Review of sediment gauging in Alameda Creek Watershed in relation to District needs

Lester McKee
San Francisco Estuary Institute

SFEI Contribution 571
January 27, 2009

This report can be cited as:
McKee, L., 2009. Review of sediment gauging studies in Alameda Creek Watershed. SFEI Contribution #571. San Francisco Estuary Institute, Oakland, CA. 25pp.

1. Introduction

The Alameda County Flood Control and Water Conservation District (ACFC&WCD; also referred to as the District) expends considerable funds each year on the collection of environmental monitoring data in its facilities. Their monitoring program has yielded volumes of data useful for informing management questions in relation to characterizing water resources, providing inputs for modeling exercises, and designing projects. However, with increasing costs and competition among projects and programs, there is pressure from managers to streamline programs and justify expenditure. The objective of this report is to review the District-funded sediment gauging programs in relation to District needs and make recommendations for improvements.

The collection of physical environmental data is an important role of the ACFC&WCD. Agencies and Special District's like ACFC&WCD charged with the management of stormwater infrastructure routinely collect, or partner with other agencies to collect, systematic long term data (Table 1). Together, all these kinds of data constitute a program of environmental observation and, like any program, the sum of individual components has greater value when combined.

The uses of data by ACFC&WCD essentially fall into three basic categories: 1. Compliance monitoring in relation to environmental laws and policies, 2. Research into pressures[1] on a desired state[2] or the causes of a particular undesirable degraded state in order to respond[3] with management solutions, and 3. Design of new, or modification of existing facilities. Data on sediment properties and flux are found in all categories (Table 2) and generally cannot be interpreted without data on climate and runoff (Table 1).

Table 1. Types of basic data systematically collected by flood control agencies and special District's.

Climate	**Runoff**	**Sediment flux**	**Morphological**	**Sediment impacts**
Rainfall	Surface flow	Suspended concentrations and loads	Longitudinal profiles	Reservoir and weir sediment infilling (e.g. Too much sediment)
Pan Evaporation	Groundwater flow	Bedload	Cross-section geometry surveys	Native and endangered species habitat quality (e.g. Too much sediment or sediment of the wrong grain size; too little sediment downstream from a reservoir)
Temperature Soil moisture	Water import and diversions	Grain size - Suspended sediment - bedload sediment - bed sediment	Bank and Levee conditions	Downstream and receiving water body impacts - Sediment loads (e.g. carrying pollutants) - Sediment deposition (e.g. wetland deposition; smoothing sub tidal habitat) - Turbidity (e.g. gill trauma)

[1] The Pressure-State-Response (PSR) framework is based on the fact that human activities exert ***Pressures*** on the environment (such as pollution, land use change, flow regulation).
[2] These pressured result in changes in the ***State*** of the environment (e.g. changes in pollutant levels, habitat diversity, or sediment deposition) which in turn result in **impacts or undesirable degraded conditions**.
[3] Society's ***Response*** to changes in pressures or state is to develop and implement environmental and economic policies or programs intended to prevent, reduce or mitigate the pressures and/or environmental and socio-economic damage that occurred as a result of the original pressures.

Table 2. Potential uses of sediment data by Alameda County Flood Control and Water Conservation District in the next five years (based on meeting minutes and conversation with District Managers during 2007 and 2008).

Type of Sediment Data	**Units**	**Compliance Monitoring**				**Research Monitoring**				**Project Design**			**Count**
		Habitat quality for native and endangered species	Pre- and post-project conditions	Monitoring outfalls to receiving waters	Sediment characterization in relation to reuse or disposal	Watershed sediment source analysis	Rates and causes of sediment deposition in the Fremont Flood Control Channel	Sediment supply in relation to Eden Landing Restoration	Monitoring local sea level rise and headward shift of the tidal depositional zone	Modeling sediment flux through Niles Canyon reach	Modeling sediment flux and deposition in the Fremont Flood Channel reach	Modeling channel configurations and levee breach scenarios in the Bay	
Continuous "real time" turbidity	Formazin nephelometric Units (FNU)	x	x	x		x	x	x	x	x	x	x	10
Spatial grab sample turbidity	Formazin nephelometric Units (FNU)	x	x	x		x							4
Substrate (bed) stability	Net flood scour (m)	x	x			x	x	x	x	x	x	x	9
Substrate (bed) permeability	Flow rate (m/s)	x	x										2
Sediment organic carbon content in relation to biological oxygen demand (BOD)	Organic Carbon (mg/L); BOB_5 (mg O_2 consumed/L)	x	x	x									3
Suspended sediment concentrations	SSC (mg/L)	x	x	x		x	x	x	x	x	x	x	10
Suspended sediment grain size	Percent mass finer than (mm)	x	x	x	x	x	x	x	x	x	x	x	11
Suspended sediment loads	Mass load (metric t/day)	x	x	x	x	x	x	x	x	x	x	x	11
Bed sediment flow rate	Sediment flux (kg/s/m)	x	x		x	x	x	x		x	x		8
Bed sediment (substrate) grain size	Percent mass finer than (mm)	x	x		x	x	x	x		x	x	x	9
Bed sediment loads	Mass load (metric t/day)	x	x		x	x	x	x		x	x	x	9
Bulk sediment deposition	Mass (metric t) Volume (cubic meters)	x	x		x	x	x	x		x	x	x	9
Sediment fingerprinting (carbon, palynology, isotopes, or mineralogical)	Method specific		x		x	x	x	x					5

This report is a short review of the sediment gauging component of the District's environmental observations program focusing on the Alameda Creek watershed with some reference to the San Lorenzo Creek watershed (adjacent to and north of Alameda Creek). This is done in the context of what are likely to be important uses for the data over the next five years (Table 2). The intent here is to move the District towards the answer to a single ultimate question: What is the most efficient and cost effective design of the sediment component of the District's environmental monitoring program? Although it might seem that data needs are constantly changing, a base program of consistent long term systematic environmental observation will in fact continue to cover most of the District's needs most of the time. Funding for such a base program may be shared with other agencies that have common needs and goals. Most of the basic data listed in Table 1 likely constitutes what could become a shared base program in the Alameda Creek watershed that could be formalized through a memorandum of understanding (MOU) among agencies. For the most part, occasional projects with special data needs will remain hard to predict, and the decision to fund data collection for those projects needs to be decided on a case-by-case basis using separate, discretionary funding. It is unlikely that agency cost sharing can occur for data collection associated with occasional projects because the objectives will be quite specific, in most cases projects will not fit the priorities of another agency, and lastly the implementation time may be too rapid.

2. Methods of evaluation of quality and use

In order to evaluate the sediment data collected by the District against management questions and needs (Table 2) in the context of a wider environmental data collection program (Table 1), the sediment component of the program must be compared to a series of success criteria (or metrics). Although these criteria are interrelated, it will be seen that there is benefit in compartmentalization primarily for organizing thought toward answering the ultimate question stated above. These criteria can be organized into five key questions listed below. For more detail and some analysis behind these questions, please see Appendix A.

1) Is the data density sufficient to represent the temporal variability of the system?
2) Does the data have historic significance in the District or for the Region as a whole?
3) Is the data quality sufficient for the District applications?
4) Do the data have multiple uses and importance relative to other program components?
5) Is the data representative of reasonable assumptions about spatial variability?

