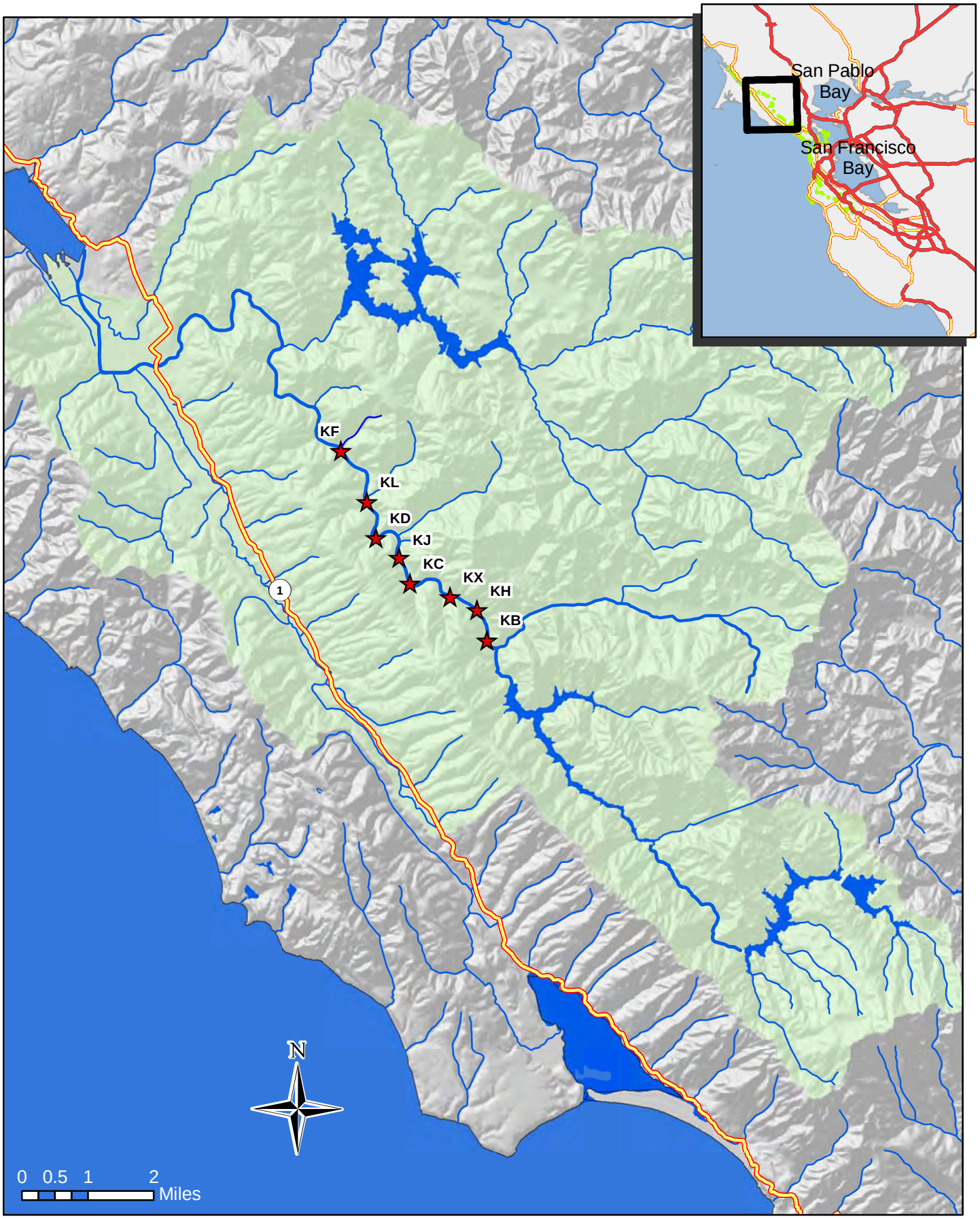

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Figure 1. Location of the Lagunitas Creek watershed, Marin County. Bed monitoring sites are shown.

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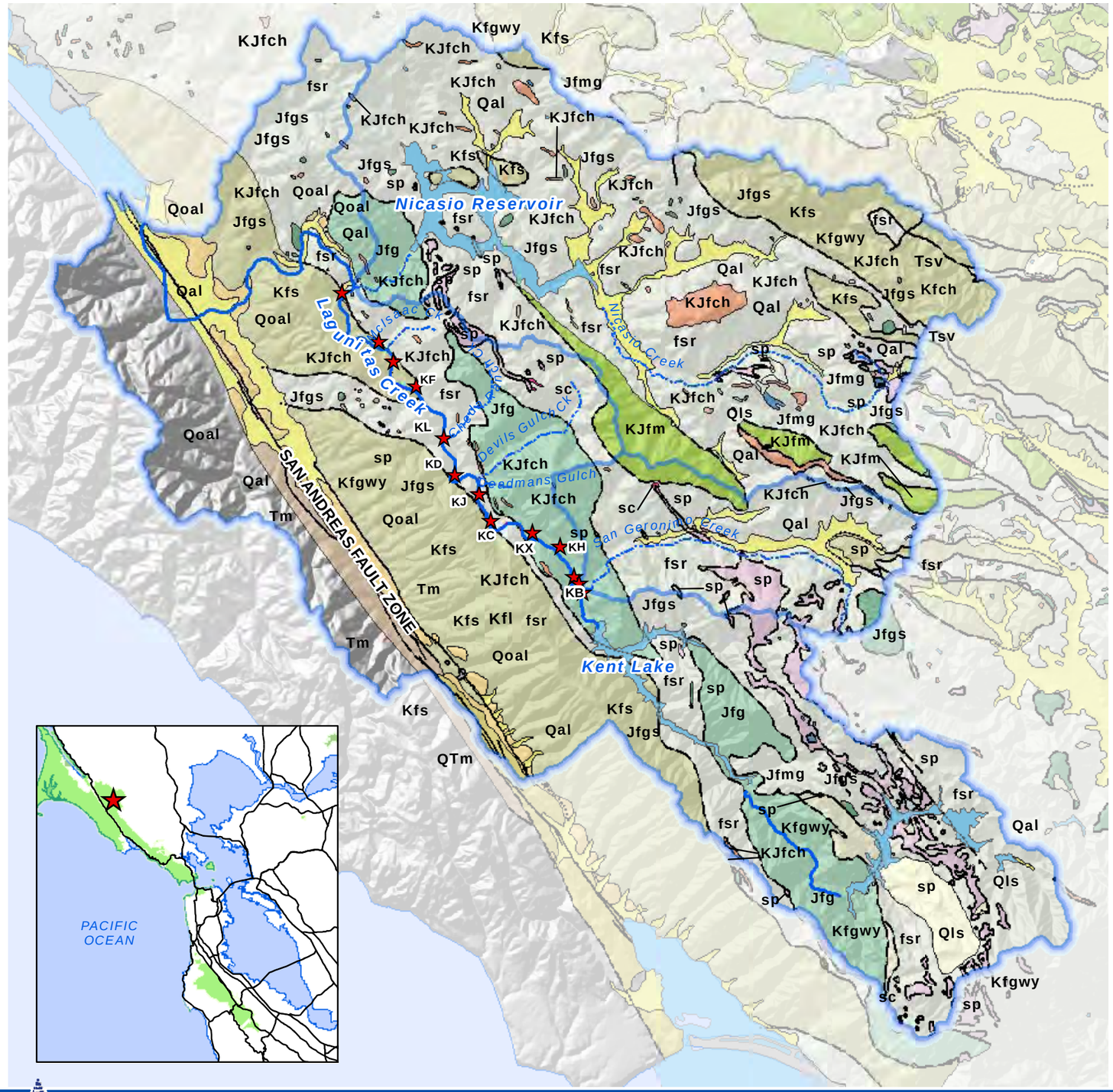

LEGEND

Bed Monitoring Site Abbreviations:

KB - Below Shafter	KC - Campground Bridge	KL - Above Cheda
KH - Kelley's Upper State Park	KJ - Big Rock	KF - Kelley's Tocaloma
KX - Above Irving	KD - Big Bend	

- Bed Monitoring Site Locations
- Lagunitas Creek
- Tributary Creeks
- Water
- Lagunitas Creek Watershed

N

0 5,000 10,000 15,000 20,000
Feet

Marin County Geology

Qls	**Landslide deposits (Quaternary)** - Largely bedrock debris.
Qal	**Alluvium (Quaternary)** - Sand, gravel, silt, and clay; loose to soft and friable; typically floodplain and lower terrace deposits.
Qoal	**Older alluvium (Quaternary)** - Poorly sorted; poorly inundated sands and gravels; lens-shaped bedding irregularly present, crossbedding common; typically older terrace deposits.
QTm	**Merced Formation (early Quaternary and late Pliocene)** - Soft, buff-weathering, blue-gray siltstone with fine-grained silty sandstone in upper part.
Tm	**Monterey Shale (late and middle Miocene)** - Siliceous shale and minor chert; shale weathers white to gray or pinkish brown and is commonly laminated to thin bedded.
Kfs	**Sandstone and shale (Cretaceous)** - Sandstone and interbedded shale, with minor conglomerate; crops out in alternating sequence of largely medium-thick to very thick sandstone beds with generally minor interbedded shale and predominantly shale with interbedded thin to medium-thick sandstone beds.
Kfl	**Limestone and chert (Cretaceous)** - Interbedded, thin-bedded gray limestone and black, red, green, and gray radiolarian chert. Beds are mostly less than 0.5m thick. Restricted in study area to 2 small masses in the San Andreas Fault Zone between Olema and Bolinas. Foraminifera from this unit south of the study area indicate that the limestone formed near the equator during the Early (Barremian) and Late (Turonian) Createceous epochs.
Kfgwy	**Graywacke (Cretaceous)** - Graywacke, shale and some metagraywacke; sandstone contains 0 to rarely as much as 5% detrital potassium feldspar. Coherent graywacke masses are as large as several miles long, but distribution is largely unknown, and only locally distinguished on map. In southern Marin County and parts of San Francisco, graywacke and shale are well-bedded, up to 300m thick, and overly chert and greenstone. Shown to scale where possible.
KJfm	**Metamorphic rocks (Cretaceous and Jurassic)** - Variably sheared, blueschist minerals; chiefly metagraywacke with slight to moderated metamorphic fabric, but includes metagreenstone, metachert, and minor amounts of metaconglomerate; forms the ridge north of San Geronimo Valley.
KJfch	**Chert (Cretaceous and Jurassic)** - Chert with shale interbeds. Chert is thin bedded, closely fractured, and parts along bedding planes; contains tests of radiolaria that range in age from early Jurassic to Middle Cretaceous.
Jfg	**Greenstone (Jurassic)** - Consists of pillow lava and less abundant tuff, breccia, and intrusive basalt, diabase, and rage gabbro. Local lenses of thin-bedded radiolarian chert are as thick as 30m. Fresh rock is hard, relatively unsheared, and ranges from essentially structureless to strongly pillowed; deeply weathered in places.
Jfgs	**Greenstone (Jurassic)** - Similar to unit **Jfg**, excepts crops out as small, discrete masses.
Jfmg	**Metamorphic rocks (Jurassic)** - Chiefly gneissic, including glaucophane-garnet schist, eclogite, and garnet amphibolite. Shown to scale where possible.
sp	**Serpentinite (Jurassic)** - Crops out as lenses and irregularly-shaped masses, largely within and along boundaries of **fsr**; most serpentinite displays a prominent shear fabric.
sc	**Silica-carbonate rock (Jurassic)** - Hard, tough rock that crops out mostly along margins of serpentinite bodies and as small discrete masses in severely sheared mélange locally contains minor cinnabar.
fsr	**Mélange** - A tectonic mixture of variably sheared shale and sandstone containing hard tectonic inclusions largely of greenstone, chert, graywacke, shale and their metamorphosed equivalents, plus exotic high-grade metamorphic rocks and serpentinite. The degree of shearing in the unit ranges from gouge to unsheared rock. Severely sheared phyllite and shale are abundant locally, shale abundant in areas where blocks are abundant.

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208052 Geology 10-09.mxd

Figure 2. Geologic map for Lagunitas Creek and bed monitoring sites, Marin County, California

Source: Marin County Geology, USGS (Blake, Graymer, Jones, Soule), 2000.

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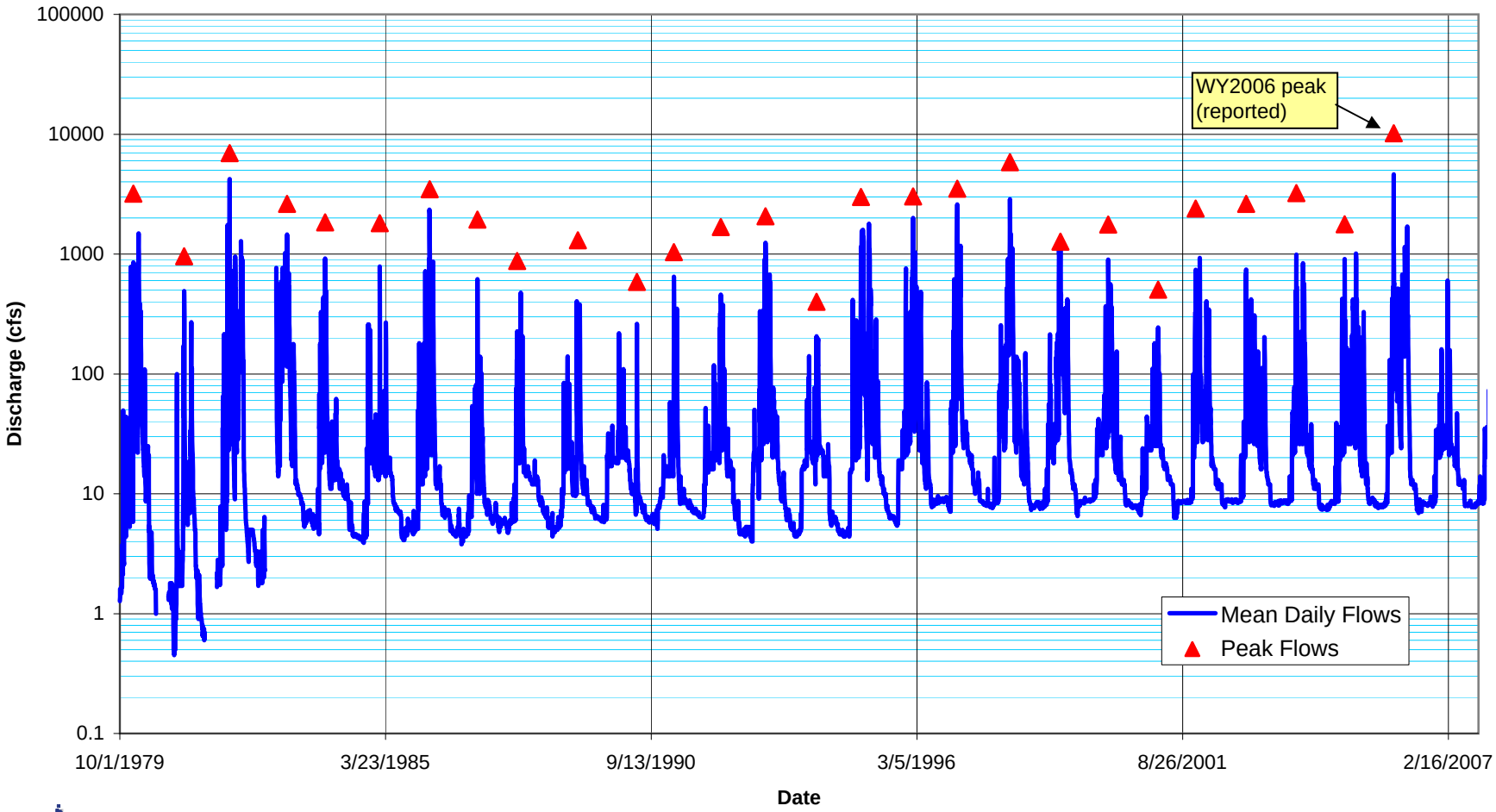

Figure 3. Mean daily and instantaneous peak flow, Lagunitas Creek at Samuel P. Taylor State Park (USGS gaging station #11460400), 1980-2007, Marin County, California. Peak flows on December 31, 2005 may have been somewhat lower than reported by USGS. Sources of data:1980-1982, measured at the Campground Bridge (Hecht 1983);1983-2007 (USGS WRD reports).

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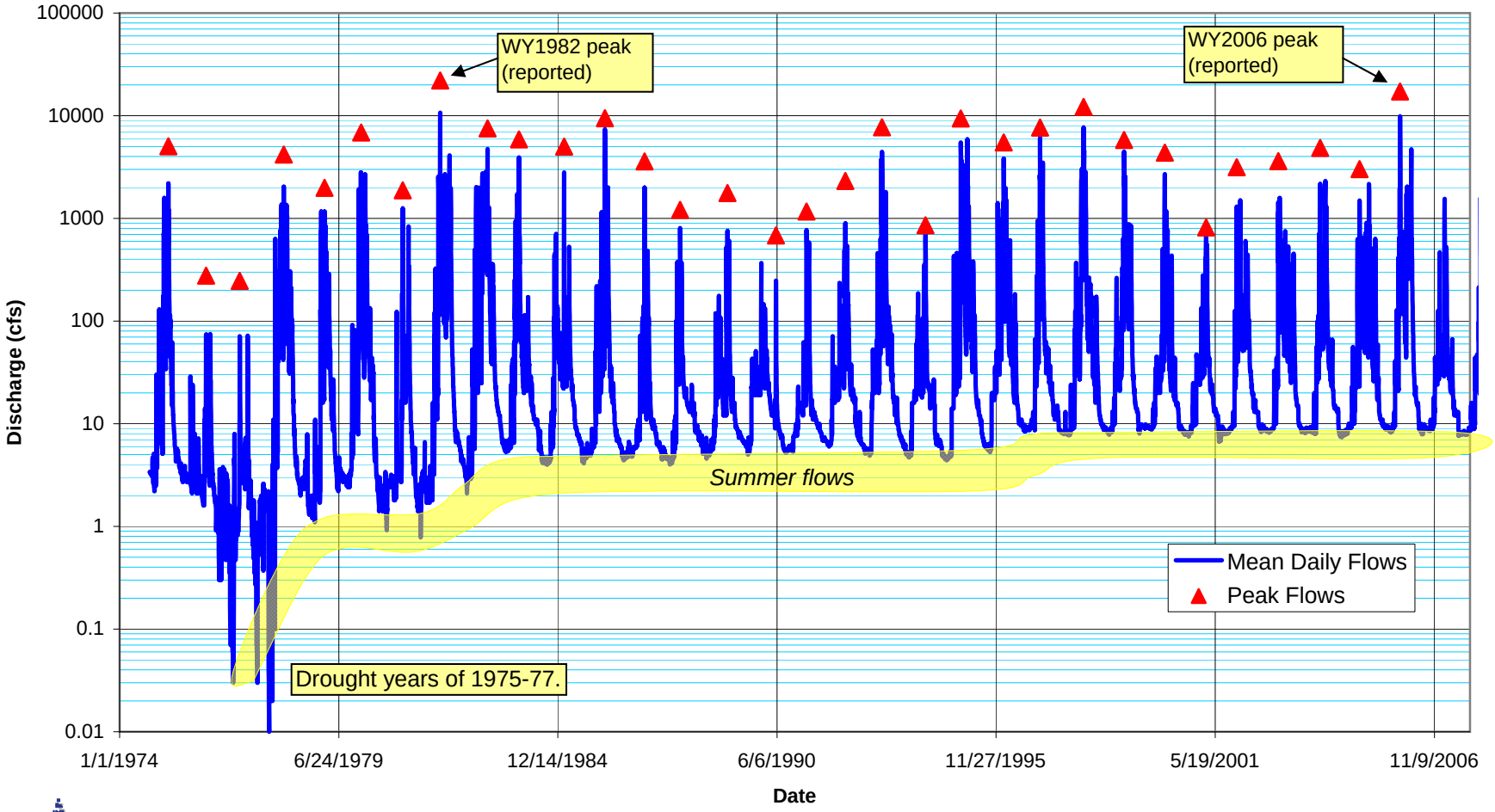

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Figure 4. Mean daily and instantaneous peak flow, Lagunitas Creek near Point Reyes Station (USGS gaging station #11460600), 1975-2007, Marin County, California. Note drought years during 1975 to 1977; also the progressive increase in minimum summer flows as more water has been released from Kent Lake and Nicasio Reservoir. Sources of data:1975-2007 (USGS WRD reports).

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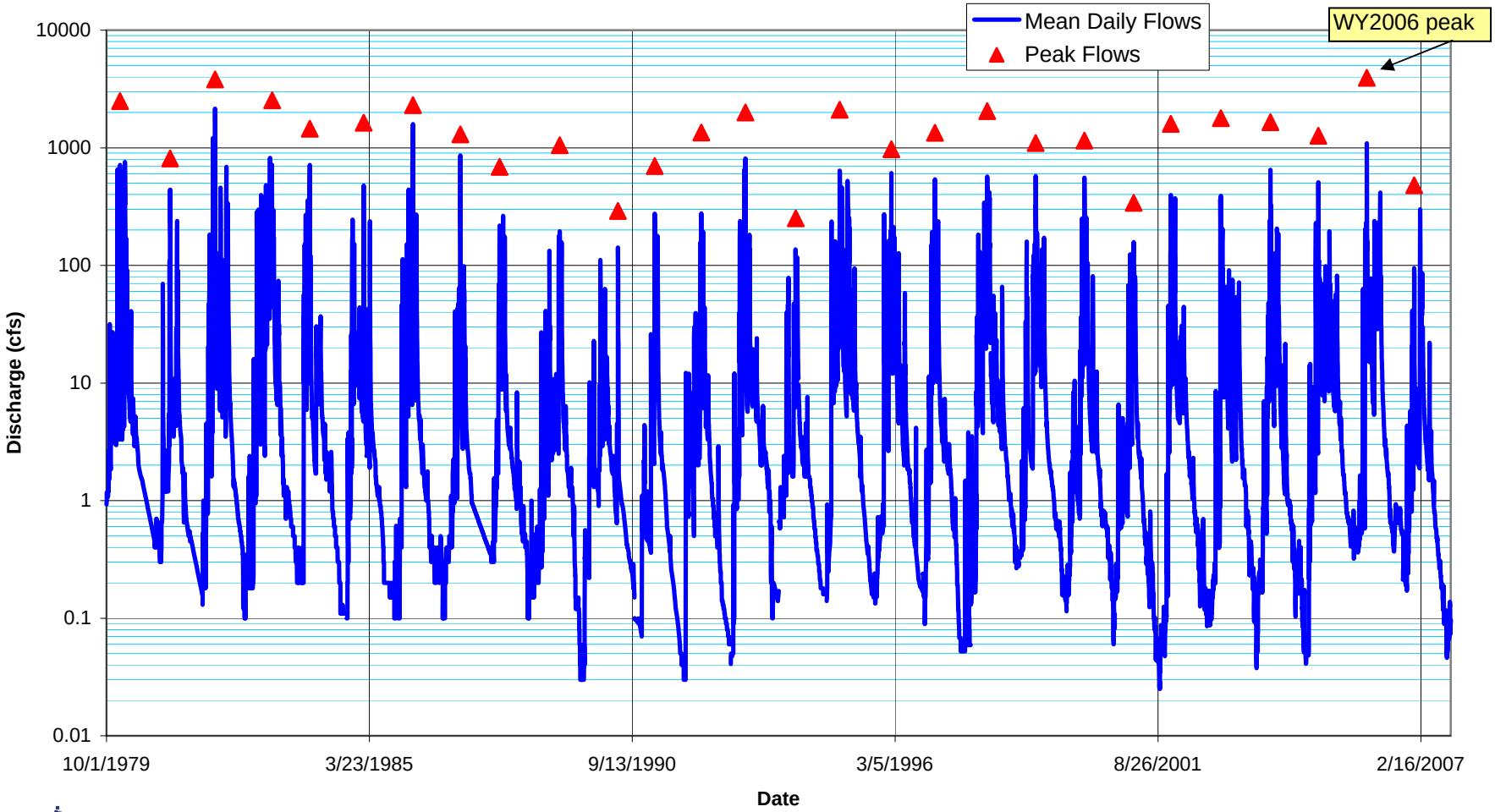

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Figure 5. Mean daily and instantaneous peak flow, San Geronimo Creek at Lagunitas Road Bridge, 1980-2007, Marin County, California. Note peak flow in 2006, similar to peak flow recorded in water year 1982 (4-Jan. 1982). All gaging by Balance Hydrologics staff.

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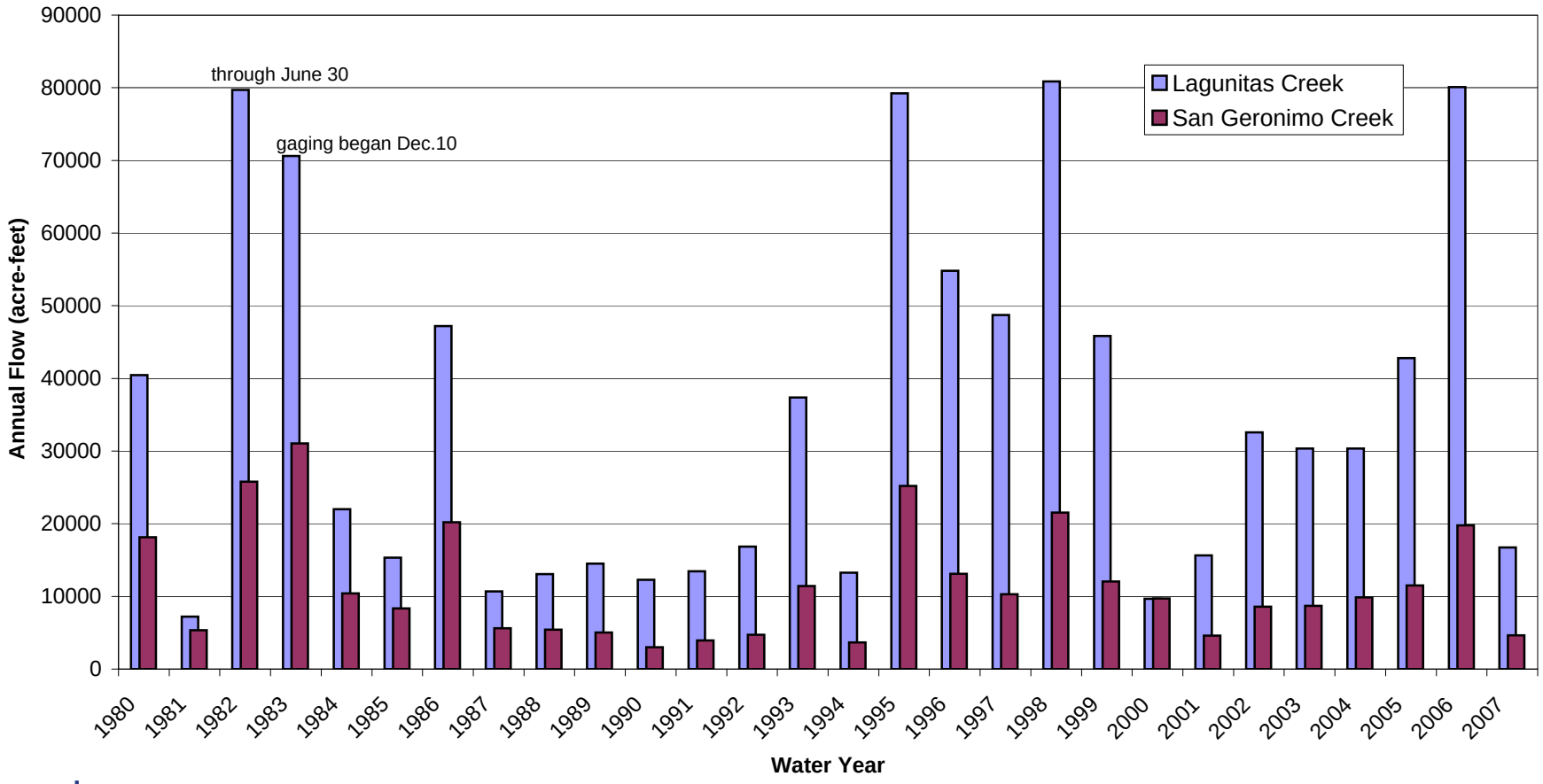

Figure 6. Mean annual flow comparison, Lagunitas and San Geronimo Creeks, 1980-2007, Marin County, California. Flows in Lagunitas Creek are influenced by filling, spills, and releases from Kent Lake; because flows in San Geronimo Creek are essentially unregulated, we consider this record reflective of flows from other unregulated tributaries. Sources of data:1980-1982, measured at the Campground Bridge (Hecht 1983);1983-2007 (USGS WRD reports). Sources of San Geronimo Creek data: annual Balance Hydrologics reports (Owens and others, 2007 and prior).

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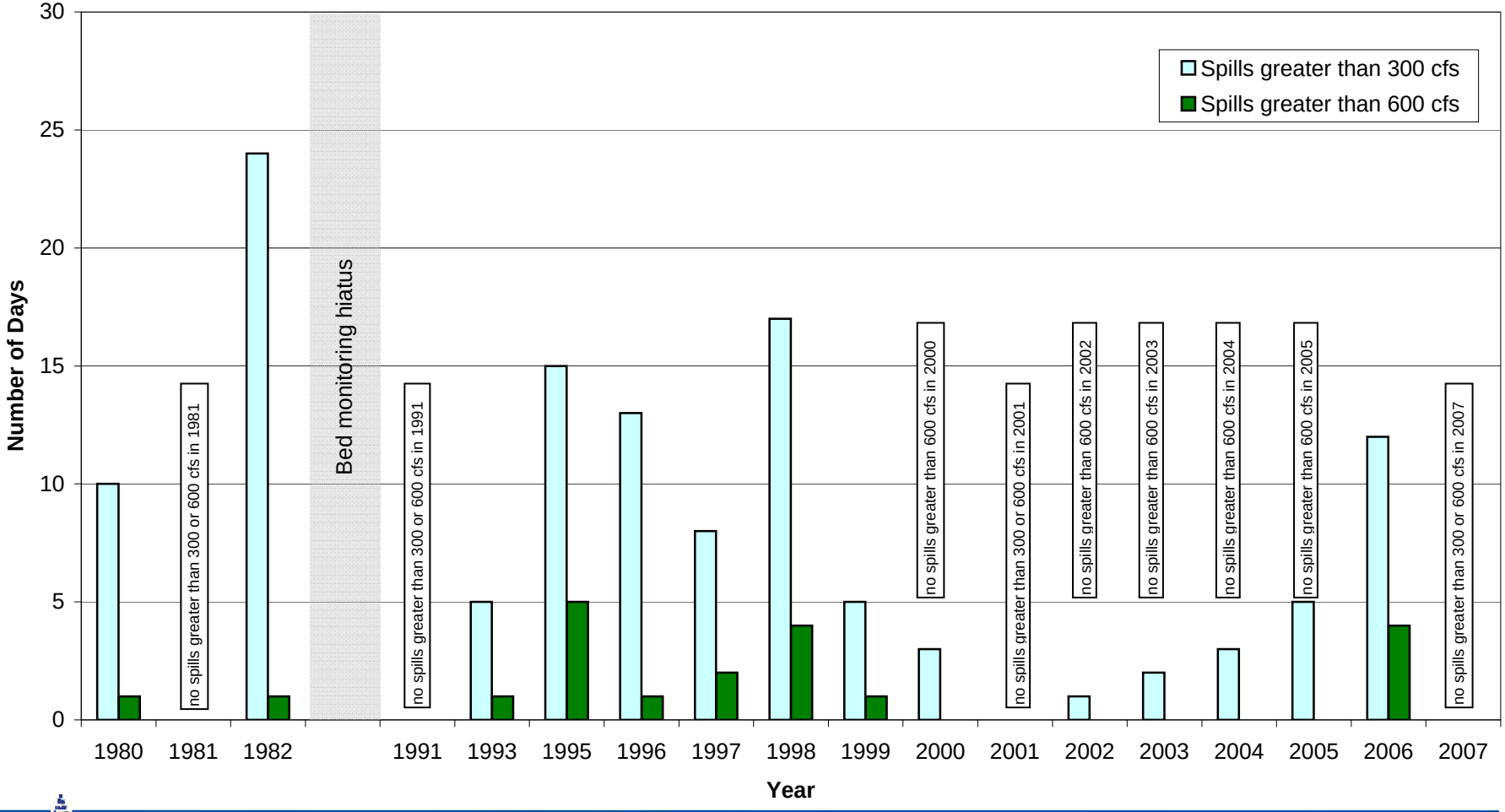

Figure 7. Number of days with spills and high-flow releases to Lagunitas Creek exceeding thresholds of 300 and 600 cfs for years when bed-monitoring data were collected. See text for explanation. [Source of flow data: MMWD]

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Figure 8. **Comparison of conditions at the 'Big Bend' site, showing the effects of the WY2006 storm events, Lagunitas Creek, California.** Note the thick deposits on the left-hand side and near the middle of the lower image. Photos were taken looking upstream from the KD glide.

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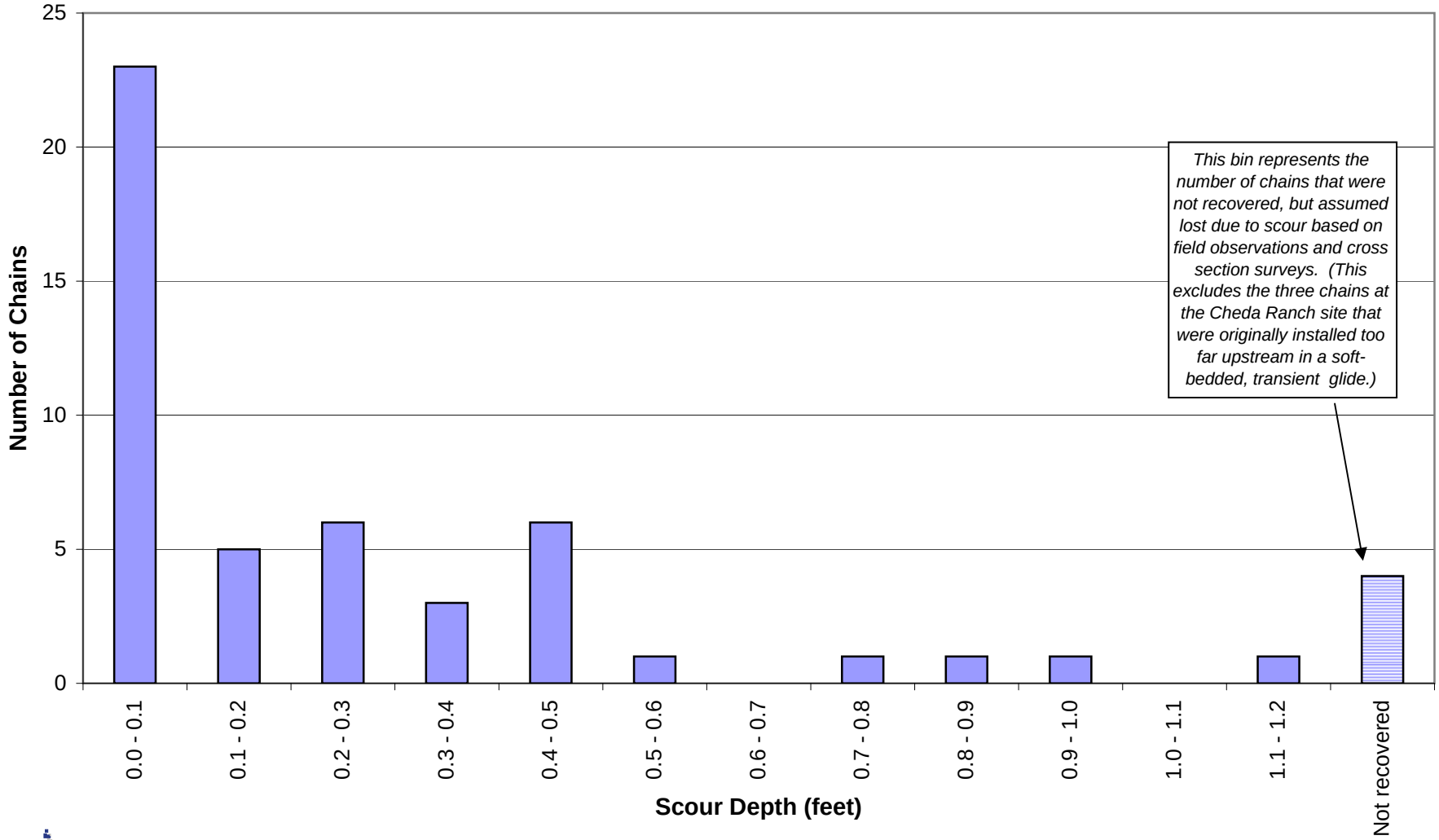

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Figure 9. Frequency of recorded scour of different depth ranges, Lagunitas Creek, Marin County, California. Note that scour greater than 0.5 feet deep is relatively uncommon at the locations where scour was measured. Data represent all scour values recorded by the scour chains over the four-year monitoring period (2002-2006). Scour chains were typically installed near the glide/riffle boundary at each of 5 monitoring sites at established cross sections where spawning had been observed in previous years.

