Sediment supply, deposition and transport in the Flood Control Facilities of Arroyo Mocho and Arroyo Las Positas from 2006-2014

Prepared for Zone 7 Water Agency

By

Sarah A. Pearce, Alicia N. Gilbreath, and Lester J. McKee

Acknowledgements

Funding for this project was provided by the Zone 7 Water Agency for the total amount of $398,000, via contract numbers A11-45-SAN and A13-50-SAN. We gratefully acknowledge and thank the following people for their support and oversight of this project, their comments, and sharing of data:

Zone 7: Joe Seto, Brad Ledesma, Ryan Gromer, Matt Katen, Jeff Tang, Larry Akinsiku, Andy Chamberlain, James Creek, Diana Gaines, and Carol Mahoney

City of Livermore: Pamela Lung, Joel Waxdeck

Bigelow Watershed Geomorphology: Paul Bigelow

Earth Systems Institute: Lee Benda

RiverMetrics: Rand Eads

Suggested citation:

Pearce, S.A., Gilbreath, A.N., and McKee, L.J., 2015. Sediment supply, deposition and transport in the Flood Control Facilities of Arroyo Mocho and Arroyo Las Positas from 2006-2014. A technical report prepared for the Zone 7 Water Agency by the Watersheds Focus Area of the Clean Water Program, San Francisco Estuary Institute, Richmond CA. Contribution No. 771.

Contents

Executive Summary 1
1. Introduction 3
2. Methods 4
2.1. Study Area overview 4
2.2. Sediment budget method 6
3. Results 10
3.1. Total sediment inputs 10
3.1.1. Total sediment inputs from gauged tributaries 10
3.1.2. Total sediment inputs from non-gauged tributaries 14
3.2. Total sediment load export 16
3.2.1. Export via channel transport 16
3.2.2. Export via sediment maintenance and removal 18
3.3. Total in-channel sediment deposition/erosion excluding the low flow channel 20
3.3.1. Methods 20
3.3.2. Uncertainties 23
3.3.3. Results 24
3.4. Total sediment budget 26
3.4.1. Uncertainties 26
3.4.2. Results 27
4. Discussion 30
4.1. Budget justification 30
4.2. How much sediment passes into the system and from where? 36
5. Recommendations 40
6. References 43
7. Appendices 46
7.1. Sediment sources and sediment transport through Zone 7 channel facilities: literature and data review 46
7.2. Wet weather field sampling manual for suspended and bedload sediment transport in Zone 7 facilities 46
7.3. Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Years 2011 through 2015 46
7.4. Geospatial terrain mapping of sediment sources within the Arroyo Mocho watershed 46
7.5. Landscape scale management strategies for Arroyo Mocho and Arroyo Las Positas: process-based approaches for dynamic, multi-benefit urban channels 46
7.6. Arroyo Mocho bulk sediment sampling 46

Executive Summary

This report summarizes five years of work on sediment processes in Zone 7 Water Agency's flood control facilities conducted by the San Francisco Estuary Institute (SFEI). The main body of the report presents a sediment budget for the Arroyo Mocho and Arroyo Las Positas channel network for the period Water Years 2007 through 2014. This budget was developed mainly from data collected and interpreted over the past five years by SFEI that is included as a series of appendices to this report. For details on past studies by agencies and consultants other than SFEI, methods of field data collection for suspended and bed sediment, suspended and bedload data at three locations (Arroyo Mocho at Pleasanton (AMP), Arroyo Mocho at Hagemann (AMH), and Arroyo Las Positas at Livermore (ALPL)) during Water Years 2011 to 2015, estimates of sediment supply from ungauged tributaries using terrain modelling, and details of the historical ecology of the valley floor, the reader is referred to these appendices.

A sediment budget approach is utilized in this summary report to organize information generated to-date and answer the following main questions:

1. How much sediment passes into the system and from where?
2. How much sediment is stored in the system?
3. How does climate influence supply and storage within the system?
4. What information is still lacking to answer these questions comprehensively?

Sediment data collected during Water Years 2011 through 2015 represent a relatively dry period compared to flows that occurred during the early to mid-1980s and during the mid-1990s. The sediment budget period (Water Years 2007 through 2014), was chosen based on the availability of LiDAR geospatial mapping that was collected during the summer of 2006 and again in the fall of 2014. However this extended period is also considered relatively dry; as such the overall interpretations of the sediment budget represent processes and rates that occur during relatively dry climatic conditions. With this caveat accepted, the results indicate the following terms of relative supply, storage and export from the channel network representing the East side of the basin, or upstream from the AMP gauge. For the budget period, 3,544 metric tonnes of total sediment load was supplied to the AMP gauge. A total of 20% of this supply passed into the system through the AMH gauge, and 58% passed into the system through the ALPL gauge; the remaining sediment supply to Zone 7's facilities upstream from the AMP gauge is estimated to have been derived from the ungauged tributaries draining the north side of the watershed. Of the sediment supplied, 89.6% was in grain sizes <0.0625 mm (silts and clays) with the remaining balance sand (0.0625-2 mm: 8.6%) and gravel (>2mm: 1.8%) size fractions. During the relatively dry budget period, flows were fully contained within the low flow channel, and sediment, with the exception of a small amount of maintenance removal, was largely transported through the system without any evidence of net deposition or erosion.

In contrast, the budget for the West side of the system upstream from the USGS gauge on Arroyo de la Laguna at Verona (ADLLV) and downstream from AMP includes measured

sediment load at ADLLV, but uses estimates of sediment supplied from the ungauged tributaries and an estimate of sediment deposited/eroded from the channel itself. For the budget period, 30,089 metric tonnes of total sediment load passed the ADLLV gauge, with only 12% passing into the system through the AMP gauge. This illustrates that during this dry budget period, sediment yields were considerably lower from the East side. Although somewhat surprising, this was justified and is consistent with rainfall gradients observed from west to east and relative production of flow.

Overall the budget for the period Water Years 2007 through 2014 indicates that sediment supplied to the system is efficiently transported downstream; any amount of sediment that is deposited in the system is small relative to the supply, and may disproportionately consist of the largest size fractions that are inefficiently transported under relatively low velocity conditions. Data are presently insufficient to describe the processes of supply, transport, and deposition during wetter periods such as those that occurred during the early to mid-1980s and the mid-1990s. Further suspended and bedload data collection during more extreme events, periodic and event-based reoccupation of a series of strategically placed channel cross sections, and increased diligence in maintenance sediment removal record keeping are recommended to address this critical information gap.

1. Introduction

Zone 7 Water Agency provides potable water and flood protection to the tri-cities of Livermore, Dublin and Pleasanton as well as untreated water for 3500 acres of agricultural land. Historically, and particularly evident in recent years, the Zone 7 Water Agency has been challenged by a loss of flood capacity in channel facilities due to sedimentation. Although the causes are not fully understood, historic channelization of the drainage network, and population growth and land use change, in the form of increased urbanization and a change from non-irrigated range land to irrigated and controlled drainage viticulture, have likely contributed to changing flow and sediment erosion in tributary watersheds and changing transport and depositional conditions within the facilities. In addition to these challenges, the role of the Zone 7 Water Agency is changing, as they increasingly must consider and include improved stream habitat and water quality function, in concert with ongoing flood control activities and operating procedures. These changing roles require improved qualitative and quantitative data on the physical processes and biological resources. This project aims to provide information on the differing timing and rates of watershed and channel sediment processes and channel management and mitigation opportunities in relation to contemporary flow conditions within Zone 7 Water Agency facilities to support the Stream Management Master Plan (SMMP). The project consisted of six main sub-tasks:

1. A review of studies prior to 2011 (See Appendix 7.1 for details),
2. Preparation of a Field Sampling Manual for Suspended and Bedload Sediment Transport in Zone 7 Facilities to support continuation of the field program by Zone 7 Water Agency staff beyond Water Year 2015 and any further involvement by SFEI (See Appendix 7.2 for details),
3. Measurement of suspended and bedload sediment transport at three locations (Arroyo Mocho at Pleasanton, Arroyo Mocho at Hagemann, and Arroyo Las Positas at Livermore) during Water Years 2011 to 2015 to better understand sediment transport and support future modeling of channel sediment transport (See Appendix 7.3 for details),
4. An analysis of sediment sources and erosion potential in ungauged tributaries of Arroyo Mocho using a combination of empirical geospatial analysis and field verification (See Appendix 7.4 for details),
5. An analysis of the historical ecology of the valley to support identification of both opportunities and constraints associated with strategies for stream management improvement, regarding riparian vegetation and floodplains, and sediment management based on a comparison of historic and modern channel function (See Appendix 7.5 for details), and
6. An analysis of bed sediment grainsize distribution to support sediment source identification, help define locations and causes of bed sedimentation and scour, and support future efforts to model sediment transport within Zone 7 Water Agency facilities (See Appendix 7.6 for details).