3. Evaluation

The data gathered by the District and its partners in Alameda Creek and San Lorenzo Creek on suspended and bedload sediment, turbidity, and grain size has been extensive, and are summarized below (Table 3). The organization of Table 3 is similar to Table 2 except since there have been no data routinely collected on substrate (bed) stability, substrate (bed) permeability, sediment organic carbon content in relation to biological oxygen demand (BOD), and sediment fingerprinting (carbon, palynology, isotopes, or mineralogical), these rows were removed. Grab sample turbidity data were collected for the District by SFEI in the summer and fall of 2007 (Gilbreath and McKee, 2008), but these are not discussed here. The District routinely collects data on cross sections and long profiles but these are not discussed here either not because they are not relevant, but rather because at present they are collected in-house. In this section, the first four key questions listed in section two are used to evaluate the existing sediment component of the District's environmental data collection program on a station by station basis (Table 4). Question five (on spatial variability and representativeness) is discussed separately because of its integrative nature.

3.1 Arroyo De La Laguna at Verona

Sediment data has been collected in Arroyo De La Laguna near Pleasanton and at Verona from WY 2000-2003, and 2007-present (Table 3). WY 2003 was a moderately wet with 117% MAP and a peak flow of about 1:5 year return (Table 4). The data and ongoing data collection at this location will likely be useful for designing projects and observing any changes associated with channel projects in the near-field upstream under low flow conditions. For example, it is possible that during any construction phases of near-field upstream channel projects, the Water Board would use the turbidity data set to monitor permit compliance during low flow condition (in these contexts there may be opportunities for sharing costs with other agencies). It should be noted that small projects or those farther a field (10s of miles upstream or upstream of a major confluence could not be monitored using this station; a specific monitoring program would need to be set up. Overall the data quality for suspended sediments including grain size is quite good prior to WY 2003 and improved by the use of turbidity as a surrogate for suspended sediment beginning WY 2007. Unfortunately, bedload sediment was not collected during WY 2007. The quality of bedload data during WY 2003 is not clear and possibly low. The sampling location has important contextual significance given ongoing channel erosion in Arroyo De La Laguna, the interest in salmonid restoration, and the ongoing need to evaluate sediment sources (Table 4).

3.2 Alameda Creek below Welch Creek near Sunol

Sediment data has been collected in Alameda Creek below Welch Creek near Sunol during WY 2000-2003, and 2007-present (Table 3). WY 2003 was moderately wet with 117% MAP and a peak flow of about 1:5 year return, however sediment data quality during that year was poor – no sampling occurred during the peak flood (USGS staff were deployed on Arroyo De La Laguna likely because they were concerned about that gauge being washed away) (Table 4). The data and ongoing data collection at this location will likely be useful for designing channel projects in the reach between the gauge at Welch Creek and Hwy 680 (in this context there may be opportunities for sharing costs with other agencies). Overall the quality of the suspended sediment data, including grain size, is quite good prior to WY 2002, poor in WY 2003, and improved by the use of turbidity as a surrogate for suspended sediment beginning WY 2007. The

Table 3. Data collection to date at District sediment gauging locations.

Type of Sediment Data	Units	Arroro De La Laguna near Pleasanton (11176900)	Arroro De La Laguna at Verona (11176900)	Alameda Creek below Welch Creek near Sunol (11173575)	Alameda Creek near Niles (11179000)	San Lorenzo Creek at San Lorenzo (11181040)
Continuous "real time" turbidity	Formazin nephelometric Units (FNU)	No data	WY 2007. 15 minute for wet season.	WY 2007. 15 minute for wet season.	WY 2007. 15 minute for wet season.	No data
Suspended sediment concentrations	SSC (mg/L)	WY 2000-03. Daily for wet season based on rating (n=50)	WY 2007. 15 minute and daily for wet season based on turbidity surrogate (n=22)	WY 2000-03. Daily for wet season based on rating (n=44). WY 2007. 15 minute and daily for wet season based on turbidity surrogate (n=7)	WY 1957-73; 2000-06. Daily for wet season based on rating (n=157). WY 2007. 15 minute and daily for wet season based on turbidity surrogate (n=9)	WY 1990-03. Daily for wet season based on rating (n=63)
Suspended sediment grain size	Percent mass finer than (mm)	WY 2000-03. Sand-silt split (n=46); Grain size distribution (n=4)	WY 2007. Sand-silt split (n=18); Grain size distribution (n=4)	WY 2000-03. Sand-silt split (n=16); Grain size distribution (n=5). WY 2007. Sand-silt split (n=3); Grain size distribution (n=1).	WY 1957-73; 2000-06 Sand-silt split (n=75); Grain size distribution (n=58). WY 2007. Sand-silt split (n=7); Grain size distribution (n=2).	Sand-silt split (n=59); Grain size distribution (n=4)
Suspended sediment loads	Mass load (metric t/day)	WY 2000-03. Daily for wet season based on rating	WY 2007. 15 minute and daily for wet season based on turbidity surrogate.	WY 2000-03. Daily for wet season based on rating. WY 2007. 15 minute and daily for wet season based on turbidity surrogate.	WY 1957-59. Annual sum only. WY 1960-73; 2000-06. Daily for wet season based on rating. WY 2007. 15 minute and daily for wet season based on turbidity surrogate.	WY 1990-03. Daily for wet season based on rating (n=63)
Bed sediment flow rate	Sediment flux (kg/s/m)	WY 2000-03 (n=9)	No data	WY 2000-03 (n=13); WY 2007 (n=2)	WY 2000-06 (n=24); WY 2007 (n=6)	WY 1990-03 (n=6)
Bed sediment (substrate) grain size	Percent mass finer than (mm)	WY 2000-03 (n=49)	WY 2007 (n=10)	WY 2000-03 (n=37). WY 2007 (n=10)	WY 1957-73; 2000-06 (n=77). WY 2007 (n=10)	WY 1990-03 (n=3)
Bed sediment loads	Mass load (metric t/day)	WY 2000-03. Daily for wet season based on rating	No data	WY 2000-07 Daily for wet season based on rating	WY 2000-07. Daily for wet season based on rating	WY 1990-03 (n=6)

Table 4. Summary of evaluations of existing gauging based in the first five questions explained in Section 2.

	Arroyo De La Laguna near Pleasanton (11177000) / at Verona (11176900)	Alameda Creek below Welch Creek near Sunol (11173575)	Alameda Creek near Niles (11179000)	San Lorenzo Creek at San Lorenzo (11181040)
Q1. Is the data density sufficient to represent the temporal variability of the system?	Possibly: Sediment data were captured during WY 2003 which has a 117% MAP and runoff at the Niles gauge was approximately a 1:5 year flow.	No: Sediment data were captured during WY 2003 which has a 117% MAP and runoff at the Niles gauge was approximately a 1:5 year flow. However the data quality was poor (see below).	Yes: The data spans water years ranging from the 2nd largest peak flow on record (WY 1958) to the lowest peak annual flow on record (WY 1961).	Possibly: The four years of data were collected during years that ranged between about a 1 year return peak flow and a 6 year return peak flow (Jan 13th 2003) however there appears to be data quality issues with flow gauging and USGS sampling did not always occur during the peak annual floods (see below)
Q2. Does the data have historic significance in the District or for the Region as a whole?	Possibly: It may end up being great bench mark data to evaluate changes in the management of the Arroyo De La Laguna reach.	Possibly: It may end up being great bench mark data to evaluate changes in the management of the Alameda reach between Welch Creek and Hwy 680 as when gravel mining ceases and fish barriers / bed level controls are removed.	Yes: Alameda Creek near Niles is the longest running water and sediment gauging station in the Bay Area. It has significant both locally and regionally. Data from this station teaches us about sediment variability in Bay Area watersheds. It can be used to check the quality of data from any other location in Alameda Creek upstream.	Yes: It is a bench mark for comparisons to any future data collection.
Q3. Is the data quality sufficient for the District applications?	Yes: Water sampling did occur on December 16th 2002 during the peak storm. It is likely that the rating curve developed for this station is reasonably accurate for WY 2003. There is evidence that bedload was not collected during the peak storm but 4 samples were collected during WY 2003. The technical quality of the data has now been improved by the deployment of a turbidity probe in WY 2007.	No: The USGS did not sample flow on December 16th, 2002 during the peak storm of WY 2003. This is a great examples of how grab sampling misses storms. They severely underestimated the concentrations and loads of suspended and bedload sediment that day. In addition, the maximum flow on December 16th (5,750 ft3/s) was estimated from a rating curve extended above 664 ft3/s. The technical quality of the data has now been improved by the deployment of a turbidity probe in WY 2007.	Yes: Mainly because the length of the records smoothes out the errors in SSC and loads estimation. The technical quality of the data has now been improved by the deployment of a turbidity probe in WY 2007. The bedload data quality could be improved by ensuring data capture during the peak flood each year.	No: The peak discharge record on February 4th 1991 is anomalous but USGS sediment sampling did occur on that date. USGS sampling for suspended sediment did occur on the peak flow in WY 1993 (Jan 13th 1993) but there is no record of when bedload was sampled. Red flags for bedload include no record of grain size distribution in the paper copy of the CA water data.