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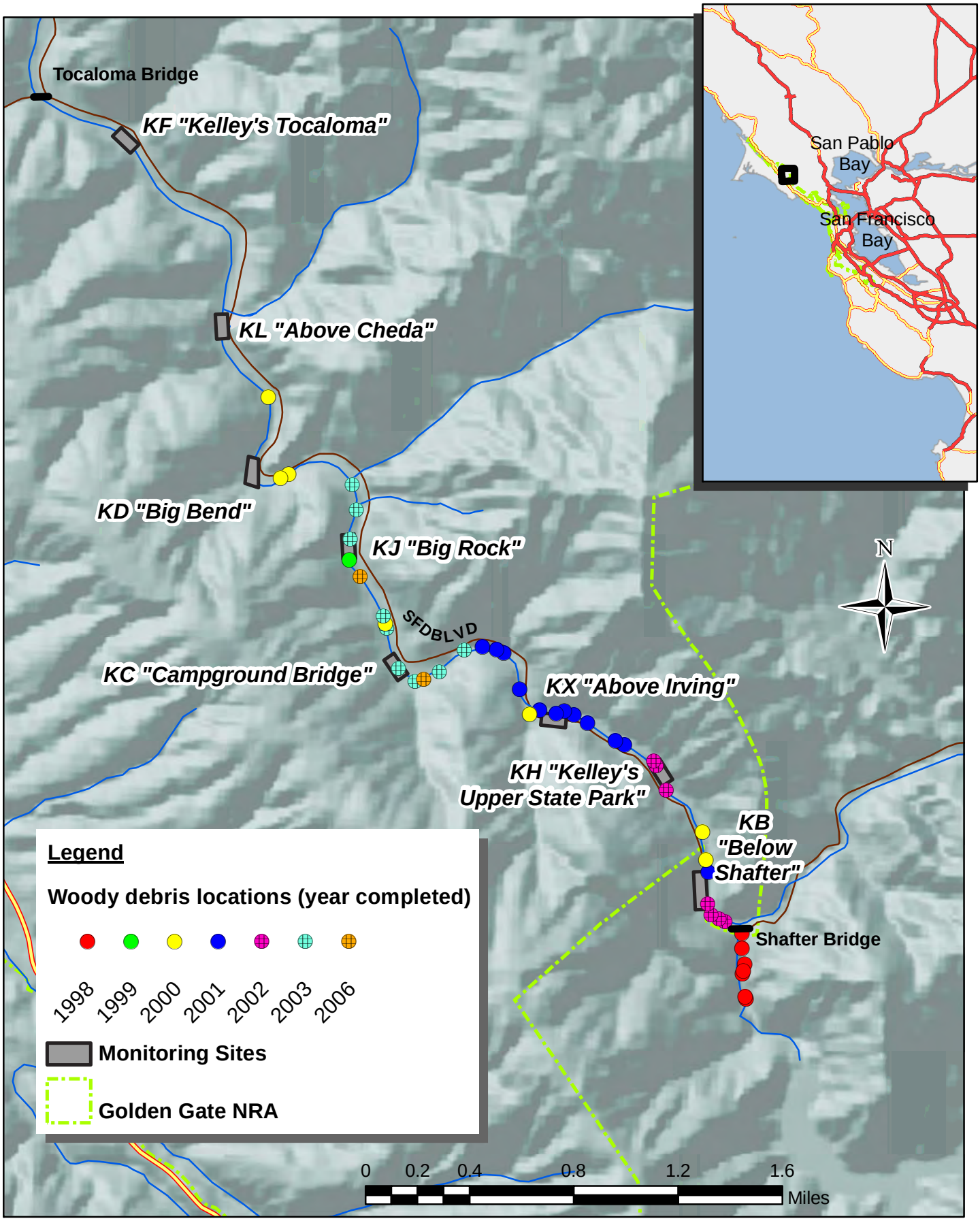

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Figure 10. Bed-monitoring sites and MMWD's woody debris structure locations, Lagunitas Creek, Marin County, California

208052 woody debris.mxd

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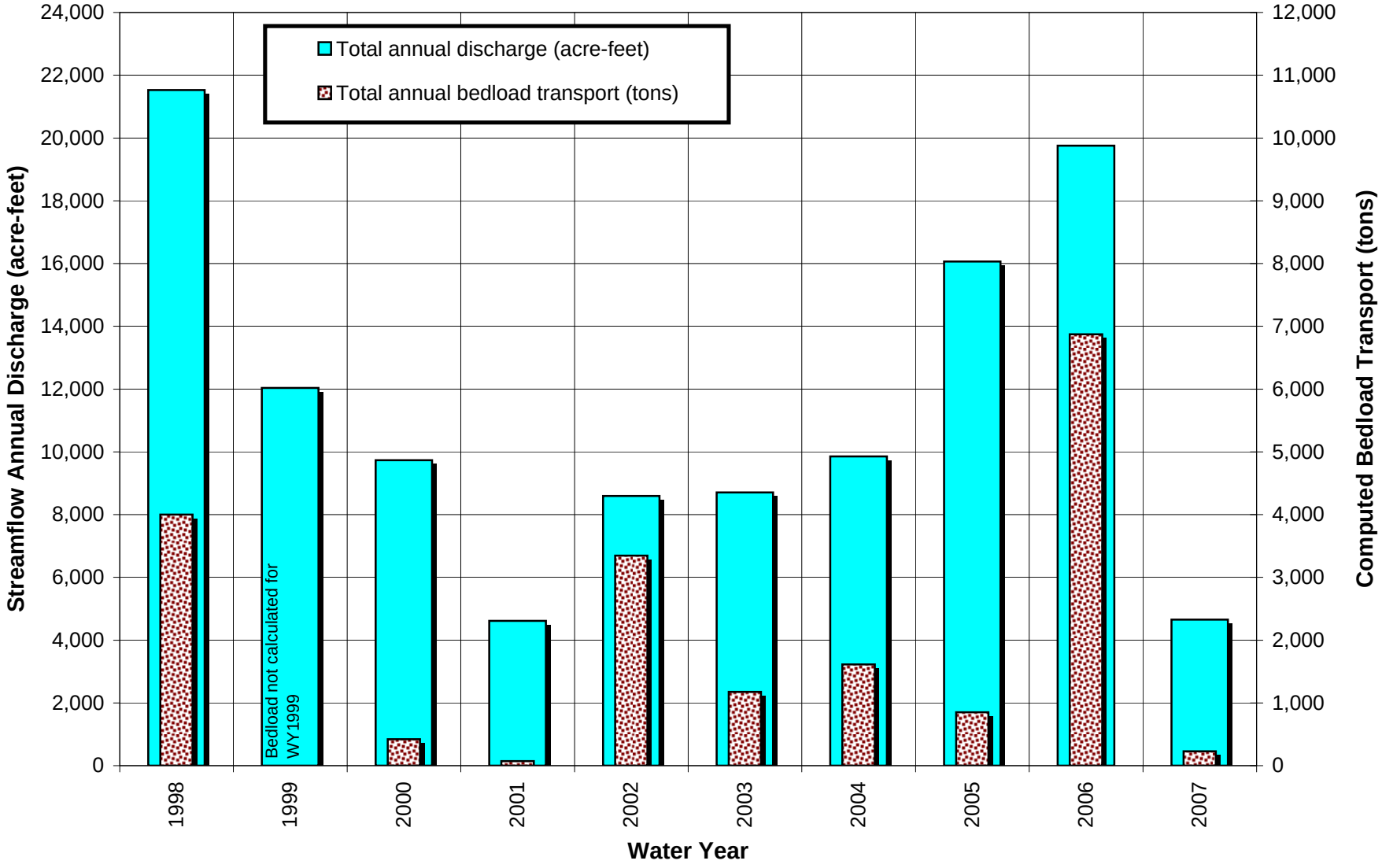

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Figure 10a. **Total annual streamflow and bedload discharge, San Geronimo Creek at Lagunitas Road Bridge, WY1998-2007.** Note the high sediment totals for WY1998 and WY2006, associated with high total volumes of flow. The pulse in WY2002, however, represents a fundamental shift in the bedload rating curve. See Figure 32 for an alternate representation of this shift.

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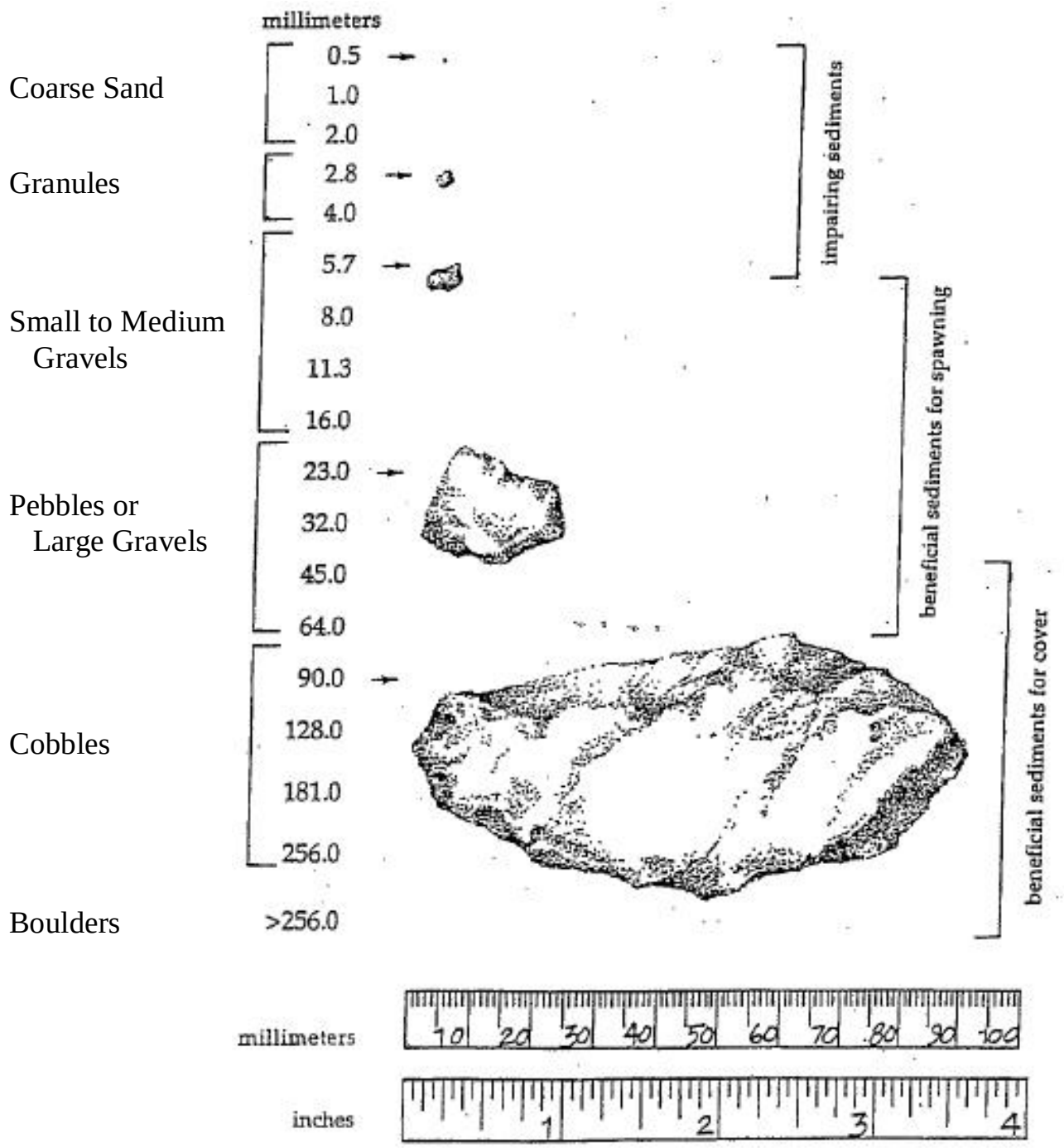
Smallest Particles (Fines):	
Clay	<0.0039 mm
Fines to Medium Sand	0.0625 – 0.250 mm
Silt	0.0039 – 0.0625

Coarse Particles:



Source: modified from Prunuske Chatham, Inc., 1996

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Figure 11. Illustration of stream sediment classification used, Lagunitas Creek, Marin County, California

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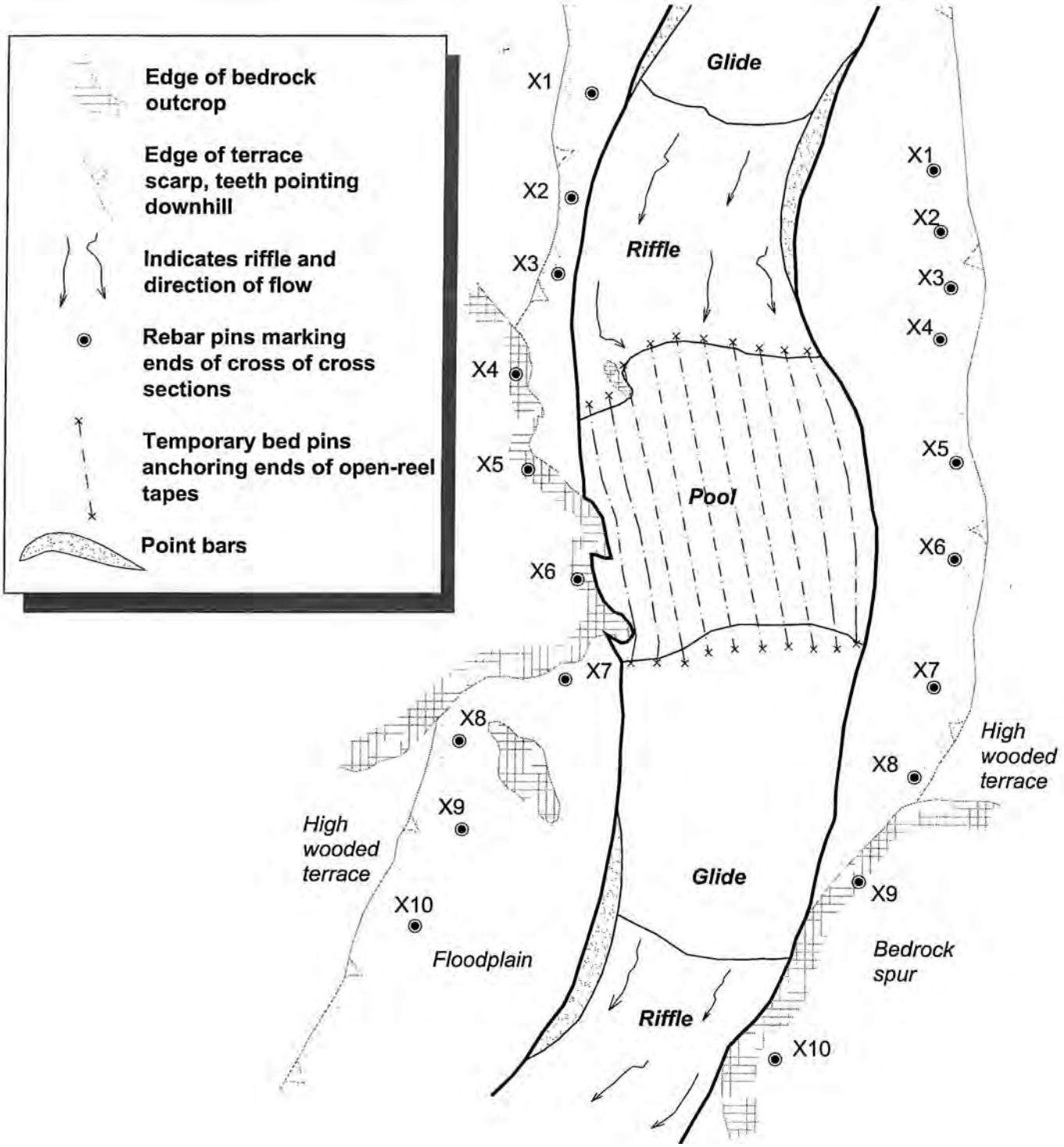

Source: Hecht and Glasner, 2002

Figure 12. Sampling sketch showing locations of longitudinal passes and cross sections relative to segments (riffles, pools, glides) in Lagunitas Creek. Each segment is sampled at 10 to 15 locations along each of the 10 passes. Passes are arrayed approximately 9, 18, 27, 36, 45, 55, 64, 73, 82 and 91 percent of the width of the stream from the left bank, and may be bowed slightly to adjust for bank indentations and projections. Example shows open-reel tapes stretched prior to conducting the bed census for the pool at this site.

One sampler moves upstream along the odd-numbered passes, measuring size and embeddedness of particles immediately beneath pre-set regularly-spaced points along the tapes marking the pass; the other sampler moves along the adjoining even-numbered pass, as the two samplers alternate their measuring 'calls' to the note-taker. Cross sections are spaced to describe changes in the bed; these average about 0.7 to 1.0 channel widths apart at each site at the seven sites. Rebar pins marking the ends of cross sections are usually set at the high-water marks of a recent flood moderately above bankfull depth, providing an energy slope for the sequence; occasionally, pins are set higher, at the marks left by major floods (see X8).

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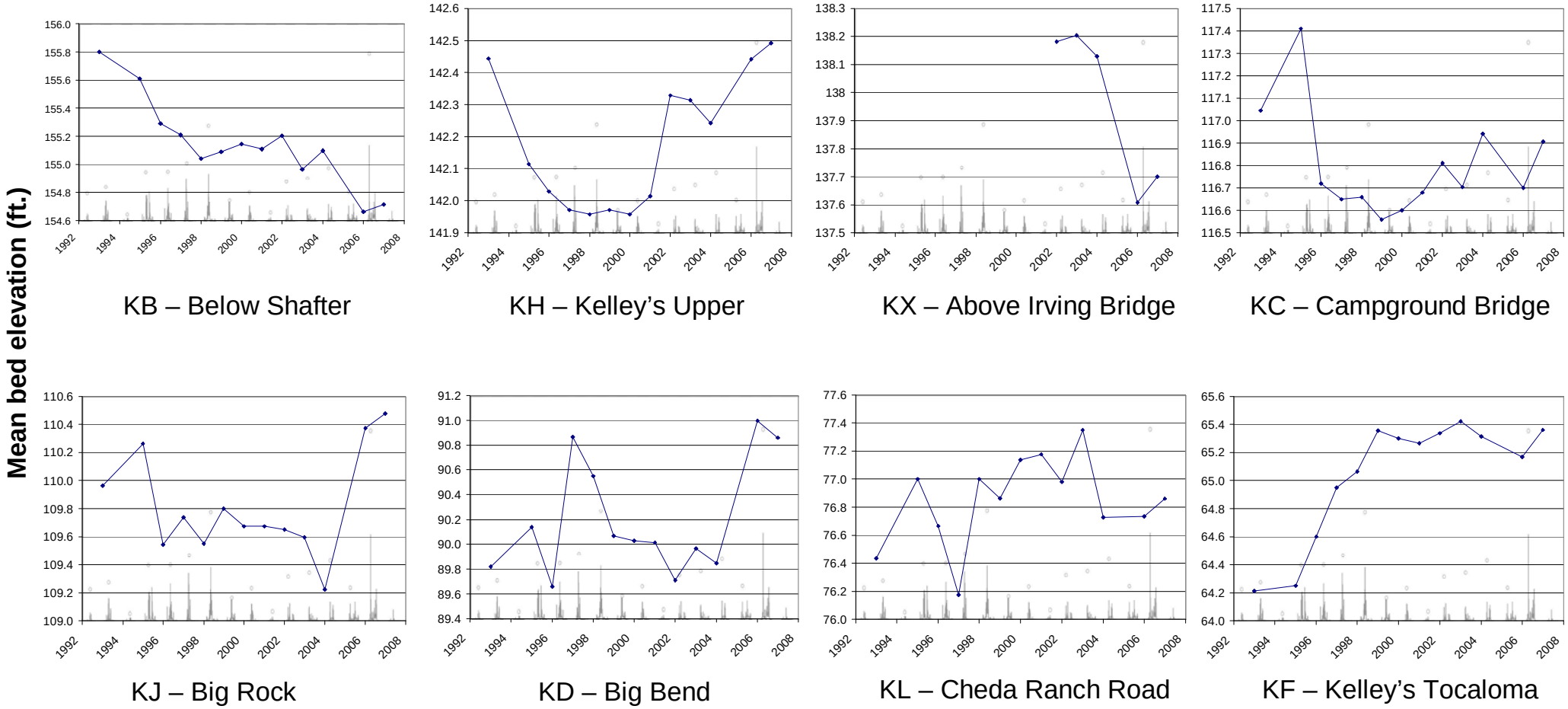

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Figure 13a. Changes in mean bed elevation (bed elevation averaged over all cross sections at each site), Lagunitas Creek, Marin County, California, 1993-2007. Note the differences in vertical scale and exaggeration for each plot. KB is largely incising, while KF in largely aggrading. Reaches in between (KH through KL) exhibit more dynamic behavior. Note beginning-of-record similarities in aggradation-incision between KC and KJ, end-of-record similarities in aggradation between KJ and KD, and possibly lagged cycle of incision followed by aggradation in 1996-97 at KD and 1997-98 at KL and KF. Mean daily and peak flows plotted as watermark.

208052 Figure 13, 12-23.ppt

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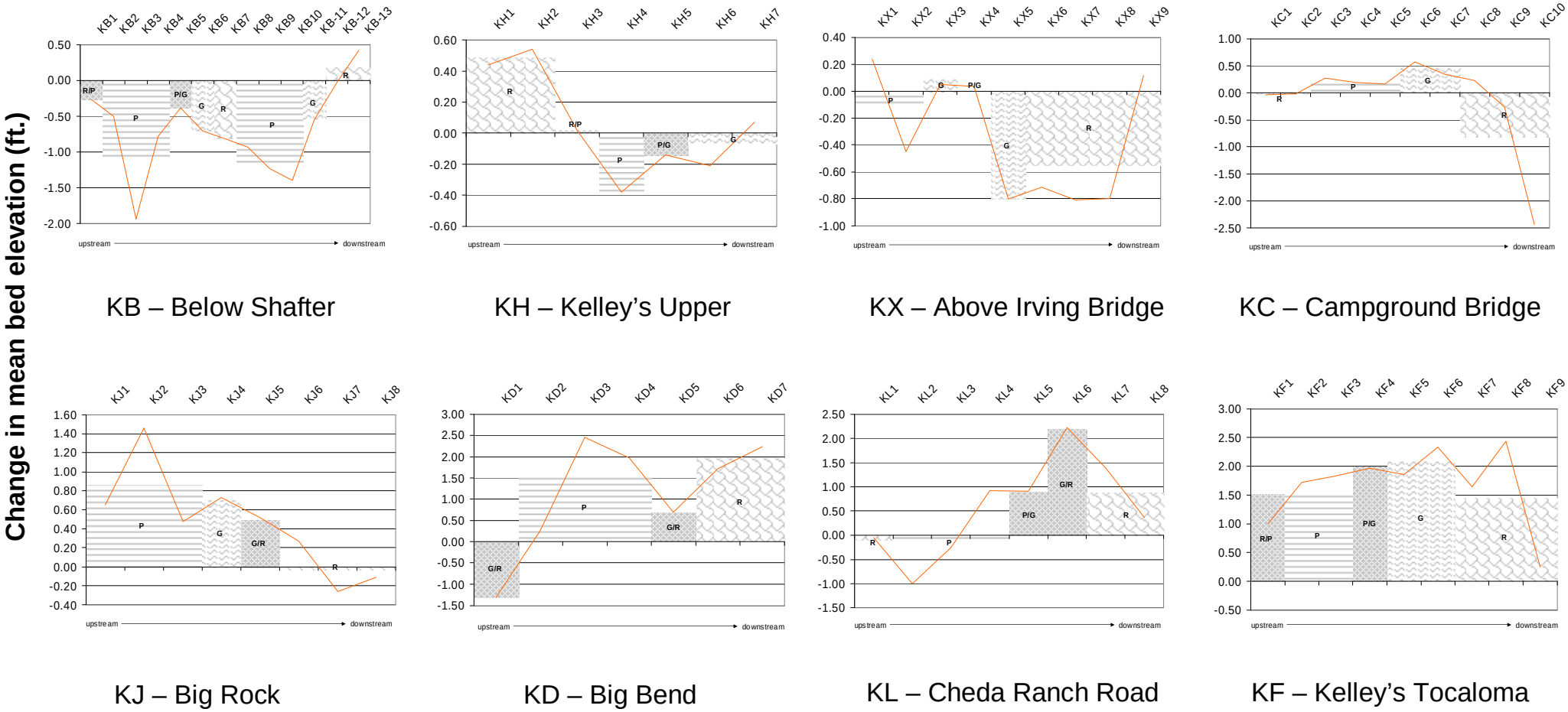

Cross Section

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Figure 13b. Overall change (1993-2007; 2002-07 for KX) in mean bed elevation at each cross section at all sites, and mean change in mean bed elevation for each type of segment within each site, Lagunitas Creek, Marin County, California. Mean bed elevation is the mean of surveyed elevations across a given cross section. Bar graph shows average of the mean bed elevations across a segment (riffle [R], pool [P], or glide [G]). Transitional segments (R/P, P/G, or G/R) are ones that have changed from year-to-year due to longitudinally-migrating boundaries of bedforms. KF1 changed from a riffle in 1979 to a pool by 1981, when large storms removed LWD deposited in 1980 and scoured a pool.

Mean elevation change per segment type:

- Riffle (R)
- Pool (P)
- Glide (G)
- Transitional (R/P, P/G, G/R)
- Overall change at each cross section

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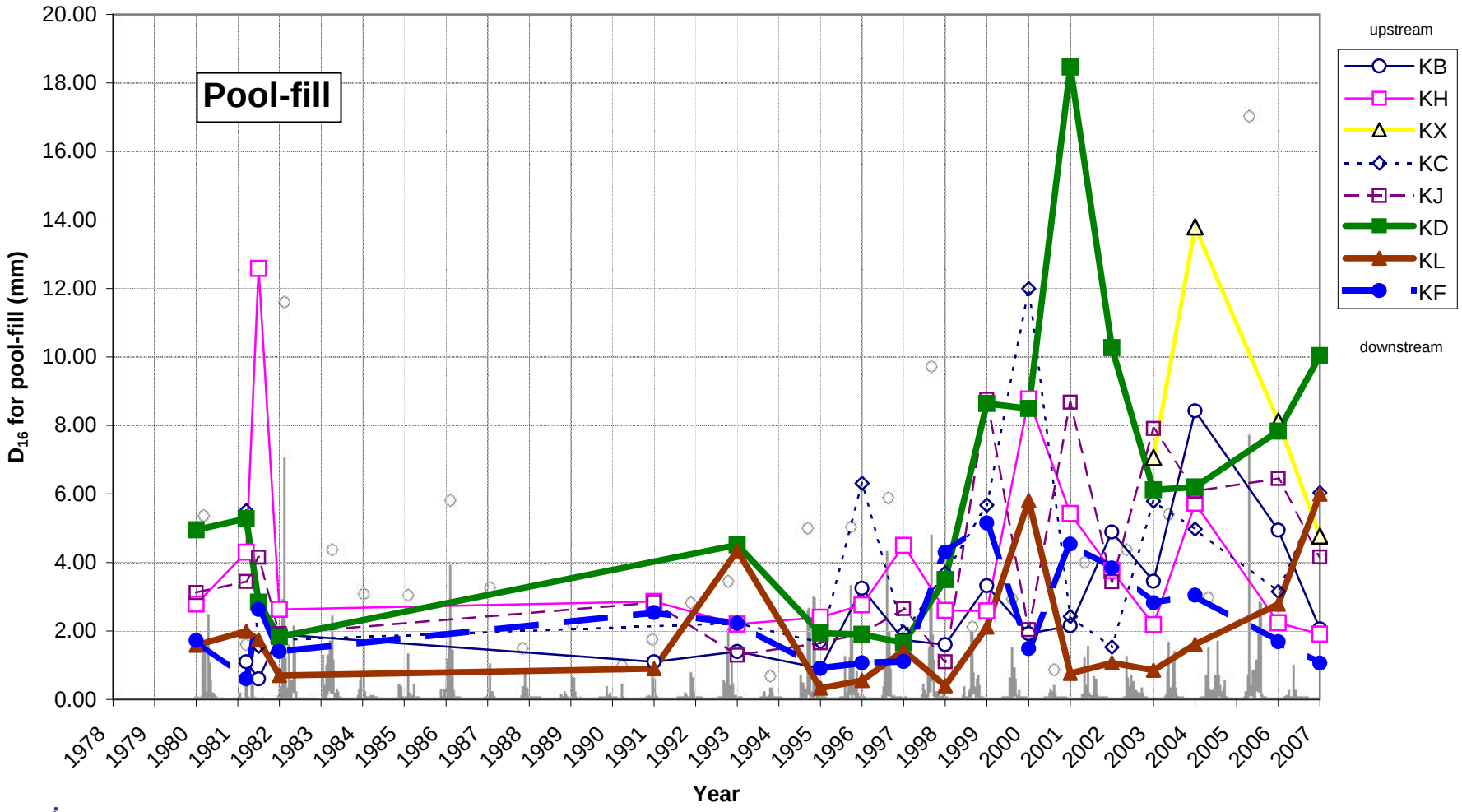

Figure 14. Trends in sub-surface bed-material size (D_{16}) over time, Lagunitas Creek, Marin County, California. Sites appear to be coarsening, perhaps with the exception of KL. D_{16} is exceptionally coarse at KH in 1982, KC in 2000, KD in 2001, and KX in 2004. Mean daily and peak flows at Samuel P. Taylor State Park plotted as watermark; see Figure 3 for watermark scale.

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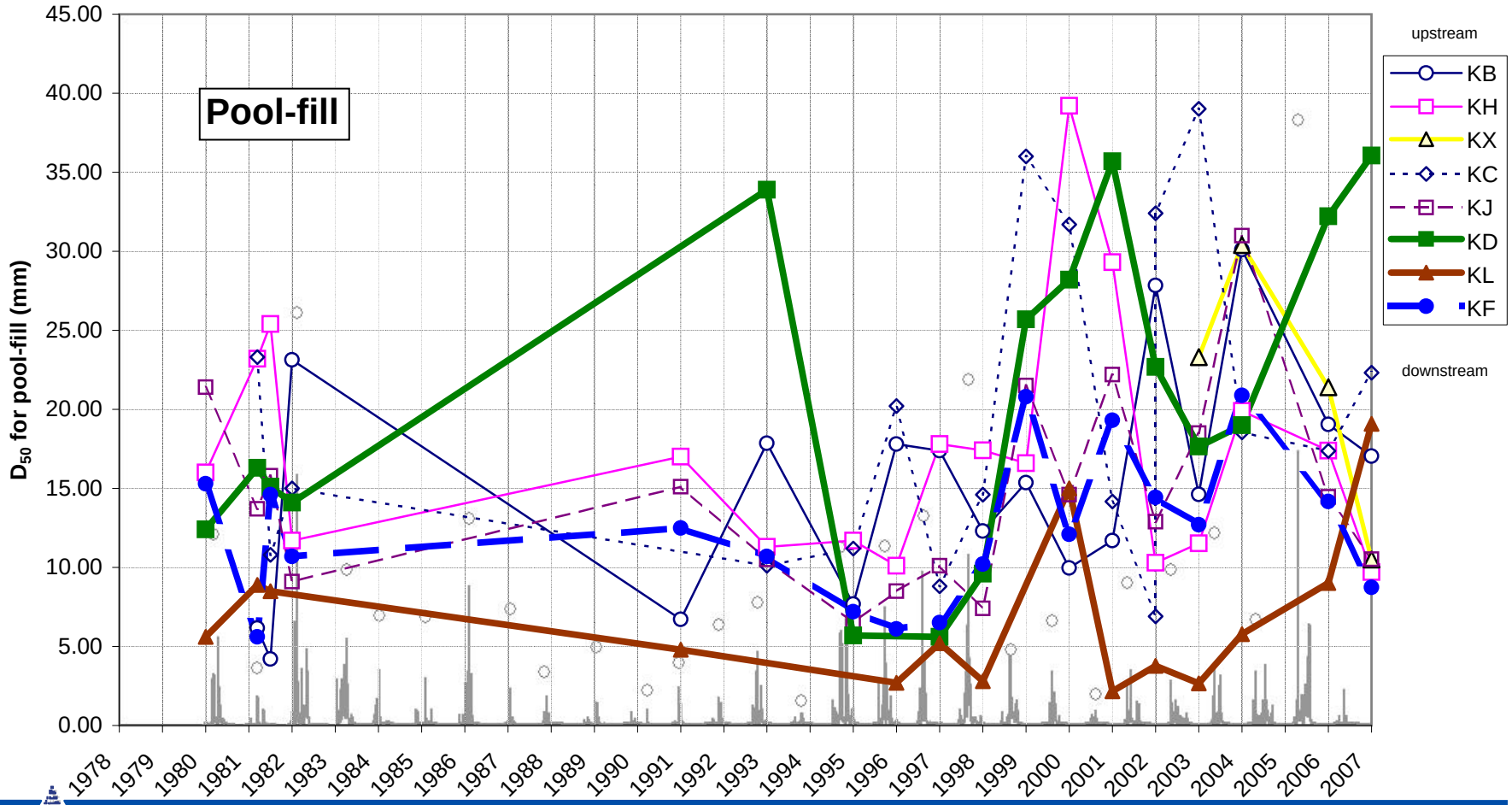

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Figure 15. Trends in sub-surface bed material median size (D_{50}) over time, Lagunitas Creek, Marin County, California. Sites appear to be coarsening, with the exception of KL. Note the response at the three sites downstream of the Big Bend events in 1995-1997 introduced large amounts of fine material at and downstream of KD. Mean daily and peak flows at Samuel P. Taylor State Park plotted as watermark; see Figure 3 for watermark scale. Note that these samples are collected from below the surface at the pool/glide boundary; they should not be compared with results from riffles and spawning sites.

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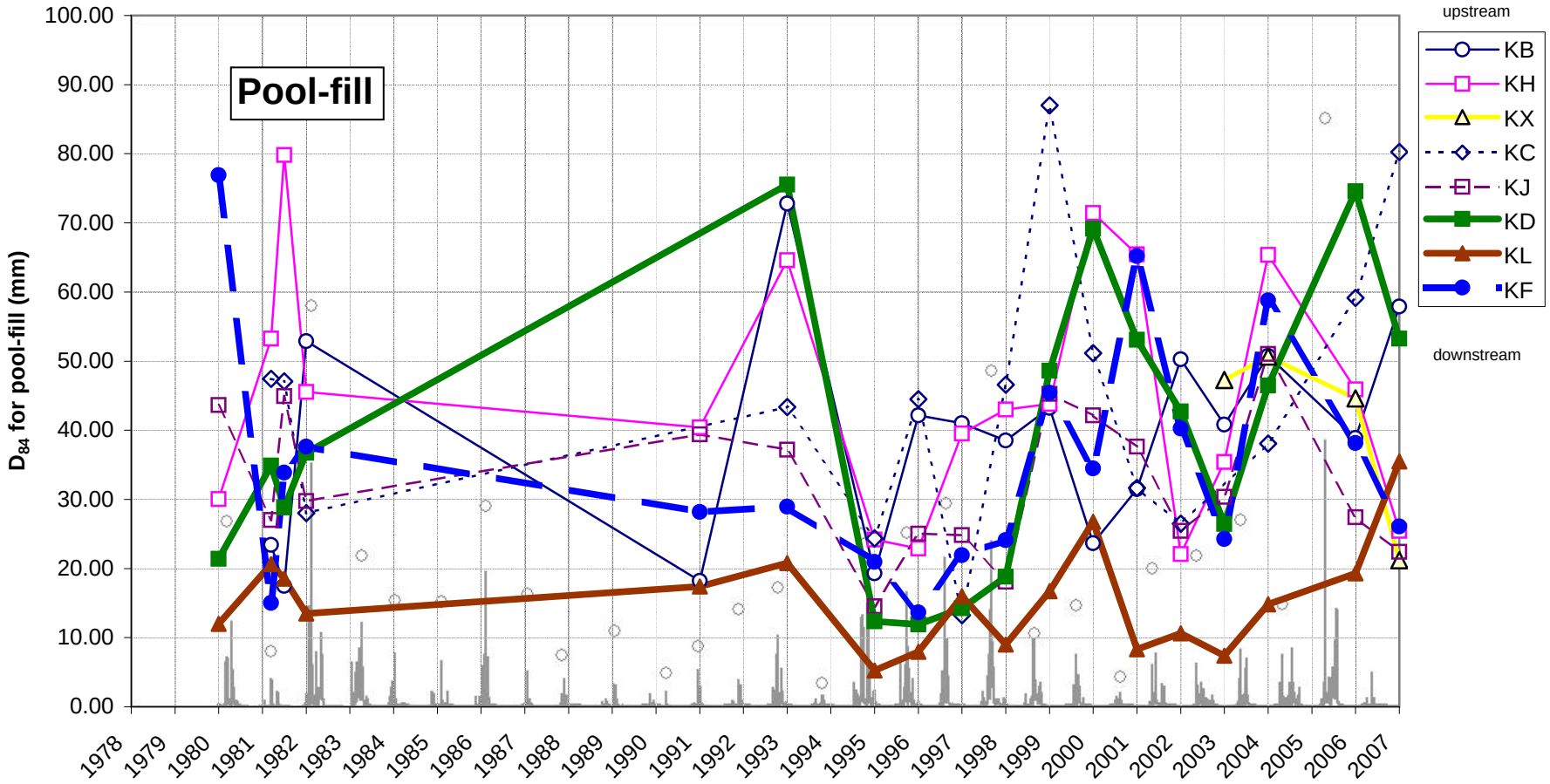

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Figure 16. Trends in sub-surface bed material median size (D_{84}) over time, Lagunitas Creek, Marin County, California. Sites appear to maintain consistent D_{84} through time, with one notable spike at site KC in 1998. Mean daily and peak flows at Samuel P. Taylor State Park plotted as watermark; see Figure 3 for watermark scale. Note that these samples are collected from below the surface at the pool/glide boundary; they should not be compared with results from riffles and spawning sites.