The final task and the subject of this FINAL REPORT is a synthesis of the main sediment sources, erosion, transport, and depositional processes in the Zone 7 Water Agency facilities to further assist in identifying management and mitigation opportunities. A sediment budget is used as the primary framework for collating and organizing this information. The main questions we aimed to answer were:

- How much sediment passes into the system and from where?
- How much sediment is stored in the system, as it relates to sediment basins and channel capacity?
- How does climate influence supply and storage within the system, and when might channel maintenance be required?
- What information is still lacking to answer these questions comprehensively?

2. Methods

2.1. Study Area overview

The Arroyo Mocho and Arroyo Las Positas watersheds (the focus study area) drain the northern and eastern portions of the Alameda Creek watershed (Figure 1). The watershed has a Mediterranean style climate characterized by dry hot summers and moderate temperature winters with a mean annual precipitation of 15.2 inches measured at Livermore for the period 1981-2010[1] (Gauge 044997: WRCC, 2015). An average of 94% of the annual rainfall occurs between October and April on 58 rain days[2]. Runoff is similarly seasonable with high inter-annual variation typical of arid California (USGS 2015a). The focus study area includes 11.56 miles (18.6 km) of channel between the confluence of Arroyo Mocho and Alamo Canal and the upstream boundaries of the sediment budget (the Arroyo Mocho at Hagemann bridge gauge station, and the Arroyo Las Positas at Livermore gauge station) (Figure 2). Of the 11.56 miles of channel, approximately 4.5 miles (7.2 km) of channel are owned and maintained by the Zone 7 Water Agency.

[1] Thirty years is deemed to be an appropriate averaging period given the inter-annual variability of climate in California. Although the 1981-2010 period must be considered the best estimate of current annual average climatic conditions, it is important to note that climate has been changing. The annual average rainfall at the Livermore gauge (044997) for the climatic periods of 1961-1990, 1971-2000, 1981-2010 was 14.15 inches, 14.73 inches, and 15.2 inches respectively (WRCC, 2015). This change is consistent with a recent analysis carried out for the broader Bay Area that showed an increase in storm intensity over the 120 year period ending in 2010, with the intensity of the largest events increasing the most. Although mean annual precipitation was also shown to increase but not by as much, Russo et al. (2013) demonstrated that a greater fraction of precipitation fell during large events. This coupled with increasing urbanization and associated runoff in the Livermore Valley may be causing increasing peak discharge during storms in Zone 7 facilities.

[2] A rain day in this case is any day where >0.01 inches of rainfall was recorded.

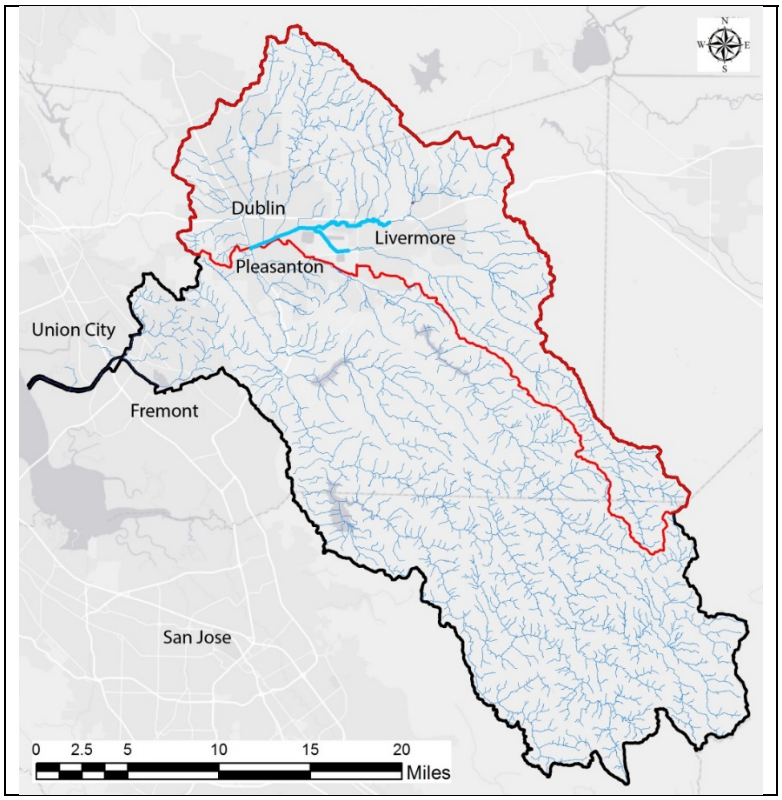


Figure 1. Alameda Creek watershed shown in black, with the Arroyo Mocho watershed in red, and the focus study area channels highlighted in light blue.

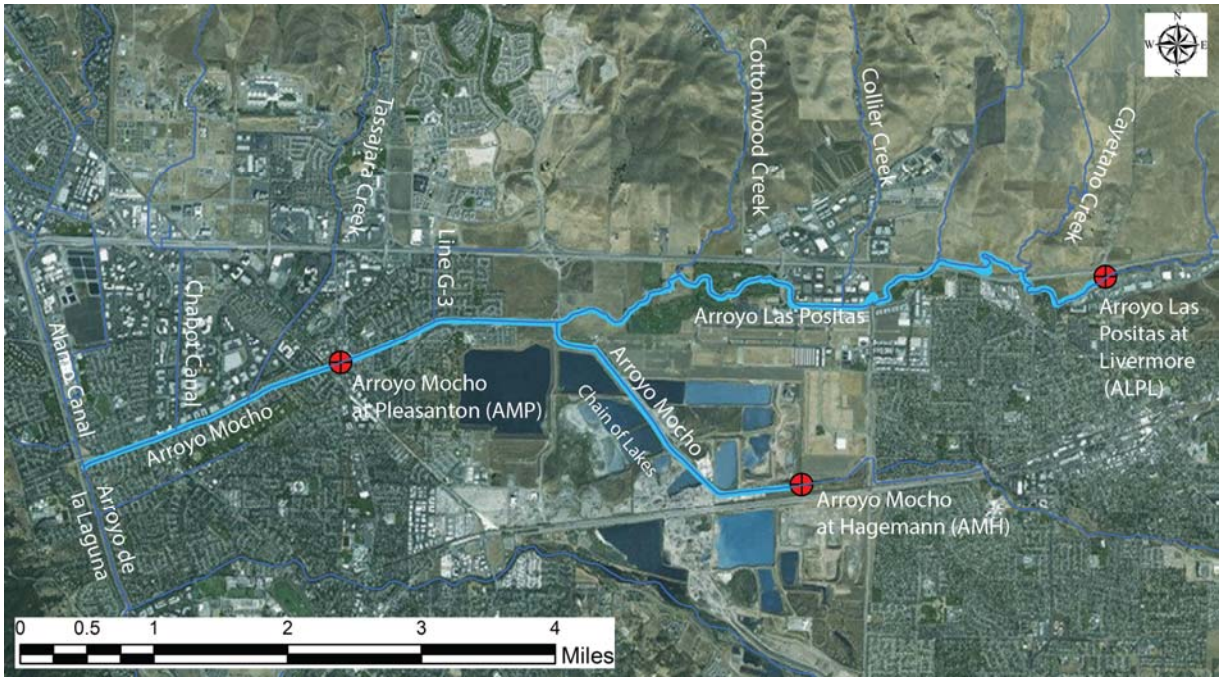


Figure 2. Focus study area channels (highlighted in light blue) with the three gauge station locations shown as red circles.