Table 4 (continued). Summary of evaluations of existing gauging based in the first five questions explained in Section 2.

	Arroyo De La Laguna near Pleasanton (11177000) / at Verona (11176900)	**Alameda Creek below Welch Creek near Sunol (11173575)**	**Alameda Creek near Niles (11179000)**	**San Lorenzo Creek at San Lorenzo (11181040)**
Q4. Is the data important in the context of other program components?	Yes: Data collected here when combined with data collected near Niles allows the continual evaluation of the sediment budget for the eroding banks of the Arroyo De La Laguna reach.	Yes: Data collected here when combined with data collected near Niles allows the continual evaluation of the sediment budget for the eroding banks of the Arroyo De La Laguna reach and other out of channel sources.	Yes: Sediment data at the Niles gauge is extremely important. It provides comparative data for all other locations upstream and is extremely important for interpreting any water quality impacts measured by other program components downstream.	Yes: It is a bench mark for comparisons to any future data collection and it will in the absence of any other data continue to be used for modeling channel processes in San Lorenzo Creek and other out of channel sources.
Q5. Does the data have multiple uses?	Yes: The data is useful for learning about habitat quality for salmonids, particularly the sand fraction, pre/post project conditions (permit compliance during any upstream channel projects), watershed sediment sources, sources of sediment deposited in the Fremont Flood Control Channel, and modeling sediment flux through Niles Canyon.	Yes: The data is useful for learning about habitat quality for salmonids, particularly the sand fraction, pre/post project conditions, watershed sediment sources, sources of sediment deposited in the Fremont Flood Control Channel, and modeling sediment flux through Niles Canyon.	Yes: The data is useful for learning about habitat quality for salmonids, particularly the sand fraction, pre/post project conditions, sediment characterization in relation to sediment disposal or reuse, watershed sediment sources, sources of sediment deposited in the Fremont Flood Control Channel, sediment supply to the Eden Landing restoration area, modeling sediment flux through Niles Canyon, and modeling levee configurations and channel breach scenarios in the Baylands reach (bed load data). . Note, the reuse of the suspended load is unlikely; however, the fine fraction loads are important for the marsh survival during the sea level rise.	Yes: The data is useful for learning about pre/post project conditions, sediment characterization in relation to sediment disposal or reuse, watershed sediment sources, and sources of sediment deposited in the catch basin. . Note, the reuse of the suspended load is unlikely; however, the fine fraction loads are important for the marsh survival during the sea level rise.

quality of bedload data during WY 2003 is not clear and probably low. The sampling location has important contextual significance given potential changes in the operation of the Calaveras reservoir upstream and likely changes in the channel downstream including restoration of two fish barriers and the potential for cessation of gravel mining at some time in the future. At present, the supply of sediment from this tributary is relatively small in the context of the Fremont Flood Control Channel but this could change as management in this tributary changes such as relatively rapid changes to sand mining permits, removal of barriers, or changes to reservoir operation. Watershed stewardship could also change the supply of fine and coarse materials but over a longer time frame.

3.3 Alameda Creek near Niles

Sediment data has been collected on Alameda Creek near Niles from WY 1957-73 and WY 2000-present (Table 3). The Alameda Creek near Niles gauge has special significance and the distinction of being the longest running flow record (WY 1892-present) and suspended sediment record (WY 1957-73; 2000-present) in the Bay area. The sediment record is of particularly high quality both because of its length relative to land use changes and because it has covered, for all intents and purposes, the entire range of climatic variation seen in the watershed to-date (Table 4). In addition, the quality of the record has been improved by the installation of the turbidity surrogate methodology, the bench mark for high quality suspended sediment records. Historic data on bedload grain size (not found yet but likely exists) and substrate grain size may be useful for learning about trends in sediment character passing through the gauge and into the Flood Control Channel. The data have multiple uses in relation to the District needs. Turbidity data is particularly useful for understanding the quality of habitat for salmonids in the Niles Canyon, in particular chronic and acute physiological impacts such as gill trauma, behavioral impacts such as alteration of feeding and foraging activities, and habitat effects such as loss of pool volume or dissolved oxygen demand. The load of suspended and bed sediment passing though the gauge annually provides important comparative data for better understanding of depositional processes in the Fremont Flood Control Channel downstream, and to inform modeling processes in the Flood Channel and Baylands. Alameda County Water District also finds the data valuable for learning about sedimentation processes and informing the operations of their recharge facilities, and in this context, may be interested in cost sharing.

3.4 San Lorenzo Creek at San Lorenzo

Sediment data has been collected on San Lorenzo Creek at San Lorenzo from WY 1990-93 (Table 3). Historic sediment data collected on San Lorenzo Creek at San Lorenzo include suspended sediment concentrations and grain size and bed load sediment and grain size. Historic data on bed load grain size and substrate grain size may be useful for learning about trends in sediment character passing through the gauge (Table 4), however, the methods and survey design might need to be reviewed to ensure modern data comparability. There appears to be data quality issues with the collection of peak flow for this gauge and there is no record of bedload collection during the largest storm in the record (January 13th 1993). Nevertheless, the historic data provides a bench mark for comparisons to any future data collection and will undoubtedly be used for any new channel designs on this Creek. If a gauging operation is reinstated and a turbidity probe installed, the data could be used for monitoring pre/post project conditions, sediment characterization in relation to sediment disposal or reuse, watershed sediment sources, and sources of sediment deposited in the catch basin. It is possible that the Water Board would use turbidity data to monitor permit conditions during any channel construction projects upstream.

3.5 Spatial representativeness of all gauges combined

Alameda Creek is the largest watershed in the nine-county Bay Area conurbation covering an area of 1,662 km^2 (642 mi^2) upstream from the head of tide. Although runoff from about 50% of the area is regulated by reservoirs, the remaining area is geologically and topographically diverse and managed for a variety of land uses including agriculture, mining, public lands, and cityscape. Spatial coverage is a basic and fundamental attribute of environmental data. The USGS and their funding partners have gauged sediment flow characteristics at a number of locations in the watershed over the period 1957 to present (Figure 1). If designing a program from first principles, usually the objective is to characterize as much of the landscape diversity as is practical in the context of management needs. In reality however, the gauging that has occurred has evolved through time in relation to funding and changing needs. Despite this evolution, Alameda Creek may be characterized as a well gauged watershed if the objective is to measure sediment entering the upper reaches of the Fremont Flood Control Channel (Niles gauge). At the very basic level, the fact that 98.6% of the watershed is gauged (near Niles) for suspended and bedload sediment may be a good indicator of a successful District sediment component of the overall environmental program.