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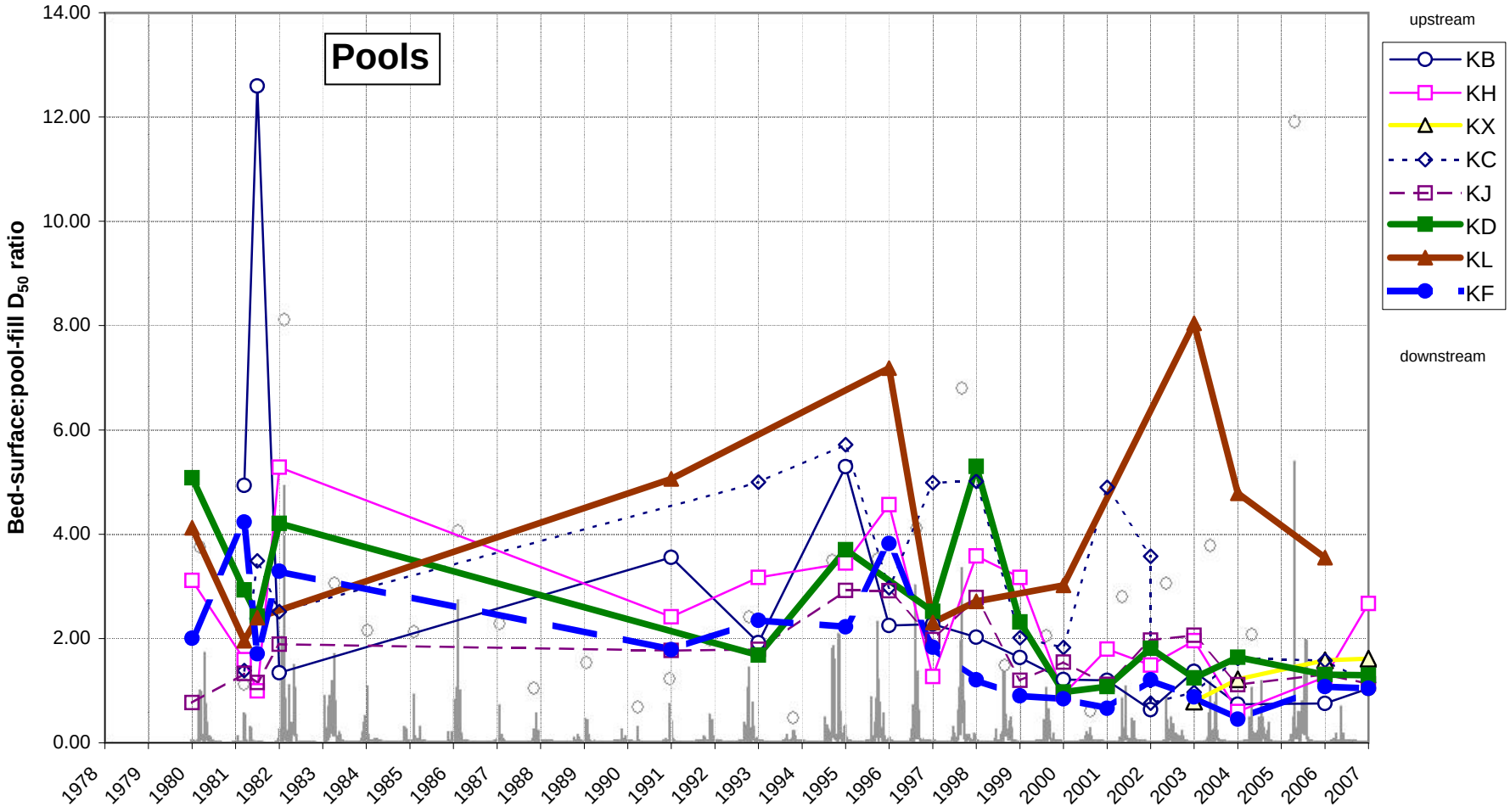

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Figure 17. Trends in the ratio of pool surface bed material to pool-fill median size (D_{50}) over time, Lagunitas Creek, Marin County, California. Note decreasing variability of the ratio after 1995 for all sites except KC, KD, and KL. Even KC and KD appear to stabilize after 2002. Mean daily and peak flows at Samuel P. Taylor State Park plotted as watermark; see Figure 3 for watermark scale. Pool KL is anomalous because it is a plunge pool downstream from a logjam, and tends to fill with fine sand.

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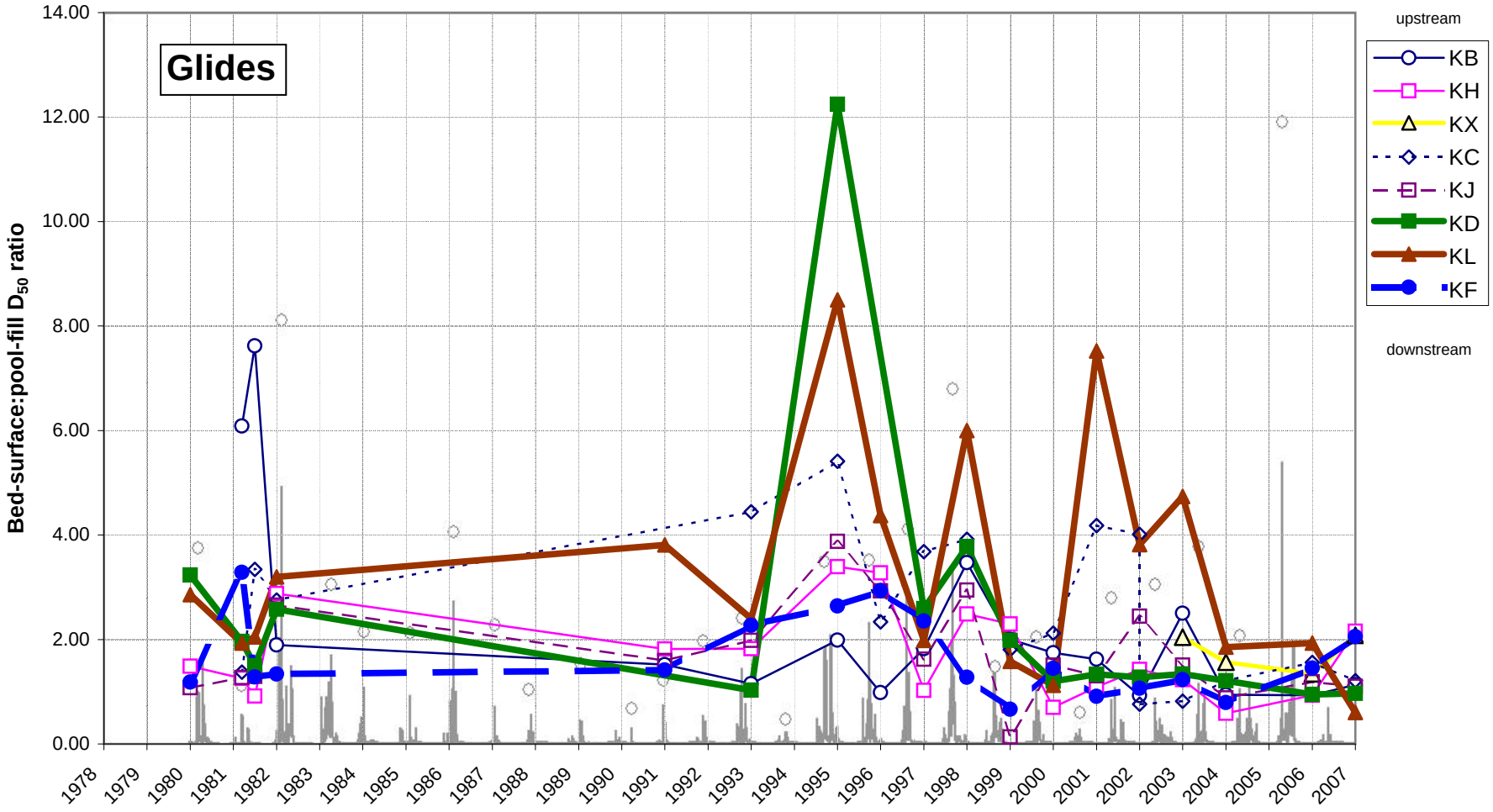

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Figure 18. Trends in glide surface bed material to pool-fill median size (D_{50}) ratio over time, Lagunitas Creek, Marin County, California. Note decreasing variability of the ratio after 1995 for all sites except KC, KD, and KL. Mean daily and peak flows at Samuel P. Taylor State Park plotted as watermark; see Figure 3 for watermark scale.

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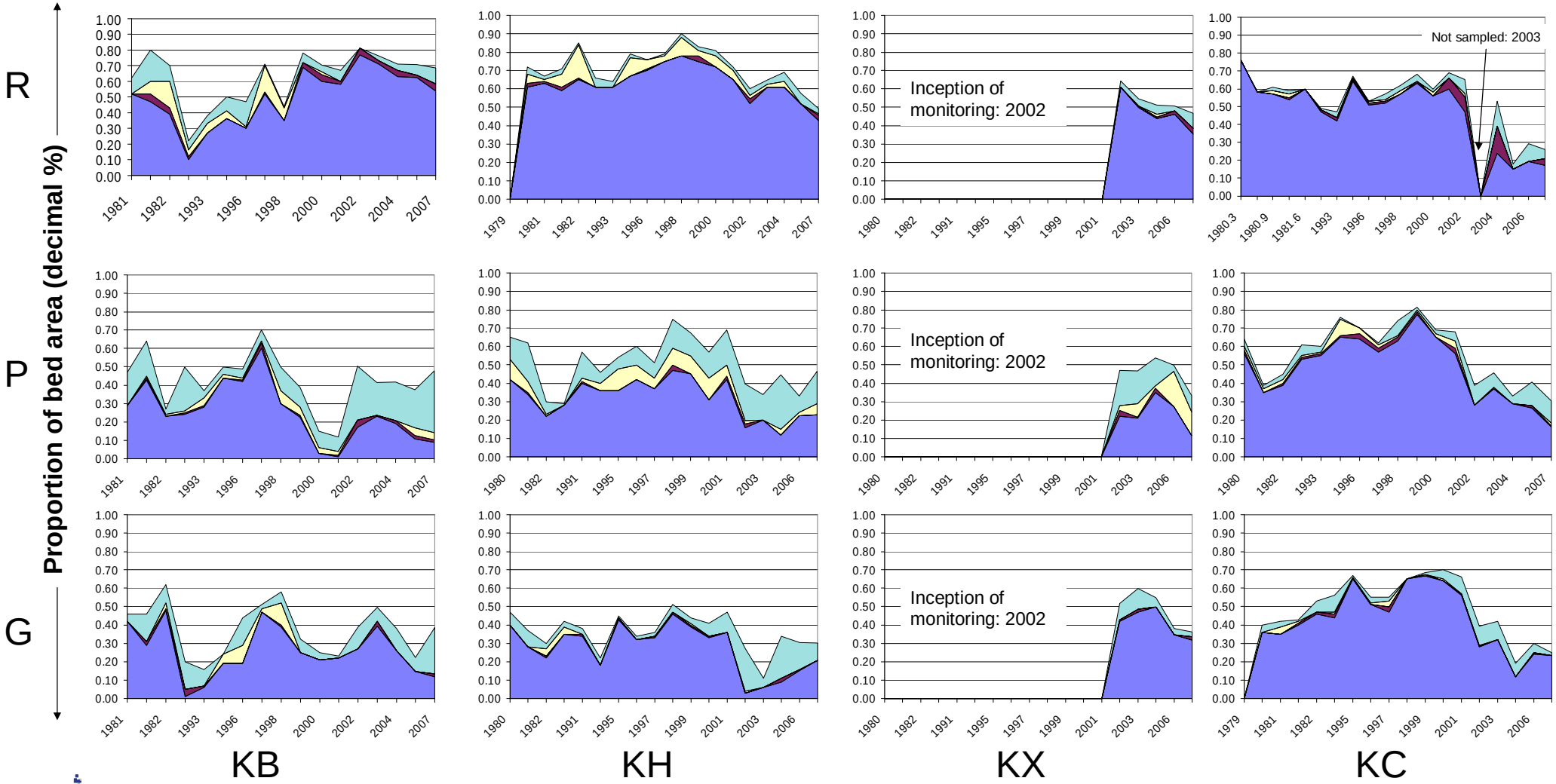

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Figure 19a. Changes in proportions of the bed surface in which bedrock, mid-size or large woody debris, and sand were encountered at the bed surface, organized by site. Note abundance of cobble, increasing sand fraction after 1997, and response to 1982, 1997 and 1998, and 2006 storm seasons. R=riffle; P=pool; G=glide.

- Large Organics
- Sand
- Gravels
- Cobbles
- Bedrock

208052 Figure 13, 12-23.ppt

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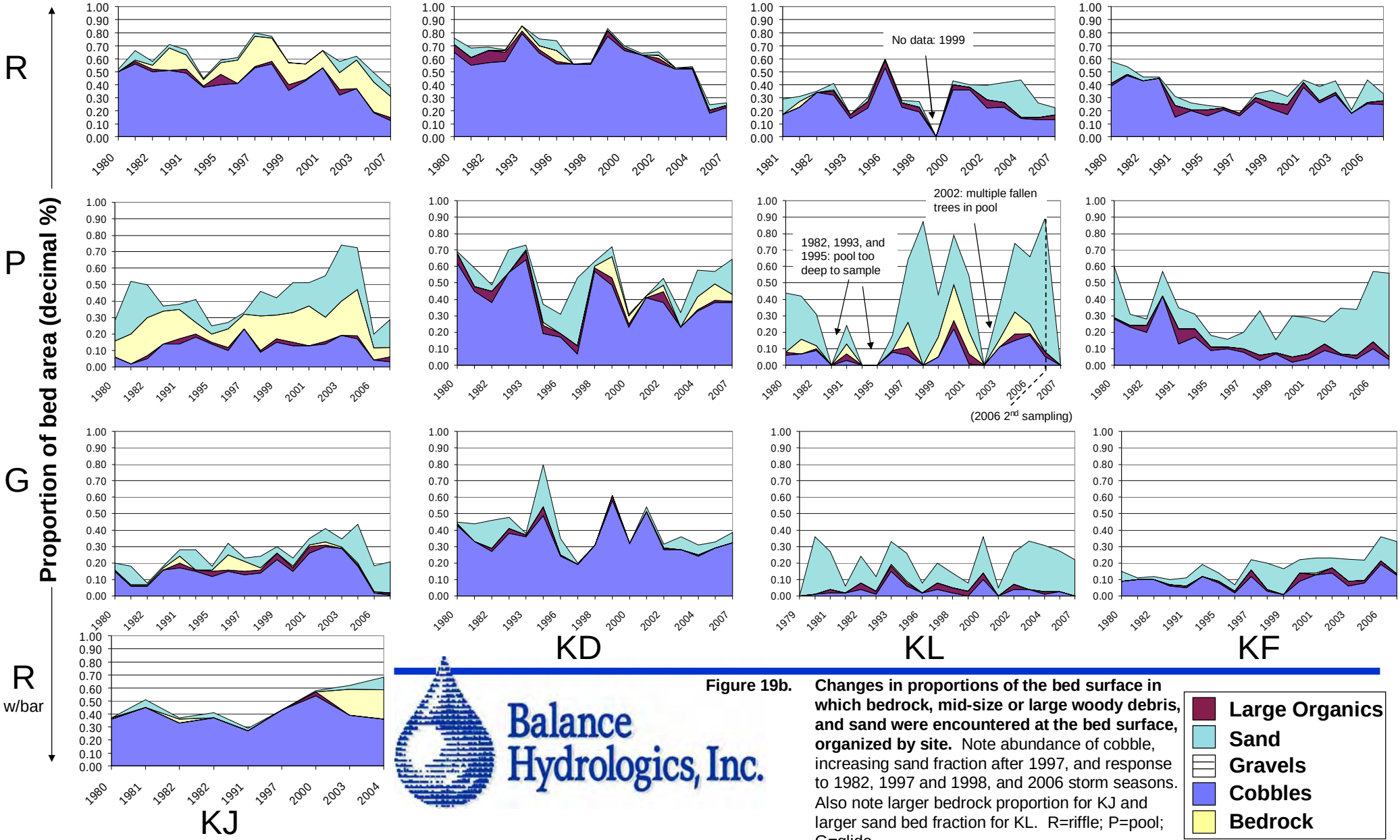

Figure 19b. **Changes in proportions of the bed surface in which bedrock, mid-size or large woody debris, and sand were encountered at the bed surface, organized by site.** Note abundance of cobble, increasing sand fraction after 1997, and response to 1982, 1997 and 1998, and 2006 storm seasons. Also note larger bedrock proportion for KJ and larger sand bed fraction for KL. R=riffle; P=pool; G=glide.

- Large Organics
- Sand
- Gravels
- Cobbles
- Bedrock

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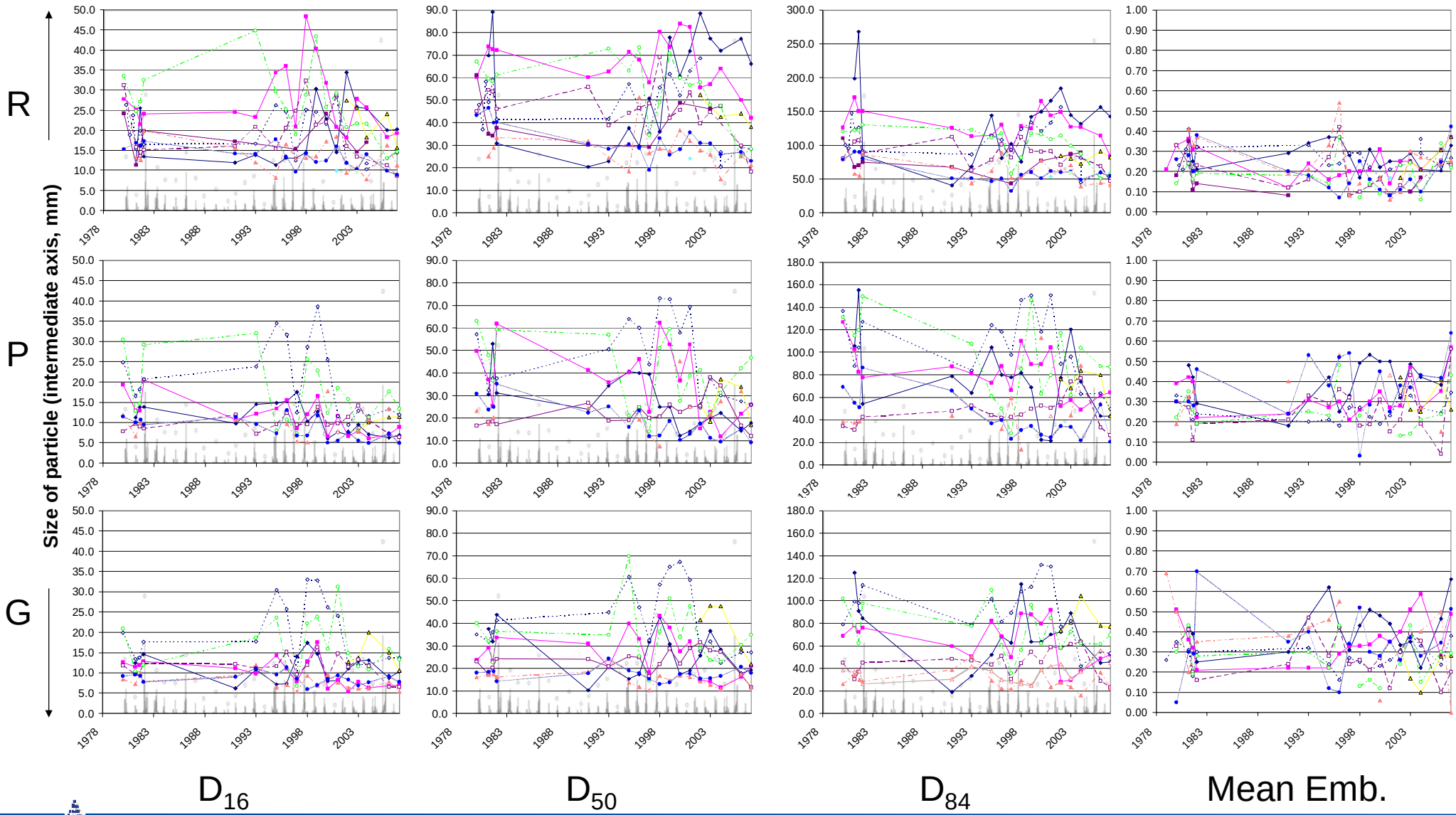

Figure 20. Trends in surface bed material size classes and mean embeddedness over time, Lagunitas Creek, Marin County, California. R=riffle; P=pool; G=glide. Sites upstream tend to be coarser. D_{84} tends to be less than 150mm. Data extends to 2007. Mean daily and peak flows plotted as watermark.

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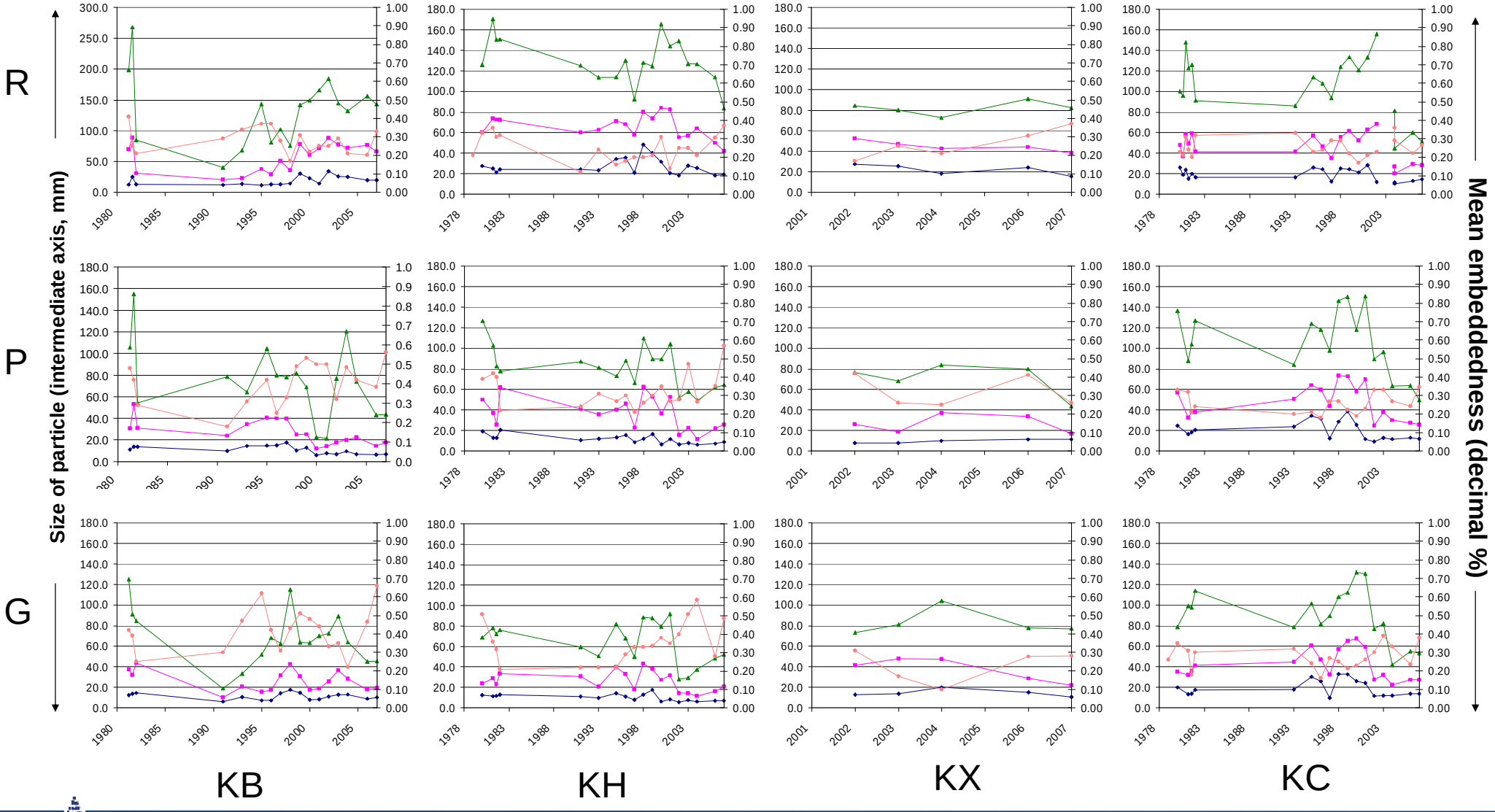

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Figure 21a. Trends in surface bed material size classes and mean embeddedness over time, organized by site to permit comparison between size fractions and embeddedness at a site, Lagunitas Creek, Marin County, California. R=riffle; P=pool; G=glide. Data extends to 2007. Mean daily and peak flows plotted as watermark.

D-16
D-50
D-84
Mean Embeddedness (>45mm)

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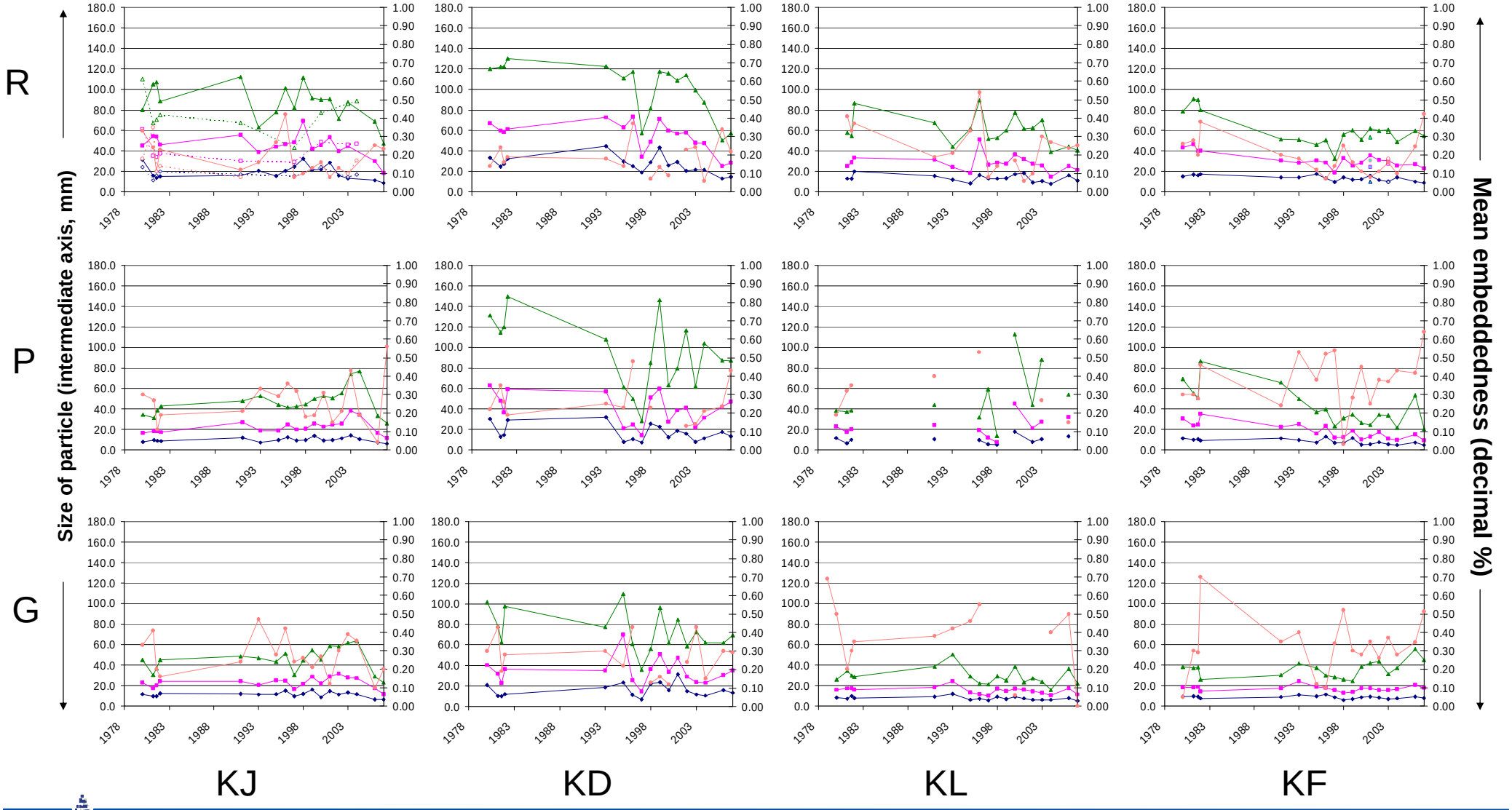

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208052 Figure 13, 12-23.ppt

Figure 21b. Trends in surface bed material size classes and mean embeddedness over time, organized by site to permit comparison between size fractions and embeddedness at a site, Lagunitas Creek, Marin County, California. R=riffle; P=pool; G=glide.

D-16
D-16 (minor riffle)
D-16 (riffle incl. bar)
D-50
D-50 (minor riffle)
D-50 (riffle incl. bar)
D-84
D-84 (minor riffle)
D-84 (riffle incl. bar)
Mean Embeddedness (>45mm)
Mean Embeddedness (minor riffle)
Mean embeddness (riffle incl. bar)

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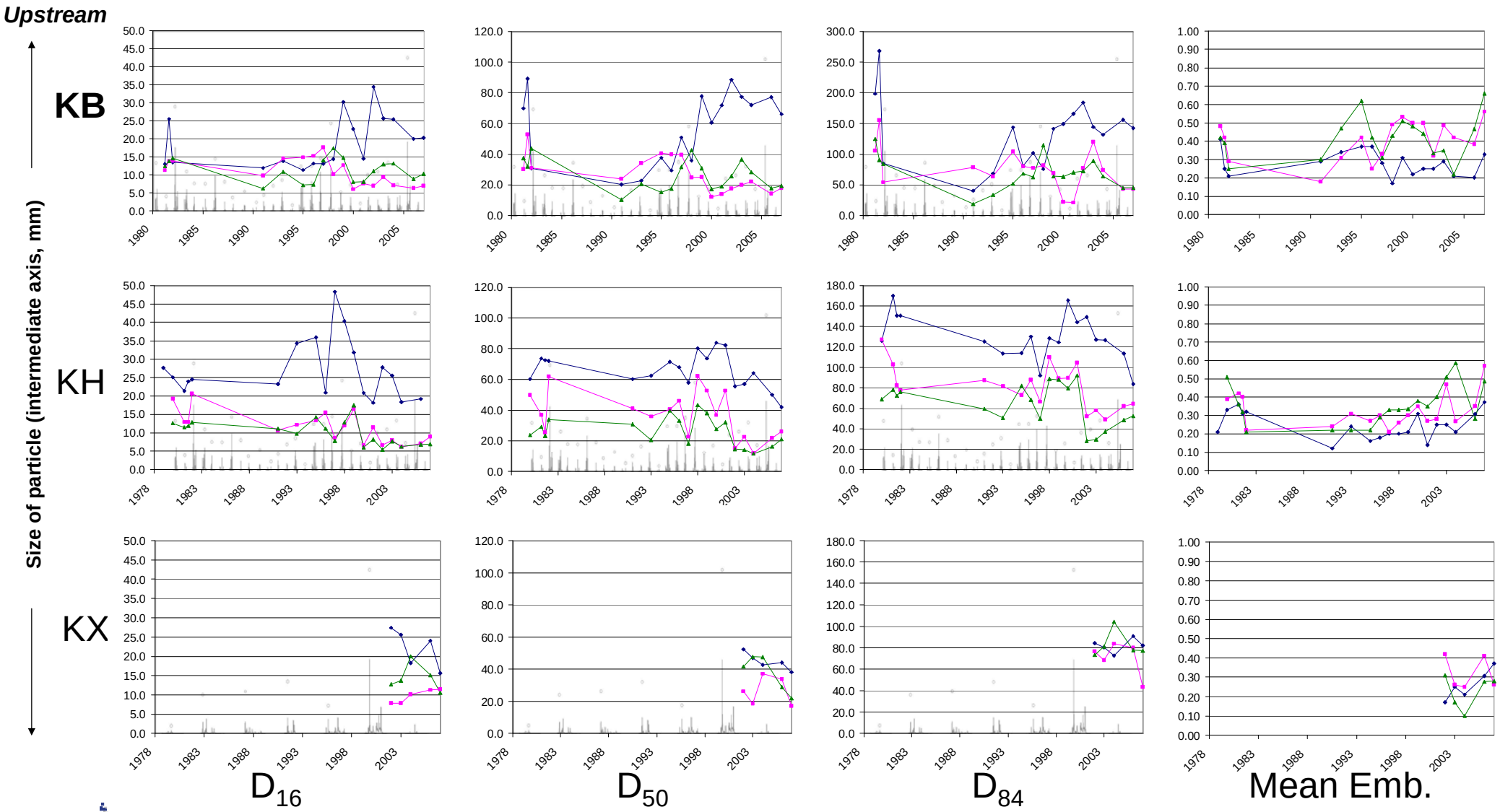

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Figure 22a. Trends in surface bed material size classes and mean embeddedness over time, organized by site to allow comparison between segments at a site, Lagunitas Creek, Marin County, California. Note that KX, KC, and KF all exhibit similar size fraction magnitudes for their riffles, pools, and glides; particles tend not to differ substantially in size between riffles, pools, and glides at each site, and their changes through time are positively correlated and in phase. Note that monitoring began in 2002 at site KX. KB is upstream-most site; KF is downstream-most. Data extends to 2007. Mean daily and peak flows plotted as watermark.

Riffle
Pool
Glide

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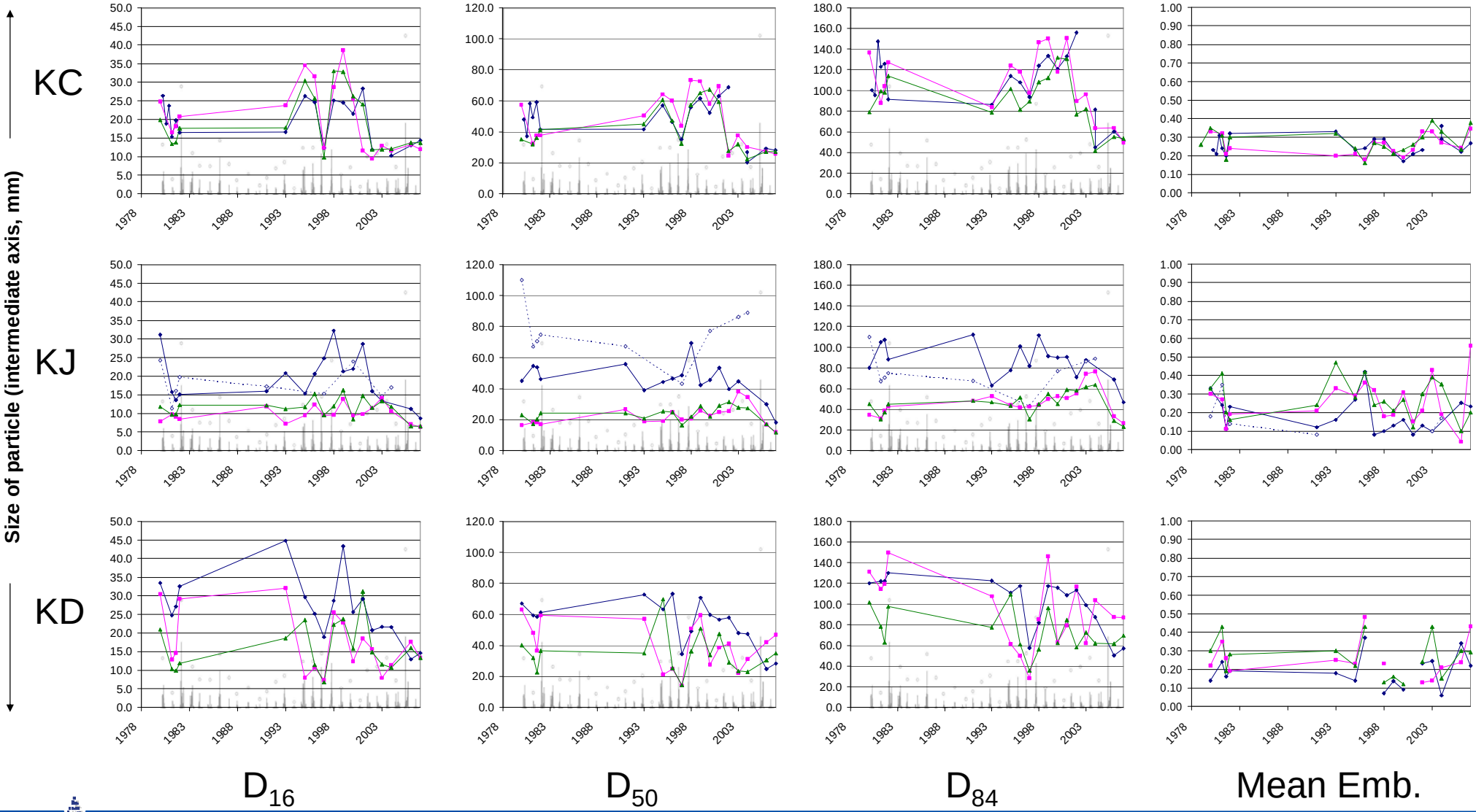

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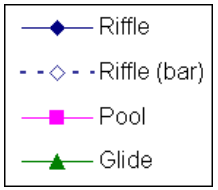
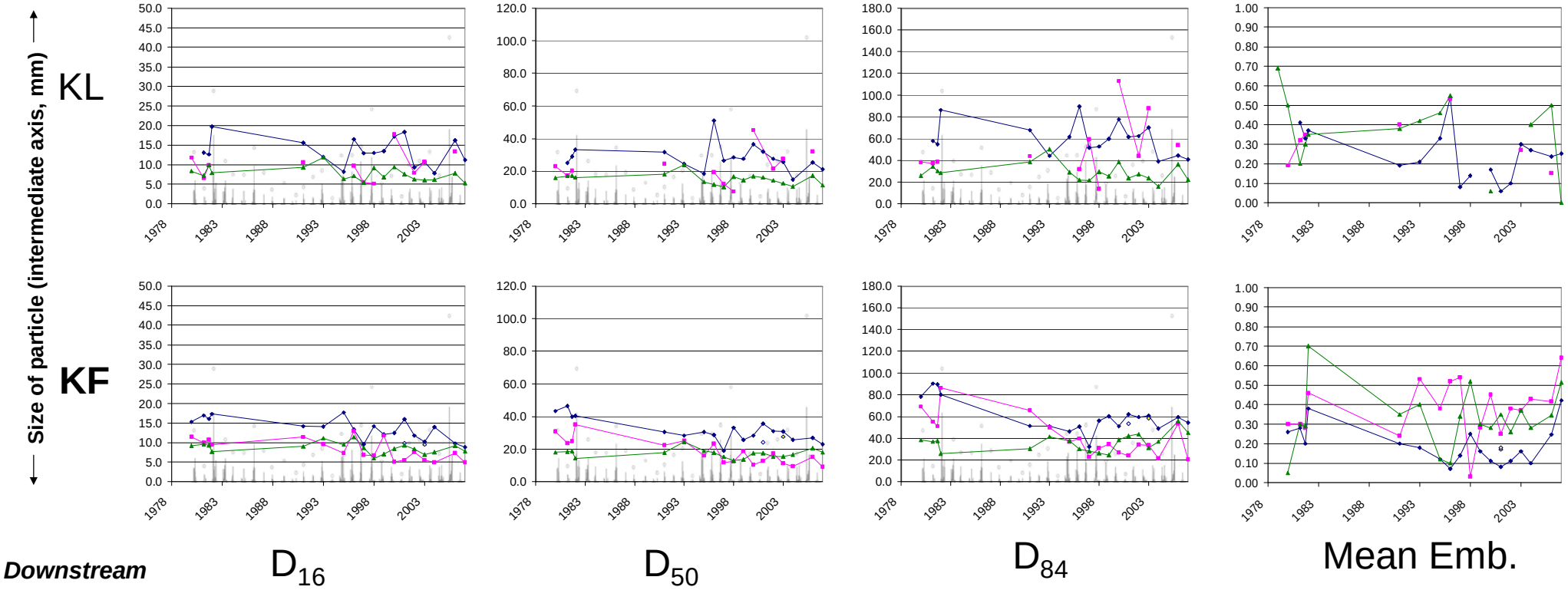
Figure 22b. Trends in surface bed material size classes and mean embeddedness over time, organized by site to permit comparison between segments at a site, Lagunitas Creek, Marin County, California. Note that KX, KC, and KF all exhibit similar size fraction magnitudes for their riffles, pools, and glides; particles tend not to differ substantially in size between riffles, pools, and glides at each site, and their changes through time are positively correlated and in phase. Data extends to 2007. Mean daily and peak flows plotted as watermark.