The lowest 3.72 miles (6.0 km) of channel, from the Alamo Canal confluence to the Arroyo Mocho and Arroyo Las Positas confluence, is entirely owned by Zone 7. This reach is a constructed soft-bottom earthen trapezoidal flood control channel, which is managed and maintained for flood conveyance. Much of this channel is characterized by older deposition of sediment, forming an inner bench within the trapezoid that varies in height from approximately 4 to 9 ft (1.2 to 2.7m). This inner bench is not thought to represent bankfull elevation, or the floodplain that is inundated on an annual basis, but instead is likely a depositional terrace that was formed during larger flow events, perhaps during the wet 1982-1983, or 1995-1998 periods or both. Only higher recurrence interval floods access this surface. Vegetation in the flood control channel is primarily annual grasses, herbs and forbs. The channel gradient is 0.19%, and bed elevation is controlled by a number of grade control structures. Many of the bridges crossing the channel have in-channel footers or narrow lateral abutments that may cause complex flow dynamics or constrict flow, potentially causing local sediment deposition. Upstream of the Mocho and Las Positas confluence, Arroyo Las Positas continues for approximately 4.7 miles (7.6 km) as both flood control channel and as natural channel up to the Arroyo Las Positas at Livermore (ALPL) gauge station. This reach is both publically and privately owned, has a gradient of 0.36%, and is primarily a natural meandering channel with a discontinuous woody riparian corridor. A fish ladder and drop structure exist in the lowest portion of this reach, just upstream of the confluence with Arroyo Mocho. Areas of erosion due to channel meandering, and thus bank failure, are observable along many portions of the reach. From the Mocho and Las Positas confluence, the Arroyo Mocho channel continues approximately 2.4 miles (3.9 km) upstream to the Arroyo Mocho at Hagemann Bridge (AMH) gauge station. This reach is not owned by Zone 7, but instead is privately owned, has a gradient of 0.35%, and is a narrow leveed channel running between the Chain of Lakes quarry ponds. The reach has natural bed and banks, with numerous eucalyptus trees, small willow shrubs, and mixed annual grasses. Although all reaches of channel experience annual sediment erosion and deposition, the channel in the constructed and leveed reaches is much more confined and homogenous in form than the natural reaches. This reach also has a fish ladder and drop structure immediately upstream of the confluence with Arroyo Las Positas.

2.2. Sediment budget method

Sediment budgets are a widely accepted tool for documenting the relative importance of sources, storage, and losses of sediment from an area of management interest. They can be developed for a whole watershed, or for parts of a watershed depending on the management questions (Reid and Dunne, 1996). In this case, a channel sediment budget was developed for the 11.56 miles (18.6 km) of channel in the Arroyo Mocho and Arroyo Las Positas watershed, including the flood control facilities owned and operated by the Zone 7 Water Agency, as a tool for describing the main sources and processes affecting function. This budget contains detail about processes in the channel, but lumps all the detail about hillslope erosion, storage and transport into the supply elements for the channel. Details about hillslope and tributary

processes are found in Appendix 7.4. Data utilized in this budget were provided in both English and metric units, and thus we will use a mixture of units throughout the report. However, the sediment budget is reported in metric tonnes (metric t), as this is the common unit used in geomorphic literature.

Although a channel sediment budget of this type could be developed on an annual time scale, the processes of erosion and supply, sediment deposition, and sediment transport usually operate over timescales of a decade or more in semi-arid California systems (Bigelow et al., 2008). Since sediment eroded and transported during large storms can take years to pass down a channel, and sediment deposited in a channel system during a large storm can be reworked and passed through during subsequent storms and years, a sediment budget for a single year will provide limited understanding of sediment supply, storage, and transport dynamics. In addition, data on changes in cross-sections and longitudinal profiles as well as the mapping of erosion and sediment transport for non-gauged tributaries are rarely available at annual time scales. The period from July 2006 to October 2014 was used for the budget described here and matched the flight dates of the available LiDAR datasets. The budget period roughly corresponds to eight water years (WY 2007 through WY 2014) and is not ideal given the short period relative to variability in channel processes, and given that it corresponds to a relatively dry period. Unfortunately, a sediment budget during a dry period provides limited information on sediment dynamics because it does not capture extreme events that dominate decadal sediment supply and channel form in California coastal basins (e.g. Bigelow et al., 2008; Ellen and Wieczorek, 1982; Nolan et al., 1987; Griggs, 1987; Hecht, 1993), often triggered in warm and wet El Niño years (e.g. Inman and Jenkins, 1999). For example, Arroyo Mocho is tributary to Alameda Creek, where a single flood event comprised 48% of the total load over a 13-year period (Brown and Jackson, 1973). Still, given the constraints of a dry period or drought sediment budget, some information on sediment dynamics can still be inferred for wetter periods that include large events, when the bulk of geomorphic work occurs. This study constructs a sediment budget using average annual metric t as the basic unit for a time period of eight years.

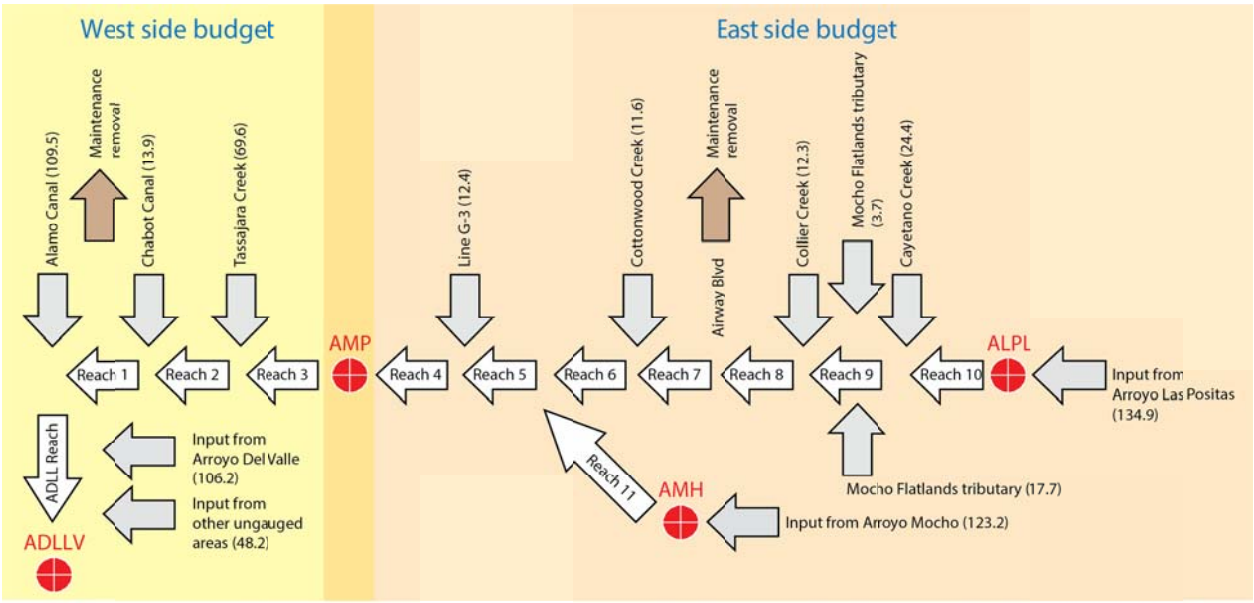
Two sediment budgets were developed; an “East side” budget and a “West side” budget to make best use of the available data. All sources, sinks, and loads could be accounted using available data for the East side of the basin, whereas the mass associated with some terms in the West side budget had to be estimated by difference. For the East side budget, the upstream boundaries of the channel sediment budget were set as the cross sections at each of the two upstream gauging locations: Arroyo Las Positas at North Livermore Avenue Bridge (ALPL), and Arroyo Mocho off Stanley Boulevard between El Charro Road and Kitty Hawk Road at Hagemann Bridge (AMH). The downstream boundary of the East side budget was set as the cross section at Arroyo Mocho at Pleasanton at Santa Rita Road Bridge (AMP). Sediment flux at the upstream boundary gauge locations was summed and averaged for the eight year period along with estimates of sediment entering the mainstem channel from the main tributary sub-watersheds, sediment removed by maintenance, and sediment either eroded or deposited

within East side budget reaches. This budget was divided into eight smaller reaches, based upon tributary confluences or other important features controlling how sediment was entering or leaving the system (Table 1). Dividing the budget in this way allows for the possibility of assessing the influence of sediment supply from each major tributary that enters the mainstem throughout the length. This budget can be referred to as "closed" – that is, all major inputs, storage, and losses to this length of channel have been accounted for (Figure 3; Equation 1).

Table 1. Sediment budget channel reaches for the two budgets.

Reach number	Downstream boundary	Upstream boundary	Drainage basin area draining to the downstream boundary (km^2)
West side sediment budget			
ADLL	Arroyo de la Laguna at Verona gauge station (ADLLV)	Confluence of Arroyo Mocho and Alamo Canal	657.8
1	Confluence of Arroyo Mocho and Alamo Canal	Chabot Canal	446.0
2	Chabot Canal	Tassajara Creek	431.5
3	Tassajara Creek	Arroyo Mocho at Pleasanton gauge station (AMP)	361.6
East side sediment budget			
4	Arroyo Mocho at Pleasanton gauge station (AMP)	Line G-3	358.8
5	Line G-3	Confluence of Arroyo Mocho and Arroyo Las Positas	346.4
6	Confluence of Arroyo Mocho and Arroyo Las Positas	Cottonwood Creek	213.8
7	Cottonwood Creek	Airway Blvd	200.4
8	Airway Blvd	Collier Creek	199.3
9	Collier Creek	Cayetano Creek	186.3
10	Cayetano Creek	Arroyo Las Positas at Livermore gauge station (ALPL)	138.4
11	Confluence of Arroyo Mocho and Arroyo Las Positas	Arroyo Mocho at Hagemann bridge (AMH)	131.9

Separately we completed the West side sediment budget for channel processes downstream from the AMP gauge, extending beyond the study focus area downstream to the Arroyo de la Laguna at Verona (ADLLV) USGS gauge station. This budget is also "closed" – that is all major inputs, storage, and losses to this length of channel have been accounted for (Figure 3; Equation 2). However, the budget does include unknowns, or elements for which data was not collected or analyzed during this study (e.g. sediment supplied from ungauged downstream tributaries). Despite adding unknowns into the budget, extending the West side budget to ADLLV allows for incorporation of USGS-collected sediment data. Setting up two budgets in this manner provides a framework that maximizes the use of all the available data while minimizing indeterminable imbalances associated with unknowns and errors.