The majority of the ungauged area is associated with Dry Creek, a tributary that enters the Alameda Flood Control Channel at Trailside Way in Union City. Sediment loads from this urbanizing 23 km^2 (9 mi^2) tributary may be disproportionably large for its size. The human population in Union City has risen by 24% from 1990 to 2000, a rate much faster than the county as a whole (13%) and akin to the rates being experienced in Dublin (29%) and Pleasanton (26%). In addition, the USGS has documented episodic debris flows on hillsides in the area (Figure 2) and likely punctuated sediment supply to the Dry Creek channel. Based on a cursory review an aerial photo of the confluence, there appears to be a depositional bar formed in the Flood Control Channel adjacent and downstream of Dry Creek that is not present in the reach upstream. Although the formation of this bar may be a coincidence or an artifact from a dredging history, its presence does support a hypothesis that Dry Creek is supplying significant sediment load. Colma Creek in South San Francisco and Zone 6 Line B at Warm Springs Boulevard in Fremont are examples in the Bay area where USGS measurements have occurred in rapidly urbanizing watersheds. The average annual unit export for Colma Creek was 1,136 t/km^2 for the period 1966 - 1977. The unit export for Zone 6 Line B was 13,493 t/km^2 for the period WY 2000 - 2002. Thus it is not inconceivable that suspended sediment loads from Dry Creek may be in excess of 31,000 metric tons or in excess of 18% of the estimated annual average suspended load passing through the Niles gauge for the period 1994-2006 (171,000 metric tons). These back of the envelope estimates to not take into account bedload which is likely to be proportionally large in such a small tributary. The lack of measurements of suspended loads and particularly bedload sediments (these have proportionally greater impact on the flood control channel stability than the suspended load) in Dry Creek may be a data gap worth considering in relation to modeling and managing the Flood Channel and wetlands on the Bay margin.

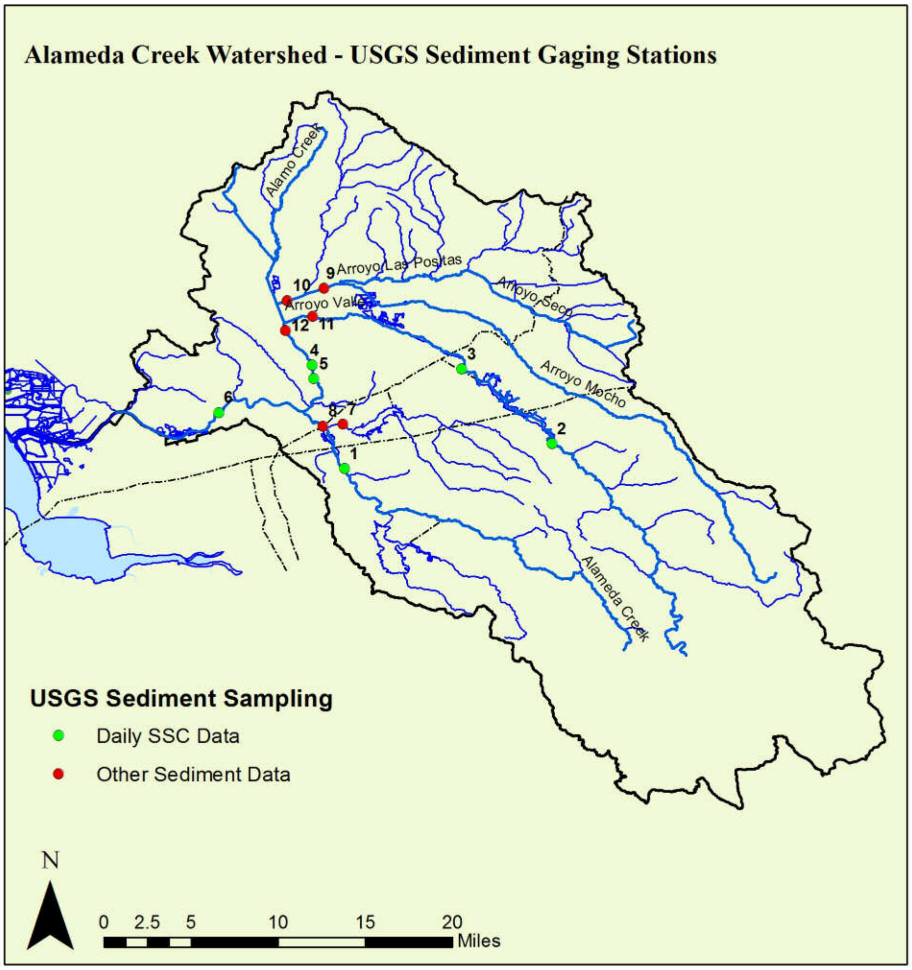

Figure 1. Sediment gauging stations operated by the District and other agencies in Alameda Creek Watershed (1957-present).
1, 11173575, ALAMEDA C BL WELCH C NR SUNOL CA;
2, 11176400, ARROYO VALLE BL LANG CN NR LIVERMORE CA;
3, 11176500, ARROYO VALLE NR LIVERMORE CA;
4, 11176900, ARROYO DE LA LAGUNA A VERONA CA;
5, 11177000, ARROYO DE LA LAGUNA NR PLEASANTON CA;
6, 11179000, ALAMEDA C NR NILES CA;
7, 11174000, SAN ANTONIO C NR SUNOL CA;
8, 11174060, ALAMEDA C A HWY 680 NR SUNOL CA;
9, 11176200, ARROYO MOCHO NR PLEASANTON CA;
10, 11176325, ARROYO MOCHO A HOPYARD RD A PLEASANTON CA;
11, 11176600, ARROYO VALLE A PLEASANTON CA; 12, 11176710, ARROYO DE LA LAGUNA A BERNAL AVE A PLEASANTON CA.

Figure 2. Debris flows on natural hillslopes behind Union City triggered by the February 2-3 1998 storm (Photo Credit: http://landslides.usgs.gov/recent/archives/1998sanfranrpt.php)

An additional means of evaluating the spatial completeness of the District sediment program is to consider the main geomorphic units of the mainstem based on stream slope and power (stream power is a function of slope, discharge, and width). Alameda Creek watershed is unique in the Bay Area in that water and sediment are forced to pass through a canyon. As a consequence, much of the sediment eroded from upland areas is likely stored in the lower gradient Sunol and Livermore Valley reaches. In this way, sediment supply and transport to the Flood Control Channel and Bay margin are likely controlled and at least partially mediated by the existence of the narrow valley of Niles Canyon (especially the larger size fractions). The main geomorphic units in the watershed are the:

1. Watershed upstream from the Livermore/ Sunol Valleys (most sediment supply),
2. Livermore/ Sunol Valley depositional reaches,
3. Niles Canyon transport reach,
4. Non-tidal Freemont Flood Control Channel depositional reach, and the
5. Tidal flood control channel/ Baylands depositional reaches.

From a geomorphic standpoint, an ideal sediment gauging program would make measurements at locations in the upper reach of each transition zone between these main geomorphic units (See Appendix, Figure A2). The existing District gauges at Welch Creek on the southern Alameda side and on Arroyo De La Laguna at Verona on the northern side neither constrain sediment supply strictly from the moderate to high gradient upper watershed areas nor are they placed fully downstream from the major depositional reaches of the Livermore/ Sunol Valley floor. That said, on the northern side, no one gauge location would suffice, thus it may be cost prohibitive to rectify this data gap without considerable cost sharing with other agencies. If this were possible, additional gauges could be placed on Alameda Creek at Hwy 680 and on Arroyo de la Laguna at Sunol (Hwy 84) or a single gauge could be reinstated at the old Sunol Dam to characterize sediment loads passing into Niles Canyon. The Niles gauge itself is not ideally placed and from a geomorphic standpoint would be better placed a few hundred meters upstream of where Old Canyon Road passes over Alameda Creek in the transition zone between the Niles Canyon transport reach and the Flood Control Channel. These things said there are other important reasons for maintaining the gauges at Welch, Verona, and most importantly Niles Canyon in their current locations (discussed above).