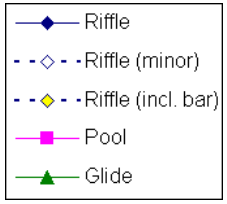


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Figure 22c. Trends in surface bed material size classes and mean embeddedness over time, organized by site to permit comparison between segments at a site, Lagunitas Creek, Marin County, California. Note that KX, KC, and KF all exhibit similar size fraction magnitudes for their riffles, pools, and glides; particles tend not to differ substantially in size between riffles, pools, and glides at each site, and their changes through time are positively correlated and in phase. Data extends to 2007. Mean daily and peak flows plotted as watermark.

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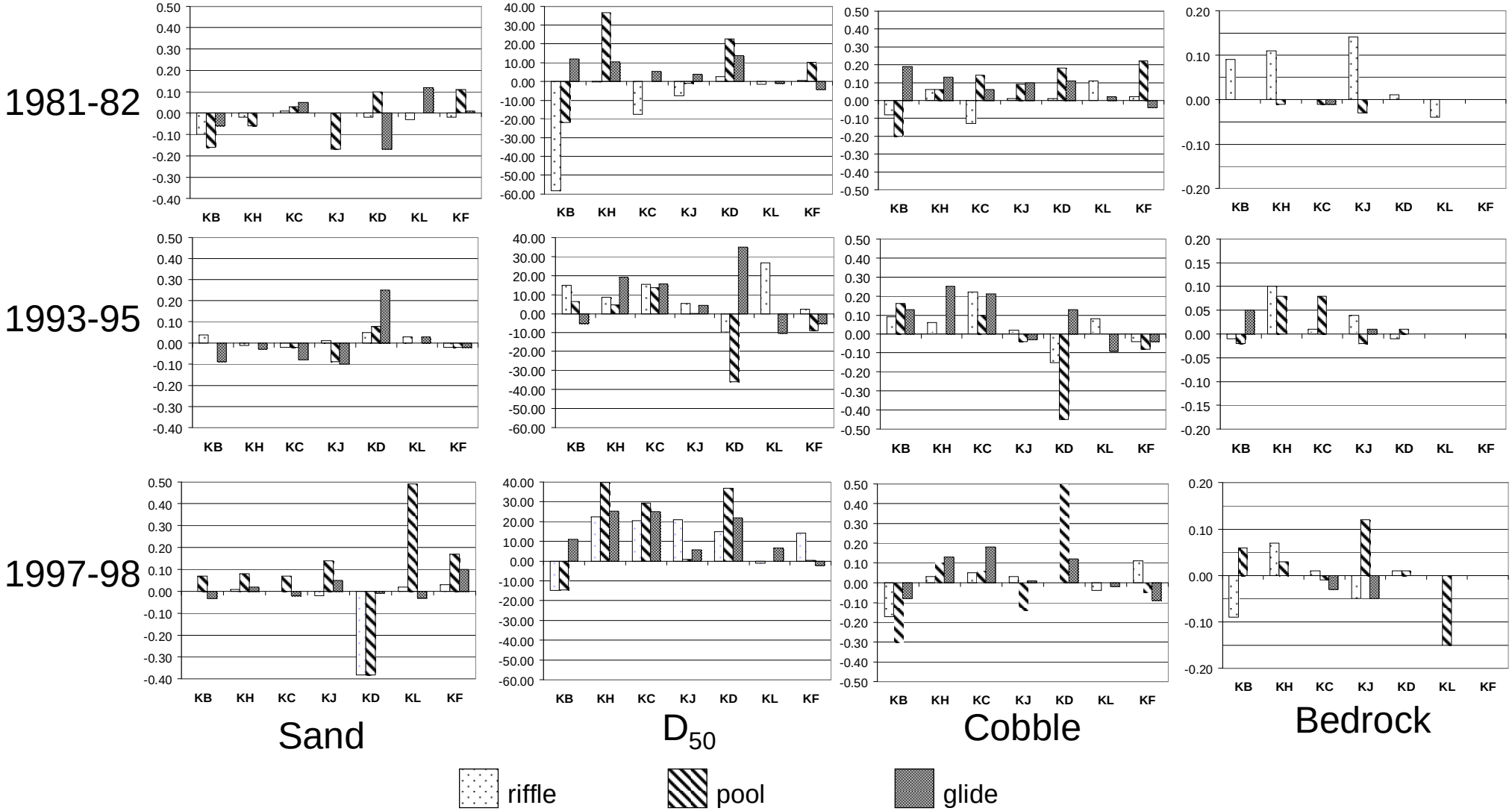

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Figure 23a. Changes in proportion of sand, cobble, bedrock, large organics covering the bed, and D_{50} (median particle size) during three winters with high flows, Lagunitas Creek, Marin County, California. At most sites, the proportion of cobble increased in response, but notice the loss of cobble at KD in 1993-95 at the expense of sand deposition. Pools generally became sandier after the 1997-98 flow events.

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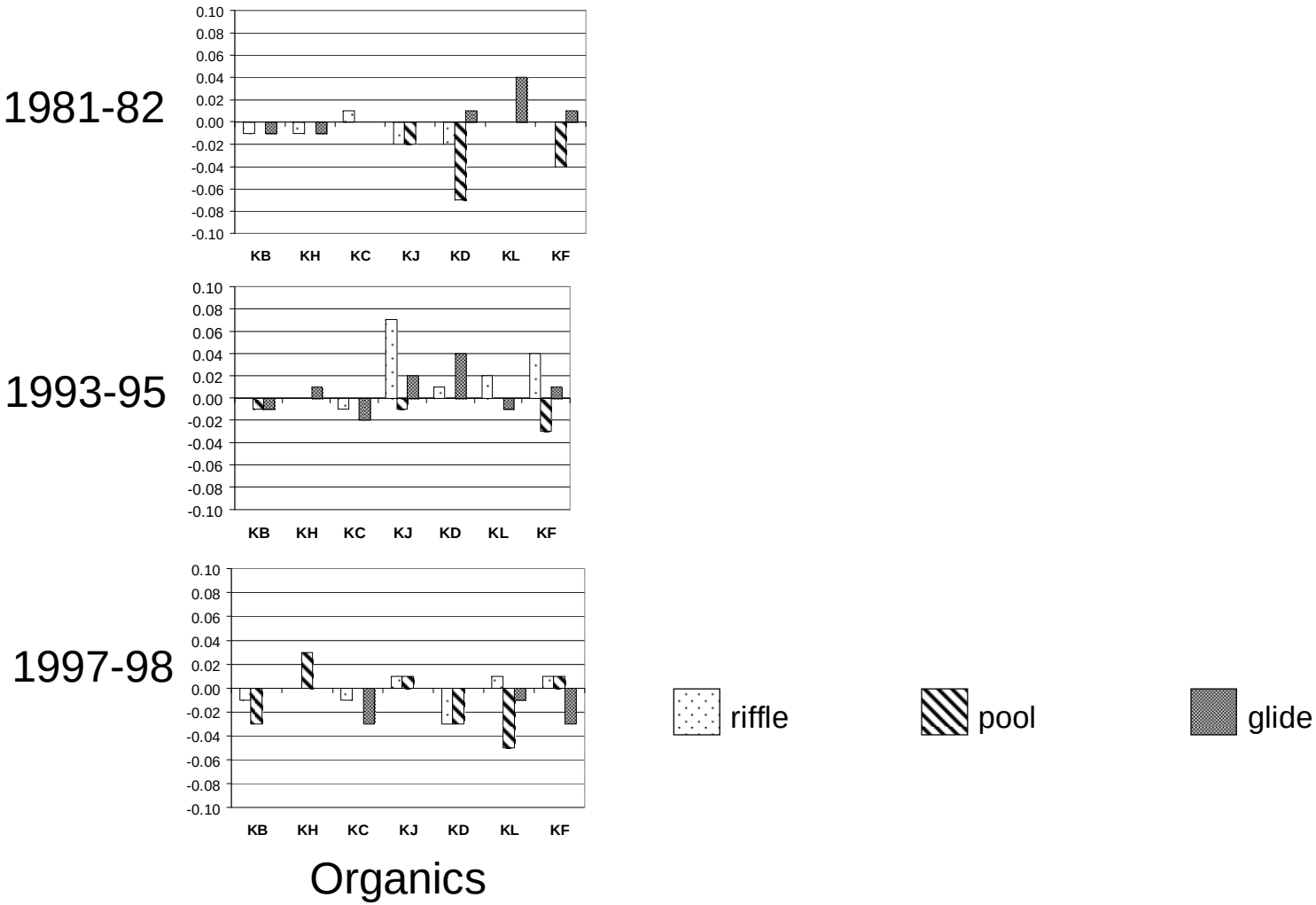

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208052 Figure 13, 12-23.ppt

Figure 23b. Changes in proportion of sand, cobble, bedrock, large organics covering the bed, and D_{50} (median particle size) during three winters with high flows, Lagunitas Creek, Marin County, California (continuation of Figure 23a). At most sites, the proportion of cobble increased in response, but notice the loss of cobble at KD in 1993-95 at the expense of sand deposition. Pools generally became sandier after the 1997-98 flow events.

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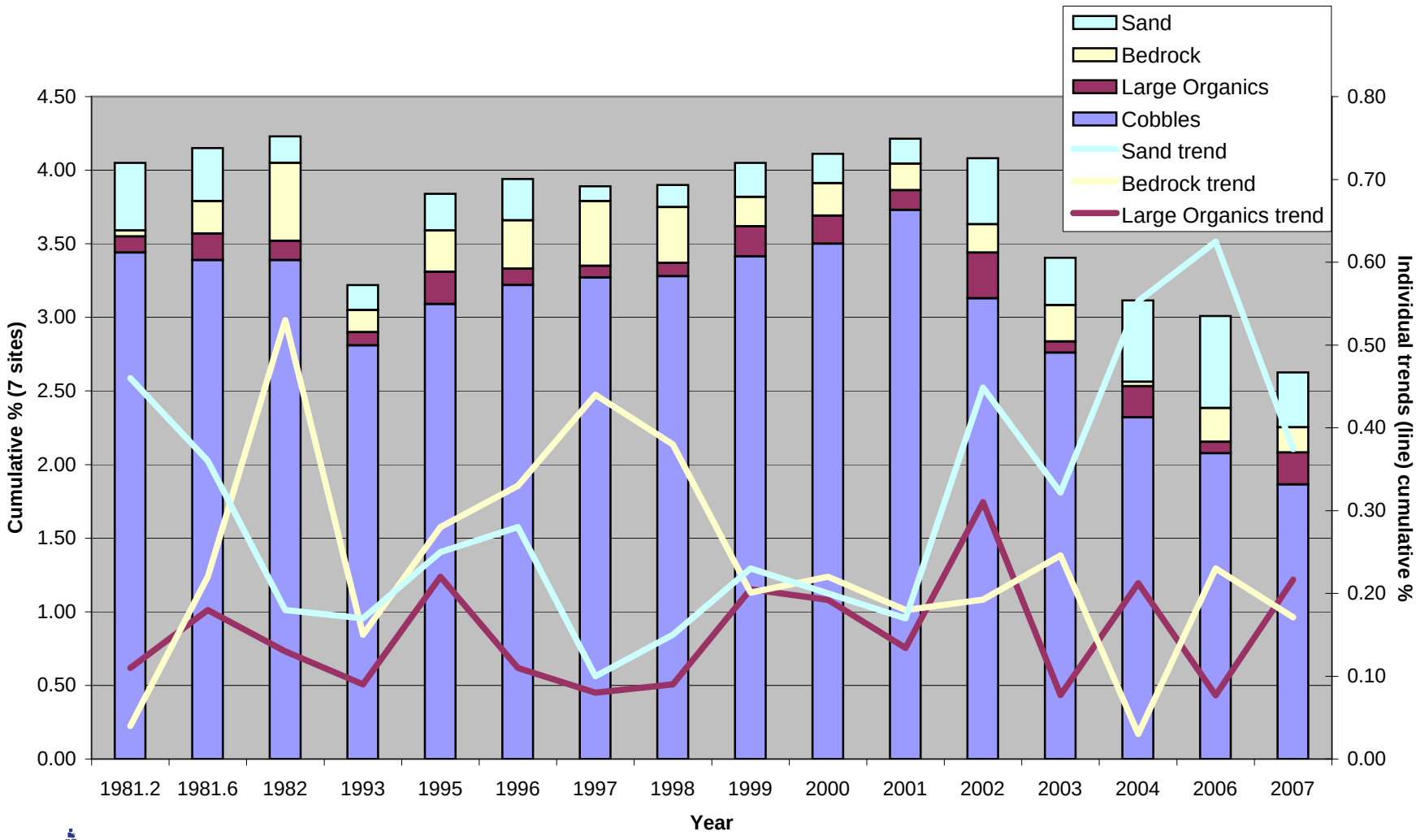

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Figure 24a. Cumulative percent of bed area occupied by bed-surface populations at riffles (summed over all sites except KX), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Backwater riffle at KC in 2004 not included; low-flow riffle (excluding high-flow bar) used for KJ; data missing for KF in 1999.

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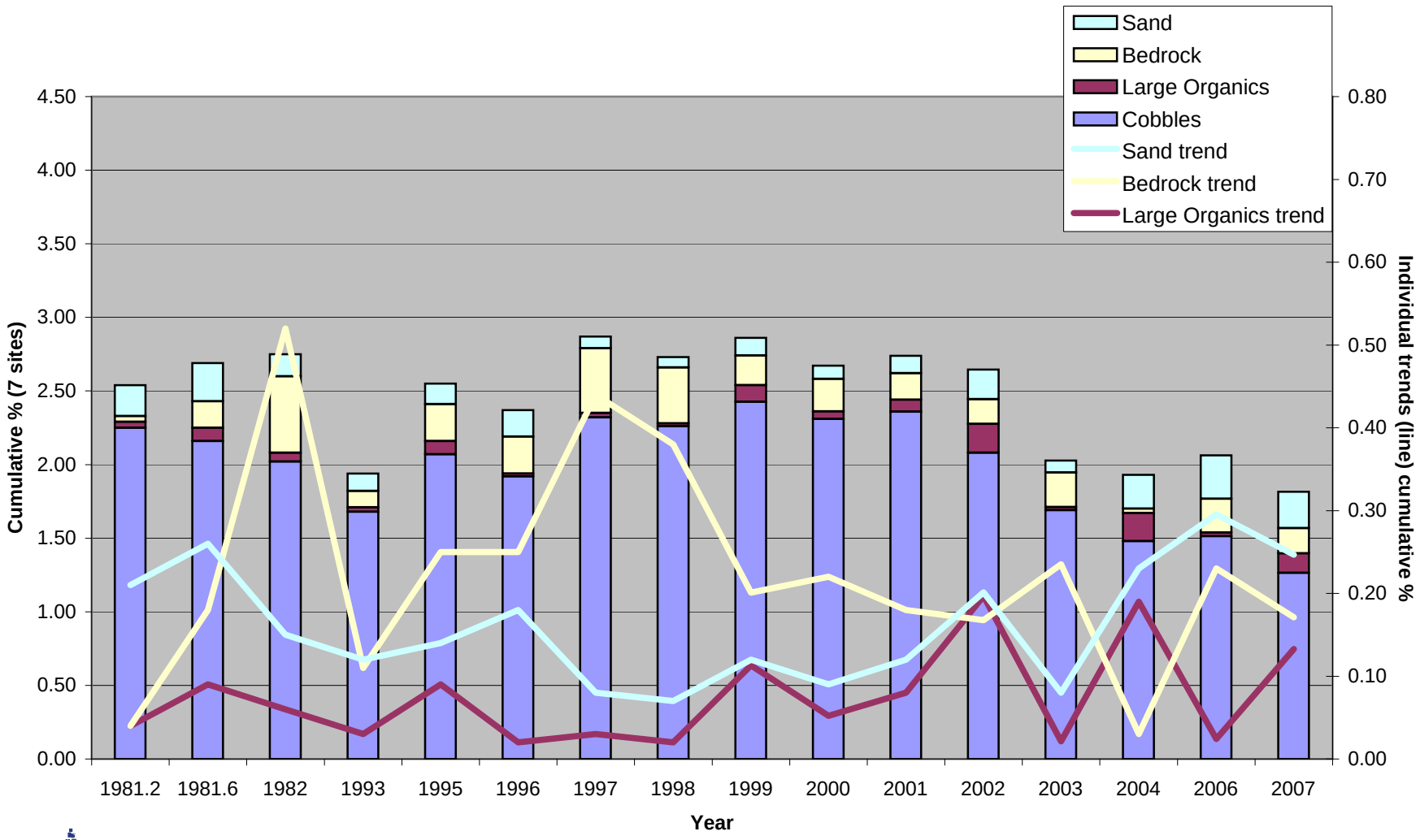

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Figure 24b. Cumulative percent of bed area occupied by bed-surface populations at riffles (summed over all sites except KX, KD, KL, and KF), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Backwater riffle at KC in 2004 not included; low-flow riffle used for KJ; data missing for KF in 1999.

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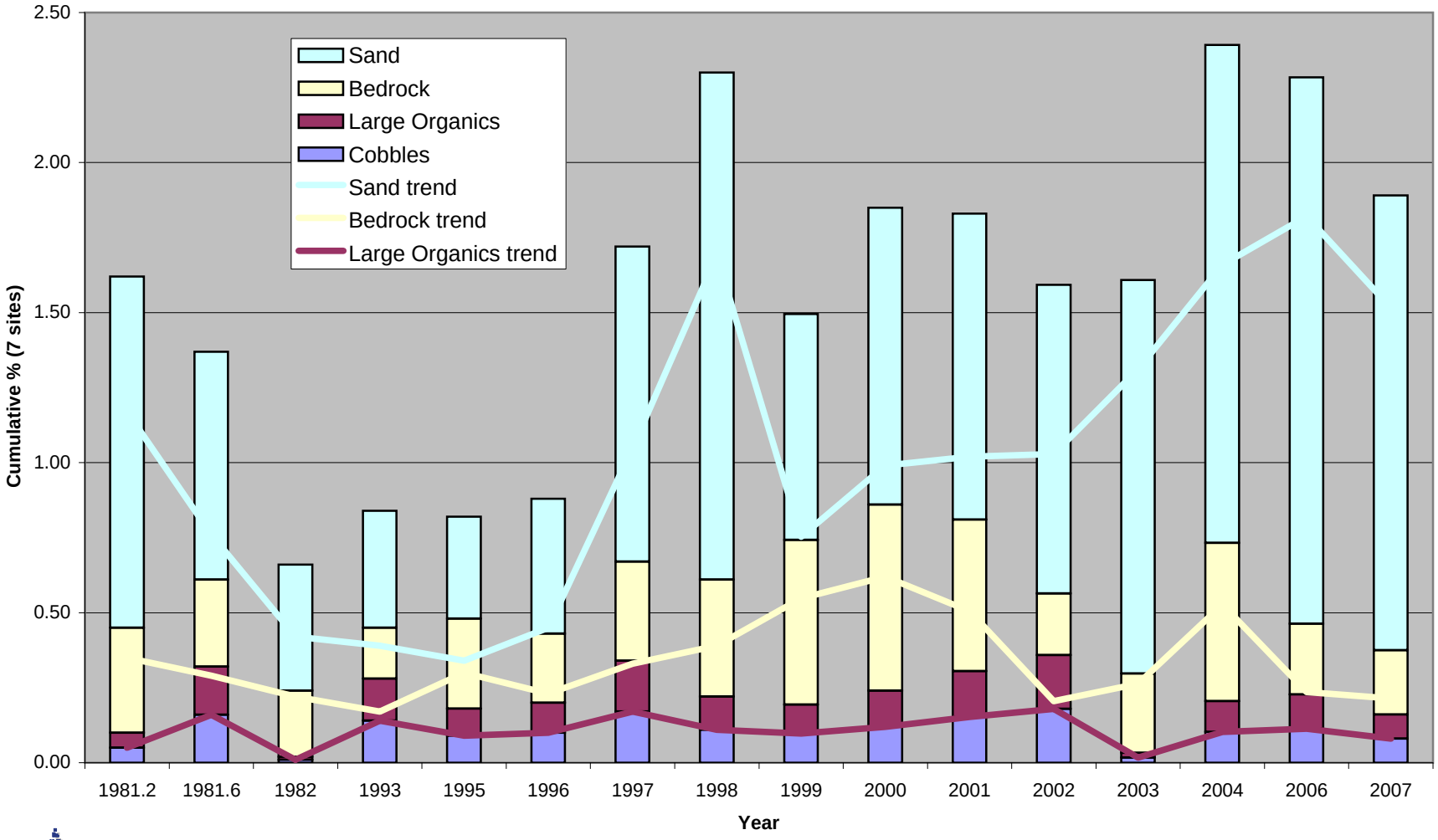

Figure 25a. Cumulative percent of bed area occupied by bed-surface populations at pools (summed over all sites except KX), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Pool data incomplete at KL: 2nd pool at KL in 2001 not used.

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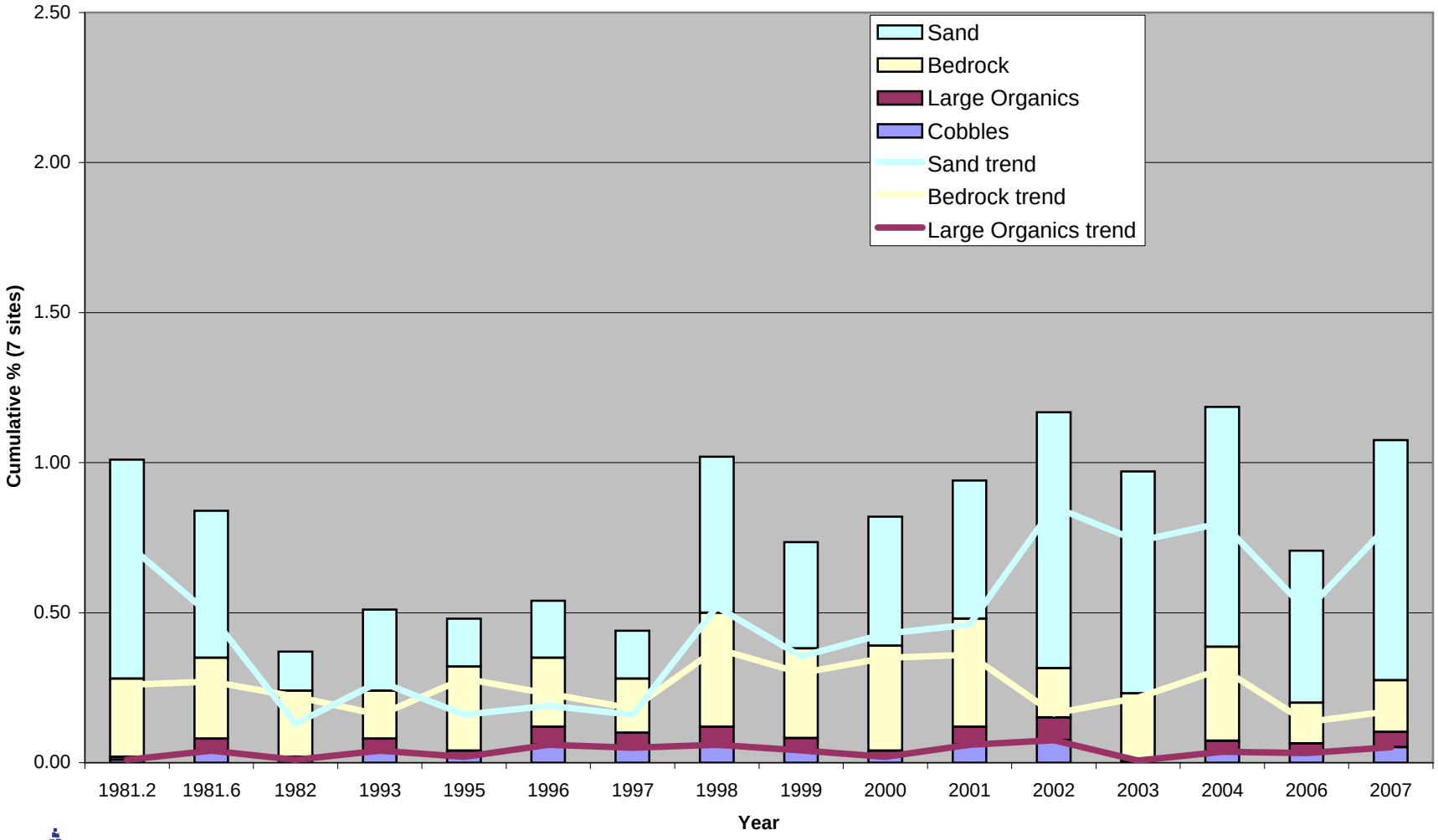

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Figure 25b. Cumulative percent of bed area occupied by bed-surface populations at pools (summed over all sites except KX, KD, KL, and KF), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Pool data incomplete at KL: 2nd pool at KL in 2001 not used.

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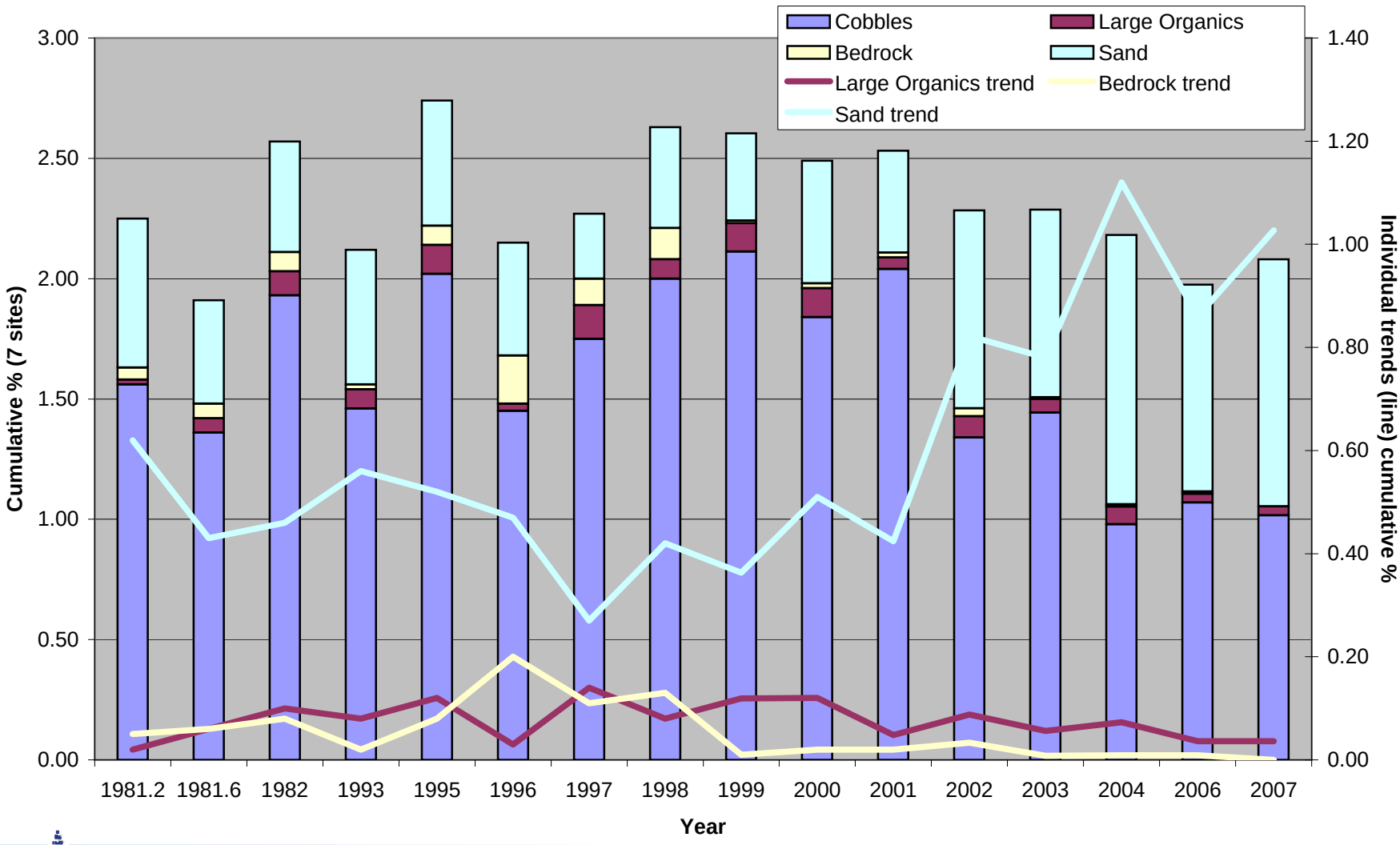

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Figure 26a. Cumulative percent of bed area occupied by bed-surface populations at glides (summed over all sites except KX), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Pool data incomplete at KL.

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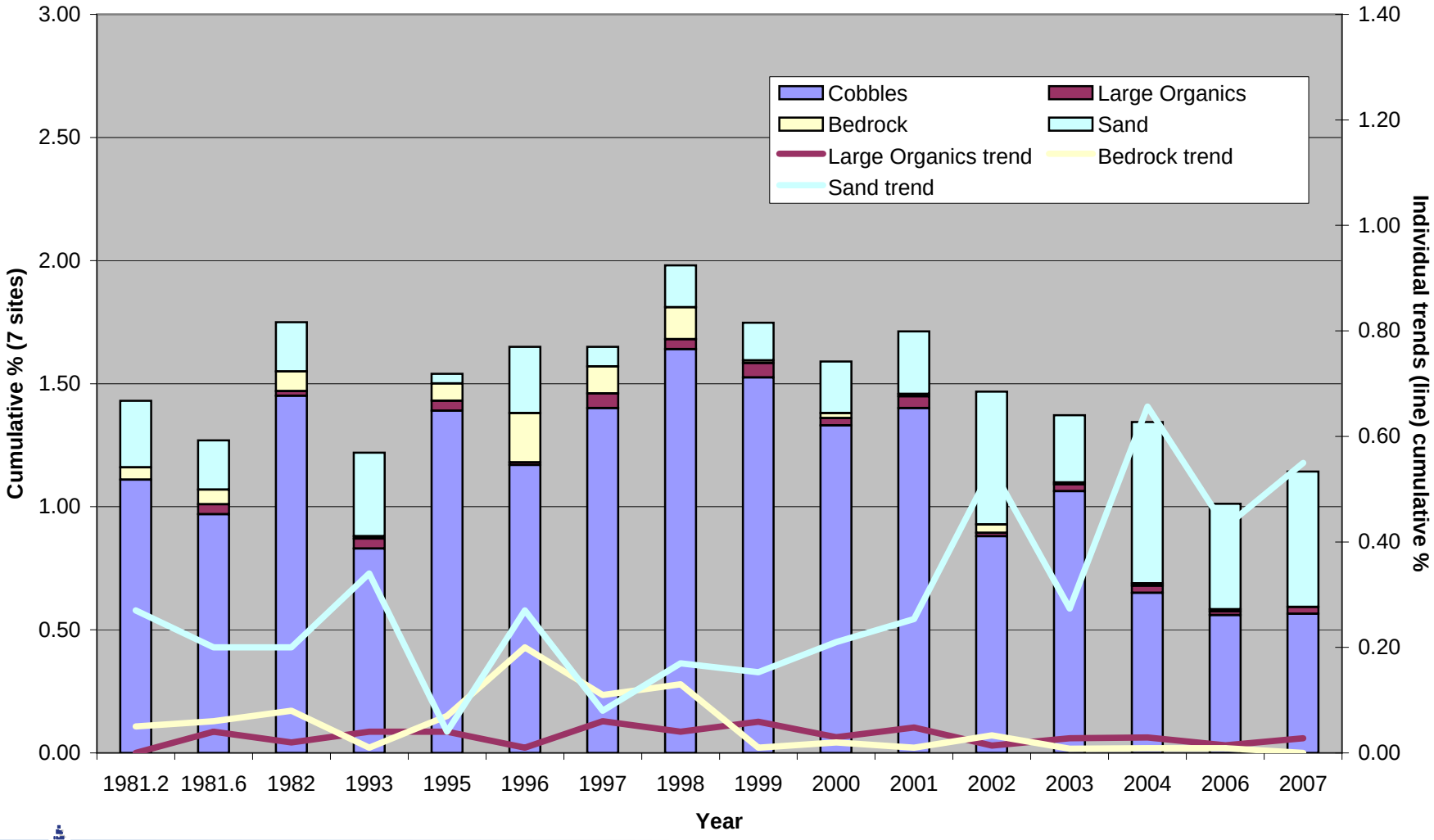

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Figure 26b. Cumulative percent of bed area occupied by bed-surface populations at glides (summed over all sites except KX, KD, KL, and KF), Lagunitas Creek, Marin County, California. Data from 1991 and years prior to 1981 not used because not all sites were censussed. Pool data incomplete at KL.

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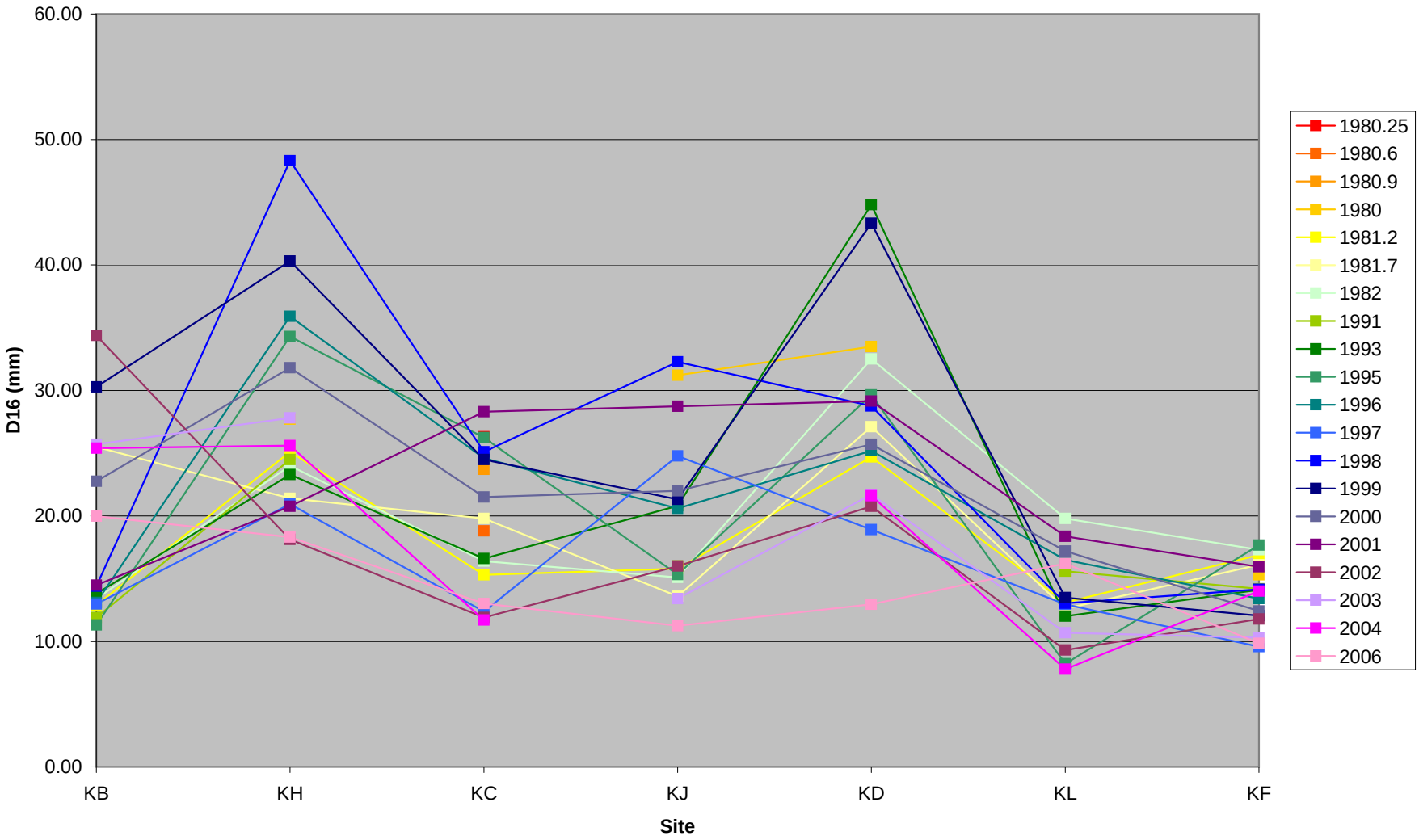

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Figure 27. Downstream trends over time of bed-core sediments at pool-to-glide transition, Lagunitas Creek. See figures 2 or 9 for site locations.
Note that these are the most early moved of the bed sediments filling pools, and that the data are not pertinent to spawning.