Equation 1- East side budget

Input from gauged tributaries (ALPL and AMH)
+
Input fron non-gauged tributaries (Cayetano Creek, Mocho Flatlands tributaries, Collier Creek, Cottonwood Creek, Line G-3)
-
Total sediment exports (AMP and sediment removal via maintenance)
-
Channel sediment deposition/erosion
=
Residual

Equation 2- West side budget

Input from gauged tributaries (AMP)
+
Input fron non-gauged tributaries (Tassajara Creek, Chabot Canal, Alamo Canal)
-
Total sediment exports (ADLLV and sediment removal via maintenance)
-
Channel sediment deposition/erosion
=
Residual (Input from Del Valle, input from other ungauged area, channel sediment deposition/erosion in ADLL)

Figure 3. Sediment budget structure and equations. Drainage basin area (km^2) of each tributary shown in parentheses.

3. Results

3.1. Total sediment inputs

3.1.1. Total sediment inputs from gauged tributaries

3.1.1.1. Methods

In order to develop a sediment budget for the project area for the period WY 2007 to 2014, an estimate of total sediment inputs into the project area was needed. We used daily and annual flow data from the Zone 7 Water Agency for the period of interest at the two gauge locations (ALPL and AMH) that form the upper boundary inputs for the sediment budget. Suspended sediment and bedload sediment load was measured at the same gauge locations for a shorter period of five years from WY 2011 through WY 2015. Since the LiDAR data were only available through to 2014, the budget period ended in 2014 despite sediment loads data being available for 2015. However, 2015 data were used to generate the rating equations that were subsequently used to estimate loads during years when only flow data were available. As described in detail in Appendix 7.3, these load measurements were based on 5 to 15 minute-interval stage and turbidity measurements, and flow and suspended sediment rating curves based on velocity and suspended sediment concentration, and bedload samples collected during storm events. Estimates for WY 2007 to 2010 (the unmeasured years) were made based on an annual rating curve between the annual measured flow volume and annual wet season loads of suspended and bedload sediment (Figure 4). Monthly rating curves were also tested and found to give similar results. However, previous analyses for the Bay Area as a whole demonstrated that annual rating curves are appropriate for estimating annual average loads over the long term (McKee et al., 2013). The average grain size of the total sediment load was determined by disaggregating the continuous suspended and bedload records at each of the sites for the measured five year period into the grain size distribution of those loads based upon estimates of grain size in relation to flow (determined using regression of grain size distribution for measured suspended and bedload samples versus instantaneous flow). Note that the relationships between discharge and grainsize in each fraction were logical but not strong; typical of this type of data.

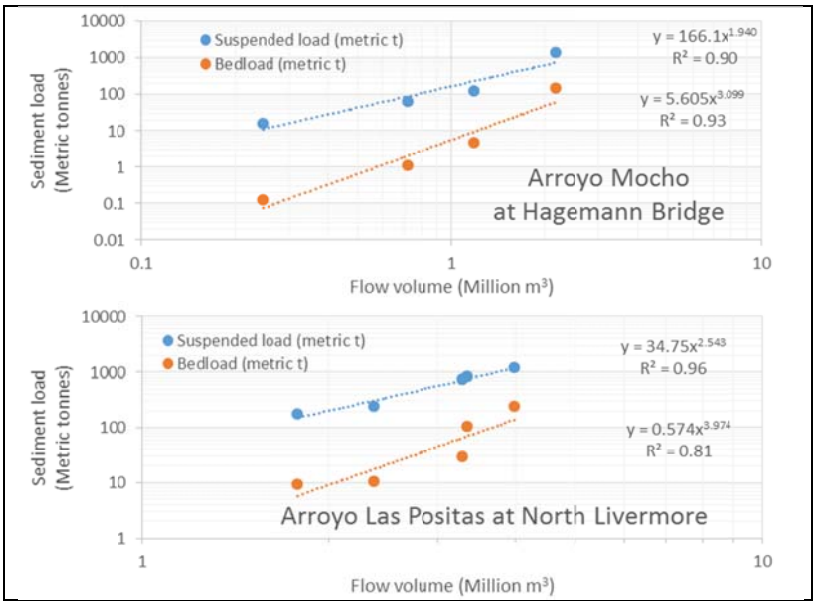


Figure 4. Relationships between annual flow volume and suspended and bedload transport for the wet season at the two upstream gauges. Note, dry season loads were assumed to be a minor part of the budget and not included (see McKee et al., 2003 for a detailed explanation).

3.1.1.2. Uncertainties

The uncertainties in suspended sediment loads are usually lesser than those for bedload due to the more ephemeral nature of source activation and transport of bedload, but also due to the difficulty of measurement. Bed load records are computed from a rating curve that is usually based on few dozen spot measurements each year whereas suspended sediment loads were estimated using turbidity surrogate regression – a relatively accurate measure based on 10s of thousands of turbidity measurements. Assuming the flow gauging records are accurate, the suspended sediment loads data for WYs 2011-2015 should be considered reasonably accurate although there were some challenges; the measured bedload for the same period should be considered less accurate (see appendix 7.3 for details).

The available suspended sediment and bedload data for WY 2011 to 2015 are representative of a relatively dry period compared to the last 40 years (Figure 5). Consequently there is a great deal of uncertainty when inferring spatial patterns of sediment supply from dry years to wet years including large floods that dominate decadal sediment supply and the bulk of geomorphic work occurs, this is discussed in detail later. The average flow at the Arroyo De La Laguna at Verona gauge (ADLLV; USGS gauge number 11176900) for WYs 2007 to 2014 was 49 cfs and 68% of the average flow for WYs 1976 to 2015 (73 cfs). However, flows during the unmeasured period of WY 2007 to 2010 were of a similar magnitude to those of the measured period WY 2011 to 2014 (Figure 5). For example, average flow for WYs 2007-2014 (49 cfs) compared closely to average flows for WYs 2011-2014 (48 cfs). Therefore, although there are always uncertainties with estimating sediment loads for periods with no records, in this case those uncertainties are lesser than what could have been if we had needed to compute loads for

much wetter climatic periods (e.g. the winter seasons of 1982, 1983, 1986, 1998, or 2006); the uncertainties of estimating sediment loads for these years would be very large given the non-stationary nature of rating curves in coastal California watersheds (Warrick, 2015). Similarly, the recurrence interval of peak flow for 2008 and 2010, the largest single storms during the budget period, were 1:7 and 1:6 respectively, not too dissimilar to peak flows during the measured period and substantially smaller and of more frequent recurrence than flows experienced during wetter periods (e.g. 1998 and 2006 which both have a recurrence interval of about 1:15 years).