Perhaps the most important missing sediment gauging location is in the transition zone between the Fremont Flood Control Channel and the tidal Baylands. There are a number of potential uses for a sediment data set of high temporal resolution collected in a vicinity of the railroad trestle or perhaps Union City Blvd. Management of the Flood Control Channel encompasses a program of modeling to better understand transport and depositional processes and a program of maintenance that includes sediment removal. One dimensional (1D) and 2D models require water and sediment discharge data to constrain their boundary conditions. Presently no data is available at the Bay margin; modelers are forced to use data collected from the axis of the Bay. Given the potential to use sediment for restoration in the Baylands and the potential for changing depositional conditions as sea level rises, there appears to be an important opportunity to begin a data collection program to inform these pressing and expensive management decisions. Some may argue that sediment supply from the local watersheds is the only hope for the marsh survival during sea level rise. The flow of water and sediment in tidally influenced reaches can be achieved with an Acoustic Doppler Current Profiler (ADCP) (Rule and DeRose, 2004; Kosaschuk et al., 2005; Rennie et al., 2007). An ADCP measures three dimensional velocity profiles using the principal of Doppler shift whereby the spectrum of light reflected back to the instrument from the water column is shifted by a magnitude related to velocity. The bottom tracking function and the acoustic backscatterance can be used to estimate bed load and suspended sediment concentrations. A full review of these instruments, their costs, and a comparative analysis of other options (such as deploying a turbidity probe equipped with wiper) is beyond the scope of this report.

4. Summary and Recommendations

Here, the sediment component of the District Environmental Monitoring Program was reviewed with the objective of moving the District towards implementing the most efficient cost effective design in relation to project and management needs. The focus here was to develop a framework for completing the evaluation, carry out a brief review of current gauging and make preliminary recommendations. A complete analysis of the sediment component in relation to District needs is presently hampered by several main factors:

1. No Alameda specific (or regionally applicable) analysis of magnitude and frequency in relation to effective discharge, channel forming processes, and bed load movement. If this were available, the definition of the most important flows and return frequency of these flows would provide a success criterion for complete data collection in relation to sediment transport
2. A full understanding of future projects either planned or conceptualized so that targeted data collection could be recommended

These things admitted, the following recommendations are made:

Arroyo De La Laguna at Verona (11176900)

Recommend continue gauging for 5 more years: The basis for the recommendation is mainly is three-fold: 1. This tributary is presently the main sediment supply to the flood control channel, 2. Data from this gauge will provide the benchmark in relation to any management changes upstream, and 3, The turbidity data may be used by the Water Board for compliance monitoring in relation to near-field projects upstream.

Alameda Creek below Welch Creek near Sunol (11173575)

Recommend continue gauging for 5 more years: The basis for the recommendation is mainly is four-fold: 1. Data collected so far has been either poor quality (WY 2003) or for relatively dry conditions, 2. Data from this gauge will provide the benchmark in relation to any management changes upstream in association with Calaveras reservoir, 3. Data will be important for channel design in the reach between Welch Creek and Hwy 680 as management changes in relation to salmonid habitat, and 4. The turbidity data will be important for assessing salmonid habitat quality once the reach is restored.

Alameda Creek near Niles (11179000)

Recommend continue gauging indefinitely: The basis for the recommendation is mainly is two-fold: 1. The gauge has historic significance both locally and regionally, and 2. High temporal resolution data has multiple District uses, the most important of which is managing the Flood Control Channel through Fremont.

San Lorenzo Creek at San Lorenzo (11181040)

Recommend gauging for 10 years: The basis for the recommendation is mainly for informing design of channel configurations in the Castro Valley and Hayward reaches.

Additional sediment gauging to consider

Dry Creek at Union City: The basis for the recommendation is mainly because this represents an ungauged input of both suspended and bed load sediment that is likely disproportionably large and likely depositing in the Flood Control Channel.

Alameda Creek in Union City within the tidal reach: The basis for the recommendation is two-fold: 1. The data are needed for constraining models in relation to both sedimentation in the Flood Control Channel and processes in the Baylands, and 2. Such data would be an ideal means for monitoring local sea level rise and related changing sedimentation in the downstream reach of the Flood Control Channel.

Full redesign of the sediment component of the Districts Environmental Monitoring Program: The basis for the recommendation is the recognition than none of the current gauges are located in a geomorphic transition zone (see Figure A2). In addition, the length of time and methods for monitoring are likely different for suspended sediment compared to sandy and gravelly bed load sediment. Under this scenario, the only sediment gauge of those currently funded by the District that would be continued would be Alameda Creek near Niles on the basis of its historic significance. The rest of the gauges would be repositioned and the methods and time period for monitoring completely revised based on the combination of a program of field observation for suspended sediments (<0.25 mm size classes) coupled with bedload (>0.25 mm size classes) field measurement employed to calibrate computational equations for bed load. This combination over the longer term would likely achieve the highest quality of information at a lower long term averaged cost.

4. References

Bathurst, J.C., 2007. Effect of coarse surface layer on bed-load transport. Journal of Hydraulic Engineering 133(11), 119201205.

Bigelow, P., Pearce, S., McKee, L., and Gilbreath, A., 2008. A Sediment Budget for the Alameda Creek Channel between Niles Canyon, Arroyo De La Laguna at Verona and Alameda near the Welch Creek Confluence. A Technical Report of the Regional Watershed Program: SFEI Contribution #550. San Francisco Estuary Institute, Oakland, CA. 140pp + Appendix.

Bunte, K., and Abt, S.R., Potyondy, J.P., and Ryan, S.E., 2004. Measurement of coarse gravel and cobble transport using portable bedload traps. Journal of Hydraulic Engineering-ASCE 130 (9), 879-93.

Bunte, K., and Abt, S.R., 2005. Effect of sampling time of measured bedload transport rates in a coarse-bedded stream. Water Resources Research 41, W11405. 12pp.

Dunne and Leopold, 1978. Water in Environmental Planning. W.H. Freeman and Co., Yew York.

Ferguson, R.I., 1986. River loads underestimated by rating curves. Water Resources Research. 22, 74-76.

Finlayson, B.L., and McMahon, T.A., 1988. Australia v the world: A comparative analysis of stream flow characteristics. In Warner R.F. (ed.). Fluvial geomorphology of Australia. Academic Press of Australia, Sydney. p17-40.

Gilbreath, A.N, and McKee, L.J, 2007. Spatiotemporal variation of turbidity in Alameda Creek and selected tributaries: August thru December 2007. A Technical Report of the Regional Watershed Program: SFEI Contribution 547. San Francisco Estuary Institute, Oakland, CA. 53pp

Gaudet, J.M., Roy, A.G., and Best, J.L., 1994. Effect of orientation and size of Helley-Smith sampler on its efficiency. Journal of Hydraulic Engineering-ASCE 120(6), 758-766.

Gomez, B., 1991. Bedload transport. Earth Science Reviews 31(2), 89-132.

Habersack, H. M., and Loronne, J. B., 2002. Evaluation and improvement of bedload discharge formulas based on Helley-Smith sampling in an alpine gravel bed river. Journal of Hydraulic Engineering 128 (5), 484-499.