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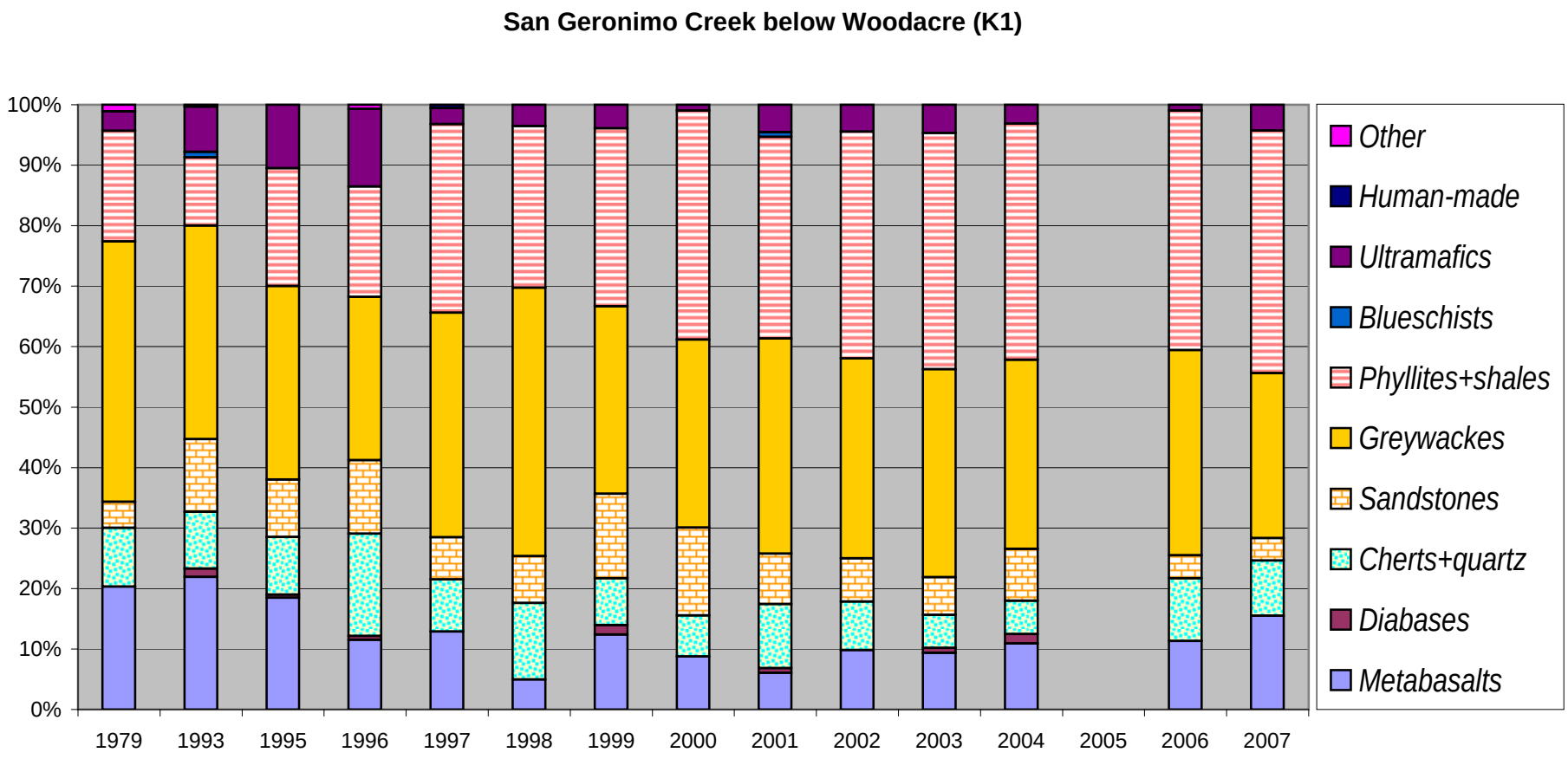

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Figure 29a . **Changes over time in lithologies of gravels at the water treatment plant, downstream from Woodacre (SIte K1).** Decreases in the proportion of metabasalts -- which outcrop only in the southwestern portion of Woodacre -- show diminishing contributions over time from the Woodacre fork of San Geronimo Creek, perhaps as erosion-control and stabilization measures have taken effect.

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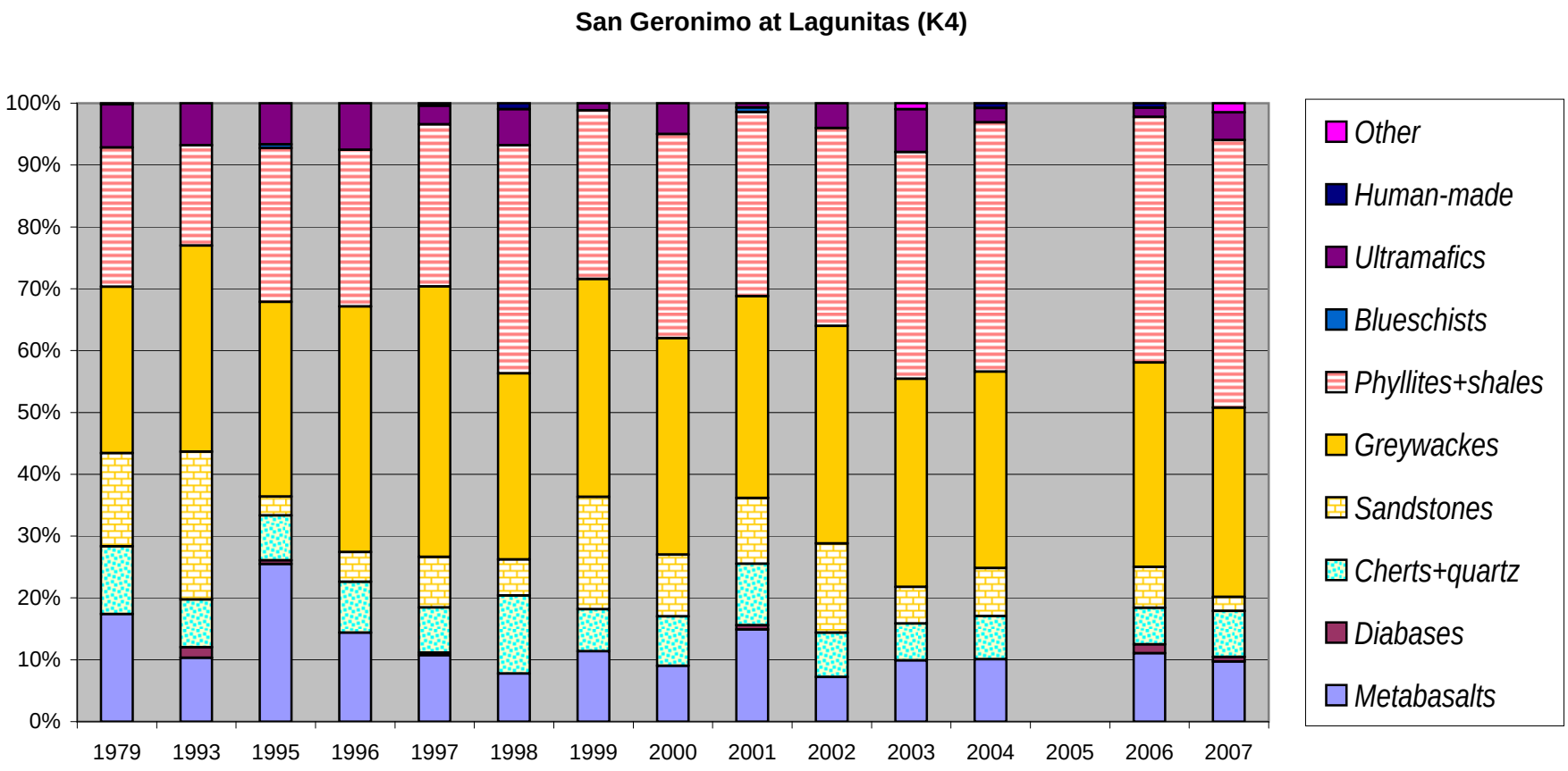

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Figure 29b . **Changes over time in lithologies of gravels at the lower San Geronimo Creek gage site (K4) at Lagunitas Road.** A decrease in contributions from the Woodacre branch is suggested, as the percentage of metabasalts decreases. The source(s) for the gradual increases in phyllites are not yet known, but may potentially be the melange areas in the central portion of the valley and along the north fork.

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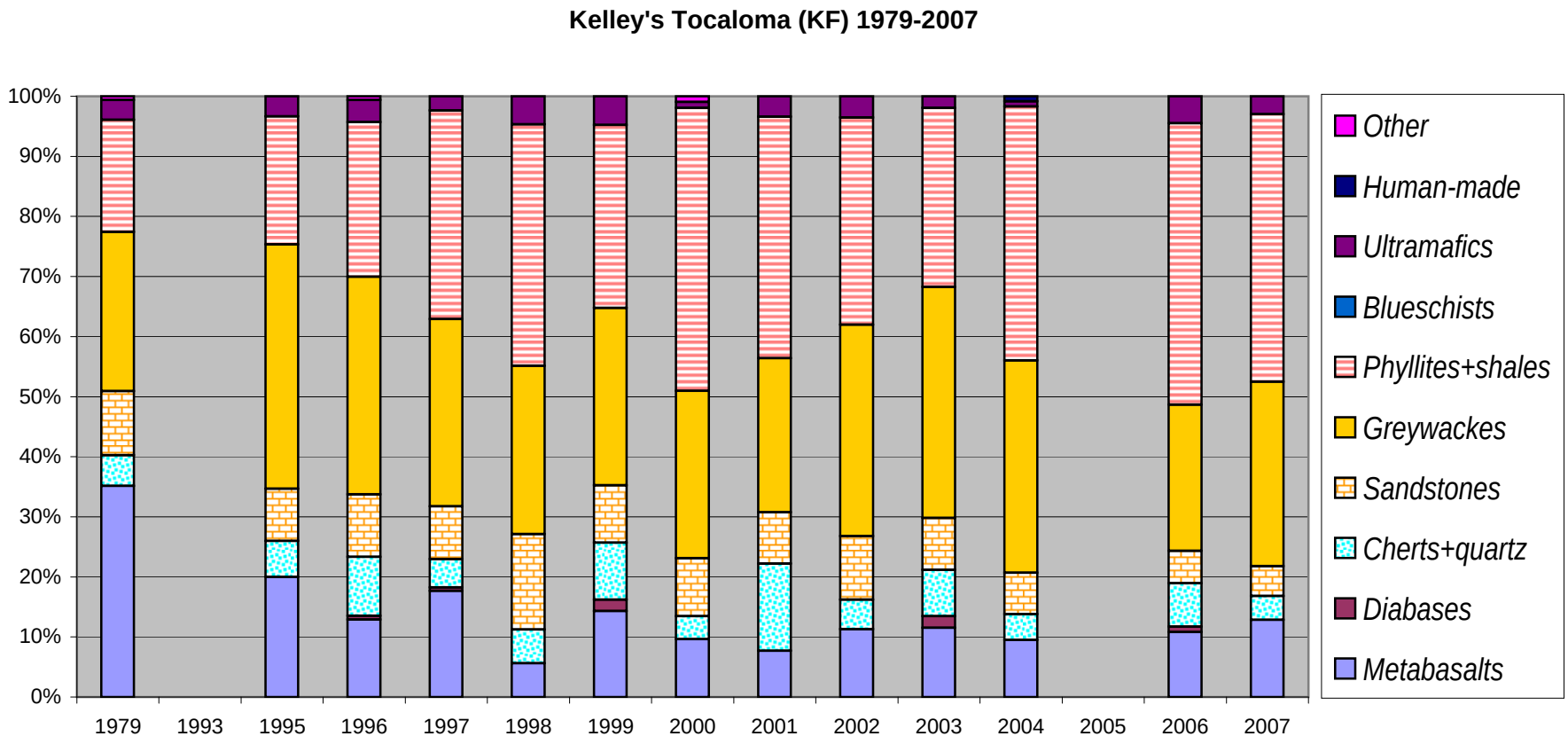

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Figure 29c . **Changes over time in lithologies of gravels at the Kelley's Tocaloma site, near the downstream end of the study reach.** Initially rich in gravels of San Geronimo origin (1979; 1993), we infer that an influx of Big Bend material (1995 through 1997) from 3 miles upstream appears as increases in phyllites and sandstones, gradually diminishing during the mid-2000s, followed by a renewed increase in San Geronimo material beginning in 2003, shown by an increase in phyllite, but not sandstone. Noticeably greater proportion of metabasalt gravels in 1979 may be remnant of pre-Peters Dam sources.

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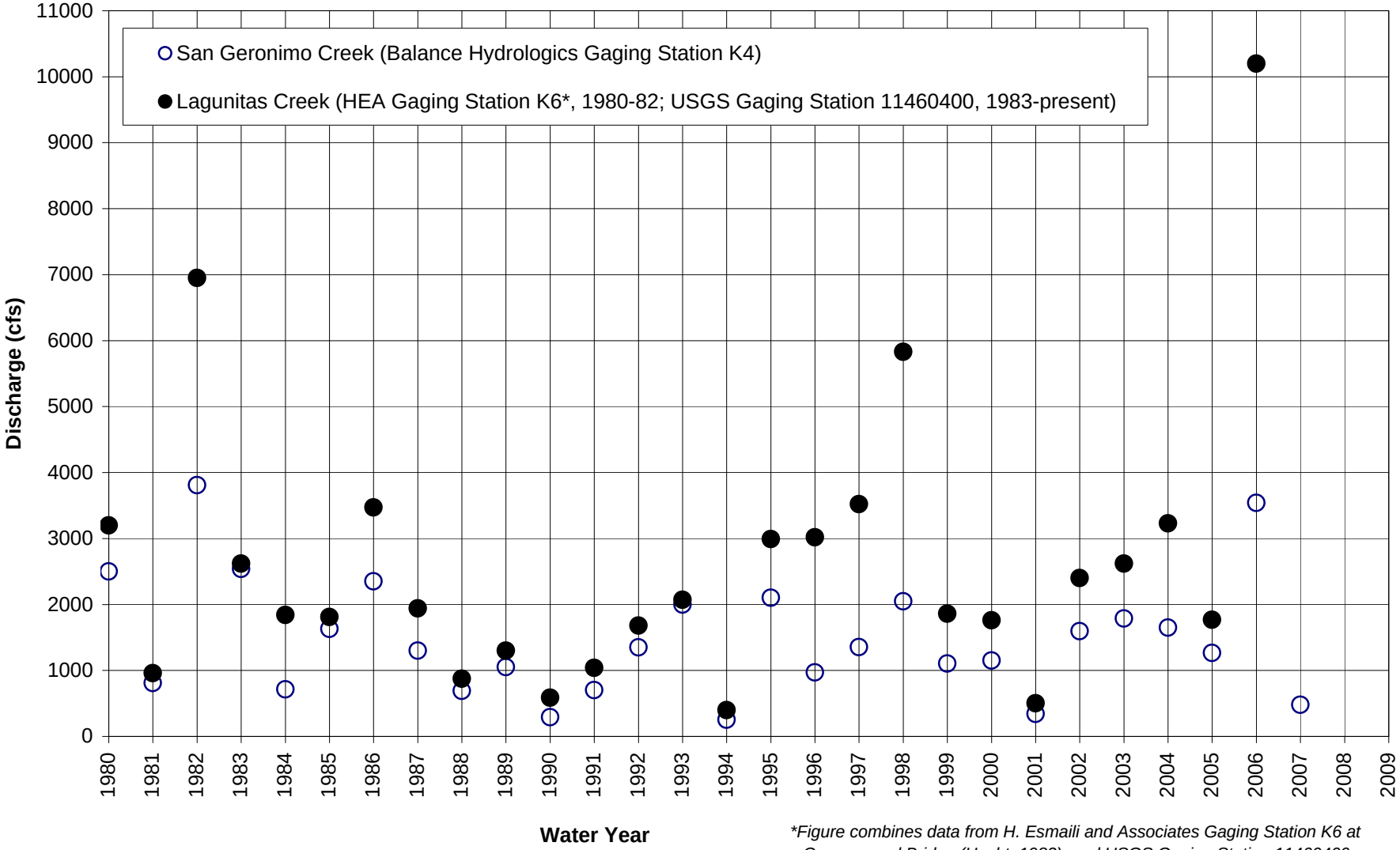

**Figure combines data from H. Esmaili and Associates Gaging Station K6 at Campground Bridge (Hecht, 1983), and USGS Gaging Station 11460400*

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Figure 30. Annual peak discharge, 1980-2007, Lagunitas and San Geronimo Creeks, Marin County, California. Note: Balance Hydrologics staff believe that the Dec. 31, 2005 peak flow on Lagunitas Creek was actually somewhat below 7000 cfs (see discussion in text).

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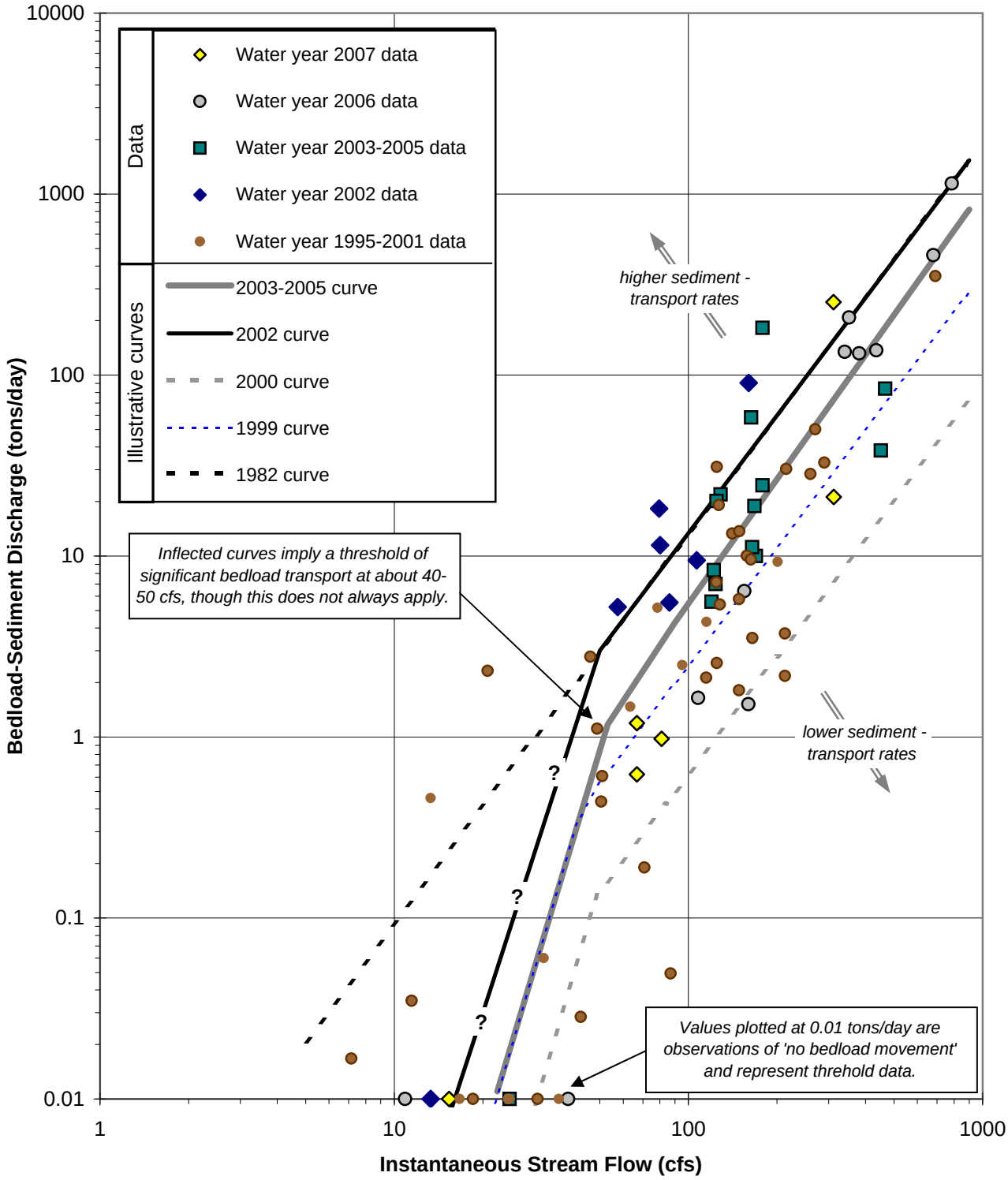

Figure 31. Comparison of recent bedload transport rates to rates from the early 1980s and late 1990s: San Geronimo Creek at Lagunitas Road bridge (K4). Note that bedload transport rates in 2002 were 10 to 20 times higher at any given flow (>50 cfs) than in 2000. Curves shown in this graph are simplified for illustration, and may differ slightly from those used in the annual reports prepared by Balance Hydrologics for MMWD. See Hecht (1983) for detailed discussion on establishing the slope of the curves.

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APPENDIX A

Proposed bed conditions monitoring program, February 1992

PROPOSED BED-CONDITIONS MONITORING PROGRAM LAGUNITAS CREEK, BELOW KENT LAKE MARIN COUNTY, CALIFORNIA

Prepared for:

Marin Municipal Water District

Prepared by:

Barry Hecht
Balance Hydrologics, Inc.

February 1992

A report prepared for:

Marin Municipal Water District
220 Nellen Ave.
Corte Madera, CA 94925

PROPOSED BED-CONDITIONS MONITORING PROGRAM, LAGUNITAS CREEK BELOW KENT LAKE, MARIN COUNTY, CALIFORNIA

Balance Hydrologics, Inc. Assignment 8802.1

by

Barry Hecht

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February 1992

PROPOSED BED-CONDITIONS MONITORING PROGRAM, LAGUNITAS CREEK BELOW KENT LAKE

1. Introduction

The Marin Municipal Water District (MMWD) diverts water from the Lagunitas Creek watershed to serve 170,000 District residents. Protection of aquatic biota and habitat values in Lagunitas Creek and its tributaries is a goal of MMWD, responsible agencies, and the local community. Prior work by District consultants has identified bed sedimentation as a habitat constraint to the anadromous fishery of the stream, including silver salmon and steelhead. Reducing bed sedimentation and improving substrate conditions may be a viable means of enhancing habitat values.

MMWD has reached agreement with the Marin County Resource Conservation District (MCRCD) to sustain a 10-year sediment-management program in the San Geronimo Valley. The MCRCD will monitor stream bed conditions below Kent Lake so that long-term changes in habitat values can be described. The attached proposed monitoring program identifies our suggestions for:

a. overall sampling strategy

b. duration of the monitoring program

c. reaches in which bed sedimentation is to be measured

d. indicators of sedimentation thought to describe the conditions most likely to affect habitat values, and the methods by which they are to be monitored

e. the means by which the results are to be analyzed, reported, reviewed and archived.

The proposed monitoring program draws heavily upon work conducted in Lagunitas Creek by biologists Don Kelley, David Dettman, Stacy Li, Paul Bratovich, Heidi Rook, and Larry Eng. These efforts focused primarily upon habitat use and needs of coho salmon, steelhead trout, and a freshwater shrimp, Syncaris pacifica. It is also based on earlier geomorphic and hydrologic studies by Barry Hecht and Mark Woyshner. The pertinent reports developed

from these field investigations are cited in the final section of this monitoring plan.[1] These reports contain important background regarding the environmental processes, channel history, and field methods previously utilized in Lagunitas Creek. The program is intended, in part, to assess the effectiveness of source-control and sediment-removal efforts, such as the program proposed by Prunuske/Chatham (1990) upon bed conditions and habitat values in Lagunitas Creek.

Goals, objectives and strategies for monitoring are proposed in Section 2. Bed descriptors to be monitored are detailed in Section 3, and methods to be used in monitoring are suggested in Section 4. Section 5 outlines the annual work program by task, and describes several additional steps which may be needed at the beginning and ending of the long-term monitoring program. Responsibilities for reporting about the program are presented in Section 6.

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[1]Habitat needs and preferences are summarized in Kelley (1978), Kelley and Dettman (1980), Bratovich and Kelley (1988), Li (1981) and Eng (1981). Substrate properties and methods used in their description are summarized in Bjornn and others (1977) and Hecht (1983). Hecht and Enkeboll (1979, 1981), Hecht and others (1981), and Hecht and Woyshner (1988), also quantify or explain key substrate issues in Lagunitas Creek.

2. Bed Monitoring Goals and Approach

2.1 Goals and Objectives

Bed monitoring is intended to identify whether bed conditions are changing in senses likely to impair or enhance habitat values. This goal will be met through a program directed toward evaluating particular groups of changes which are thought to affect habitat values:

a. **Bed configuration**: Is the topography of the bed changing, affecting the depth, relative definitions of pools and riffles, spawning areas, or bars? Is usable bed area narrowing or widening? Are riffles becoming wider and passage more difficult during upmigration?

b. **Bed composition:** Is the particle-size composition of the bed changing, potentially affecting abundance and stability of spawning habitat, or the availability of cobbles and boulders to provide cover?

c. **Fines deposition:** Are sand, silt and very fine gravel covering bars and filling pools, resulting in:

   1) likelihood of diminished fry survival and alevin emergence during the coming spawning season

   2) lower primary and secondary productivity

   3) less cover available for juvenile or yearling salmonids

   4) fines filling the quiet-water sites used by Syncaris pacifica?

The monitoring program is also designed to identify where in the stream system bed conditions may be changing, and whether these changes are persistent or are dynamic, ephemeral adjustments to local channel influences.

2.2 Sampling Approach

The approach we recommend for monitoring bed conditions in Lagunitas Creek is to conduct annual, very careful measurements of a limited number of indicator parameters, at 7 sites distributed through the reach of main habitat concern. The 7 sites, which were all intensively monitored during the early 1980s, were randomly selected within each 1 kilometer length of the stream from Shafter Bridge to Tocaloma. Each site contains a contiguous pool, glide, and riffle -- the habitat segments consistently utilized by biologist

Don Kelley and his co-workers. The sites average approximately 78 meters of channel and provide nearly an eight percent sample of the total stream length, more than is usually used in intensive geomorphic studies of bed conditions. The habitat indicators we have chosen, collectively provide a reasonably complete and balanced picture of bed configuration, bed composition, and the distribution of fine deposits on or within the bed surface.

Prior work by the aquatic biologists has indicated that most of the spawning and nearly all of the rearing activity in this system occurs in Lagunitas Creek between the Shafter and Tocaloma Bridges. The earlier geomorphic work indicates that the reaches most likely to be affected by the operation of Kent Lake extend from the Shafter Bridge downstream to Jewell, and perhaps as far as Tocaloma. We propose to concentrate the monitoring efforts within this portion of Lagunitas Creek, which includes all of the State Park reach (as defined by Kelley, 1978; and Hecht, 1983) plus an additional mile of channel extending to the Tocaloma Bridge in which conditions are transitional to those prevailing in the lower reaches of the stream.

After some consideration, we have chosen to recommend against active monitoring of bed conditions between Tocaloma and Nicasio Creek, or from Nicasio Creek to the mouth of the stream. This recommendation is based on our observation that bed conditions prevailing downstream from Tocaloma will vary primarily with storm patterns, the location of log jams, and other factors which are not likely to be influenced by management of sediment further upstream. Habitat values may benefit from efforts to control headwater erosion in the San Geronimo Valley, but to a much lesser extent. Conditions in this reach may perhaps be best assessed qualitatively by a senior habitat professional, either a fisheries biologist or geomorphologist. If sustained deterioration of habitat is observed, repetition of the measurements made by the Balance Hydrologics staff during the early 1980s at the Tocaloma Pump (KM), Zanardi (KN), and Maple City (KO) sites can be repeated to discern long-term trends. Limited monitoring, however, is recommended for San Geronimo Creek.

2.3 Sites to be Monitored

We suggest bed conditions at 7 sites be monitored as part of this program:

KB	Below Shafter
KH	Kelley's Upper State Park Site
KC	Above SPTSP Campground Bridge
KJ	Big Rock
KD	Big Bend
KL	Cheda Ranch Creek/Jewell
KF	Kelley's Tocaloma Site

Monitoring involves re-occupying sites where intense observations were made in 1979 or 1980 through 1982 or 1983. Site KD was substantially damaged by mudflows from a left-bank tributary in 1982 and 1983; if found to be unusable or non-representative, it may be omitted from the program without undue effect. Site KG, immediately downstream of Shafter Bridge, was originally directed toward certain short-term objectives and is not recommended for further long-term monitoring (see Figures 2, 3; also Hecht, 1991).

Conditions observed at these sites during the mid-winter (February and early March) and summer 1981 monitorings are thought to be representative of conditions prevailing at the time, and may be used to describe baseline conditions.

Locations of these sites are shown in Figure 1.

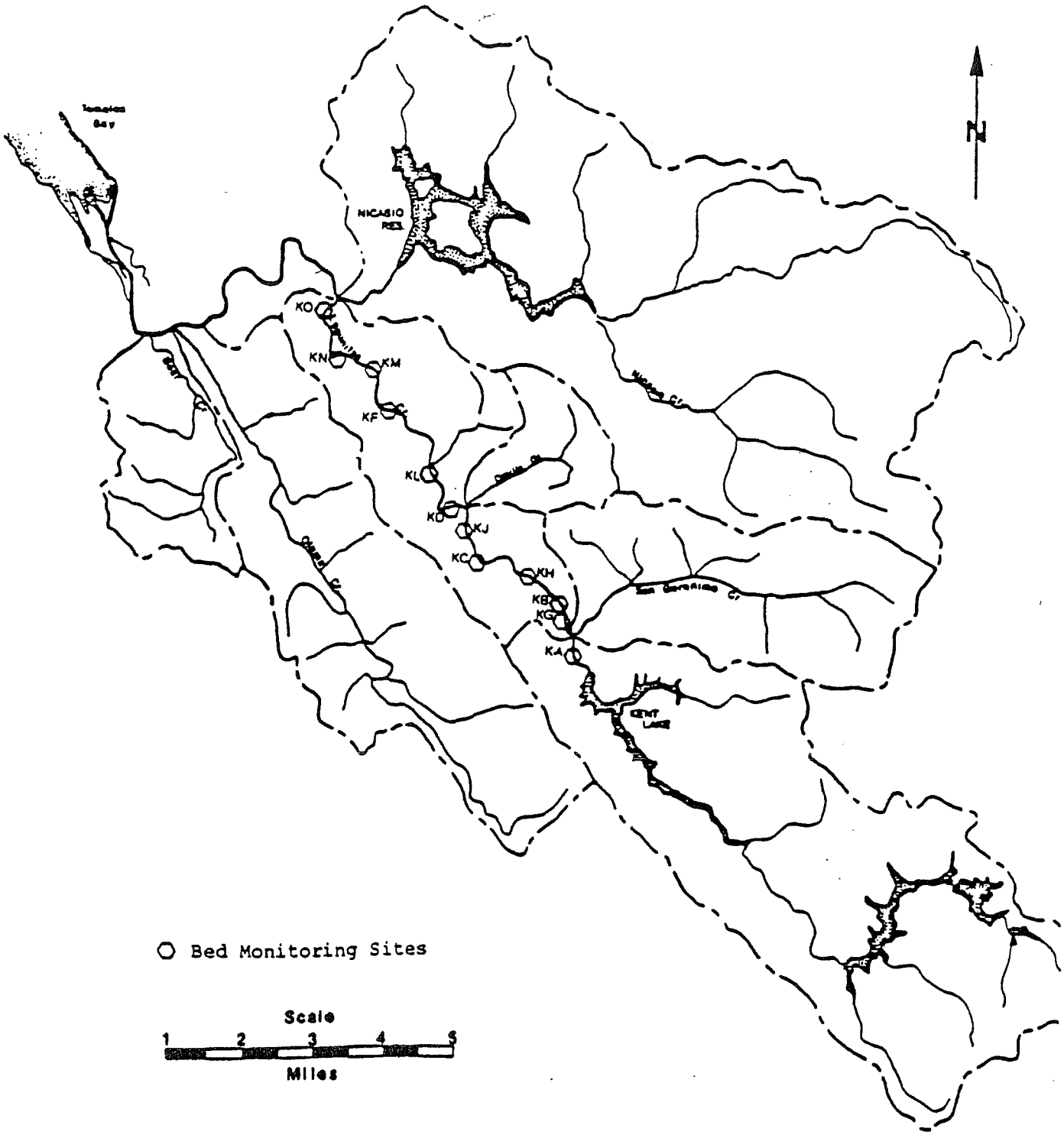

Figure 1 Location of bed-monitoring sites.

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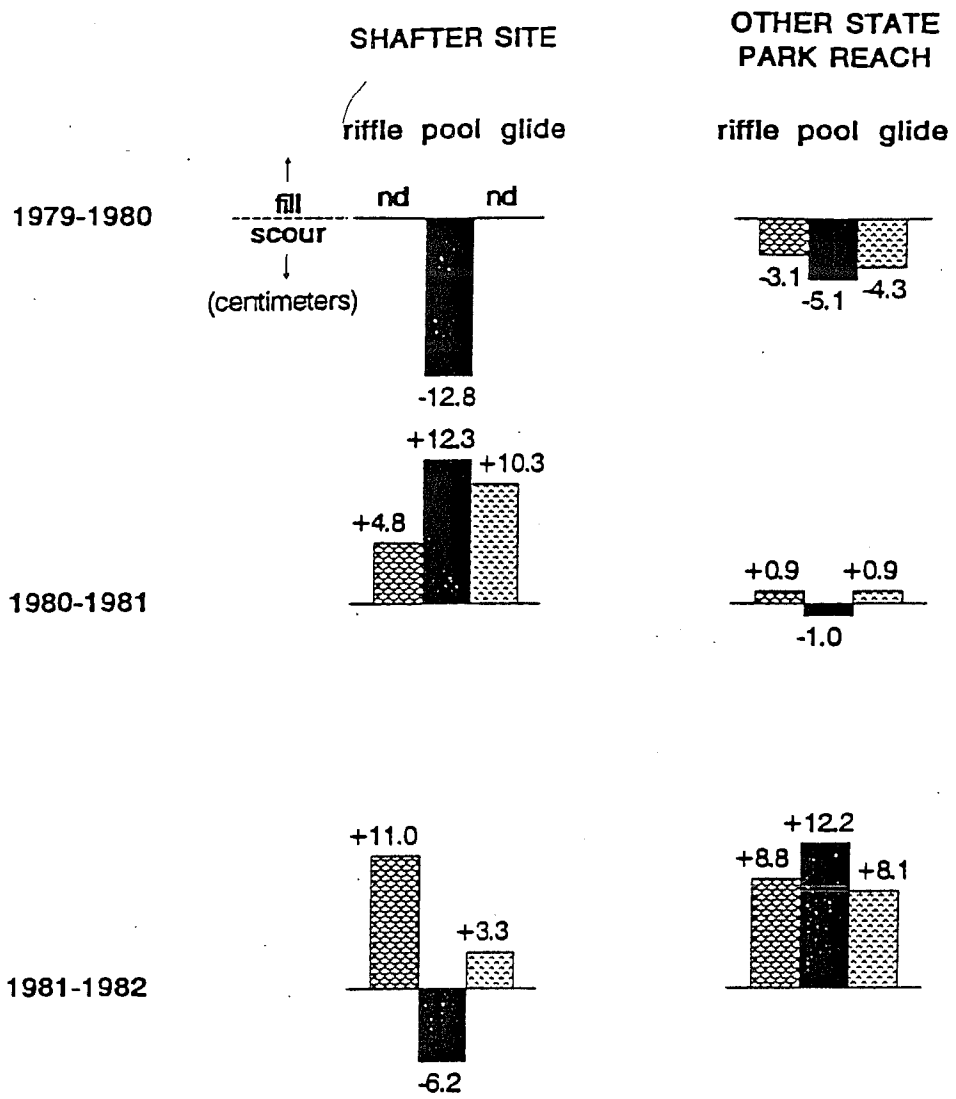

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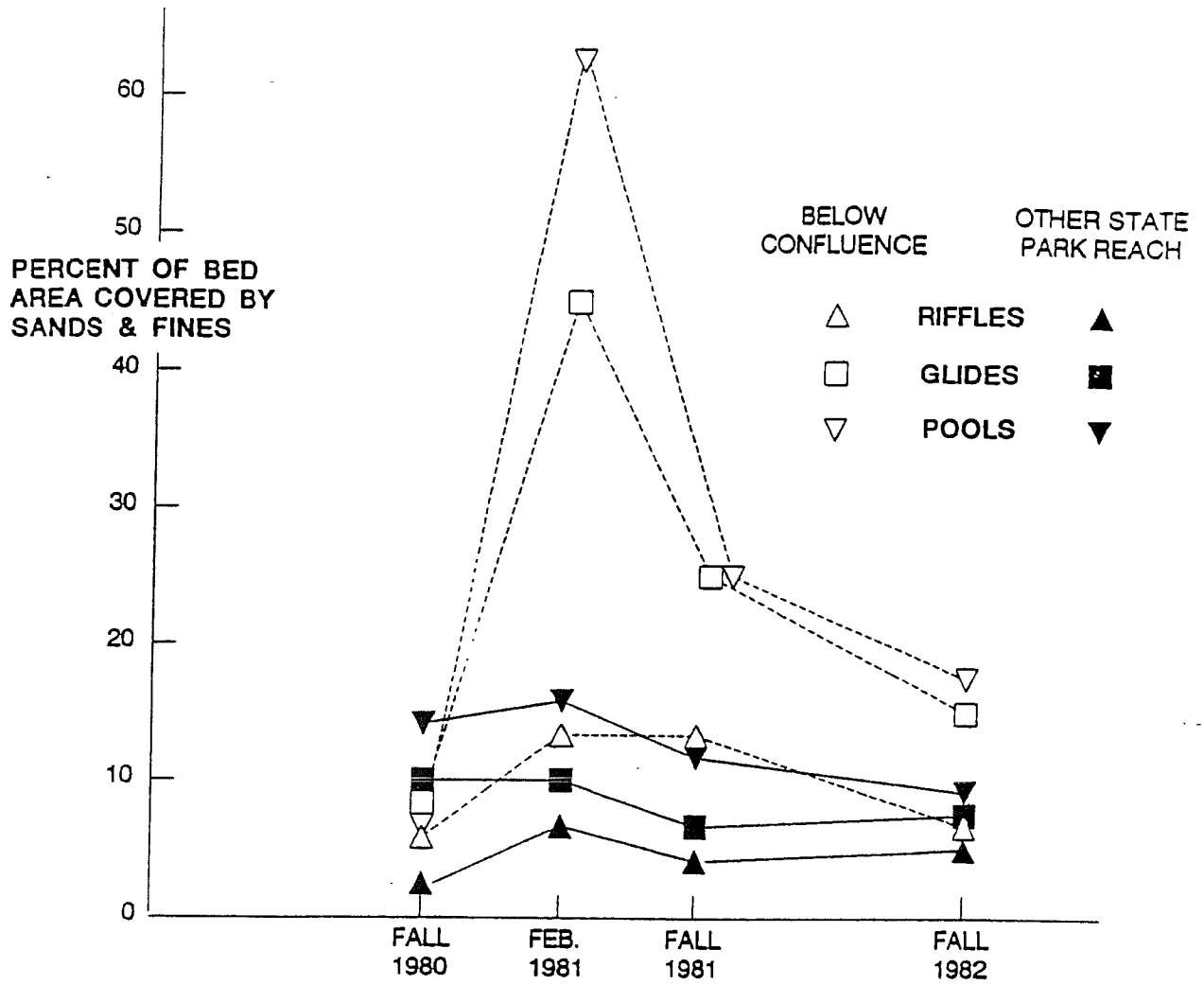
RELATIVE DEEPENING AND SHOALING POOLS, RIFFLES AND GLIDES, LAGUNITAS CREEK

Figure 2 — Relative deepening and shoaling of riffles, pools and glides, as measured by changes in mean bed elevation, Lagunitas Creek, 1979 - 1982. In the State Park Reach, which includes 6 of the 7 sites proposed for bed monitoring, pools deepened relative to glides and riffles in 1979–80 and 1980–1, and became shallower during the major floods and releases of 1981-2. The Shafter site (KG on figure 1) was selected as representative of below-confluence sequences, a special situation; it is not proposed for long-term monitoring (from Hecht, 1991)



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CHANGES IN PERCENT OF THE BED COVERED BY FINES DURING A SEDIMENTATION CYCLE IN A BELOW - CONFLUENCE SUBREACH.
SUBREACH MEANS FOR SIX OTHER SITES IN THE STATE PARK REACH SHOWN FOR COMPARISON.