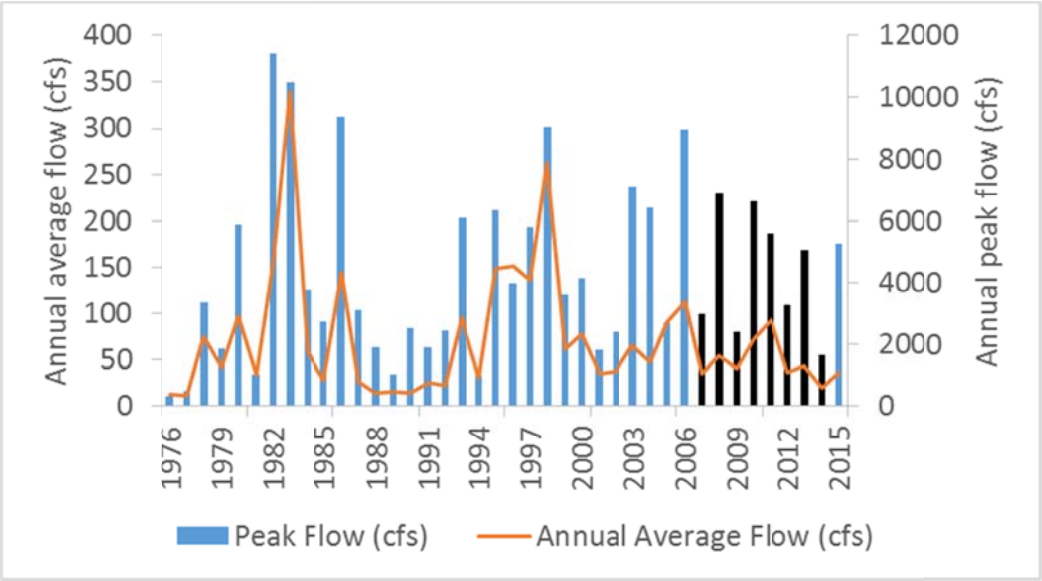


Figure 5. Flow characteristics at Arroyo De La Laguna at Verona (ADLLV) over the past 40 years. Data shown from 1976 to 2003 are from USGS gauge 11177000 Arroyo de la Laguna at Pleasanton; data from 2004 to 2015 are from USGS gauge 11176900 Arroyo de la Laguna at Verona, which is the newer location after the previous gauge location washed out. The black bars indicate the budget period. Based on instantaneous peak annual flows for WY 1970-2014 (absent 1984-1987) the recurrence interval of peak flow for 2008 and 2010, the largest single storms during the budget period are indicated and were 1:7 and 1:6 respectively. Storms of this magnitude were much more frequent than peak flows of 2006 (1:15) or 1982 (1:25).

3.1.1.3. Results

Computed suspended sediment loads based on field measurements ranged between 177 and 820 metric t per year for Arroyo Las Positas at Livermore (ALPL) and 16 and 1,409 metric t per year for Arroyo Mocho at Hagemann (AMH) for water years 2011 through 2014 (Table 2). Computed bedload for the same water years provided an additional 0.8% to 11% of loading at the sites in relation to total load. Based on grain size analysis completed on field samples, an

estimated 9.5% of the sediment transported from the upper Mocho watershed into the downstream flood control channel was in the sand size fraction (62.5 µm to 2 mm) and 2.9% was in the gravel size fraction (>2 mm). The loads coming in from Arroyo Las Positas were slightly coarser than those from the Mocho watershed with an estimated 10.3% sand size (62.5 µm to 2 mm) and an estimated 4.1% gravels (> 2 mm). Total loads estimated using annual regression with flow for water years 2007 through 2010 were much greater than those during the measured period. Based on these measurements and estimates, annual average total sediment loads for water years 2007 through 2014 were 2,061 metric t for ALPL and 720 metric t for AMH. The loads estimated for ALPL were considerably larger than the average for the observed period adding to uncertainties. Normalized to the watershed areas upstream from these gauges, these represent yields of 14.9 and 5.9 t/km^2/yr for ALPL (138 km^2) and AMH (123 km^2) respectively.

Table 2. Measured and estimated discharge (million cubic meters) and total sediment loads (metric tonnes) at upstream gauges Arroyo Mocho at Hagemann (AMH) and Arroyo Las Positas (ALPL) at Livermore during Water Years 2007 to 2014.

Water Year	ALPL (138 km^2)				AMH (123 km^2)			
	Annual Discharge (Mm^3)	Suspended load (metric t) [%]	Bedload (metric t) [%]	Total sediment load (metric t)	Annual Discharge (Mm^3)	Suspended load (metric t) [%]	Bedload (metric t) [%]	Total sediment load (metric t)
2007	4.24	*1,369 [88]*	*179 [12]*	*1,548*	0.49	*41.9 [98]*	*0.6 [2]*	*42.5*
2008	5.37	*2,496 [85]*	*457 [15]*	*2,953*	2.11	*710 [93]*	*57 [7]*	*767*
2009	5.90	*3,173 [83]*	*665 [17]*	*3,838*	1.70	*464 [94]*	*29 [6]*	*493*
2010	7.18	*5,219 [78]*	*1,447 [22]*	*6,666*	3.99	*2,432 [86]*	*408 [14]*	*2,840*
2011	3.29	732 [96]	29 [4]	760	*1.84**	*539 [94]*	*37 [6]*	*576*
2012	2.37	236 [96]	10 [4]	247	0.72	63 [98]	1 [2]	64
2013	3.35	820 [89]	102 [11]	921	2.17	1,409 [91]	143 [9]	1,553
2014	1.78	177 [95]	9 [5]	186	0.25	16 [100]	0 [0]	16
Average	4.19	1,713	348	2,061	1.66	644	76	720

Note, all data are provided to at least two significant figures (where possible) to allow data post-processing by others and do not represent a claim of relative accuracy or precision.

Red = estimated using annual rating curve (see methods section)

** Indicates missing discharge estimated using a ratio to flow downstream at Arroyo Mocho at Pleasanton gauge (AMP).*

3.1.2. Total sediment inputs from non-gauged tributaries

3.1.2.1. Methods

Sediment supply from the many ungauged small tributaries that enter the mainstem channel within the project area was estimated using the relative or generic erosion potential (GEP) component of NetMap (a digital terrain model and watershed analysis tool http://www.terrainworks.com/; Benda et al., 2009), based simply on slope, planform curvature (convergence or divergence of flow), and the size and density of vegetation. The slope and slope convergence characteristics were derived from the 2 m LiDAR digital elevation model (2006) while the vegetation height and density characteristics were derived from the raw LiDAR. See Appendix 7.4 for details.

The dimensionless GEP estimates were checked in the field and calibrated to gauge data for the budget period to provide spatially explicit estimates of sediment yield for the ungauged portions of the watershed. The original analysis (see Appendix 7.4) was calibrated using 155 metric t/km^2/yr for the ADLLV gauge (1994 to 2006). Here, we calibrated the sediment yield estimates using gauge data from our drier sediment budget period (July 2006 to October 2014) and split it into two areas: the East side, which is upstream of Arroyo Mocho at Pleasanton (AMP) and the West side, downstream from AMP. Two separate calibration values were used based on the location of gauges. An average annual yield of 9.6 metric t/ km^2 was used to calibrate GEP for the upstream (East side) basin based on estimated loads for the AMP gauge station during that period. An average annual yield of 77 metric t/ km^2 was used to calibrate GEP for the downstream (West side) basin based on estimated loads for the ADLLV gauge station. This value is the difference in loads at ADLLV (30,089 metric t) and AMP (3,544 metric t) from WYs 2007-2014, divided by the unregulated watershed area downstream from AMP flowing to ADLLV (344.5 km^2). Calibration to the ADLLV gauge assigns a larger mass of sediment to the west side tributaries, reflecting the wetter climate on west side of the basin during the budget period (see later discussion on the precipitation gradient).

3.1.2.2. Uncertainties

Like all geospatial tools and models, this approach can be adapted and improved for specific applications and objectives. The estimated sediment yield for ungauged portions of the basin represents an average condition using only topographic and vegetation attributes that characterize chronic (annual or persistent) sediment supply, primarily from bare steep channel banks. However, sediment supply in many landscapes is highly variable in both space and time resulting from episodic processes driven by interactions among storms, vegetation, and topography (Benda and Dunne, 1997). In the San Francisco Bay region, episodic mass wasting triggered during El Niño storms can dominate decadal sediment supply (Ellen and Wieczorek, 1982; Bigelow et al., 2008). Accounting for these episodic mass wasting sources within NetMap would require further calibration and adjustment, for example, simply using digitized maps of

active earthflows and local literature values of earthflow rates to appropriately increase the sediment yield estimates at these discrete locations within the watersheds (e.g. GMA, 2007; Bigelow et al., 2013). Such accounting may not be an important factor for this present study since it was a relatively dry period. Another weakness of the model is the use of linear scaling. It is conceivable that more erosive areas of a watershed may exhibit much greater variation in erosion and sediment production between years of contrasting climate than less erosive areas. Linear scaling forces the assumption that sediment production from all sub-watersheds is equally variable between drier and wetter climatic years for all geological types.

Overall, the NetMap model provides a good estimation method for total load of sediment. There is no provision in the model for estimating sediment grain size. However, sediment transport and depositional processes are strongly linked to sediment grain size; coarse sediment tends to be trapped closer to eroding source areas and within flood control channels more preferentially than fine sediment. In addition, sediment can change size through abrasion during transport; more indurated lithology may produce coarse materials whereas sediment eroded from areas of weaker lithology may abrade to smaller size fractions within relatively short distances. These potential weaknesses accepted, NetMap was calibrated using local sediment gauging data to make estimates for total sediment transport to the mainstem channels for the study location and budget period.