Hean, D.S., and Nanson, G.C., 1987. Serious problems in using equations to estimate bedload yields for coastal rivers in NSW. Australian Geographer 18(2), 114-124.

Heim Jr, R.R., 2002. A Review of Twentieth-Century Drought Indices Used in the United States. Bulletin of the American Meteorological Society, August 2002, p 1149-65.

Kleinhans, M.G., and Ten Brinke, W.B.M., 2001. Accuracy of cross-channel sampled sediment transport in large sand-gravel-bed rivers. Journal of Hydraulic Engineering-ASCE 127(4), 258-269.

Kostaschuk, R., Best, J., Villard, P., Peakall, J., and Franklin, M., 2005. Measuring flow velocity and sediment transport with an acoustic Doppler current profiler. Geomorphology 68, 25-37.

Lewis, J., 1996. Turbidity-controlled suspended sediment sampling for runoff-event load estimation. Water Resources Research. 32(7), 2299-2310.

Martin, Y., and Ham, D., 2005. Testing bedload transport formulae using morphologic transport estimates and field data: lower Fraser River, British Columbia. Earth Surface Processes and Landforms 30, 1265-1282.

McKee, L., Leatherbarrow, J., Pearce, S., and Davis, J., 2003. A review of urban runoff processes in the Bay Area: Existing knowledge, conceptual models, and monitoring recommendations. A report prepared for the Sources, Pathways and Loading Workgroup of the Regional Monitoring Program for Trace Substances. SFEI Contribution 66. San Francisco Estuary Institute, Oakland, Ca.

McKee, L., Hossain, S., and Eyre, B., 2002. Magnitude-frequency analysis of suspended sediment loads in the subtropical Richmond River basin, northern New South Wales, Australia. *In* Proceedings of the Structure, Function and management Implications of Fluvial Sedimentary symposium.

Meyer-Peter, E., and Müller, R., 1948. Formulation for bed load transport. Proceedings International Association of Hydrologic Research, 2nd Congress, Stockholm, p39-64.

Nolan, K.M., Lisle, T.E., and Kelsey, H.M., 1987. Bankfull discharge and sediment transport in northwestern California. In Erosion and Sedimentation in the Pacific Rim (Proceedings of the Corvallis Symposium, August 1987). IAHS Publication No. 165, p439-449.

Pfannkuche, J., and Schmidt, A., 2003. Determination of suspended particulate matter concentration from turbidity measurements: particle size effects and calibration procedures. Hydrological Processes. 17, 1951-1963.

Rennie, C.D., Rainville, F., and Kashyap, S., 2007. Improved estimation of ADCP apparent bed-load velocity using real-time Kalman filter. Journal of Hydraulic Engineering ASCE, December 2007, 1337-44.

Rule, C.A., and DeRose, J.B., 2004. Investigations of hydroacoustic flow-monitoring alternatives at the Sacramento River at Freeport, California: Results of the 2002-2004 pilot study. USGS Scientific Investigations Report 2004-5172.

Ryan, S.E., and Porth, L.S., 1999. A field comparison of three pressure-difference bedload samplers. Geomorphology 30, 307-322.

Sterling, S.M., 2002. Sediment trapping characteristics of a pit trap and Helley-Smith sampler in a cobble gravel bed river. Water Resources Research 38 (8), 1144. 11pp.

Walling, D.E., and Webb, B.W., 1988. Reliability of rating curve estimates of suspended sediment yield: some further comments. *In* Bordas, N.P., and Walling, D.E. (eds). *Sediment budgets.* Proceedings of the Porto Alegre Symposium, IAHS Publication 174, 337-350

Webb, B.W., and Walling, D.E., 1982. Magnitude and frequency characteristics of fluvial transport in a Devon drainage basin and some geomophological implications. Catena. 9-23.

Wilcock, P.R., 1997. A method for predicting sediment transport in gravel-bed rivers. A report prepared by Johns Hopkins University for the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station. March, 1997.

Wilcock, P.R., 2001. Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. Earth Surface Processes and Landforms 26, 1395-1408.

Wilhite, D.A., and M.H. Glantz, 1985: Understanding the drought phenomenon: The role of definitions. Water International. 10, 111-120.

Appendix A

Q1. Is the data representative of reasonable assumptions about temporal variability? Bay Area watersheds exhibit a runoff variability that is amongst the highest in the world, a fact that poses great challenges for data collection and modeling (McKee et al., 2003). An analysis of annual runoff data collected at the Niles gauge on Alameda Creek shows a coefficient of variation (CV; standard deviation divided by the mean x 100) of 101% (McKee et al., 2003). The CV of runoff on San Lorenzo Creek at Hayward is 94%. To put this in context, the average CV for discharge in river systems based on analysis of 974 watersheds from around the world was 43%, and the average for North America was found to be 31% (Finlayson and McMahon, 1988).

Unfortunately, the concept of variability gets even worse when we consider the sediment component of the District's environmental observation programs. Based on 25 years of suspended sediment data collected by the USGS near Niles gauge from water year (WY) 1957-73 and WY 2000-07, suspended sediment loads passing through the Niles gauge have varied from 9 to 766,500 metric tons. The average for these 25 years was 103,100 metric tons, the standard deviation was 169,600 metric tons, and the CV was 164%. Bedload data is more limited and even more variable. Due to this variability, an important question to consider is: how does the District determine how long to carry out environmental observations to capture a reasonable level of variability in the context of management needs? In the next few paragraphs two methods of answering this question will be explored.

The definition of dry and wet years is an argued concept with multiple functional scientific definitions. For example, definitions of drought can be categorized as meteorological, climatological, atmospheric, agricultural, hydrologic, and water management (Wilhite and Glantz, 1985) and all serve a useful purpose in the context that they are applied. Heim (2002) provided a more recent review of drought indices; however, definitions of what constitutes a wet year are not as common, largely because the human risks are perceived to be less. At a practical level, climatologists classify years as dry (drought) if the rainfall does not exceed 70% of the mean annual precipitation (MAP) and wet if rainfall exceeds 130% MAP (McKee et al., 2003). Long-term monthly and annual rainfall records are available for Alameda Creek watershed at Livermore from 1904-present (105 years of record: NOAA gauge number 044997). Since there is discussion that rainfall is increasing in the Bay Area in response to climate change, two analyses were performed; the first on all 105 years of data and the second on the last 40 years only. This analysis shows that if monitoring was carried out for 7 consecutive years the District would have an 82% chance of collecting sediment data during a wet year (130% MAP) (Table A1). The chance increases to 90% if monitoring is done for 10 years and 100% if monitoring is done for 15 years (Table A1). If monitoring an even wetter year is desired then longer periods of time are necessary.

Table A1. Analysis of the probability that an environmental program in Alameda Creek watershed if run for 5, 7, 10, or 15 consecutive years would capture at least one year when a rainfall in the City of Livermore exceeded 130% of the mean annual rainfall for Livermore (1903-2008: 14.1 in; 1969-2008: 14.29 in).