Figure 3 — Changes in the percent of bed area covered by sand and fines, State Park Reach of Lagunitas Creek, 1979–82. Site KG, immediately downstream fromthe mouth of San Geronimo Creek, received heavy deposition during 1981, while other sites were not affected. Site KG was intended to represent the special cases of below-confluence reaches, and is not included in the long-term bed-monitoring program

2.4 Duration of Monitoring

We recommend that monitoring be sustained for ten years. Measurements should be made during summer flows in each monitoring year. Prior work indicates that little change in bed conditions occurs in years without significant storm crests or annual flows.

Both field experience since our studies commenced in 1979 and the results of simulated accumulation and depletion of bed sedimentation (Hecht and Woyshner, 1988) indicate that many conditions and events expected to affect the magnitude of bed sedimentation are likely to occur over a 10-year period, including:

- drought
- major floods
- sediment-producing events such as wildfires, landslides, or insufficiently-controlled land-development or highway construction activities
- sequences of years without large, sediment-transporting spills from Kent Lake.

Monitoring can be extended, if needed, should a broad-enough range of influences and conditions not occur within 10 years. The recommended means of extending the record is to include the record of the early 1980s (Hecht, 1983), which includes years of high flows thought to effect most of the geomorphic change which occurred during that decade.

2.5 Pools, Riffles, Glides: Basic Units of Analysis

Rearing habitat has been identified in a number of studies as a primary management concern in Lagunitas Creek. Biologist Don Kelley and his colleagues have found it most useful to quantify rearing habitat in Lagunitas Creek using riffles, pools, and glides as basic units. They developed habitat-use curves based on 1979 observations, with some supplemental observations from 1984. They and others (c.f. Bjornn and others, 1977) have found the salmon preferentially to rear in pools, especially deeper, quieter pools. Li (1981) and Eng (1981) both found Syncaris pacifica to use isolated segments of deep, quiet pools with very

low velocities as winter habitat; summer habitat also resulted in differing use of pools and riffles. Since pools, riffles and glides also are related to channel dynamics and bed-sediment accumulation or depletion, these basic morphologic and habitat units are suitable for long-term analysis of bed conditions.

Aquatic biologists usually consider riffles as any shallower portion of the stream with a broken water surface at low or medium flows. Generally, the riffled surface extends the entire width of the stream, or nearly so. Flow through pools is slower and results in an unbroken water surface at the lower flows characteristic of late spring and summer. Undercut banks are a common property of pools in Lagunitas Creek. Many observers of streams are familiar with the role of pools in storing sediment -- pools are shallower when sediment has accumulated on the bed, and are deeper when the bed has been depleted. As with riffles, pools extend the entire width of the channel, or very nearly so; much narrower deep areas around rocks, snags, or other large roughness elements are more properly termed "scour holes."

Glides (or "runs") are intermediate in character. Empirically, they are recognized by aquatic biologists as areas of smooth water surface, and depths generally are less than one foot. Under spring or summer conditions, streamflow is usually converging and accelerating toward riffles. Glides are perhaps more common in coastal streams, especially those with a gravelly bedload, than elsewhere. Spawning occurs in the downstream parts of glides in Lagunitas Creek; no other locations were observed to be used for spawning (Bratovich and Kelley, 1988).

The positions of riffles, pools, and glides and riffles on Lagunitas are quite stable by comparison with many other streams. Fewer than 10 percent of sections to be monitored at the seven sites experienced a change in status, even during the major floods and flushing flows of 1982, and some of these changes are regarded as ephemeral. Important changes in the configuration of the channel within individual riffles, pools and glides, however, did

occur, and the shape of the channel should be measured in the future. . Most such changes were regarded as ephemeral.

Working in 1979, Kelley and Dettman (1980) found that riffles constituted about 23 percent of the length of the stream in the State Park Reach, with pools and glides comprising 35 to 42 percent, respectively. About 14 percent of the channel length between Jewell and Tocaloma Bridge was in riffles, 19 percent in pools, and 67 percent in glides.

Riffles, pools, or glides are the basic units to be monitored in the bed-condition program. These morphological units usually occur consecutively as "sequences," each consisting of one pool, riffle, and glide. Each bed-monitoring site consists of a sequence.

3. Bed Descriptors to be Monitored

In December 1990, Don Kelley and Barry Hecht reviewed with Dana Roxon of the MMWD staff the assessments of bed conditions found to be significant in the aquatic habitat investigations and bed monitoring of the prior studies. Based on this review and related work on salmonid habitat elsewhere in the Pacific Coast states, Balance Hydrologics staff suggest that the following five bed descriptors should be monitored in the pool, riffle, and glide at each monitoring site:

a. Mean bed elevation: channel configuration

b. Particle-size distribution of bed surface

c. Embeddedness of cobbles and boulders

d. Abundance of cobbles and boulders

e. Percent of the bed covered by sand, silt, and other fine material.

The descriptors, which encompass the full range of bed-monitoring objectives, are more completely described in the next section of plan, which also outlines methods suggested for use in sampling and measurement.

4. Methods Suggested For Monitoring Bed Conditions

The following suggested methods are adapted from those used by the present Balance Hydrologics staff in previous descriptions of bed conditions in Lagunitas Creek. The adaptations allow for more efficient data collection. Results obtained using these methods may be comparable to those obtained in 1979 through 1982, provided that sufficient care and quality control be applied.

The proposed bed monitoring may best be seen as two separate sets of measurements at each site. The first set is a series of cross-sectional surveys which describe channel configuration, and distinguish pool, glide, and riffle. The second set is a bed census -- a sampling of the bed surface, using a grid of stretched tapes. All bed descriptors to be monitored may be measured using one or both of these activities. Prior to conducting either set of measurements, the site and the sequences immediately upstream should be examined for unusual circumstances or conditions (see the description of Task 1 in Section 5.1, below).

4.1 Channel Configuration: Mean Bed Elevation

Changes in mean bed elevation in riffles, glides, and pools not only help identify shifts in habitat values, but also quantify the net accumulation or depletion of sediment, and serve as a check of the visual classification of pool, riffle and glide boundaries. This measurement of channel configuration is perhaps the single most useful descriptor of bed conditions in Lagunitas Creek. Figure 2 shows annual changes in sediment accumulation and depletion (measured as mean bed elevation changes) in Lagunitas Creek.

Cross sections are level-surveyed at 7 to 10 locations at each site, using monuments previously installed. Tapes are stretched to a pre-determined length at each section, so that distances along the tape correspond to those of previous surveys. Approximately 15 to 25 points on the bed and banks are surveyed to the nearest 0.01 foot. Results are entered into either an appropriate digital code, or are plotted manually on graph paper and planimetered. The mean bed elevation between the base of the banks is then computed for each cross section, and may be compared with prior surveys. Mean bed elevations are then averaged

for each pool, glide, and riffle, to establish how these have changed relative to each other. Mean bed elevations at each site are then averaged to compute the net accumulation or depletion of sediment at the site.

4.2 Particle-Size Distribution of the Bed Surface

The surface of the bed affords most of the rearing habitat available during summer in Lagunitas Creek. The bed-surface composition also is an important influence upon spawning habitat, the configuration of critical riffles through which salmonids migrate, and the overall stability of the bed at high flows. The bed-surface material is regarded as distinct from the sediment which lies beneath it; in Lagunitas Creek, the sizes of particles on the bed are commonly two to three times coarser than in the accumulated sediment comprising the bulk of the bed. The bed-surface material is also distinct from the partial overlay of silt and sand which can mantle the bed surface or fill pools, impairing habitat quality. A more complete discussion and quantification of these differences is included in the Phase IIIb report (Hecht, 1983).

The particle-size distribution of bed-surface material is quantified as part of the bed census, which also results in measurements of embeddedness, cobble abundance and percentage of fine sediment on the bed. Hence, the sampling procedure described below also applies to these other bed descriptors. If carefully conducted, the bed census need be done only once to obtain all four sets of measurements.

The bed census is conducted by creating a grid over the entire active bed area of each glide, pool, or riffle. The grid consists of measuring tapes stretched between rebar pins temporarily set into the bed at locations that are 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95 percent of the width of the channel at the upper and lower ends of the sampled morphological unit. Approximately 80 to 150 points are sampled immediately beneath pre-selected points on the tapes spaced at regular intervals. The census results in a stratified random sample drawn equally from all parts of the pool, glide or riffle at each site which are submerged at summer flows.

The sampled point is classified as coarse sediment (gravel, cobble, or boulder), fine bed sediment (smaller than 4 mm.), bedrock, or limbs or other organic debris large enough to provide local habitat value. The sizes of all coarse sediment particles are measured, and the embeddedness of the cobbles and boulders are estimated (see below).

The size of each particle sampled is measured along its intermediate axis, and classified within standardized metric size categories. These categories vary as the square root of 2 (e.g., 4 mm. to 5.6 mm.; 5.6 mm. to 8 mm.; 8 mm. to 11.3 mm.; 11.3 mm. to 16 mm., and so forth up through large boulder sizes), a now-widespread adaptation of the standard Wolman (1954) criteria used worldwide. Results may be expressed either as a frequency distribution, or by the equivalent size of specified percentiles; the 16th, 50th, and 84th percentiles are most commonly used in stream habitat analysis, and were presented with the Phase IIIb report.

4.3 Embeddedness

Kelley and Dettman (1980) established a strong, inverse correlation between the mean embeddedness of cobbles and boulders on the bed, and use by juvenile steelhead. Other workers, such as Bjornn and his colleagues (1977) have reported similar relations for salmon. Embeddedness of cobbles is therefore considered an important direct predictor of rearing habitat use, and also indirectly describes aspects of habitat influences upon other life stages.

The embeddedness measurement is a visual estimate of the proportion of a cobble (larger than 45 mm.) or boulder embedded in much finer material. In Lagunitas Creek, the embedding sediment is usually sand or very fine gravel, generally finer than 4 mm. Embedded estimates are usually made to the nearest one-tenth of the particle's height. For the size distributions found in Lagunitas Creek, about 60 to 80 particles should be counted for valid sampling of embeddedness in a given riffle, pool, or glide; a smaller sample may also be accepted if few cobbles are present, or if cobbles are found only in a small proportion of the area of the riffle, pool, or glide.

Because embeddedness is a visual estimate, estimates developed by different observers can vary, sometimes considerably. Careful quality control is needed to minimize such differences, which among experienced observers can be up to 0.05 units. Systematic training of new observers is suggested, as such observers tend to overestimate values by 0.1 to 0.15 units until calibrated against more experienced individuals.

4.4 Cobble and Boulder Abundance

Juvenile salmonids use the interstices between and beneath large cobbles and boulders resting on the bed for cover and shelter. These niches are not available for use during this critical life stage if: (a) cobbles and boulders are embedded in fine sediment, or (b) few cobbles and boulders are present or otherwise available to them. Cobble and boulder abundance is one means of describing the presence of these key habitat components, particularly when used in combination with embeddedness.

David Dettman, in the course of making observations of rearing-habitat utilization, carefully noted the sizes of cobbles actually used for cover by young-of-the-year and yearling steelhead. He concluded that cobbles slightly less than two inches in intermediate diameter are used, if relatively unembedded (Kelley and Dettman, 1979; pers. comm.). A special local definition of cobbles as being larger than 45 mm. was used throughout the biological and geomorphic investigations. Boulders, particles larger than 256 mm. (10 in.), usually form less than five percent of the bed area in Lagunitas Creek, and are utilized much as are cobbles.

Cobbles and boulder abundance is the proportion of bed area in which particles larger than 45 mm. in intermediate diameter are encountered, using the bed census sampling procedure.

4.5 Percent of the Bed Area Covered by Fine Sediment

Fine sediment is found in Lagunitas Creek between the gravels and cobbles which form the bed-surface material. At times when significant sediment has accumulated on the bed, the amount of fine sediment can be substantial, covering some of the gravel and cobbles in riffles

and glides, and filling pools. Abundant fine sediment results in diminished egg survival and alevin emergence; less availability of cover during the summer; lower primary and secondary productivity; less winter habitat for Syncaris pacifica; and, because the fines present a high-contrast background, an assumed higher rate of predation for all aquatic organisms.

In Lagunitas Creek, the fine sediment is usually silt, sand, and very fine gravel. All bed sediments finer than 4 mm. are considered as "fine sediment" for this indicator, as well as for embeddedness. The percent of the bed covered by fine sediment is the percent of sampled points within the pool, glide, or riffle, at which fine material was encountered during the bed census, when measuring directly below the designated sampling point.

Embeddedness and "percent fines" are both measures of availability of habitat-impairing fine sediment, but they describe different effects and depositional sites. A considerable degree of embeddedness can develop before significant proportions of the bed are covered with fines. Where pools or bars are covered with fine sediment (particularly affecting coho salmon and Syncaris pacifica), embeddedness becomes a less sensitive descriptor, as cobbles and boulders are sparse or totally covered. The relation between the two measures is weak, particularly at the lower and higher ends of the observed range of values; both measures are needed to describe bed conditions.

5. Work Scope by Task

The monitoring program can be implemented through six tasks, conducted during the summers following years of significant flows. Three additional tasks are needed during the initial year to establish the program. Eventually, a final analysis of the monitoring results should be prepared; the scope and focus of this analysis will depend on the conditions observed, and is not included in this work program.

5.1 Annual Monitoring Tasks

Task 1: Preliminary site visit -- Each year, the senior professional will visit each site and the area upstream prior to monitoring, to identify any significant new conditions or events likely to affect particular sites. The senior professional will evaluate whether freshly-fallen trees, new landslides or cutbanks, or other visible disturbance requires modification of the monitoring program, or relocation of the site. Modifications will be made, as needed, prior to onset of the monitoring. A qualitative review of overall bed conditions from Tocaloma Bridge to the mouth of Nicasio Creek will also be made, with photographs taken at several locations.

Task 2: Site Monitoring -- Bed censuses and channel geometry measurements will be made at each of the designated seven sites, as described above. Photographs will be taken looking upstream and downstream through each site.

Task 3: Data reduction -- Field data will be reduced to quantify changes in channel configuration, bed-surface particle-size distributions, embeddedness, and the percentage of fines. Data will be presented in summary form, perhaps in a manner similar to that used in Tables 12, 13 and 16 of the Phase IIIb report.

Task 4: Summary report and data transmittal -- A report will be prepared summarizing the bed conditions encountered, plus any unusual events or circumstances which may have affected these conditions. The report should be readable to non-specialists, with a few pertinent summary tables and graphics, as

needed.

Task 5: Data backup and archiving -- Paper and/or digital copies of the data collected each year will be prepared to serve as a backup in event of loss of the primary data set. Duplicate copies of photographs should be labelled and enclosed. Diskettes of all programs used in data reduction should be included, unless these are widely-used, copy-protected programs.

Task 6: Project Administration -- The monitoring plan coordinator will administer the annual program, providing accounting for funds expended and authorizing payments.

5.2 Tasks Needed at Inception of Monitoring

Task A: Site reoccupation and modifications -- The seven monitoring sites will be re-established by MMWD. Monuments will be relocated. Although relatively few changes are expected since the early 1980s, such major changes in the channel configuration and the pool/riffle/glide boundaries which may have taken place will be noted, and recommendations for modification of the program will be made.

Task B: File initiation -- Monumentation records and graphs for prior surveys will be copied and transferred to the monitoring plan coordinator. The summer 1981 configuration and bed-surface composition of the channel will be entered into the manual or data-base record to serve as a baseline.

Task C: Demonstration of methods -- MMWD will provide personnel familiar with the methods described above and used in previous studies to demonstrate the measurement and record-keeping procedures, should the monitoring plan coordinator so request.

6. Responsibilities, Registration, and Reporting

The monitoring plan coordinator selected by the Marin County Resource Conservation District, in consultation with MMWD, will be responsible for conducting, reporting, and archiving the monitoring results for the ten years of the program. The coordinator may, at his or her discretion, contract with a qualified consultant to conduct portions of these activities; the coordinator retains the responsibility, however, to report the results of the monitoring. MMWD will be responsible for coordinating funding for the monitoring program.

The professional responsible for conducting the monitoring program will be making fundamental decisions regarding what is to be sampled, modifications at sites and adaptation of procedures, quality assurance and control, and whether the methods and results conform with generally-accepted professional practice. This individual should be experienced in channel mechanics or bed sedimentology, and registered to practice in California as appropriate to regulations in effect at the time. The responsible professional will direct and participate in field activities at each site, such that changed or anomalous conditions can be noted and accommodated in the conduct of the monitoring. This individual will certify to the program coordinator that monitoring activities have been conducted in conformance with the approved monitoring program, and identify any modifications deemed necessary.

An annual report will be delivered to MMWD or its designee by November 1, describing the results of field work conducted during the prior summer.

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APPENDIX B

Major primary and secondary events affecting bed conditions by year, 1995 – 2004, 2006 - 2007

Appendix B

Major Primary and Secondary Events Affecting Bed Conditions by Year, 1995 - 2007[1]

The following descriptions provide a sequential 'digest' of events or conditions affecting reaches and sub-reaches of Lagunitas Creek. Usually, these had a measurable effect at more than one segment and generally more than one site. Logjams, effects of tributaries or debris flows which had a narrower influence are not included in this list, but could be tabulated from the annual subjective reconnaissance reports. The events and occurrences, and their effects, have been drawn from the reconnaissance reports, field notes and sketches, correspondence, and from memory.

Changes During Year	Peak Flows		Narrative Description
Water Year 1995	January 8 March 10		At the Devils Gulch confluence, it appears that Lagunitas is storing a substantial amount of Devils Gulch cobble. Significant cobble has probably already been moved downstream; more can be expected based on storage and likely disturbances along Devils Gulch. In the Big Bend Reach, the channel moved to the left alternate channel as far downstream as section KD5 or 6, and about 1,000 to 1,500 tons of coarse sediment (material coarser than fine sand, generally transported as bedload in Lagunitas Creek) may have been mobilized as the left channel scoured to bedrock and widened by several dozen feet. Two very large alders have been uprooted, generating scour of up to 8 feet at locations within the pool. The RB alternate channel is filled with the one of the most massive logjams we have seen on Lagunitas, perhaps 70 feet wide, 125 feet long, and 8 feet high, and packed solid; perhaps 100 –150 tons of coarse sediment (largely sand) has been deposited in the interstices or on the bars flanking the debris. Probably several hundred tons of sediment has been deposited at the upper end of the large RB overflow channel. Extensive sedimentation of the terrace has occurred from what appears to be a debris flow from the downstream tributary. Between 300 and 500 tons of coarse sediment has been deposited on the LB terrace upstream of section KD-8, with probably 2000 to 5000 tons of sediment introduced into the channel and subsequently washed away. The reach below Big Bend is heavily sedimented by these episodic sources. Coarse sediment storage in this reach is enormous; some of the storage medial bars range as high as 7 or 8 feet above low water level. The upper 100 to 150 yards of the "Above Cheda Ranch Reach" is dominated by a large bar/confluence delta at the large LB tributary at Jewell, with up to about 4 feet of deposition apparently from the past season. Deltaic deposition in this reach was only observed at Cheda Ranch Creek. One very large logjam was noted about 0.25 mile d/s from Cheda Ranch Creek; this could cause change in main channel to the alternate LB channel, and seems to have done so briefly during the main storm(s) of the season. This jam was 11 feet high at its apex. In the upper Tocaloma reach, we enountered only two logjams that required a bypass or a clamber. There is an 8-foot high logjam in the center of three alternate channels near MP 20.15, at the Trifurcation Point below Kelley's Tocaloma site, diverting flows into north bank toward McIsaac's barn and causing about 30 lineal feet of bank erosion - - the first time that we have observed any below site KF.

[1] Drawn primarily from annual "subjective reconnaissance" accounts, photos on file at Balance and recall of observers.

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Changes During Year	Peak Flows		Narrative Description
Water Year 1996	Dec.1995, Jan 1996, Feb 4 peak.		Intense rain and winds resulted in sediment pulses and substantial fallen limbs and trees in channels. Extensive sedimentation at lower San Geronimo gage. Delta formed by Irving Creek under Irving Bridge. Walked up Irving Creek about 0.2 miles. The number of windfalls is astounding. Three consecutive logjams between park headquarters and Barnabe Creeks cause shift of main flow to LB alternate channels. Logjam between Big Rock and section KJ5 may have led to finer material on the bed in the glide and pool, and coarsening of the riffle. The logjam is not large enough to affect the next site d/s. Unnamed stream at campsite 24 delivered lots of sediment from campground. Bank repairs were needed at Devils Gulch but delivery in 1996 is less than usual. Apparently 5000-10,000 tons of sediment delivered to Lagunitas Creek at the Big Bend site from (a) bank erosion between the Green Bridge and cross-section KD-4 (b), continued delivery of sediment from LB tributary which broke loose in 1995 (c) new delivery of sediment from the upper LB tributary which broke loose this year (as in 1982), and (d) erosion of the gravel bar on the inside of Big Bend. The bed is brand new, finer, aggraded, and disturbed. Absent the deep pool and large-cobble riffle, it is much easier to walk downstream from the Green Bridge, and the extent of visitor re-working of the bed surface is quite noticeable, prompting us to make earlier pebcounts in subsequent years. Pools and glides are so disturbed that, for this year only, we move (after consulting with Steve Chatham and Dana Roxon) the pools and glide monitoring sites to the first sequence downstream of the confluence of the bend and overflow channels. Lots of sediment in storage in the upper Tocaloma reach; stream has completely filled active channel in places. Bed is visibly finer, and pools (where they exist) are shallower. Delta accumulation at mouth of Left Bank Upper Tocaloma tributary just upstream of Kelley's Tocaloma site may have delivered 1,000 to 1,500 tons of coarse sediment. Large organic debris, lumber pile at the downstream end of Tocaloma reach in central alternate channel; It has a volume of about 110 feet long, 45 feet wide, and a thickness of about 3.5 feet. Logjam at the confluence of McIsaac Creek may have backed up flows at site KF. Low densities of juvenile fish observed throughout.
Water Year 1997	Jan. 1 1997 peak flow		Devils Gulch and Cheda Ranch Creeks contributed appreciably to sedimentation. Changes in bed conditions dominated by sudden geomorphic events at the Big Bend site where channel shifted to a former overflow channel. Associated with huge logjam at the Big Bend site, burying cross-sections KD-7, KD-8. Approximately 3000 cubic yard of mainly coarse sediment enter Lagunitas Creek. Unnamed large LB tributary near milepost 18.9 (just downstream from Jewell) has formed a debris fan well into Lagunitas Creek. At least several hundred yards of large gravel and small cobbles have been mobilized from this delta, which appears to have formed early in the season. Upper Tocaloma LB tributary has had massive sedimentation and may be source for d/s deposits at KF. Just below the community of Upper Tocaloma and 100 yards u/s of this large LB tributary, stream has aggraded 1.0-1.5 feet (5). Two small LB tributaries just u/s of Tocaloma bridge have delivered a moderate amount of sediment and debris to Lagunitas Creek, adding to the riffles just downstream.

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Changes During Year	Peak Flows		Narrative Description
Water Year 1998	Feb.3 1998 peak flow exceeds 5000 cfs		48" fir has fallen across Sec. KB-4 after the peak flows & broken into 3 pieces; will affect this site for at least several years. Scour has eliminated the RB floodplain at KB4. Irving Creek delta has grown substantially. Eagle (Wildcat) Creek is contributing large amounts of sediment. Two sizable new logjams between Devils Gulch and Green Bridge. Several hundred cubic yards of gravelly debris from Devils Gulch remain in channel, likely (plus larger volumes) washed downstream. Upstream of Jewell, Lagunitas Creek is highly (remarkably?) sedimented, with bars often occupying 70 to 80 percent of the active channel width. One very large logjam on left bank (upper Jewell reach) just u/s of the State Park boundary. Unnamed large LB tributary at the lower end of Jewell is a major source of sediment. Enlarged delta at mouth of Cheda Ranch Creek. Lower 400 yard of Cheda Ranch Creek is a significantly disturbed reach, storing much coarse sediment. Did not proceed further upstream. A number of downed alders across the channel at 3 locations just upstream of Upper Tocaloma. Slug of sediment perhaps from Cheda Ranch Creek or Big Bend evident in channel from this point downstream to site KF (Kelley's Tocaloma) upstream of Tocaloma. Multiple changes in channel alignment below McIsaac Creek due to logjams. Greywacke, bedrock observed in bed at 3 locations downstream of McIsaac Creek, one extending fully across channel. Barry had never seen bedrock across the bed of the stream downstream of upper Tocaloma.
Water Year 1999	Feb.17 1999 peak flow		Fan at mouth of Deadman's Gulch larger than in previous years. Aggradation associated with Big Bend sediment pulses seems to have drowned trees in Lower Big Bend Reach. There is a sequence of logjams in this reach d/s of Cheda Ranch Creek. Delta at mouth of LB tributary d/s from the community of Upper Tocaloma has grown considerably. Three moderately large willows have fallen at Kelley's Tocaloma site, altering riffle and inhibiting bed census. Logjam 300 meters d/s of McIsaac Creek has accumulated more wood; still directs flow toward McIsaac barn.
Water Year 2000	Large Feb.12-13 event plus Significant late season storms.		Late season pulse from San Geronimo Creek to Lagunitas Creek leaves pockets of sand in pools as far d/s as Irving Bridge. This is the first observable pulse from SG during the past 9+ years with possible exception of 1997. The fallen fir tree at the "Below Shafter" site has altered the original segmentation, and we have to move the riffle segment monitored from the upstream to the downstream ends of this site. Extensive scour to bedrock beneath the fallen fir introduced several dozen cubic yards of angular metavolcanic bedrock into channel, forming a small riffle at sections KB6-7, Bed has downcut several inches near mouth of the large RB tributary u/s of Irving Bridge. Deposition from Irving Creek occurred beneath the bridge and is about 5 to 10 cubic yards in residual volume. In the Barnabe Reach, one new logjam has closed off portions of the LB channel at the head of the bedrock controlled island in the lower end of the reach. The other logjam near the d/s end of the island contributes to minor bank erosion along the RB, and significant erosion at the entry road downstream. Reach from Big Rock to Campground Bridge has additional large wood, which is partially responsible for more definition in pools, a coarser bed and improved habitat. RB tributary about 100 yards below KJ8, has built a small delta, likely resulting from grading actively to re-bed a road on the north side of SFD. LB tributary below Jewell contributed moderately large amount of large gravel and cobble this year.

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Changes During Year	Peak Flows		Narrative Description
			Considerable amounts of gravel coming from Cheda Ranch Creek. Channel has removed all of sandy bar that comprised beach at the Old Bay Beach location upstream of Upper Tocaloma. Three significant logjams in reach through the community of Upper Tocaloma. Coarse sediment delivery from the LB tributary d/s of Upper Tocaloma. Delta is longer, coarser, and lower than previous year, with small angular cobbles.
Water Year 2001			The lowermost 50 yards of San Geronimo Creek retains large pockets of dark sand and soil mantled by this year's vegetation. Ugly conditions. The lowermost 50 yards of Lagunitas Creek upstream of San Geronimo Creek looks very habitable for salmonids. The large logjam and 1998 tree fall at KB preclude the use of the upstream portion of the site for bed census. The large logjam has created two somewhat overlapping scour holes along the RB between cross-sections KB-3 and KB-5. The long pool u/s from the head of the riffle of cross-section KB12 to KB-7 is almost entirely covered with fine gravel from San Geronimo Valley, with an estimated 6-8 inches of aggradation this past season. At the "High Water Mark" Bar, there are two new places where large alders have fallen across the stream. The northeast banks are undercut at each place where this has occurred. At the Irving Pool, there is a large twin alder which has fallen across the pool two or three feet above the current water level. There is apparently some fill upstream and related to this fallen log, largely coarse gravels perhaps from Irving and San Geronimo Creeks. The bedrock pools near the mouth of the four Barnabe Creeks were filled with considerably more sand and fine gravel. Continued evidence of drowned trees in the Upper Big Bend Reach. The cutoff channel formed at Big Bend in 1997 continues to widen and incise. This incision may be introducing large gravel and cobbles. There is an expanded delta at the LB Jewell tributary. Large logjam just above the mouth of Cheda Ranch Creek, mobilizing a substantial amount of LB bank sediment into Lagunitas Creek (probably a few hundred cubic yards). Dying alders fell into the creek, causing the jam. In the Upper Tocaloma to Old Bay Beach reach there are two large bars from 1998 and 2000 storms, each holding 200 to 250 cubic yards, mostly medium to coarse gravel. At the upper end of the Upper Tocaloma Reach, there are five separate large woody debris jams crossing the channel. Three of them have formed large gravel reservoirs, probably totaling between 700 and 1000 cubic yards of relatively fresh deposition. Several large trees have fallen across the stream between the mouth of Cheda Ranch Creek and the community of Upper Tocaloma, with substantial erosion of the 1998 high-flow bar. Cheda Ranch Creek still contains 2 to 2.25 foot-high bars from the 1998 storms. At the LB tributary above Kelley's Tocaloma, substantial fresh deposition was observed this year, largely fine gravels. This tributary continues to be a significant sediment source. At Kelley's Tocaloma Site (KF) there is substantial encroachment of vegetation into the channel creating deeper pools and more storage of sands and fines, especially at the toes of both banks.
Water Year 2002	December 1 and 2		High-water marks (HWMs) at Kelley's Tocaloma are about 6 feet above May 7 water level, and contain a surprising amount of fine-divided organic debris.

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Changes During Year	Peak Flows		Narrative Description
	No spills from Kent Lake		Noticeable growth of willows, encroaching into channel from Upper Tocaloma downstream to Tocaloma Bridge
			Alders below Upper Tocaloma are stressed from sedimentation and arealmost in advanced or moderate stages of die back, being replaced by willows and Oregon ash.
			McIsaac Creek delta has advanced into Lag Cr, extending 30% of way across L.Cr.
			In the left-bank unnamed tributary just upstream of Kelley's Tocaloma site, a mudflow or density current passed though the lower end of the culvert and into Lagunitas Creek sometime during the past winter, apparently late in the season. Our estimate is that it introduced ". . .several hundred cubic yards of sediment into L. Cr., of which ~30% gravel and cobble. Biggest debris flow in our memory at this site.
			"To a growing extent, as we move upstream, Eric notes that the banks of the channel are increasingly eroded, particularly at the toe. This is a pattern that we have not seen before. It suggests that the channel may be shoaling and widening as a result of the significant sediment introductions upstream."
			Extensive aggradation downstream of Upper Tocaloma flashboard dam.
			Huge new logjam 8 to 9 feet high across creek in Upper Tocaloma.
			Evidence of an impounded lake and a dissected delta extends about 250 yds upstream to upstream most home in Upper Tocaloma.
			Alder die-off and tree-fall evident in previous years is diminishing: "We had a little trouble walking upstream through this reach, in contrast to previous years when it was occasionally quite difficult with a lot of clambering over fallen alders and logjams."
			Extensive deltaic sedimentation at mouth of Cheda Ranch, which is "filled with fine to medium gravels, a conditions have not observe before". Large gravel and cobble bars extending downstream about a quarter mile in L. Cr., sometimes occupying 75% of the width of the channel. Delta at Cheda Ranch mouth extends half-way across L. Cr.
			Logjams between site KL and mouth of Cheda Ranch Creek have washed away, releasing as much as 1000 cu yds of sediment accumulated at KL.
			Extensive changes in logjams and wood at upper end of site KL
			This year's HWMs are distinctly visible ~ 7 inches above the Jan. 1978 HWMs (at which the pin-tops were set), which had an estimated recurrence of 3 to 4 years. Extends u/s far enough that logjam effects at KL are likely not a factor.
			Jewell LB tributary has deposited a delta one-third of the way across L. Cr.
			Visible depletion of gravel bars in lower Big Bend reach at W end of State Park.
			Improved organization of pools and bars in upper Big Bend reach; HWMs 6' above today's water level.
			Devils Gulch within 200 yds of L. Cr. has less sand "than I can recall", with deeper pools
			Extensive treefall into the pool upstream of USGS gage, which occurred after the HWMs of the Dec. 2 storm. Enough fallen wood that Eric believes that stage-discharge has shifted due to wood (same gage height conveys less flow).
			LB tributary entering at KJ-4 has a large delta again (first time since 1981), partly trimmed back by the flows of Dec. 2.
			Scour through reach between Campground Bridge and USGS gage
			Site KC (Campground Bridge) altered by installation of one of the first woody debris structures, which obstructs 75 to 80 percent of the flow.

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Changes During Year	Peak Flows		Narrative Description
			Wildcat Cr sediment pool is empty of sediment, with silts and clays on bottom
			Site KX established Oct. 2002
			Construction of 6 to 8 LWD structures between Campground and site KH.
			Observable fresh sediment of San Geronimo origin observable u/s of Irving Bridge, and clear not present d/s of Campground Bridge.
			Site KH altered by placement of LWD structure just downstream, at former PCI apex weir
			Extensive sedimentation of SG origin observed near KH and upstream. "Throughout this relatively long reach, sand and fine medium gravels have accumulated within the pools and upper halves of glides. It is possible to walk on at least one side of the pool without encountering bedrock in all but 2 or 3 pools, which did not prevail during late 1990s. The degree of pool sedimentation is discernibly greater than last year, and much greater than 3 or 4 years ago."
			Placement of LWD structures in pool and glide at site KB
	2002 summary		*Substantial influx of sediment from McIsaac and Cheda Ranch Creeks and most LB tribs as far upstream as the campground.*
			Treefall of alders d/s of Big Bend continues but is attenuating
			Major pulse of sediment from SG Creek, but little or none from Wildcat and Irving
			Woody debris structures are altering a lot of the reach, including several sites.
	2003		Peak flows on Dec 14 (~1200 cfs) and Dec. 14(`1800 cfs) at K4 (lower San Geronimo gage)
			Only minor spills reported from Kent Lake. The combination of minimal spills and large peak flows in tributaries resulted in conditions most likely to creat deposition on the bed of Lagunitas Creek. The two observers were aware of this possibility when beginning the reconnaissance.
			High-water marks (HWMs) are about 3 to 3.75 ft above low-water level (12 cfs)
			Two lower left-bank tribs have been cleared of undergrowth
			HWMs in McIsaac Creek were 3.7 to 4.5 feet, compared with 2.8 feet the year before. Big delta
			Bed elev at Kelley's Tocaloma site appears to have stabilized after 5-6 years of aggradation
			No deposition at mouth of unnamed left bank creek, despite large mudflow previous year
			Nine-foot high logjam in Upper Tocaloma washed away, with downstream pulses of wood and fine gravel+sand. HWMs are 4 to 5 feet above low-water level, considerably higher than downstream; we speculate that significant attenuation may have occurred behind the 9-foot logjam. Upstream, alders are largely gone on left bank as far as Old Bay Beach.
			"Eric remarked that for the first time during the six years he has walked the stream, sediment seems to be depleting throughout the entire length of stream that we have walked today. The bars are being stripped and eroded, by sandy bars and pools are coarsening, and no aggradation seems to be occurring for the first time at Kelley's Tocaloma. The observations of depletion are contrary to our hypothesis entering the channel, when we expected to see fresh deposition due to the relatively large tributary inflows and the degree of hydrograph truncation this year."
			Delta at mouth of leftbank Jewell trib extends 22-25 feet into channel; prior to 2002, had never seen extensive deposition at this site.