3.1.2.3. Results

The NetMap analysis aggregates sediment supply estimates down to the channel and through the network so that upstream sediment contribution at any point on the channel network can be estimated. Table 3 summarizes the estimated sediment supply for the ungauged tributaries to the sediment budget reach, providing estimates for the ungauged component of the sediment budget (see Section 3.3). Normalized to area, the NetMap model predicts that sediment production from the east side tributaries excluding the flatter areas varies 2-fold. These tributaries incorporate a variety of land uses (urban, rural residential, vineyard, grazing, open space), underlying geology (Livermore gravels, Tertiary sedimentary formations, etc.), and topography (steep uplands, gentle lower portions) which help to explain the variation in sediment production. The tributaries on the west side are estimated to produce much greater annual loads per unit watershed area in relation to approximately twice the annual average rainfall and associated runoff (based on gauge data, see discussion for more details). While NetMap does not predict grain sizes, very brief field reconnaissance suggests that the northern tributaries (Cayetano, Collier, Cottonwood Creeks, Line G-3 and Chabot Canal) contribute finer-grained material as compared to Arroyo Mocho upstream of Hagemann and even compared to Tassajara Creek (of note, Alamo Canal was not observed).

Table 3. Average annual NetMap-estimated sediment supply, calibrated to 9.6 metric t/km^2 for the East side tributaries upstream from the Arroyo Mocho at Pleasanton gauge station (AMP) and to 77 metric t/km^2 for the West side tributaries.

Tributary	Area (km^2)	Average annual sediment supply (metric t)	Average sediment yield (t/km^2/y)
East side tributaries			
Cayetano Creek	24.4	225	9.2
Lower Mocho flatlands tributary- downstream of Cayetano	3.7	40	10.8
Lower Mocho flatlands tributary- south side draining Livermore	17.7	39	2.2
Collier Creek	12.3	150	12.2
Cottonwood Creek	11.6	147	12.7
Line G-3	12.4	80	6.5
West side tributaries			
Tassajara Creek	69.6	4,557	65.5
Chabot Canal	13.9	714	51.4
Alamo Canal	109.5	5,291	48.3

3.2. Total sediment load export

3.2.1. Export via channel transport

3.2.1.1. Methods

To estimate total sediment transport via the channel out of the project area for the budget period (July 2006-October 2014), we used daily and annual flow data from Zone 7 for the Arroyo Mocho at Pleasanton (AMP) gauge, the lower boundary for the East side sediment budget. Suspended sediment and bedload sediment load has been measured at this gauge for a period of five years from water year 2011 through water year 2015. Estimates for water year 2007 to 2010 (the unmeasured years) were made based on an annual rating curve between the annual measured flow volume and measured wet season load (Figure 6) in a similar manner as for the ALPL and AMH gauge locations. The average grain size was also estimated using the technique described above for the ALPL and AMH gauges.

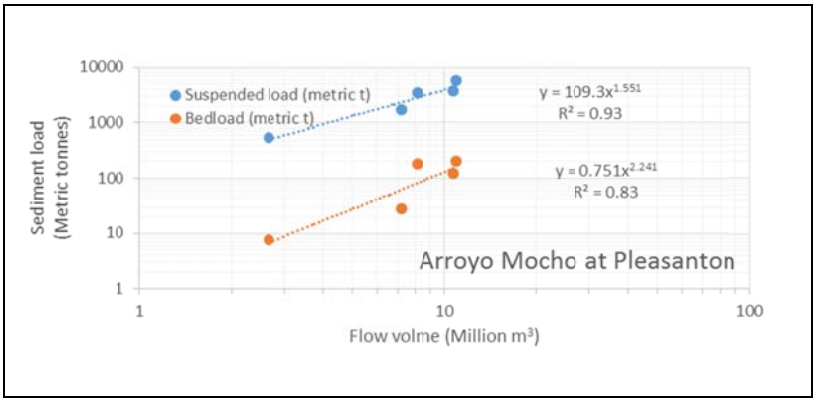


Figure 6. Relationships between average annual flow and suspended and bedload transport for the wet season at the Arroyo Mocho at Pleasanton (AMP) gauge location. Note, dry season loads were assumed to be a minor part of the budget and not included (see McKee et al., 2003 for a detailed explanation).

3.2.1.2. Uncertainties

The uncertainties of this budget term are similar to those described above for the Arroyo Las Positas (ALPL) and Arroyo Mocho at Hagemann Bridge (AMH) gauges. These include the uncertainties in computation of suspended sediment loads and bedload for the water years when measurements were taken (WYs 2011-2015) and uncertainties associated with extrapolation of those data using annual rating curves when only flow measurements were made (WYs 2007 to 2010). As discussed above, since the flow characteristics for the unmeasured years were not too dissimilar to the measured years, the uncertainties are likely more minimal than if unmeasured years had sustained much higher discharges, and the dry weather rating curves had been used to estimate wet weather conditions.

3.2.1.3. Results

Computed suspended sediment loads based on field measurements ranged between 533 to 5,755 metric t per year for AMP (Table 4). Computed bedload for the same water years provided an additional 1.4 - 3.4% of loading in relation to total load. Based on grain size analysis completed on field samples, an estimated 8.4% of the sediment transported from the watershed into the downstream flood control channel was in the sand size fraction (62.5 µm to 2 mm) and 1.5% was in a size fraction >2 mm (gravels or larger). Total loads estimated using annual regression with flow for water years 2007 through 2010 were 37% larger than those during the measured period. Based on these measurements and estimates, annual average total sediment loads for water years 2007 through 2014 were 3,544 metric t at this gauge location. Normalized to the watershed area upstream (368 km^2) this annual average load is equivalent to an average annual yield of 9.6 $t/km^2/yr$.

Table 4. Measured and estimated flow (million cubic meters) and sediment loads (metric tonnes) at Arroyo Mocho at Pleasanton (AMP) during Water Years 2007 to 2014.

Water Year	AMP (368 km^2)			
	Discharge (Mm3)	Suspended load (metric t)	Bedload (metric t)	Total sediment load (metric t)
2007	6.31	*1,903 [98]*	*47 [2]*	*1,950*
2008	9.19	*3,412 [97]*	*108 [3]*	*3,521*
2009	10.16	*3,985 [97]*	*136 [3]*	*4,121*
2010	13.87	*6,456 [96]*	*272 [4]*	*6,729*
2011	10.97	5,755 [97]	201 [3]	5,956
2012	7.23	1,650 [98]	28 [2]	1,678
2013	10.75	3,736 [97]	120 [3]	3,856
2014	2.66	533 [99]	7 [1]	541
Average	8.89	3,429	115	3,544

Note, all data are provided to at least two significant figures (where possible) to allow data post-processing by others and do not represent a claim of relative accuracy or precision.

Red = estimated using annual rating curve (see methods section)

3.2.2. Export via sediment maintenance and removal

3.2.2.1. Methods

Data on sediment removal from the channel system was compiled from reports by Zone 7 Water Agency and the City of Livermore[3]. The Cities of Pleasanton and Dublin do not perform any channel maintenance as the reach of Arroyo Mocho flowing through their city limits is maintained by Zone 7. Data from removal events were provided either in tons or in cubic yards. Data were converted using separate density factors for suspended and bed loads based on experiences in another Bay Area watershed (Table 5). See Uncertainties section below for caveats around usage.

Table 5. Conversion factors for sediment between mass measurements and volumetric measurements (After: NDC, 2010).

	Conversion factors		
	US t/yd^3	**yd^3/metric t**	**yd^3/US t**
Suspended loads	1.25	0.73	0.80
Bed loads	1.4	0.65	0.71

Use of these conversion factors for conversion of the fluvial loads data is not recommended without verification of utility for this purpose.

3.2.2.2. Uncertainties

As a general rule, our experience with many Cities, Counties and Flood Control Districts is that sediment removal data, including date, location, volume (or mass), cost, grain size, and fate is generally not recorded in a central database, and thus is not well documented. Data are typically housed with individual project records, or sometimes may not even be recorded, and often are forgotten or lost as staff turnover or retire, or older paper records are discarded. These type of data losses cause a low bias in the estimate of total sediment removed. However, because the sediment budget period is recent, and staff that conducted the removals are still employed, the removal records are much more reliable than for an earlier time period. The data relevant to constructing a sediment budget (date, location, volume/mass) was available for most records gathered. Information about grain size was not available for any records. Although not critical for the budget, grain size information can assist in understanding the type of sediment that is deposited in-channel, so that inferences about source or deposition timing can be made. We recommend that grainsize information be generated and documented for all future sediment removal events.