	Sediment program running for consecutive years			
	5-year	**7-year**	**10-year**	**15-year**
Probability in the last 40 years	66	82	90	100
Probability in the last 105 years	61	73	83	92

From a geomorphic standpoint, another way of defining a wet year is to consider discharges greater than bankfull discharge, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels in the most effective (Dunne and Leopold, 1978). The recurrence interval of bankfull discharge is a debated topic (for a California discussion see Nolen et al., 1987). A common definition is a flood of 1.7-3.5 year return being most effective (Dunne and Leopold, 1978). The importance higher flows in the sediment transport of a particular system can be predicted by the skew of daily flows; the greater the skew, the greater the portion of sediment transported during larger floods. An analysis of daily flows in Alameda Creek near Niles for WY 1892-2008 (42,790 data points) yields a skew of 12.4. For San Lorenzo Creek at Hayward, data for the analysis were available for WY 1968-1978 and WY1988-2008 and the skew is 10.0. Unfortunately, the importance of magnitude-frequency in sediment transport has not been studied in Alameda County or the Bay Area (and is beyond the scope of this review) but may very important for designing monitoring programs. In the absence of this analysis we are left with a range between the common definitions that may not apply in incised channels in disequilibrium (a flood of 1.7 year return being most effective: Dunne and Leopold, 1978) and a flood of a 16 year return interval (the extreme case of Nolan et al, 1987).

So based on these hydrological definitions of geometrically important regimes, we will test the chances of a monitoring program of capturing a flood of 1.5, 3, 5, and 10 year return (Figure A1) in 5, 7, 10, and 15 years based on the past 40 years of record. This might seem like an intuitive simple mathematical

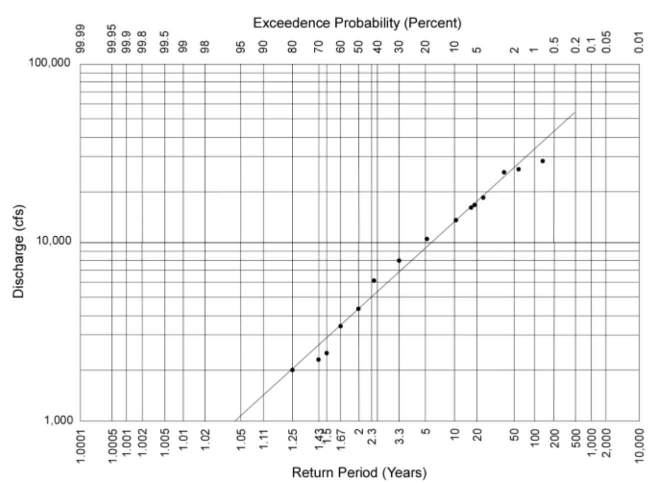

Figure A1. Recurrence interval of annual peak flow based on the partial series and a log Pearson type III (LP3) distribution.

calculation, but in reality it is not because of the tendency for climate in the Bay area to cycle between wet and dry periods lasting 5-7 years (McKee et al., 2003). The return frequency of discharges of a given magnitude was carried out using the partial series (the series of annual peak flow recordings for the period of record). In the case of Alameda Creek near Niles, the record is the longest in the Bay Area spanning the period WY 1892-2007; 116 years). Discharge of 1.5, 2, 3.3, 5, 10 year return interval in Alameda Creek is 1,950, 3,400, 6,900, 9,200, 13,600 cfs (Figure A1). Based on this analysis, the District would have a 74, 85, 93, and 100% chance of collecting sediment data during a year with in excess of a 5 year return discharge if monitoring was carried out for 5, 7, 10, or 15 consecutive years (Table A2). This appears to be roughly consistent with the 130% MAP definition of a wet year used above. The chance of capturing a 10 year return event with 10 years of monitoring is 73%. The disadvantage with both these wet year definitions is that they do not take into account the possibility of either:

1. A "reactive" sampling program being designed where money is set aside each year for monitoring and then storms of only specific sizes are monitored so that over the longer term knowledge is gathered on a range of storm sizes and used to drive models
2. That data could be gathered to locally calibrate sediment transport equations where equations are run for two grainsize fractions
    a) the gravel fraction that is commonly caught in the flood control channel 2 mm – 256 mm and
    b) the sand fraction that is highly mobile and largely deposited on the Bay margin (<2 mm)

There may be cost efficiencies associated with devising and coupling a more sophisticated field program directly with using empirical equations or models. These will be touched upon further below in the section on data quality.

Table A2. Analysis of the probability that an environmental program in Alameda Creek watershed if run for 5, 7, 10, or 15 consecutive years would capture at storm of the specified exceedance.

	Sediment program running for consecutive years			
	5-year	**7-year**	**10-year**	**15-year**
Exceed 1.5 year return (2,950 cfs)	100	100	100	100
Exceed 2 year return (3,400 cfs)	100	100	100	100
Exceed 3.3 year return (6,900 cfs)	89	100	100	100
Exceed 5 year return (9,200 cfs)	74	85	93	100
Exceed 10 year return (13,600 cfs)	37	52	73	88

Q2. <u>Does the data have historic significance in the District or for the Region as a whole?</u> The length of a record of environmental data has intrinsic value. Given the extreme climatic variability in the Bay Area, long term datasets are extremely useful for teaching us about what we might expect to see at a neighboring location where there is a shorter record or where records are absent altogether. At least 40 years are needed to see all the climatic variability for a given gauge. Although each watershed is different, 40 years also represents about a doubling of human population; a data set of 40 years therefore also provides reasonable power for an analysis of impacts associated with changes in land management. There are presently no 40-year records of suspended sediment in the Bay Area.

Q3. Is the data technically sound? For the purposes of the District's needs it is useful to consider the quality of data collection in three size classes: 1. Suspended sediment, 2. Fine (sand) bed sediment and 3. Coarse (gravel) bed load sediment. On average, about 80% of the suspended sediment in Bay Area watersheds is <0.0625 mm in size and about 100% is less than 0.25 mm. For example, on average 60% of the suspended sediment load in Alameda Creek at Niles is <0.020 mm (20 micons), on average 78% is <0.0625 mm, and on average 94% is <0.25 mm (based on 7 samples collected by the USGS during WYs 2002-2007). Most (although we have no measure of just how much) suspended sediment likely passes through the system including the Flood Control Channel and deposits on the Bay margin where it is reworked by tides and deposited in the wetlands or dispersed into the Bay. Sand bed load is by practical definition sediment that is between 0.25 mm and 2 mm. This sediment impacts salmonid habitat by clogging spawning gravels and filling pools, and a large but unknown portion is deposited in the Fremont Flood Control Channel with likely moderate amounts also passing into the Bay. The coarse gravel fraction of bed load is desirable for maintaining salmonid habitat but unfortunately once transported to the Fremont Flood Control Channel, we predict that most if not all of it is trapped; little getting to the Baylands.

The collection of quality suspended sediment and bedload sediment records is extremely difficult and costly. Flood flows can occur at any time of the day on any day of the wet season. It is nearly impossible to have staff on call to capture samples for laboratory analysis for every flood and even more difficult to capture samples at peak flow when the majority of sediment is discharged and when there is the most danger to field staff. Even if this is achieved, in order to calculate hourly, daily, or annual sediment loads, the limited number of water samples have to be interpolated in time. Classically this is done with a rating curve (a relationship between water flow and suspended sediment concentration or load).

Suspended sediment is relatively easy to measure accurately. The use of rating curves for estimating suspended sediment loads was the subject of much critical literature in the 80s (Walling and Web 1988) when it was recognized that, in most cases, the resulting estimates are bias low by an amount that is somewhat proportional to the scatter around the rating (regression) equations (Ferguson 1986). Luckily, a new technique was being developed at the time and is now considered the most accurate method, that of using turbidity as a surrogate (Webb and Walling 1982; Lewis 1996; McKee et. al. 2002; Pfannkuche and Schmidt 2003). The advantage of using turbidity is that it can be automated to provide a very accurate measure of sediment concentrations during peak flow in addition to very accurately capturing hysteresis. Assuming that the turbidity probe is calibrated using depth-integrated, cross-sectionally averaged samples where the whole samples are analyzed for suspended sediment concentrations, the result is measurement of suspended sediment load that is accurate to better than +/-15%. It is this method that is now being used at Niles for example.