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Changes During Year	Peak Flows		Narrative Description
			Gradual depletion of large bars and coarsening of pool beds observed near Jewell. Coarsening continues upstream to Big Bend, but bars have been accumulating cobble and coarse gravel; may be due to incision of the new cutoff channel at Big Bend. Sand now covers less than 10-15 % of pool beds; mainly fine gravels.
			Significant delta at mouth of cutoff channel at Big Bend; this channel has continued to organize, and now has regular pool-riffle structure
			Devils Gulch channel extends almost fully across L.Cr.
			Less wood noticed in channel from USGS gage upstream to Campground Bridge; may be due to capture at new LWD structures upstream.
			HWMs generally 3.5 to 4 feet above water level at 8 cfs -- less than downstream; probably reflects attenuation in Kent Lake due to early-season storms.
			Sediment depletion from Campground Bridge downstream, but accumulations of fine gravels noted upstream; Wildcat Creek basin, empty last year, has nearly filled.
			Massive sediment accumulation noticed in reach between Bike Bridge and Irving Bridge. Sand patches and stringers observed above Irving Bridge -- indicator of net sedimentation.
			Formerly-deep pools which we had walk around are now filled, with a max depth of 6 inches, with fine material (80%<8 mm), which globs off the sharpshooter blade rather than rolling off
			Widespread deposition of gravels observed between sites KH and KB (Below Shafter).
			"A significant amount of sediment seems to be entering from SG Creek, although discernibly less than in 2002.
	Summary of 2003		*1. 2002 sediment pulse has been moving downstream, with gravels accumulating down to the Bike Bridge, and sand apparent as far d/s as the USGS gage.*
			2. Deltas have been formed at the mouths of most tributaries, reflecting major storms but no spills.
			3. "I was somewhat surprised by the prevalence of gravels composed of metavolcanics and diabases/dolerites (lithologies largely locally-derived from Peters Dam or Shafter downstream to the Campground Bridge) in the medium- to coarse-gravel fraction. At the USGS gage, near Big Rock, above Wildcat Creek, and in the Irving Pool, I noted that many of the gravels larger than 16 millimeters seem to be of metavolcanic origin, with some notably sub-angular or angular. One possible explanation is that the constructed and natural logjams are scouring sufficient amounts of gravel from deep in the bed such that the coarse gravel supply is being augmented. Another less likely explanation is that there was sufficient delivery
	2004		Flow peaked in San Geronimo at about 1400 cfs on Dec. 29. Flows in main stem were above bankfull; tributary flows appear to have been slightly below or above bankfull. An unusually intense rainfall occurred on February 25; hence different storms may have generated peak flows of season. Although a dry year elsewhere in the Bay Area, rainfall in west Marin was near normal. Two major windstorms during this previous winter led to many fallen alders, most of which seem to have died as a result of the Big Bend sedimentation events.
			Fine sediment observed throughout lower McIsaac Creek, perhaps foreshadowing the 2006 massive sedimentation event

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Changes During Year	Peak Flows		Narrative Description
			Much fine to medium gravel reported in pools downstream from Upper Tocaloma to below McIsaac Creek; this seems to be associated with release of sediment ponded behind the 9-foot logjam formed during 2002 at Upper Tocaloma. Most noticeable upstream of site KF, so this slug may be in the early stages of working its way through the fluvial system.
			General aggradation noted from Upper Tocaloma to Cheda Ranch Creek, attributed to past several years rather than just 2004. Noticeablely high proportion of serpentinites, cherts and other "Cheda Ranch" lithologies, implying heavy sed contributions from that tributary.
			Large deltaic bar at the mouth of Cheda Ranch Creek assigned primarily to Dec. 29 event. Heavy sedimentation to SFD culvert.
			Silght aggradation -- and perhaps more importantly, absence of discernible downcutting -- generally reported from Cheda Ranch Creek upstream through Jewell. Uncharacteristic spawning site selection near several unstable riffles created by downed trees.
			Signs of depletion of the large bars in the Below Big Bend reach above Jewell.
			Bar at the mouth of Devils Gulch has been eroded away.
			HWMs are 6.5 to 7 feet above low-water levels.
			Upstream of Devils Gulch at least as far as Irving Bridge, gravels seem to have been augmented (general slight aggradation), but sands are much less visible than in 2003. Fewer sands observed within the bed, at least in places. One contributing factor could be more large wood transport, resulting a lot of localized scour as wood moves through. Sand depletion is massive at the beach upstream of Campground Bridge and at the Irving Creek delta.
			Wildcat Creek sediment basin is now completely filled. Substantial sand and silt at top.
			Log structure at Irving site (KX) moved 150 downstream, with much localized change.
			Substantial new sand + gravel noted in pools above Irving, suggestive of SG source. Note the marked difference -- sand depletion below Irving, accumulation above.
	2004 summary		*Large peak flows on Dec. 29 (about 1400 cfs at K4) and intense rain on Feb. 25, with minimal spills favor sediment accumulation*
			Two windstorms this winter. Much large wood in and moved through channel, probably leading to local scour.
			Sand depletion from Jewell to Irving Bridge is noticeable; accumulation of sand and fines upstream of Irving. Observations suggest influx of SG sediment late in season.
	2005		No subjective reconnaissance or bed census conducted
	2006		Year of major flood peaks on Dec. 31 and long continuous sub-bankfull flows from March 3 through April 16. Highest or second-highest flows since our first observations in 1979, both in Lagunitas through SPTSP and in San Geronimo Creek.
			Massive logjams at and downstream from Trifurcation Point, just u/s from the easternmost of the McIsaac barns. Numerous smaller 4- to-5-log jams upstream to McIsaac Creek.

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Changes During Year	Peak Flows		Narrative Description
			Extensive overbank flow throughout the floodplain as far upstream as the downstream end of Upper Tocaloma; HWMs diminish downstream from 12-14 ft above low water at Upper Tocaloma to about 9 feet upstream of Tocaloma Bridge.
			Although foreshadowed by scattered mention of slight bank retreat during the prior few years, 2006 is the first year in which general lateral erosion of the banks is reported -- most noticeably from Upper Tocaloma downstream to Tocaloma Bridge, but with bar depletion noted upstream to Big Bend. This is may be in part an adjustment to Big Bend sedimentation (since 2006 is the second really high flows since sediment was introduced at this site) and partially a dying off of the protective alders/blackberries/dogwood/vinca that stabilize the lower banks, esp. from site KF downstream.
			Evidence of massive debris flows from McIsaac Creek. Probably a minimum of several hundred cubic yards of sediment introduced from this source, then washed downstream by the March-April flows.
			Extensive debris flows from unnamed left bank tributary just u/s of McIsaac Creek. Several feet of sedimentation in channel d/s of bike path.
			Sedimentation downstream from large logjam area at the bend in the community of Upper Tocaloma, as flow occupies the right alternate channel, discharging large volumes of medium gravels downstream.
			No evidence of massive sedimentation from Cheda Ranch Creek; in fact, downcutting in Lagunitas bars at and downstream from CRC was reported
			Continuing expansion of channel and re-working of bars at Big Bend site, especially in the lower half of the cutoff channel developing through the meander bar.
			Significant sedimentation in lower Devils Gulch during the March-April rains, unlike elsewhere
			Two separate debris-flow events in lower Deadmans Creek, points to source upstream.
			Huge amounts of wood accumulated at and just downstream from the USGS gage
			All left-bank tributaries upstream of Jewell, as esp. of Devils Guch, as far as Irving Creek, have large deltas, suggesting intensities of rainfall may have been particularly severe on Bolinas Ridge.
			Between Irving Bridge and MP 15.7, noticeable changes in sediment storage, "which has increased this winter, manifested in point bars, in lee bars or lee trains and in pools. Pool depth, except in the immediate proximity of bedrock or snags, is seldom more than 18 inches. Point bars extend 60, 70 or even 80 percent of the way across the channel. . ."
			Between Irving and Shafter, pool fill material seems well washed, with limited turbidity plumes emanating from digs into the pool beds. Could be windnowed during March/April storms.
			At least 6 structures washed out or moved downstream between Irving and Shafter, likely contributing to scour.
	2006 Summary		*During 2006, flows in Lagunitas Creek were as high as they had been since 1982, and they approached and perhaps equaled those in at least one or two places along Lagunitas Creek. These were followed by repeated near- or bankfaull events on at least four occasions in March and April; these smaller events appear to have moved fine gravel and sand from the riffles into the pools*
			As might be expected following the highest flows in 24 years, a tremendous amount of wood was moved through the system. Much of the larger wood accumulated (a) in the mile between the community of Upper Tocaloma and the Tocaloma Bridge and particularly from the confluence of McIsaac Creek to Tocaloma Bridge, and (b) in the half-mile upstream between Devils Gulch and the Big Rock site (KJ).

Appendix B

Changes During Year	Peak Flows		Narrative Description
			Several alternate channels became active this year. In several cases, the main thread of flow now goes through an alternate channel; in most cases the alternate channel simply conveyed the flows that overtopped the floodplain bars. This may be a recurrent pattern following storms creating episodic sedimentation. Avulsions (sudden channel changes) to alternate channels can be significant sources of bed gravels.
			A significant amount of coarser, typically subangular sediment entered the stream during WY2006 from scour beneath WDSs and logjams, or through delivery from cobble-transporting tributaries such as Wildcat and Irving Creeks.
	2007		Very low total and peak flows this year, and no spills
			First winter for the woody debris structure constructed at Big Rock, strongly affecting site conditions
			Deposition of about 250 yards of material in the three pools and riffles upstream of the bedrock cascade above site KB.
	2007 summary		*Minor re-working and coarsening of the bed between Devils Gulch and Irving Bridge, sometimes with occasional addition of medium gravels (16-32 mm), increasing upstream to a clear point of delivery from SG Creek. Re-working of the bed surface appears to have winnowed much sand out of the surface gravels, with the sand re-deposited in low-gradient reaches such as the Irving picnic area to Site KH and in backwater areas such as the USGS gage to Big Rock (KJ).*
			Sediment delivery from tributaries was nominal and minor this year. Distinctive inflows were observed only from the LB tributary at KJ-4 in the State Park (30 cu yds) and from the tributary on the left bank at Big Bend KD-4 (about 40 cu. yds).
			All subjective recon walkers this year were impressed with the rate of willow regrowth, reversing the removal of impingeing willows which occurred during the WY2006 're-set'. In many reaches, willows extend perhaps 25 percent of the channel width from one bank or both
Water Year 1995	January 8 March 10		At the Devils Gulch confluence, it appears that Lagunitas is storing a substantial amount of Devils Gulch cobble. Significant cobble has probably already been moved downstream; more can be expected based on storage and likely disturbances along Devils Gulch. In the Big Bend Reach, the channel moved to the left alternate channel as far downstream as section KD5 or 6, and about 1,000 to 1,500 tons of coarse sediment (material coarser than fine sand, generally transported as bedload in Lagunitas Creek) may have been mobilized as the left channel scoured to bedrock and widened by several dozen feet. Two very large alders have been uprooted, generating scour of up to 8 feet at locations within the pool. The RB alternate channel is filled with the one of the most massive logjams we have seen on Lagunitas, perhaps 70 feet wide, 125 feet long, and 8 feet high, and packed solid; perhaps 100 –150 tons of coarse sediment (largely sand) has been deposited in the interstices or on the bars flanking the debris. Probably several hundred tons of deposition have occurred at the upper end of the large RB overflow channel. Extensive sedimentation of the terrace has occurred from what appears to be a debris flow from the downstream tributary. Between 300 and 500 tons of coarse sediment has been deposited on the LB terrace upstream of section KD-8, with probably 2000 to 5000 tons of sediment introduced into the channel and subsequently washed away. The reach below Big Bend is heavily sedimented by these episodic sources. Coarse sediment storage in this reach is enormous; some of the storage medial bars range as high as 7 or 8 feet above low water level. The upper 100 to 150 yards of the "Above Cheda Ranch Reach" is dominated by a large bar/confluence delta at the large LB tributary at Jewell, with up to about 4 feet of deposition apparently from the past season. Deltaic deposition in this reach was only observed at Cheda Ranch Creek. One very large logjam was noted about 0.25 mile d/s from Cheda Ranch Creek; this could cause change in main channel to the alternate LB channel, and seems to have done so briefly during the main storm(s) of the season. This jam was 11 feet high at its apex.

Appendix B

Changes During Year	Peak Flows		Narrative Description
			In the upper Tocaloma reach, we enountered only two logjams that required a bypass or a clamber. There is an 8-foot high logjam in the center of three alternate channels near MP 20.15, in Kelley's Tocaloma reach, diverting flows into north bank toward McIsaac's barn and causing about 30 lineal feet of bank erosion - - the first time that we have observed any below site KF.
Water Year 1996	Dec.1995, Jan 1996, Feb 4 peak.		*Intense rain and winds resulted in sediment pulses and substantial fallen limbs and trees in channels.* *Extensive sedimentation at lower San Geronimo gage.* *Delta formed by Irving Creek under Irving Bridge. Walked up Irving Creek about 0.2 miles. The number of windfalls is astounding.* *Three consecutive logjams between park headquarters and Barnabe Creeks cause shift of main flow to LB alternate channels.* *Logjam between Big Rock and section KJ5 may have led to finer material on the bed in the glide and pool, and coarsening of the riffle. The logjam is not large enough to affect the next site d/s.* *Unnamed stream at campsite 24 delivered lots of sediment from campground.* *Bank repairs were needed at Gulch but delivery in 1996 is less than usual.* *Apparently 5000-10,000 tons of sediment delivered to Lagunitas Creek at the Big Bend site from (a) bank erosion between the Green Bridge and cross-section KD-4 (b), continued delivery of sediment from LB tributary which broke loose in 1995 (c) new delivery of sediment from the upper LB tributary which broke loose this year (as in 1982), and (d) erosion of the gravel bar on the inside of Big Bend. The bed is brand new, finer, aggraded, and disturbed. Absent the deep pool and large-cobble riffle, it is much easier to walk downstream from the Green Bridge, and the extent of visitor re-working of the bed surface is quite noticeable, prompting us to make earlier pebcounts in subsequent years. Pools and glides are so disturbed that, for this year only, we move (after consulting with Steve Chatham and Dana Roxon) the pools and glide monitoring sites to the first sequence downstream of the confluence of the bend and overflow channels.* *Lots of sediment in storage in the upper Tocaloma reach; stream has completely filled active channel in places. Bed is visibly finer, and pools (where they exist) are shallower.* *Delta accumulation at mouth of Left Bank Upper Tocaloma tributary just upstream of Kelley's Tocaloma site may have delivered 1,000 to 1,500 tons of coarse sediment.* *Large organic debris, lumber pile at the downstream end of Tocaloma reach in central alternate channel; It has a volume of about 110 feet long, 45 feet wide, and a thickness of about 3.5 feet. Logjam at the confluence of McIsaac Creek may have backed up flows at site KF.* *Low densities of juvenile fish observed throughout.*
Water Year 1997	Jan. 1 1997 peak flow		*Gulch and Cheda Ranch Creeks contributed appreciably to sedimentation.* *Changes in bed conditions dominated by sudden geomorphic events at the Big Bend site where channel shifted to a former overflow channel. Associated with huge logjam at the Big Bend site, burying cross-sections KD-7, KD-8. Approximately 3000 cubic yard of mainly coarse sediment enter Lagunitas Creek.* *Unnamed large LB tributary near milepost 18.9 (just downstream from Jewell) has formed a debris fan well into Lagunitas Creek. At least several hundred yards of large gravel and small cobbles have been mobilized from this delta, which appears to have formed early in the season.* *Upper Tocaloma LB tributary has had massive sedimentation and may be source for d/s deposits at KF. Just below the community of Upper Tocaloma and 100 yards u/s of this large LB tributary, stream has aggraded 1.0-1.5 feet (5).*

Appendix B

Changes During Year	Peak Flows		Narrative Description
			Two small LB tributaries just u/s of Tocaloma bridge have delivered a moderate amount of sediment and debris to Lagunitas Creek, adding to the riffles just downstream.
Water Year 1998	Feb.3 1998 peak flow exceeds 5000 cfs		*48" fir has fallen across Sec. KB-4 after the peak flows & broken into 3 pieces; will affect this site for at least several years. Scour has eliminated the RB floodplain at KB4.* *Irving Creek delta has grown substantially.* *Eagle (Wildcat) Creek is contributing large amounts of sediment.* *Two sizable new logjams between Devils Gulch and Green Bridge.* *Several hundred cubic yards of gravelly debris from Devils Gulch remain in channel, likely (plus larger volumes) washed downstream.* *Upstream of Jewell, Lagunitas Creek is highly (remarkably?) sedimented, with bars often occupying 70 to 80 percent of the active channel width. One very large logjam on left bank (upper Jewell reach) just u/s of the State Park boundary. Unnamed large LB tributary at the lower end of Jewell is a major source of sediment.* *Enlarged delta at mouth of Cheda Ranch Creek. Lower 400 yard of Cheda Ranch Creek is a significantly disturbed reach, storing much coarse sediment. Did not proceed further upstream.* *A number of downed alders across the channel at 3 locations just upstream of Upper Tocaloma. Slug of sediment perhaps from Cheda Ranch Creek or Big Bend evident in channel from this point downstream to site KF (Kelley's Tocaloma) upstream of Tocaloma.* *Multiple changes in channel alignment below McIsaac Creek due to logjams. Greywacke, bedrock observed in bed at 3 locations downstream of McIsaac Creek, one extending fully across channel. Barry had never seen bedrock across the bed of the stream downstream of upper Tocaloma.*
Water Year 1999	Feb.17 1999 peak flow		*Fan at mouth of Deadman's Gulch larger than in previous years. Aggradation associated with Big Bend sediment pulses seems to have drowned trees in Lower Big Bend Reach. There is a sequence of logjams in this reach d/s of Cheda Ranch Creek. Delta at mouth of LB tributary d/s from the community of Upper Tocaloma has grown considerably. Three moderately large willows have fallen at Kelley's Tocaloma site, altering riffle and inhibiting bed census. Logjam 300 meters d/s of McIsaac Creek has accumulated more wood; still directs flow toward McIsaac barn.*
Water Year 2000	Large Feb.12-13 event plus Significant late season storms.		*Late season pulse from San Geronimo Creek to Lagunitas Creek leaves pockets of sand in pools as far d/s as Irving Bridge. This is the first observable pulse from SG during the past 9+ years with possible exception of 1997.* *The fallen fir tree at the "Below Shafter" site has altered the original segmentation, and we have to move the riffle segment monitored from the upstream to the downstream ends of this site. Extensive scour to bedrock beneath the fallen fir introduced several dozen cubic yards of angular metavolcanic bedrock into channel, forming a small riffle at sections KB6-7,* *Bed has downcut several inches near mouth of the large RB tributary u/s of Irving Bridge. Deposition from Irving Creek occurred beneath the bridge and is about 5 to 10 cubic yards in residual volume. In the Barnabe Reach, one new logjam has closed off portions of the LB channel at the head of the bedrock controlled island in the lower end of the reach. The other logjam near the d/s end of the island contributes to minor bank erosion along the RB, and significant erosion at the entry road downstream.* *Reach from Big Rock to Campground Bridge has additional large wood, which is partially responsible for more definition in pools, a coarser bed and improved habitat. RB tributary about 100 yards below KJ8, has built a small delta, likely resulting from grading actively to re-bed a road on the north side of SFD. LB tributary below Jewell contributed moderately large amount of large gravel and cobble this year.* *Considerable amounts of gravel coming from Cheda Ranch Creek. Channel has removed all of sandy bar that comprised beach at the Old Bay Beach location upstream of Upper Tocaloma. Three significant logjams in reach through the community of Upper Tocaloma.*

Appendix B

Changes During Year	Peak Flows		Narrative Description
			Coarse sediment delivery from the LB tributary d/s of Upper Tocaloma. Delta is longer, coarser, and lower than previous year, with small angular cobbles.
Water Year 2001			*The lowermost 50 yards of San Geronimo Creek retains large pockets of dark sand and soil mantled by this year's vegetation. Ugly conditions. The lowermost 50 yards of Lagunitas Creek upstream of San Geronimo Creek looks very habitable for salmonids.* *The large logjam and 1998 tree fall at KB preclude the use of the upstream portion of the site for bed census. The large logjam has created two somewhat overlapping scour holes along the RB between cross-sections KB-3 and KB-5. The long pool u/s from the head of the riffle of cross-section KB12 to KB-7 is almost entirely covered with fine gravel from San Geronimo Valley, with an estimated 6-8 inches of aggradation this past season.* *At the "High Water Mark" Bar, there are two new places where large alders have fallen across the stream. The northeast banks are undercut at each place where this has occurred.* *At the Irving Pool, there is a large twin alder which has fallen across the pool two or three feet above the current water level. There is apparently some fill upstream and related to this fallen log, largely coarse gravels perhaps from Irving and San Geronimo Creeks.* *The bedrock pools near the mouth of the four Barnabe Creeks were filled with considerably more sand and fine gravel.* *Continued evidence of drowned trees in the Upper Big Bend Reach. The cutoff channel formed at Big Bend in 1997 continues to widen and incise. This incision may be introducing large gravel and cobbles. There is an expanded delta at the LB Jewell tributary.* *Large logjam just above the mouth of Cheda Ranch Creek, mobilizing a substantial amount of LB bank sediment into Lagunitas Creek (probably a few hundred cubic yards). Dying alders fell into the creek, causing the jam.* *In the Upper Tocaloma to Old Bay Beach reach there are two large bars from 1998 and 2000 storms, each holding 200 to 250 cubic yards, mostly medium to coarse gravel. At the upper end of the Upper Tocaloma Reach, there are five separate large woody debris jams crossing the channel. Three of them have formed large gravel reservoirs, probably totaling between 700 and 1000 cubic yards of relatively fresh deposition.* *Several large trees have fallen across the stream between the mouth of Cheda Ranch Creek and the community of Upper Tocaloma, with substantial erosion of the 1998 high-flow bar. Cheda Ranch Creek still contains 2 to 2.25 foot-high bars from the 1998 storms.* *At the LB tributary above Kelley's Tocaloma, substantial fresh deposition was observed this year, largely fine gravels. This tributary continues to be a significant sediment source.* *At Kelley's Tocaloma Site (KF) there is substantial encroachment of vegetation into the channel creating deeper pools and more storage of sands and fines, especially at the toes of both banks.*

APPENDIX C

Summary account of sediment delivery at Big Bend Site 1995-2006

Memo

To: **206051 Lagunitas Bed Conditions Monitoring 2006**

From: Scott Brown

Date: March 26, 2007

Subject: Assessment of stream channel changes at Big Bend, Lagunitas Creek, Marin County, California

Introduction

The Big Bend reach of Lagunitas Creek, downstream of Green Bridge, has been one of the most dynamic sections of the stream over the past ten years, with several notable channel shifts and debris flow events from side-canyon tributaries. During the subjective reconnaissance of Lagunitas Creek by Barry Hecht and Eric Austensen on May 10, 2006, this reach was flagged for further study due to the significant changes over the past several years. A brief, preliminary assessment of the Big Bend reach was included in the stream reconnaissance memo. The following memo expands on the reconnaissance, summarizing the findings of a supplementary analysis completed on a separate field visit by Scott Brown on May 17, 2006.

Methods

The Big Bend supplementary analysis was performed in the course of an afternoon, using sketch-maps, a hand-held gps unit[1], and measuring tape to delineate the various channels and other features within the reach. Interpretations of key features were made in the field, referenced to waypoints taken with the gps, and recorded in the field notes. Digital photographs were taken of the key features and from known locations, so that they could be used for comparison in potential future studies. Several digital photographs were also taken to compare to past conditions, where previous photos were available. Following the field survey, the data were analyzed and compiled in a composite map of the site to illustrate the key features and progression of events identified at the site.

Findings

Figure 1 diagrams the approximate channel configuration of the Big Bend reach as of May 2006. The most complex portion of the reach is located just downstream of the KD monitoring site, in the location of a major channel shift attributed to the 1996 storm events; however, significant channel change was noted throughout the reach during WY2006. The following section

[1] The hand-held gps unit was a Garmin V, which does not provide survey-grade accuracy. Generally, waypoint accuracy with this unit was about +/- 25 feet. The waypoint data from the gps was used to refine the scale of the sketch maps when compiling the final map, and therefore the scale on those maps should be considered approximate.

describes the major features and channel changes that occurred during water year 2006, generally from upstream to downstream.

The left-bank gravel/cobble bar approximately 50 feet downstream of Green Bridge and upstream of KD-1 was significantly higher than in years past (up to 3 feet in places). The bar is steep-sided along the current flow path, having been eroded into by late-season moderate-flow events. The bar also extends much further downstream than in past years, probably an additional 20 feet (Figure 2). If colonized and eventually fixed in place by vegetation, portions of this bar not removed by flows in subsequent years could easily become part of the floodplain, which is not very much higher.

A berm of loose gravel and cobbles was present along the entire right bank of the KD pool, partially burying many of the willows that were growing on that bar. The deposition is an obvious continuation of the bar deposited on the left bank just upstream, dissected by the current flow path. The average depth of the newly deposited sediment on this bar was approximately two feet, with some areas buried up to three or possibly four feet (Figure 3). In addition, the secondary low-flow channel that once cut through the right-bank bar is now gone, having been completely filled in with sediment.

A debris flow from a left-bank tributary at the KD monitoring pool deposited a significant amount of sand, gravel, and cobbles on the left-bank terrace (which itself is predominately composed of earlier debris flow deposits). The main portion of the recent debris flow deposits spanned an area of approximately 20 by 20 feet, with a depth reaching up to about three feet. These deposits were dissected by later flows, cutting a three-foot wide channel down to approximately the level of the original terrace. Just downstream of the main debris flow channel the left bank showed signs of recent erosion, possibly by as much as two feet laterally (Figure 4). The older debris flow deposits exposed in the bank appeared to have a higher concentration of angular cobbles than the more recent deposits. Overall, the debris flow, re-incision and bank retreat have probably contributed about 100 cubic yards (or about 140 tons) of sediment to Lagunitas Creek, of which perhaps 50 percent is coarse sediment.

Downstream of the KD pool is an extensive cobble bar at the head of the original 1996 channel avulsion that marks the beginning of the braided reach. The upstream portion of the bar has scoured slightly, extending the left-bank portion of the pool further downstream than in the past, and much of the vegetation on the bar as a whole has been removed. On the right-bank portion of the bar is some evidence of recent gravel deposition, especially prevalent along the downed alder[2] that parallels the low-flow channel and along the left bank near the downstream end of the low-flow riffle (Figure 5). Beyond these changes, however, the main portion of the bar appears to have changed relatively little. Likewise, the pre-1996 channel had little evidence of significant change (deposition, scour, or bank erosion), other than the loss of some of the scrub vegetation in that area.

A second, small left-bank tributary joins Lagunitas Creek near the upstream end of the pre-1996 channel. Significant amounts of sand, gravel, and cobbles were deposited on the left-bank

[2] Identifiable as one of the two fully mature alders uprooted by the 1995 change in channel course (see 1995 report and Appendix B of the 5- and 10-year reports

terrace, with the distal end of the deposits at the approximate elevation of the 2006 high-water mark. The recently deposited sediment is up to four feet deep, though later flows cut a steep-walled channel into the deposits down to the approximate level of the original terrace (Figure 6).

Below the main portion of the riffle at the right bank (post-1996 channel) there was evidence of significant bank scour, with high flows cutting into the right bank terrace deposits. The deposits exposed in this terrace are markedly finer than those exposed in the left bank terrace upstream, being composed primarily of overbank deposits and organic debris. The scour along this bank will likely continue, as the fallen alder at the right side of the cobble bar, along with the recently deposited gravel and cobbles on that portion of the bar, constrains flows along the right bank.

Further downstream, extensive deposition is again present, with large bars of loose gravel present on alternate sides of the baseflow channel. The gravel deposits are as deep as three to four feet in some places, and predominately located in the lee of trees or debris dams, and at the inside of the bend in the flow path. Some erosion is evident in this reach as well, mainly along the left bank of the 1996 avulsion channel, where it is cutting laterally into terrace deposits that were cut off by the avulsion channel. Additional erosion is evident in the loose gravel deposits that define the baseflow bank of the stream, suggesting that the gravel deposits were originally more extensive following the late-December event (possibly extending across the entire channel) but were eroded by the smaller, late-season events.

Approximately 450 feet downstream of the top of the KD riffle, the avulsion channel widens, creating a complicated pattern of channel braids. There are several large debris jams and downed trees in this reach, as well as several trees that are still standing within the channel (Figure 7). The current baseflow channel is constrained to the left-bank side of the avulsion channel, flowing along the cut-off 6-foot terrace to rejoin the original channel. Several distinct secondary channels are present within this section, but most are completely dry at baseflow. Deposits of loose gravel and cobbles, several feet thick in some areas, separate the distinct channels within this reach. Again, these deposits were most likely laid down during the peak of the late-December event with the secondary channels forming as the flows receded. The secondary channels were certainly active as well during subsequent large storm events, though it appears that flow was concentrated in the left-bank portion of the avulsion during the late-season events, cutting a more distinct primary channel (down to bedrock in at least one place near the original, pre-1996 channel).

At the far right-bank, downstream from the main portion of the braided reach, a distinct channel is present, separated from the main stream channel by a small “island” of remnant terrace deposits. This channel (the braid that enters the main channel furthest downstream) enters the main channel at a one-foot drop, stabilized by roots and other vegetation (Figure 8). While the presence of the downstream knickpoint suggests that it is a secondary channel carved into the terrace during high flows, the channel has fairly well-defined bedforms and therefore carried a significant amount of flow, at least for a short period of time. Several patches of loosely deposited gravel are present within this channel, most likely resulting from deposition on the lee side of fallen trees as the flows subsided or was redirected to another channel.

Summary and Conclusions

The Big Bend site experienced significant sediment deposition through the most of the reach, most likely during the late-December storm. Aggradation in many areas appears to have been on the order of three feet, and was concentrated at the lateral bar below Green Bridge (and the extension of this bar along the right bank of KD pool) and throughout the entire stretch of the avulsion channel. Subsequent storms eroded through these deposits, transporting some of the deposited material further downstream.
Two debris flows occurred in small tributary canyons in the Big Bend reach, contributing to the high sediment load in the creek. A large portion of the coarse sediment deposited in fans on the left-bank terrace, high enough that it is not available for transport by Lagunitas Creek. Future storm flow from the tributary canyons may further erode the fan deposits and deliver additional sediment to the creek.

There was also evidence of bank erosion within the reach, though this appeared almost entirely localized to three distinct areas of the channel (along the left bank of the KD monitoring pool, the right bank of the KD monitoring riffle, and the left bank below the KD montitroing riffle). In general, it appears that net deposition greatly outweighed net erosion within the reach.

The pre-1996 channel was active during the high-flow events of 2006, however there was little evidence of recent scour or deposition there, suggesting that this portion of the channel didn't receive a large portion of the flow. Vegetation in this channel was somewhat thinner than in previous years, but was predominately intact, as was the large debris jam on the south side of the large terrace dividing the old channel from the newer ones.

Using the map as a guide, along with measurements made in the field, we calculated a rough estimate of the amount of sediment generated within (and transported out of) the Big Bend reach during the WY2006 storms. We estimate that the amount of eroded sediment from the reach (above the typical level of transport during "average" years) is on the order of 1000 to 2000 cubic yards. Approximately half of this amount is likely from sediment that was deposited during the late-December event, and then eroded by subsequent storms. The remainder is from bank erosion, and inputs from the two debris flows on the left bank.

A significant amount of readily-mobilized (or 'excess') sand, gravel, and cobbles remains in storage within this reach (on the order of several hundred to a thousand cubic yards). Much of this sediment is poorly consolidated and within or near the bankfull channel, and is therefore readily available for transport during future events. These deposits will most likely contribute to higher-than-average sediment transport rates from this reach over the next several years.[3]

[3] Work conducted under supervision of California Engineering Geologist 1245.

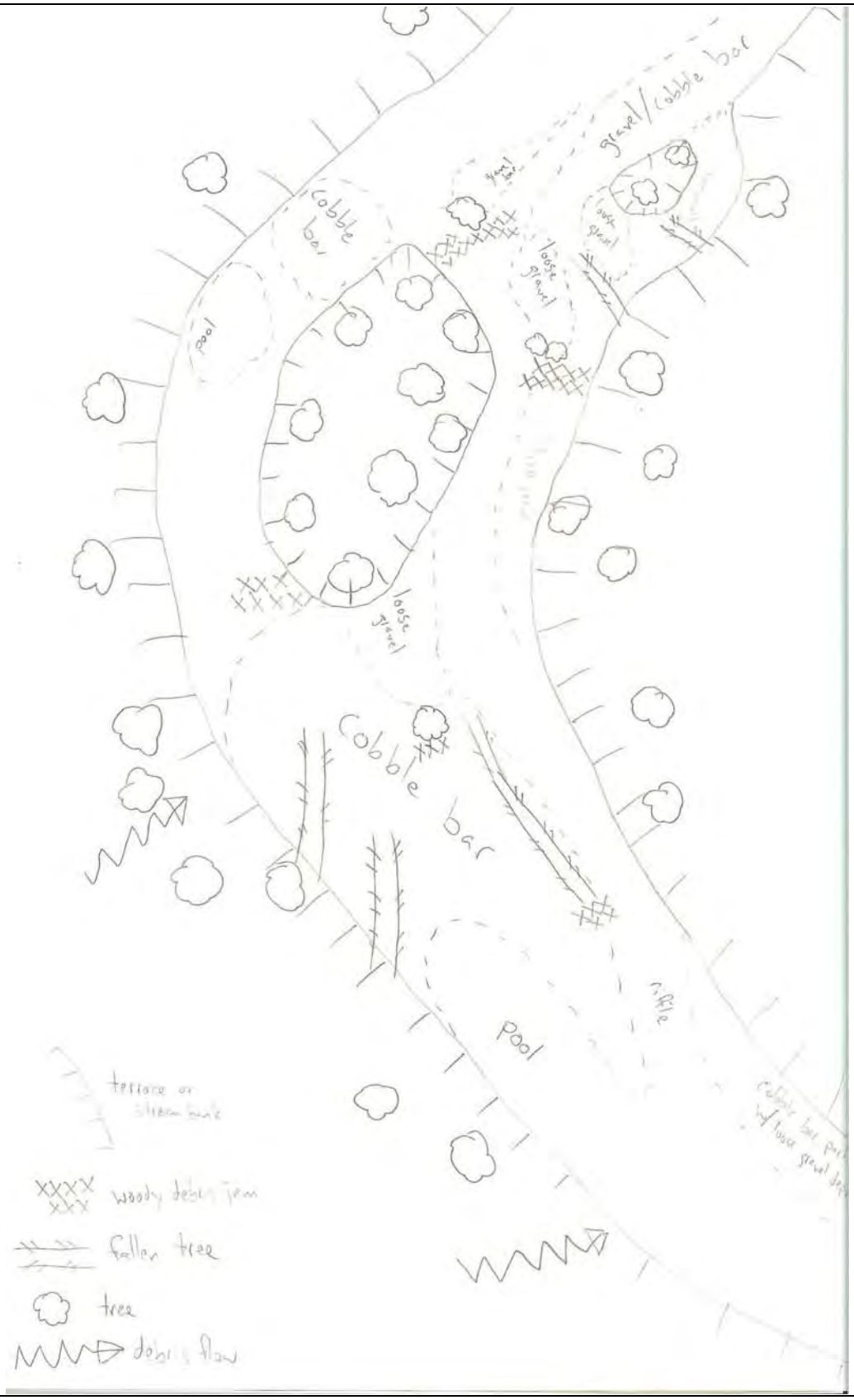

Figure C1. Field sketch of biogeomorphic conditions at the Big Bend site following the storms of WY-2006

Balance Hydrologics, Inc.

208052 Figure C1

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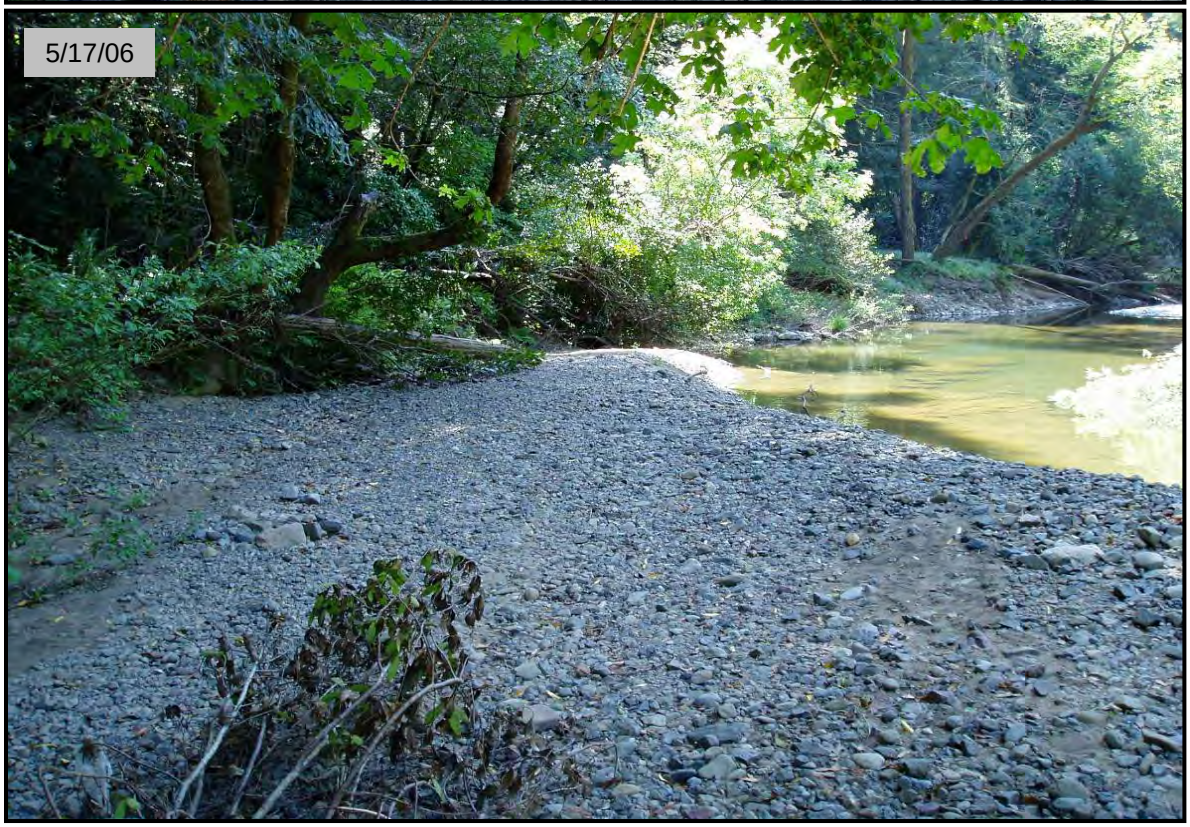

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Figure C2. Comparison photographs showing the extension of the left-bank bar following the WY2006 storm events, 'Big Bend' site, Lagunitas Creek, CA.