Conversion of data between volumetric units and mass units requires a conversion factor. We were not able to find a watershed specific conversion factor for the Zone 7 Water Agency

[3] Pamela Lung and her staff at the City of Livermore are acknowledged for making the data so readily available and for answering clarifying questions promptly.

facilities. In the absence of locally generated factors for sediment of varying grainsizes, the mass density estimates from another Bay Area watershed was assumed (NDC, 2010). Differences in geology underlying the watershed would likely influence the accuracy of this assumption but since the removal numbers are relatively small compared to the other budget elements, this accuracy concern does not pose a problem; the use of these conversion factors for other budget elements is not recommended without some verification.

3.2.2.3. Results

Only a relatively small volume of sediment has been removed from the study reach during the budget period. Removal has only occurred at two specific locations in the budget reach; the Airway Blvd bridge crossing and the sediment basin at the Arroyo Mocho and Las Positas confluence (Figure 7 and Table 6). Although grain size information was not collected during these removal events, observation at these locations and best professional judgment suggest that the material removed was likely primarily sand and fine gravel. Larger volumes of sediment have also been removed at two additional locations upstream of the Arroyo Mocho at Hagemann (AMH) gauge, outside of the budget reach. Thus, we are aware of the removal activities, however cannot account for them within this sediment budget. In addition, the City of Livermore reports that in the reach extending 200' upstream of Airway Blvd that an additional 80,000 CY of sediment is currently in storage and has been considered for removal, but removal is currently prohibited by cost and mitigation requirements (P. Lung, pers. comm). Removals outside of the budget area and pending removals were not included in our budget but are of interest as indicators of sediment production and problem areas. In the future, collecting grainsize information at all these locations would be useful for learning about transport and depositional processes.

Figure 7. Sediment removal locations. Removal locations within the budget reach shown with yellow dots, locations upstream of the budget reach shown with green dots. Sediment gauging locations are shown with red circles.

Table 6. Sediment removal total weight and volume for the budget reach during the period July 2006 to October 2014. Data in italic font has been converted using the factors in Table 5.

Location	Year(s)	Volume (CY)	Estimated weight (metric t)	Source
Sediment basin at the confluence of Arroyo Mocho and Arroyo Las Positas	2007	~100*	*~140*	Zone 7 Water Agency
Arroyo Las Positas at Airway Blvd.	2006	2,700	*3,860*	City of Livermore
TOTALS		2,800	*4,000*	
Average Annual Total		350	500	
Removal occurring at locations outside of the sediment budget reach:				
Sediment basin at the downstream end of Stanley Reach	2007 and 2013	6,200	*8,860*	Zone 7 Water Agency
Arroyo Mocho at Holmes Street	2006-2014, excluding 2013	*9,070*	12,950	City of Livermore
TOTALS (outside budget reach)	2006-2014	15,270	21,810	
Average Annual Total (outside budget reach)		1,910	2,730	

*Verbally reported data (J. Seto, pers. comm) that was not recorded in Zone 7 records.

3.3. Total in-channel sediment deposition/erosion excluding the low flow channel

3.3.1. Methods

Estimates of the total amount of sedimentation change (deposition or erosion) that occurred in the channel, but excluding the low flow channel, within the project area were made on a reach average basis using LiDAR data. The LiDAR data from July 2006 and from October 2014 were clipped to a buffered area around the channel, and then a "difference map" was created, simply comparing the ground surface elevation of each pixel in each time period and outputting the difference in elevation (Figure 8, part A). Then, in ArcGIS, polygons were created for the area of interest (the channel area), that is from the top of bank to the opposite top of bank (Figure 8, part B). Any changes in elevation occurring outside of this polygon were not considered.

Water was present in the low flow channel in 2006, however LiDAR does not penetrate the water column, thus this created an artificial flat elevation (the water surface) across the channel bed (Figure 8, part C). The 2014 data was flown when there was very little to no flow in the channel, and represents the actual channel bed for much more of the study area. Thus, when calculating the difference between the two time periods, a zone of artificial incision is created in the channel thalweg, caused by the decrease in elevation from the 2006 water surface to the 2014 bed elevation. This zone was large enough to skew any results, so another polygon was created that represents the water surface area in 2006 (Figure 8, part D).

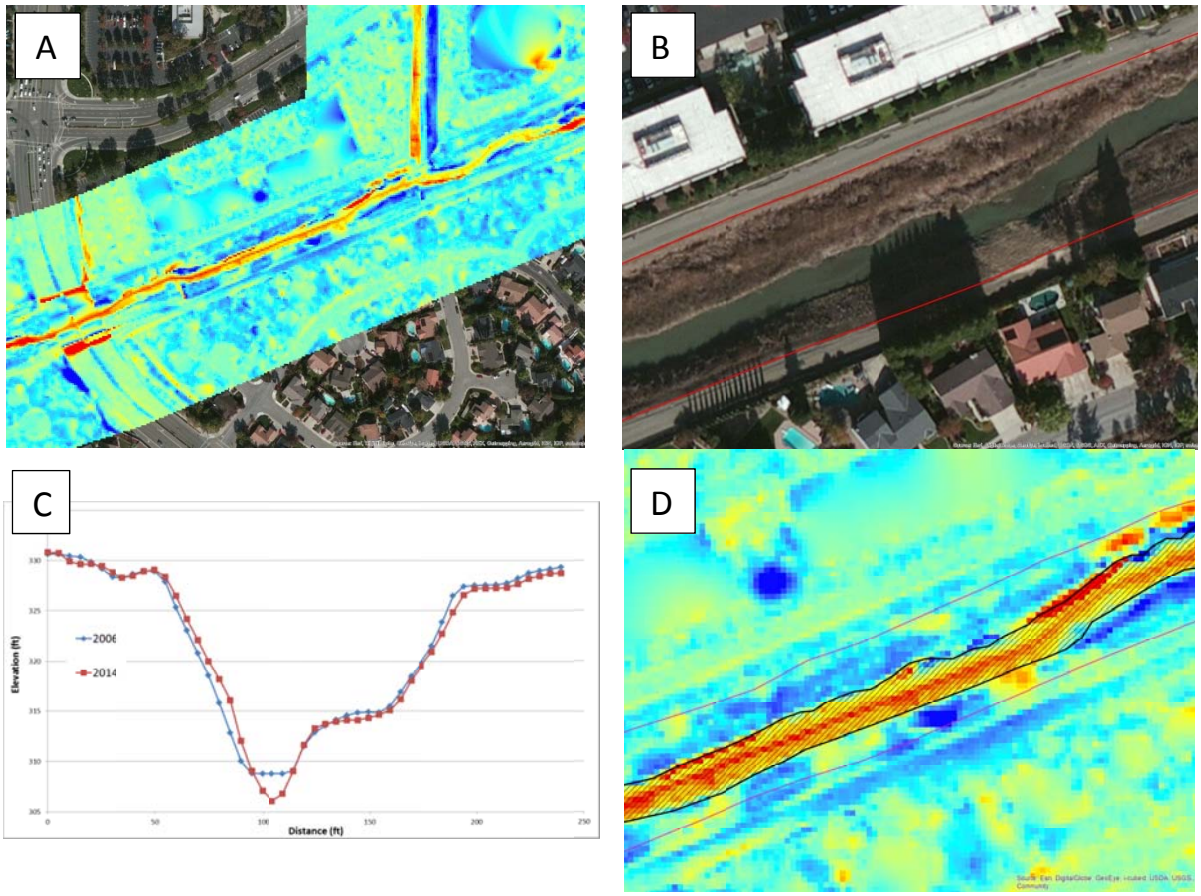


Figure 8. LiDAR data and methodology for calculating channel deposition and erosion. A) The "difference map" showing the change in elevation for each pixel between 2006 and 2014. Red indicates incision or lowering of the pixel elevation, while royal blue indicates aggradation, or increased pixel elevation. B) The channel area polygon bounding the area of interest. C) LiDAR-generated cross sections illustrating the water surface elevation present in 2006. D) The area of surface water in the black hatched polygon that was removed from the calculations. Here, red indicates approximately 3-5 ft (0.91-1.52 m) of incision, light blue indicates 0-0.5 ft (0-0.15 m) of aggradation, and royal blue indicates 2-4 ft (0.61-1.22 m) of aggradation.

For each budget reach, ArcGIS calculated the mean change in elevation for the channel area minus the water surface area. Thus, the area of the low flow channel was excluded from the analysis. The mean elevation change was multiplied by the reach area, converted to metric t using the conversion factors in Table 5 above, and normalized to the budget time period, so that an average annual amount of channel deposition or incision within the channel was reported. The LiDAR-generated cross section at a number of example locations within each budget reach was compared with the difference map to visualize the locations within the channel and magnitude of change.