In the case of bed load there are two basic methods for generating information; empirical field observations and bed load equations. The technique for sampling bedload has also been the subject of much critical review. Unlike suspended sediment, bedload is very difficult to sample. Problems include the design of the sampler, the position, orientation of the sampler, length of time it is place on the bed relative to the passage of bedform dunes, the disturbance of the local bed while sampling, the character and grain size of the bed in relation to the sampling technique, the position relative to channel features such as pools, riffles and meanders that can scour and aggrade during floods out of phase with each other and with the passing hydrograph, rapid changes in discharge rate during a single sampling pass across the channel, the choice of the number of lateral sampling bins, and human error during sampling (Gomez, 1991; Gaudet et al., 1994; Ryan and Porth, 1999; Kleinhans and Ten Brinke, 2001; Sterling, 2002; Bunte et al., 2004; Bunte and Abt, 2005). The most commonly applied sampling technique is the pressure-difference method (also known as the Helley-Smith sampler – Note SFEI owns and deploys the USGS standard FISP BL84 which is a typical example of such a device). Ryan and Porth (1999) tested three of these devices and found that measured bedload compared within 40-50% of weir-pond accumulations whereas other workers have found that the measurement quality of the HS sampler varies in relation to size of material (Sterling, 2002).

Perhaps by far the biggest issue is the need to use rating curves to interpolate the data in time from an “instantaneous” sample to a daily or annual load using a rating curve (Martin and Ham, 2005). Martin and Ham (2005) provide an example of the order of magnitude scatter expected in a rating equation for bedload demonstrating that instantaneous predictions based on such an equation may be in error by an average of +/-5 times the actual bedload. The need for capturing peak flows and a range of flows is even more critical for bed load than for suspended sediment because bedload transport occurs for a much smaller window of time and because hysteresis is even more prevalent. In addition, the legacy of previous flows plays an important role; given two flood flows in succession, the initial conditions of the bed grain size distributions and storage are different as a result of the previous flows transport interactions resulting in differing transport for each event.

The development and use of bed load equations have been around since at least the 1940s (e.g. Meyer-Peter and Müller, 1948). Do bedload equations show better promise? The performance of at least eight commonly applied bedload equations have been compared to each other and to “real measurements” under a variety of natural stream and flume conditions (Hean and Nanson, 1987; Habersack and Loronne, 2002; Martin and Ham, 2005; Bathurst, 2007). Problems in the practical use of bedload equations include assumptions such as no recognition of step-functional climatic changes (Hean and Nanson, 1987; Gomez, 1991). Equation performance has also been shown to vary with discharge and with relative mobility of different grain size classes (Habersack and Laronne, 2002). Between equation estimates have been shown to vary by up to 6 orders of magnitude but more typically 1-2 orders of magnitude (Hean and Nanson, 1987). Recently, a lot of improvements have been made in performance of formulas especially when good quality field data are available (Habersack and Laronne, 2002) but even improved formulas serve as reach average estimations and may not correctly represent the processes acting at a specific site (Bathhurst, 2007).

In terms out that a third hybrid method combining field measurements and bed load equations has been proposed (Wilcock, 1997) and tested (Wilcock, 2001). In this hybrid method, field measurements of reach averaged bed characteristics are collected and used to develop a bedload transport curve. This curve is then "calibrated" (adjusted up or down) using a smaller number of field based sediment transport observations over enough of the flow variation to define statistically the shape and position of the "real" transport curve. The advantage is that field observations can be collected during more frequent lower flow conditions leading to a cheaper safer field program while generating information with acceptable accuracy.

In summary, the quality of suspended sediment data collection methods being applied in Alameda Creek watershed is very high; the outcome of the District efforts is a fairly high cost high quality program where data generated can be used for accurate long term estimates of sub-catchment sources of suspended sediment (<0.25 mm) supply to the Bay margin wetlands. In contrast, improvements could be made in the bed load program. In order to model the Flood Control Channel transport and depositional processes, the District is most interested in predicting bed sediment loads of specific grain sizes (0.25-2mm and >2mm) under specific flow conditions. Based on this brief review it appears that if calibrated with local data, bedload equations can meet these expectations. It appears that a focused set of field measurements used for the bedload functions calibrations, is the best, and the most cost efficient method given the District's needs. Fortunately, given Alameda Creek is likely adjusting to a new dynamic semi-equilibrium (Bigelow et al., 2008) it is likely that relatively short period of measurements, capturing the dominant flow conditions, could be used combined with bed load equations to make accurate assessments.

Q4. <u>Does the data have multiple uses?</u> Data collection is inherently more cost effective if it can be amortized across a range of uses (Table 2 in main report). The limitation of Table 2, however, is that in summing the uses (far right hand column) and giving each data type a score, it was assumed that all uses have an equal financial impact with regard to the District needs. This is inherently simplistic. A more thorough evaluation is necessary, but beyond the scope of this report. Like all programs, each component can be related to another based on common use. For example, sediment data is of little use without concomitant water discharge data. In addition, there is no need to collect sediment data at a finer temporal scale than the available flow data. Within the sediment component, it is important to consider the value in inter-station comparisons. For example, suspended sediment data collected at the Niles gauge shows a strong relationship to suspended sediment data collected at the Verona gauge on Arroyo De La

Laguna. Therefore, there is benefit for continuing a long term gauge such as Alameda near Niles to provide comparative data useful for more confident analysis of data from other gauges that are operated for less time. In the context of District modeling needs, it would be of little value for the District to collect bedload data without analysis of grain size or the collection of local channel geometry data.

Q5. Is the data representative of reasonable assumptions about spatial variability? Things to consider in the context of spatial variability include an assessment of the importance of or potential impact associated with ungauged areas or sub-watersheds. In addition, spatial coverage can be thought of in terms of geomorphic units. In the case of Alameda Creek, there are five main geomorphic units (Figure A2). An ideal sediment monitoring component of the District's environmental monitoring program would assess the source, transport and storage processes associated with geomorphic units along the mainstem. Ideally, measurements would be made in the upper reach of each of the transition zones between the major geomorphic units but just upstream or just downstream of the transition zones would also suffice.

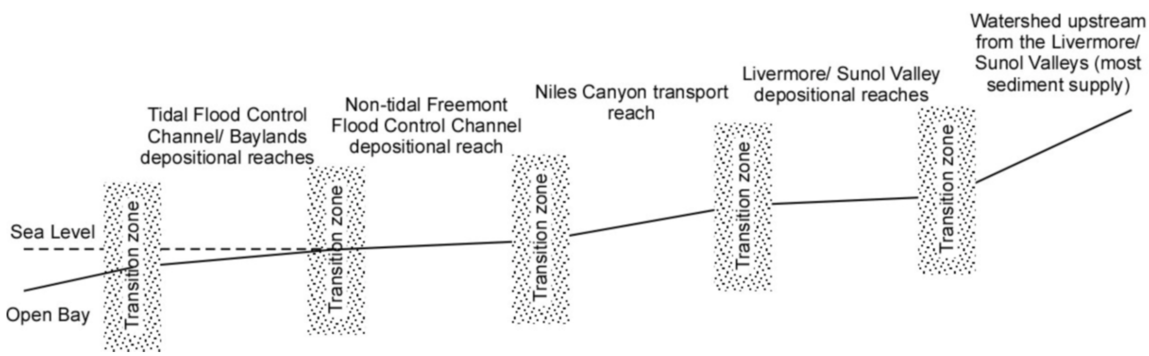

Figure A2. Conceptual model of the geomorphic units on the Alameda Creek mainstem.