Photos were taken looking downstream from the upstream end of the KD monitoring pool.

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Figure C3. Comparison photographs showing bank deposition resulting from the WY2006 storm events, 'Big Bend' site, Lagunitas Creek, CA.

Photos were taken looking upstream from the KD monitoring glide the main area of deposition is on the bank on the left side of the photo.

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Figure C4. Comparison photographs showing bank erosion resulting from the WY2006 storm events, 'Big Bend' site, Lagunitas Creek, CA. Photo taken across stream toward left bank from KD monitoring glide. Arrows point to three-tree cluster for reference.

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Figure C5. Photograph showing loosly consolidated gravel deposits along the left bank of the low-flow channel, 'Big Bend' site, Lagunitas Creek, CA.
Photo taken across the low-flow channel near the bottom of the KD monitoring riffle.

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Figure C6. Photograph showing recent debris flow deposits exposed by subsequent tributary erosion, 'Big Bend' site, Lagunitas Creek, CA.
Deposits are up to four feet deep. The confluence with the mainstem is near the upper-left corner of the photo.

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Figure C7. Photograph showing woody debris jams and gravel deposits within the avulsed channel, 'Big Bend' site, Lagunitas Creek, CA. Photo taken from top of terrace that was cut off by the 1996 channel avulsion, looking downstream.

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Figure C8. Photograph of highflow secondary channel at the downstream end of the avulsion reach, 'Big Bend' site, Lagunitas Creek, CA. Note the foot-high drop at the confluence with the main channel (at the bottom of the photo), and the trees at the right-hand side of the photo marking the remnant terrace.

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APPENDIX D

Criteria used to discriminate lithologies in Lagunitas Creek basin

BALANCE HYDROLOGICS, Inc.

Memo

To: File 207051
From: Barry Hecht
Date: 9/13/98[1], revised 9/29/00, 9/23/01, 9/7/03, 9/12/04 (all minor)

Subject: Hints re criteria used to discriminate lithologies in Lagunitas Creek basin

Cc: Carla Grandy

1. Metavolcanics:
   - presence of phenocrysts of plag, or ghost phenocrysts in those rocks showing deformation; phenocrysts are often isolated and recessive within a cryptocrystalline groundmass
   - evidence of vugs, amygdules, or ghosts of same; often filled w/ prehnite, chlorite, or pumpellyite; also, sometimes a burgundy opaline 'mineral' (jasper?)
   - occasionally, vugs remain in hand specimen, or parts of augen[2]
   - comminutes to sub-round, seldom round
   - if lots of disseminated sulfides observed, it will likely be metavolcanic rather than phyllite, but sulfides do not appear in most metavolcanics. Sulfides almost never appear in phyllites.
   - rarely but importantly, metabreccia – greywacke colored, but under hand lens shows very angular (cuspate) blue-grey clasts (pillow-rind frags), aligned, with <u>no</u> visible qtz or feldspar but occasional plagioclase lath ghost, OR aligned lith clasts with universally angular and acicular plag mini-phenocrysts and very angular glass shards.
   - if dark green and burgundy mottled, likely to be metavolcanics, not phyllite; look carefully
   - sometimes contains roundish holes, perhaps remnants of weathered-out grains (as with phyllites)

2. Diabase/Diorite
   - equant and/or equant, often-twinned crystals
   - hornblende+plag+qtz only, with some mafics; occasional orange pyroxene or olivine
   - often, 2 generations of plag phenocrysts
   - seldom rounded
   - rock fragments are often compact or equant rock shape (like a cube or rectangle)

[1] Originally modified from 93051 lithdiscrimhints, which in turn is based on pre-digital documents used in 1979.
[2] Augen are the quartz-rich 'eyes' which form in the voids between full pillows in pillow basalts. They are also contain prehnite, pumpellyite, sometimes a mica and a dark amphibole (hornblende?), or a hint of epidote. Small chunks of pillow rind are often attached or interspersed. Because augen occur only in metavolcanics, they are classified with their source rock, rather than chert and quartz.

- if clearly vein filling within metavolcanics or fragments of augen[2], should be classed as metavolcanics (see related footnote)

3. Cherts+Quartz
   - reported as a combination in data tables, but sometimes censused separately in the lab or field notebooks
   - banding, veining, or extensive outgrowths of grains needed to call it chert vs qtz
     - unless has obviously chert-like appearance
   - if mixed into greywacke or phyllite, chert must be >50%

4. Sandstone
   - discriminated from greywacke on basis of no evidence of sutured or deformed grain boundaries; generally grains stick out in high relief (often >50% of grain diameters)
   - no re-melting of matrix
   - generally, no obvious preferred orientation other than a subtle bedding
   - highly mixed lithologies, commonly w/ lots of quartz grains; if mainly qtz lith, likely ss; in general, sandstones have fewer rock frags and more quartz grains than greywacke
   - frequently, a redder or tannish cast to matrix
   - nearly all sandstone clasts are rounded, altho grains within them may not be
   - grains within a clast are usually, but not always, well sorted
   - can have a slightly elongated appearance in apparent direction of bedding
   - seldom, if ever, veined with quartz re-melted from grains.

5. Greywacke
   - usually characteristic grey-blue color; sometimes oxidized to browns
   - some re-fusing or suture of grains evident
   - preferred orientation of matrix which seems to be pressure-induced
   - often contains a very small to moderate content of dark grey or purple lithic fragments, randomly dispersed
   - grains are generally equidimensional or ovoid, except for dark lithic fragments -- few rods or plates, except where veined
   - rounds easily, generally a bit less than sandstone, but will usually be subrounded on a least one face
   - discriminates from phyllite based on nearly-universal visibility of grains under handlens, and feels gritty to the finger (see phyllite)

6. Phyllite
   - usually cryptocrystalline matrix
   - when not, typically has waxy blebbed appearance
   - occasional rounded grains or grain ghosts typical, which do not look like vug fills
   - often has a few large grains of qtz and/or chert veining; sometimes grains are eaten out, leaving holes
   - has dusky and dusty appearance to outside of the individual clasts
   - discriminates from greywacke by predominance of matrix as the fabric of the rock (a few prominent grains or grain layers doesn’t make it a greywacke)

- most rocks with multiple, similar-size ‘bubble holes’ are phyllites, not metavolcanics, as might be expected

7. Blueschists
   schistose texture, and some evidence of amphiboles or nexosilicates evident

8. Ultramafics
   - waxy texture, veined by various thicknesses of greenish annealing material which stands out in relief
   - presence of chrystotile (seldom) or altered olivine or pabstite
   - can have ‘rocky road’ texture
   - tannish green or greenish blue or yellowish/tan color
   - About 40-50% of ultramafics have a light tan matrix color, with glassy darker ‘nerve’ network veins (generally greenish-tinged)
   - Very commonly rounded or subrounded (often with one broken side)

9. Artifacts
   asphalt, glass, porcellain, brick, or similar.
   [In Lagunitas Creek, I don’t try to dscriminate quarry rocks, although Dutra (San Rafael) quarry material is often distinguishable].

Lithologic ID is performed during daylight hours, using 10x handlens or (pre-1996) binocular microscope, using criteria in discrimination hints list (see documents 98051 or 203051, 204051 or 206051 lithdiscrimhints).

Samples drawn from set of all rocks retained on 8 mm sieve, but passing the 16 mm sieve after shaking on a Rotap machine for 5 to 10 minutes. Samples drawn by splitting sample by method of quartering. Sometimes, multiple quarterings needed, or occasionally, few enough clasts of 8-16 mm size were sampled such that the entire sample was utilized.

Once quartered, all clasts in a quartered sample were used (hence variability in the number of rocks ID’d), such that no preference be given to (a) rocks near the center or each quartering (which tend to be slightly smaller) or (b) those which can easily be identified.

Most lithologic ID took 60 to 80 minutes per sample once familiarized (or refamiliarized) with criteria.

APPENDIX E

Narrative location of bed-monitoring sites

Appendix E

Location of Bed-Monitoring Sites, WY1993-WY2007[a]
Lagunitas Creek

Code	*Location/Remarks*	*Mile Marker*[b]	*Cross Sections*
KB	*Below Shafter Bridge* Approximately ¼ miles downstream of Shafter Bridge. Extends from massive pillow basalt outcrop approx.400 ft. downstream.	15.49	12
KH	*Kelley's Upper State Park Site* Downstream of spring	16.09	9
KX	*Irving Picnic Grounds*[c] Upstream of Irving Bridge	16.34	9
KC	*SPTSP Campground Bridge* Pool upstream of, glide beneath, and riffle downstream of bridge.	17.24	10
KJ	*Big Rock* Extends 350 feet upstream from MMWD's camp Taylor blowoff. LB tributary from group camp area flows in at cross-section KJ-4.	17.64	8
KD	*Big Bend* Major gravel storage area. Begins at top of first riffle below Green Bridge, at SPTSP swimming hole.	18.49	6
KL	*Cheda Ranch Creek* Extends 400 ft. upstream from head of first riffle upstream of Cheda Ranch Creek, and downstream of Jewell.	19.17	8
KF	*Kelley's Tocaloma Site* Extends 350 ft. upstream from head of first riffle above McIsaac Cr. Large high-water overflow area.	20.03	9

[a] for Additional information, including data on older sites upstream and downstream, See Appendix E of Hecht, 1983.

[b] Marin County highway marker on the Sir Francis Drake highway nearest the upstream end of the site.

[c] Since October 2002

APPENDIX F

Results of bed scour monitoring, 2002-2006

Table F1. Scour chain observer log, water years 2003-2006, Lagunitas Creek, Marin County California.

Chain		Observations								Computations	
Site	*Chain No.*[1]	*Observer*[2]	*Date*	*Exposure*[3]	*Angular Deviation*[4]	*Reset Length*[5]	*Burial depth*[6]	*Remarks*	*Assumed reason for missing chain*[7]	*Scour*[8]	*Net scour/ depostion*[9]
				(ft.)		*(ft.)*	*(ft.)*			(ft.)	(ft.)
KB Below Shafter	KB12-24	sp, sb, bh	11/19/2002	0.59	--	--	--	initial installation		--	--
		sb	11/10/2003	0.7	90L	0.7	0.4	buried 0.3-0.4'; digging on previous visit may have disturbed chain		0.11	0.24
		sb, sp	8/12/2004	--	--	--	--	did not locate; gravel is v. soft; chain may be deeply buried	buried	--	--
		sb, sds	11/1/2005	0.9	--	0.57	0.3	buried in loose cobbles and gravel; in 1.1 feet of water after reset		0.20	0.05
		sb, zr	10/25/2006	0.8	--	0.00	1.3	dug through new gravel bar (above current water surface)		0.23	1.02
	KB12-28	sb, sc	12/23/2004	1.1	--	--	--	installed in 0.6' water		--	--
		sb, sds	11/1/2005	1.3	15L	1.3	0.0	chain settled between cobbles; essentially not buried; in 6" of water		0.20	-0.20
		sb, zr	10/25/2006	1.07	--	0.42	0.7	buried by loose gravel with cobble armor on top; surface of bar is out of water		0.00	0.70
	KB12-39	sb, sc	12/23/2004	1.95	--	--	--	installed in 0.5' water		--	--
		sb, sds	11/1/2005	2.05	--	2.05	0.0	chain settled between cobbles; in 0.3' of water		0.10	-0.10
		sb, zr	10/25/2006	1.02	--	1.02	0.0	found at surface; tip of chain was broken; assume 0.3' of scour based on cross section surveys		0.50	0.00
	KB12-48	sp, sb, bh	11/19/2002	1.15	--	--	--	initial installation		--	--
		sb	11/10/2003	--	--	--	--	could not locate; tried to reinstall but failed several times	pulled out/broken	--	--
	KB12-52	sb, sc	12/23/2004	1.55	--	--	--	installed in 0.35' water		--	--
		sb, sds	11/1/2005	1.75	--	1.7	0.1	buried in gravel/cobbles		0.20	-0.10
		sb, zr	10/25/2006	--	--	--	--	did not locate chain; dug almost 2' down; lots of large cobbles in bed	high scour	--	--
	KB12-56	sp, sb, bh	11/19/2002	1.63	--	--	--	initial installation		--	--
		sb	11/10/2003	--	--	--	--	could not locate	pulled out/broken	--	--
KJ Big Rock[10]	KJ5-20	sp, sb, bh	11/19/2002	0.54	--	--	--	initial installation		--	--
		sb	11/10/2003	1.72	none	1.54	0.4	buried by 0.3-0.4' of gravel		1.18	-0.83
		sb, sp	8/12/2004	1.61	20R	1.35	0.5	buried 0.45'		0.07	0.38
		sb, sds	11/1/2005	1.25	0	0.6	0.1	chain broke during recovery; buried under a thin layer of gravel		0.00	0.10
		sb, zr	10/25/2006	--	--	--	--	did not find chain; dug down ~1.5' in very soft sand and gravel, then 0.5' in cobbles	buried	--	--

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Table F1. Scour chain observer log, water years 2003-2006, Lagunitas Creek, Marin County California.

Chain		Observations								Computations	
Site	*Chain No.*[1]	*Observer*[2]	*Date*	*Exposure*[3]	*Angular Deviation*[4]	*Reset Length*[5]	*Burial depth*[6]	*Remarks*	*Assumed reason for missing chain*[7]	*Scour*[8]	*Net scour/ depostion*[9]
				(ft.)		*(ft.)*	*(ft.)*			(ft.)	(ft.)
	KJ5-26	sp, sb, bh	11/4/2002	1.31	--	--	--	initial installation		--	--
		sp, sb, bh	11/19/2002	1.23	--	1.23	--	after 11/7/02 storm		-0.08	--
		sb	11/10/2003	2.14	15L	1.86	0.4	buried by ~0.3-0.4' of gravel		0.91	-0.56
		sb, sp	8/12/2004	1.99	5L	--	0.4	pin came loose during recovery; chain was removed; exp. is min. value		0.13	0.27
		sb, sc	12/23/2004	--	--	1.04	--	re-installed chain in 1' water		--	--
		sb, sds	11/1/2005	1.00	--	0.9	0.3	buried in soft gravel/sand		-0.04	0.29
		sb, zr	10/25/2006	--	--	--	--	did not find chain; dug down 2'; bed conditions similar to KJ5-20	buried	--	--
	KJ5-32	sp, sb, bh	11/19/2002	1.76	--	--	--	initial installation		--	--
		sb	11/10/2003	--	--	--	--	could not locate	high scour	--	--
		sb, sds	11/1/2005	--	--	--	--	dug 0.7', could not locate		--	--
	KJ5-36	sp, sb, bh	11/19/2002	0.88	--	--	--	initial installation		--	--
		sb	11/10/2003	1.36	none	1.36	0.1	buried <0.1'; 1.25' deep in pool		0.48	-0.40
		sb, sp	8/12/2004	1.84	15L	1.36	0.6	buried 0.6'		0.48	0.12
		sb, sds	11/1/2005	1.37		1.15	0.3	buried in very soft gravel/sand		0.01	0.29
		sb, zr	10/25/2006	--	--	--	--	dug down 1.25' in cobbles (some <180mm); did not find chain	buried	--	--
	KJ5-40	sp, sb, bh	11/19/2002	1.49	--	--	--	initial installation		--	--
		sb	11/10/2003	1.44	none	1.44	0.0	found at surface (under 1.5' of water); chain rusted and slightly rigid		-0.05	0.05
		sb, sp	8/12/2004	1.39	10R	1.29	0.2	damaged link 0.8' from tip; buried 0.2'		-0.05	0.25
		sb, sc	12/23/2004	1.25	none	--	0.0	found at surface (under ~2' of water); chain was brittle and broke when recovered		-0.04	0.04
		sb, sds	11/1/2005	0.13	none	0.13	0.0	found at surface (on cobbles); appears to be little change from previous year		0.00	0.00
		sb, zr	10/25/2006	--	--	--	--	did not find chain; dug down ~0.75'	pulled out/broken	--	--
											--
KD Big Bend[11]	KD5-30	sb, jo	10/31/2003	0.45	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	did not find chain	buried	--	--
										--	--
	KD5-39.5	sb, jo	10/31/2003	0.40	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	did not find chain		--	--

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Table F1. Scour chain observer log, water years 2003-2006, Lagunitas Creek, Marin County California.

Chain		Observations								Computations	
Site	*Chain No.*[1]	*Observer*[2]	*Date*	*Exposure*[3]	*Angular Deviation*[4]	*Reset Length*[5]	*Burial depth*[6]	*Remarks*	*Assumed reason for missing chain*[7]	*Scour*[8]	*Net scour/ depostion*[9]
				(ft.)		*(ft.)*	*(ft.)*			(ft.)	(ft.)
		sb, sds	9/22/2005	0.75	--	-0.08	1.0	buried 12" in cobbles/gravel; scour represents a maximum-- may have excavated slightly beyond scour depth; chain ~1' u/s of tape		0.35	0.65
	KD5-49.5	sb, jo	10/31/2003	0.90	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	1.00	45L	0.5	0.5	buried 0.5' in cobbles/gvl		0.10	0.40
		sb, sds	9/22/2005	0.96	none	0.46	0.7	buried 8.5" of gravel		0.46	0.25
	KD5-59.5	sb, jo	10/31/2003	1.81	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	1.82	--	1.51	0.4	buried 0.4' in cobbles		0.01	0.39
		sb, sds	9/22/2005	1.88	30L	1.63	0.3	buried 4" in gravel		0.37	-0.03
	KD5-66	sb, sc	12/23/2004	1.65	--	--	--	installed chain in 1.18' water		--	--
		sb, sds	9/22/2005	1.46	25L	1.17	0.4	buried in 5" of gravel	pulled out/broken	--	0.42
	KD5-72	sb, jo	10/31/2003	0.38	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	did not find chain (dug down 0.75')	buried	--	--
	KD5-74	sb, sc	12/23/2004	1.91	--	--	--	installed chain in 0.34' water		--	--
		sb, sds	9/22/2005	1.92	--	1.50	0.4	buried 5" in sand; exposure at sand/gravel contact		0.01	0.41
KL Above Cheda Ranch Cr.[12]	KLxLB4RB 6-26	sb, jo	10/31/2003	0.45	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	bed highly disturbed; could not locate	high scour	--	--
	KLxLB4RB 6-42	sb, jo	10/31/2003	1.28	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	bed highly disturbed; could not locate	high scour	--	--
	KLxLB4RB 6-58	sb, jo	10/31/2003	1.25	--	--	--	initial installation		--	--
		sb, sp	8/12/2004	--	--	--	--	bed highly disturbed; could not locate	high scour	--	--
	KL7/8-22	sb, sc	12/23/2004	0.92	--	--	--	installed 4.5' from LB; 27' d/s KL7; between slanted tree (RB) and fallen tree (LB); in 1.3' water		--	--
		sb, sds	9/22/2005	1.38	--	1.29	0.1	buried 1" near edge of sand deposit		0.46	-0.37

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Table F1. Scour chain observer log, water years 2003-2006, Lagunitas Creek, Marin County California.

Chain		Observations								Computations	
Site	*Chain No.*[1]	*Observer*[2]	*Date*	*Exposure*[3]	*Angular Deviation*[4]	*Reset Length*[5]	*Burial depth*[6]	*Remarks*	*Assumed reason for missing chain*[7]	*Scour*[8]	*Net scour/ depostion*[9]
				(ft.)		*(ft.)*	*(ft.)*			(ft.)	(ft.)
		sb, zr	10/25/2006	1.32	--	1.09	0.4	chain now at 24 on the tape (benchmark log moved); depth of water was ~1.5' before digging		0.03	0.37
	KL7/8-26.5	sb, sc	12/23/2004	0.92	--	--	--	installed 9.5' from LB; 27' d/s KL7; between slanted tree (RB) and fallen tree (LB); in 1.3' water		--	--
		sb, sds	9/22/2005	0.91	--	0.91	0.0	found at surface		-0.01	0.01
		sb, zr	10/25/2006	0.93	--	-0.2	0.3	chain broke during recovery; chain remnant reset at 0.2' below the bed surface; chain now at 29' from LB benchmark		0.02	0.28
	KL7/8-31.5	sb, sc	12/23/2004	1.2	--	--	--	installed on bar (will be dry at low-flow); 27' d/s KL7; between slanted tree (RB) and fallen tree (LB); in 0.7' water		--	--
		sb, sds	9/22/2005	1.25	--	1.25	0.1	buried 1" in fine/med sand		0.05	0.03
		sb, zr	10/25/2006	1.42	--	1.00	0.5	now at 33.8' on tape since benchmark moved; LB benchmark is 4.1' us/ KL8		0.17	0.33
KF Kelley's Tocaloma	KF6-16	sp, sb, bh	11/19/2002	2.33	--	--	--	initial installation		--	--
		sb, jo	10/31/2003	2.35	30R	2.35	0.1	buried by 1" of small gvl		0.02	0.06
		sb, sp	8/12/2004	2.41	none	2.41	0.0	on dry bar at LB; found at surface		0.06	-0.06
		sb, sds	9/22/2005	2.38	--	2.38	0.0	found on surface		-0.04	0.04
		sb, zr	10/25/2006	2.93	none	0.5	0.2	chain broke during recovery (2.43' broke off)		0.55	-0.35
	KF6-22	sp, sb, bh	11/19/2002	0.65	--	--	--	initial installation		--	--
		sb, jo	10/31/2003	0.63	30R	0.63	0.1	buried by about 1" of gvl		-0.02	0.10
		sb, sp	8/12/2004	0.9	30R	0.9	0.0	not buried		0.27	-0.27
		sb, sds	9/22/2005	0.42	--	0.42	0.1	buried by ~1" of gravel; looks like tip of chain broke off	pulled out/broken	--	0.08
		sb, zr	10/25/2006	1.20	none	0.6	0.9	original bed surface under ~0.2' of water		0.78	-0.70
	KF6-28	sp, sb, bh	11/19/2002	1.47	--	--	--	initial installation		--	--
		sb, jo	10/31/2003	1.41	none	1.41	1.0	buried by 1" of gvl; rocks on top are very secure		-0.06	0.14
		sb, sp	8/12/2004	1.77	none	1.71	0.3	buried 0.25'		0.36	-0.11
		sb, sds	9/22/2005	0.67	--	--	0.3	buried 3"; chain broken	pulled out/broken	--	n/a
		sb, zr	10/25/2006	--	--	--	--	could not find chain; dug down ~1 foot	pulled out/broken	--	--

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Table F1. Scour chain observer log, water years 2003-2006, Lagunitas Creek, Marin County California.

Chain		Observations								Computations	
Site	*Chain No.*[1]	*Observer*[2]	*Date*	*Exposure*[3]	*Angular Deviation*[4]	*Reset Length*[5]	*Burial depth*[6]	*Remarks*	*Assumed reason for missing chain*[7]	*Scour*[8]	*Net scour/ depostion*[9]
				(ft.)		*(ft.)*	*(ft.)*			(ft.)	(ft.)
	KF6-34	sp, sb, bh	11/19/2002	1.39	--	--	--	initial installation		--	--
		sb, jo	10/31/2003	1.54	0 (but LB kink)	1.54	0.1	buried 1.5" deep (average)		0.15	-0.03
		sb, sp	8/12/2004	1.97	10R	1.71	0.4	buried 0.4'; chain actually at 33.3'		0.43	-0.03
		sb, sds	9/22/2005	1.21	--	0.88	0.5	buried 6"; chain is broken	pulled out/broken	--	n/a
		sb, zr	10/25/2006	--	--	--	--	could not find chain; dug down almost 2'	high scour	--	--
	KF6-40	sp, sb, bh	11/19/2002	2.01	--	--	--	initial installation		--	--
		sb, jo	10/31/2003	2.25	15L	2.03	0.2	buired 2-3"		0.24	-0.03
		sb, sp	8/12/2004	2.84	30L	2.54	0.4	buried 0.4'		0.81	-0.41
		sb, sds	9/22/2005	2.48	35L	2.08	0.4	buried 5"; chain was intact, but broke before reset	pulled out/broken	-0.06	0.48
		sb, zr	10/25/2006	--	--	--	--	could not find chain; dug down ~1.5'	high scour	--	--

Notes

1 Chain is coded to identify site, cross section, and distance (in feet) from the left-bank pin. For example, chain KJ5-22 can be found 22 feet from the LB pin of KJ5 (Big Rock site).

2 Observer codes designate Scott Brown (sb), Barry Hecht (bh), Stacey Porter (sp), Jonathan Owens (jo), Dave Shaw (sds), Shawn Chartrand (sc), and Zan Rubin (zr).

3 Exposure is the length (in feet) from the painted end of the chain to the point of inflection when the chain is excavated after storm(s).

4 Angular deviation is measured between the flow at the time of excavation and the direction at which the chain was scoured. For example, 10L means 10 deg toward the left bank. Angular could not be indentified in many cases due to disturbance of the chain during recovery.

5 Re-set length is the length (in feet) of horizontal extension across the bed surface when the chain is reset.

6 Burial depth is the average depth of sediment (in feet) covering the chain at the time of excavation.

7 Assumptions were based on site conditions (such as soft bed condtions suggesting recent fill), and cross section survey results showing net deposition or scour.

8 Scour is calculated by subtracting the previous year's reset length from the current year's exposure length. This number represents the maximum depth of scour that occurred over the preceeding season. "--" where scour could not be determined either by chain loss, burial or damage.

9 Net scour/deposition is calculated by subtracting scour from depth of burial. A negative number represents net scour, a positive number represents net fill.

10 A log structure was placed approximately 100 feet below KJ5 in 2006, which appears to have caused over 1 foot of aggradation at the cross section. Chains are likely buried too deep for recovery.

11 No attempt was made to recover chains in 2006 due to the large amount of sedimentation at the site.

12 All three chains installed in 2003 were lost, likely due to high scour at the lower end of the pool. After further investigation, it was determined that chains were too far upstream. Chains were re-installed in 2004 further downstream, consistent with where redds have been present in the past.

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Table F2. Average depth of scour at monitoring sites, Lagunitas Creek, Marin County, California. Depth of scour was measured using scour chains installed across the full width of the channel, typically near the downstream end of the glide. Peak flow at two gages in the watershed are listed below for reference.

	WY2003				WY2004				WY2005				WY2006			
	Number of chains prior to season	Number of chains recovered	Number of chains with greater than 0.4' of scour[1]	Perecent of chains showing high scour	Number of chains prior to season	Number of chains recovered	Number of chains with greater than 0.4' of scour[1]	Perecent of chains showing high scour	Number of chains prior to season	Number of chains recovered	Number of chains with greater than 0.4' of scour[1]	Perecent of chains showing high scour	Number of chains prior to season	Number of chains recovered	Number of chains with greater than 0.4' of scour[1]	Perecent of chains showing high scour
KB--Below Shafter	3	1	0	0%	1	0	0	0%	4	4	0	0%	4	3	2	50%
KJ--Big Rock[2]	5	4	4	80%	4	4	1	25%	4	4	0	0%	4	0	0	0%
KD--Big Bend[3]	--	--	--	--	5	2	0	0%	5	5	1	20%	--	--	--	--
KL--Cheda Ranch[4]	--	--	--	--	3	0	3	100%	3	3	1	33%	3	3	0	0%
KF--Kelley's Tocaloma	5	5	0	0%	5	5	2	40%	5	2	0	0%	4	2	4	100%
Average[5]				**31%**				**33%**				**10%**				**40%**

Peak discharge (cfs), San Geronimo Creek @ Lagunitas Bridge[6]	1789	1648	1384	3553
Peak discharge (cfs), Lagunitas Creek @ Samuel P. Taylor State Park[7]	2,620	3,230	1,770	10,200

notes:

1 Chains that were lost due to high scour (see Table 1) were counted in this column

2 A log structure was placed approximately 100 feet below KJ5 in 2005, which appears to have caused over 1 foot of aggradation at the cross section. Chains were likely buried too deep for recovery in 2006.

3 No attempt was made to recover chains in 2006 due to the large amount of sedimentation at the site.

4 All three chains installed in 2003 were lost, likely due to high scour at the lower end of the pool. After further investigation, it was determined that chains were installed in a transient, soft bedded glide near the low flow riffle crest, upstream of where redds are typically present. Chains were re-installed in 2004 further downstream, consistent with where redds have been present in the past.

5 Average calculated by dividing the total number of chains showing high scour in a given year by the number of chains present prior to the season.

6 San Geronimo Creek data from Balance Hydrologics, www.balancehydro.com.

7 Lagunitas Creek streamflow data from www.usgs.gov

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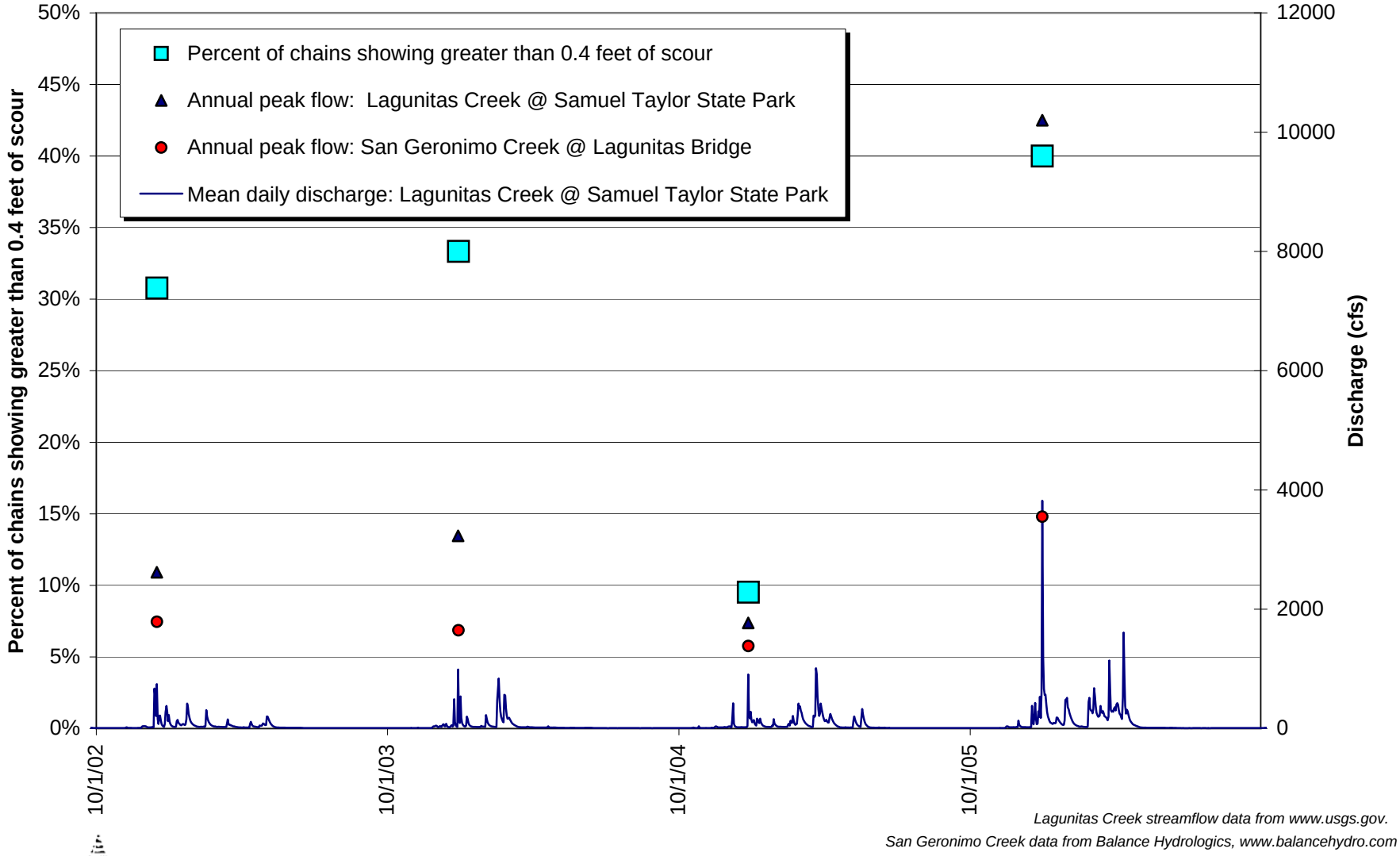

Lagunitas Creek streamflow data from www.usgs.gov.

San Geronimo Creek data from Balance Hydrologics, www.balancehydro.com

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Figure F1. Graph of flow and scour conditions in Lagunitas Creek, Marin County, California. Scour chains were installed at five different sites (3 to 7 chains per site) between the Shafter and Tocaloma Bridges. Number of scour chains recovered per year varied between 10 and 20. For unrecovered chains, a likely reason was recorded (high scour, burial, etc.) based on field conditions and cross section survey data, and those with estimated high scour are included in this graph.

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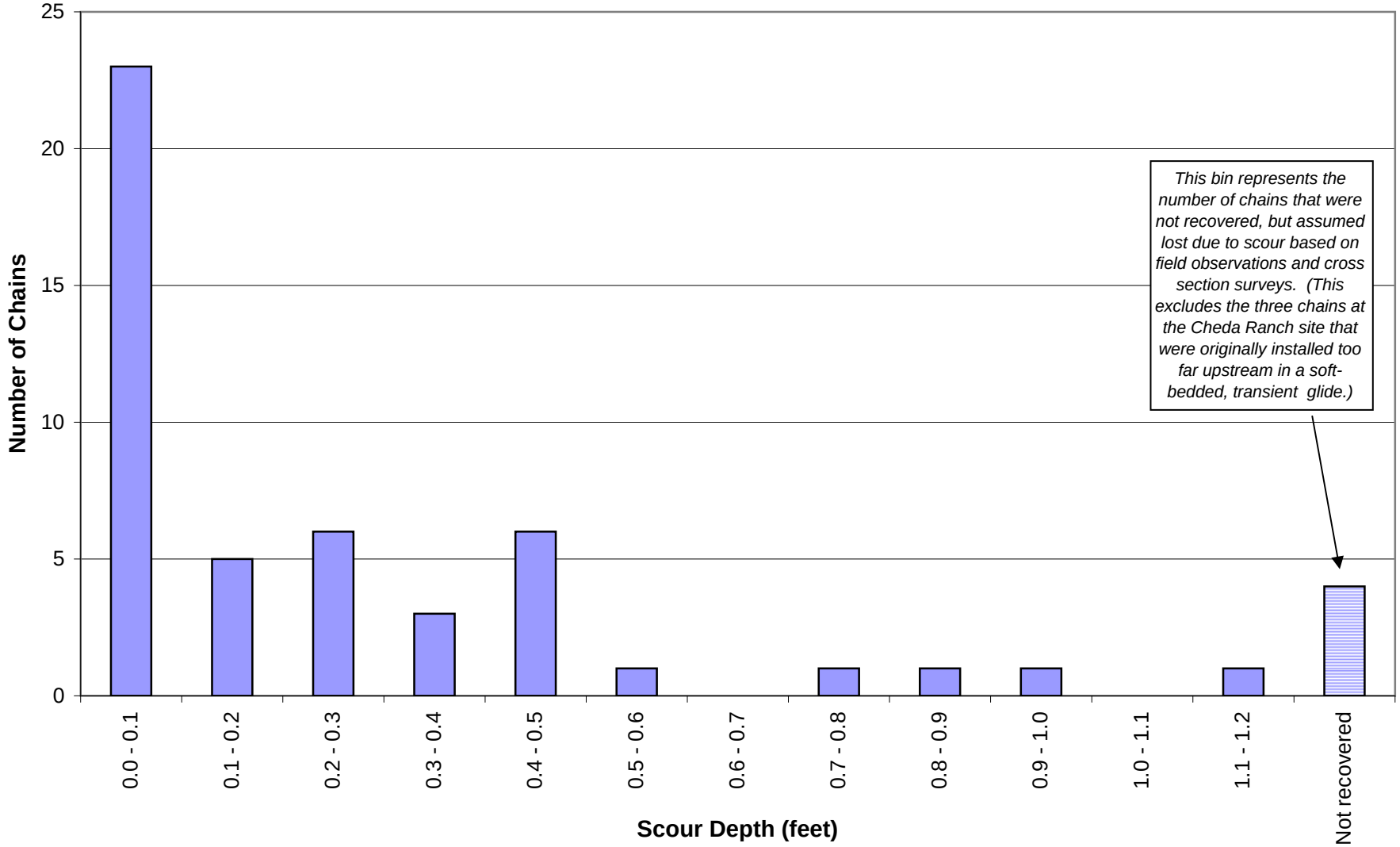

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Figure F2. Frequency of recorded scour of different depth ranges, Lagunitas Creek, Marin County, California. Note that scour greater than 0.5 feet deep is relatively uncommon at the locations where scour was measured. Data represent all scour values recorded by the scour chains over the four-year monitoring period (2002-2006). Scour chains were typically installed near the glide/riffle boundary at a given monitoring site.

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