After initial analysis of the results, the “channel area” polygons were slightly refined, and the analysis re-run. The uppermost portion of the channel cross section (nearest the maintenance roads) in the trapezoid channel reaches (Reaches 1 through 5, and Reach 8) were noted to consistently show significant deposition or erosion, depending on the reach. Given that in-channel flows during the study period have not been large, we hypothesized that any change occurring above the largest observed flows represent either channel maintenance activities, bank sloughing, or more likely errors in the LiDAR dataset. We wanted to remove these factors from the analysis, and only capture channel change related to the climatic conditions experienced during the budget period. Unfortunately stage has only been observed in three locations (the gauge stations) in the study area, however these locations do provide an opportunity to plot the highest stage observed in that channel cross section.

Using the peak stage elevations for 2008 (the largest flow during the study period), the five measured years at the AMP gauge (Figure 9) and best professional judgment, new narrower “channel area” polygons were created for each of the reaches that are trapezoidal channels to represent the area that had experienced flow during our budget period. Admittedly, extrapolating from a single location is not very accurate, however the polygons were drawn as consistently as possible, relying upon spot cross sections to check on channel morphology and upon field experience. These more narrow polygons were only created for the trapezoidal channel reaches; in these reaches, the angle of the bank likely prevents significant bank erosion due to flood water interactions with the toe of the slope. In contrast, the more natural reaches tend to have steeper banks, and in some cases vertical banks, where the likelihood of bank erosion due to scour at the toe of the slope is much higher. Additionally, the more natural reaches often had significant woody riparian vegetation, preventing observation of channel features on the aerial photographs. Therefore, the narrower “channel area” polygons created in the second analysis were used for reaches 1-5 and 8, while the wider top-of-bank polygons were used for the more natural reaches 6, 7, 9, 10, and 11.

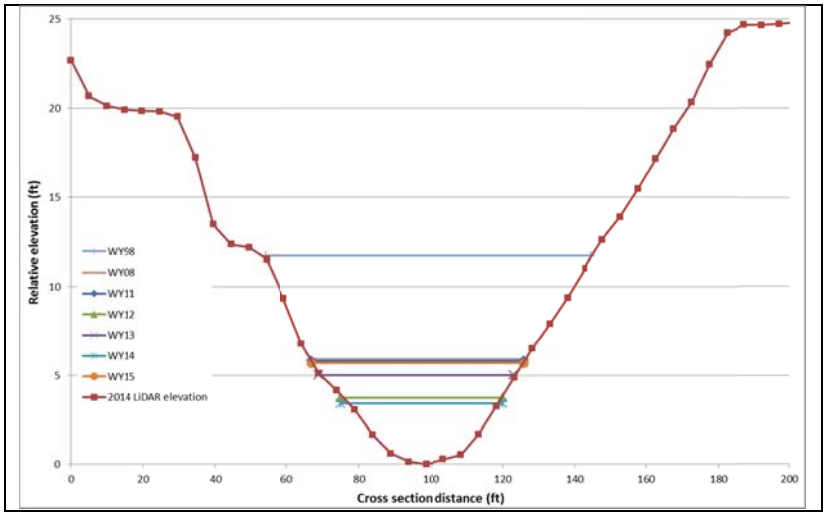


Figure 9. Arroyo Mocho at Pleasanton (AMP) gauge station channel cross section (plotted looking downstream) showing the peak stage observed during select water years (estimated using gauge offsets). For reference, the 1998 peak stage is shown, just reaching the inside edge of the lower maintenance road.

3.3.2. Uncertainties

The reported vertical error at a 95% confidence interval for the 2006 LiDAR data is +/- 0.59 ft (18 cm). Based on the reported error, we estimate the mean error (root mean square, or RMS) to be 0.59 ft/1.96, or 0.30 ft. The 2014 LiDAR error was unavailable and assumed to be the same as for the 2006 dataset given no major technological changes to the methods since 2006. Given the difference interpretative method employed (estimating elevation change based upon difference between datasets), the amount of vertical elevation change observed on average would need to be 1.18 ft or greater for it to be considered outside of the errors of the data set and interpretative method. This of course is the worst-case scenario, and most likely is much smaller. However, any vertical changes of 1.18 ft or less are essentially indistinguishable from no change.

Data for this element in the budget are calculated in cubic feet. In the absence of locally derived conversion factors, volumes calculated were then converted to mass using a conversion factor of 0.65 yd^3/metric t (NDC, 2010) (See caveats of use from Table 5 above). The conversion factor for bedload sediment, rather than suspended sediment, was chosen, although sediment deposited in channel likely is deposited on the falling limb of the hydrograph, and represents both coarse and fine sediment.

The water surface in the 2006 LiDAR data set prevents any comparison of channel change that has occurred within the low-flow channel (approximately one-third of the total channel area); the data simply do not exist to support those analyses. Thus, the amount of sediment either in storage or eroded from the channel reported here in this budget is not complete. This potentially could be a significant volume, as compared to the volume for deposition/erosion occurring within the inner bench portions of the channel area.

To address any potential bed elevation change that has occurred, the team attempted to gather any surveyed cross sections, or repeat cross sections within the budget reach. Unfortunately no cross sections exist, either at Zone 7 (J. Seto and J. Tang, pers comm) or at the City of Livermore (Pamela Lung, J. Waxdeck, pers comm). Zone 7 did have some surveys completed for maintenance projects, however upon closer inspection, we found that the sections stopped at the toe of slope, and did not include any portion of the low-flow channel (J. Tang, pers comm). Also, survey data collected in 2007 by local survey company Kier and Wright exist, but for reaches upstream of the budget reach on Arroyo Mocho in Livermore (J. Seto, pers comm).

Additionally, to place the observed changes in sediment storage within the channel into a longer-term context, the original as-builts for the reach of channel downstream of the Mocho-Las Positas confluence were requested but unavailable. Had they been available, by overlaying the contemporary cross section on the as-built, volumes of aggradation or incision could have been computed. However, likely due to the complex history of draining the Pleasanton Marsh

complex and the many generations of channel creation and modification (see Appendix 7.5), as-built drawings do not exist for the study area.

In the future, the use of bathymetric LiDAR could be explored to provide data for the low flow channel area that is under water. The data could then be combined with the traditional LiDAR data to estimate the total amount of change across the entire channel width.

3.3.3. Results

The calculated values of average elevation change for each reach are very small; the smallest amount of change is 0.008 ft (0.26 cm) while the largest amount of change was 0.49 ft (15 cm). Most importantly, the average value for each reach was always significantly smaller than the maximum potential error (1.18 ft) and also smaller than the potential RMS error (0.60 ft). This result does not significantly change by either using the wider polygons, which incorporate the entire channel area from top of bank to top of bank, or by using the more narrow polygons that only incorporate the area that has experienced flow during the budget period. Although there is no significant difference, we believe that limiting the analysis area to the portion of the channel that has experienced flow wherever we can is more valid than using the top of bank. Thus, we report results using the more narrow polygons for the trapezoidal channel reaches. , Volume and mass of calculated change for each reach is reported in Table 7. Only four of the eleven reaches were calculated to have sediment deposition during the budget period. The majority of the reaches are calculated as having net sediment erosion, either from lowering of in-channel surfaces, or from bank erosion. Combining all reaches together, the calculations show net erosion of sediment from the study reach during the budget period. These results do not necessarily match observations by Zone 7 staff or previous consultants (Ayres Associates, 2001); the previous reconnaissance efforts suggest that reaches 1, 2, 8 and the lower portion of 9 should all be showing deposition. Although the LiDAR data represent a drought period, where not much deposition or erosion are expected, the LiDAR data is showing mixed results for the reaches, not necessarily matching the previous observations.

The greatest amount of vertical change calculated was 0.49 ft (in reach 11), which is less than the reasonable errors associated with the data and interpretative methods. All other reaches were calculated to have lesser amounts of vertical change. Given these results, we have to conclude that the direction of change for each reach may be a random artifact of the error propagation and that net deposition or erosion at a reach scale was, in fact, indistinguishable from zero. Thus in Section 3.4 where the results of the total sediment budget are presented, we report zero volume or mass of deposition or erosion. This finding is corroborated by observations of Zone 7 staff, that during this relatively dry budget period, no significant deposition or erosion has occurred in channel. However, in the field we do see evidence of small packages of sediment deposition, including a slight coarsening of the grain size, immediately downstream of tributaries (see Appendix 7.6 for details), suggesting that sediment delivery from the tributaries is having an effect upon the mainstem channel.

Table 7. Results of 2006 to 2014 average annual change in channel deposition (blue) or erosion (red) using LiDAR. See Table 1 for reach locations.

Reach	Average annual volume of change (Cubic yards)	Average annual mass of change (Metric tonnes)	Direction of change	Distinguishable from zero?
1	10	7	deposition	No
2	-26	-17	erosion	No
3	231	150	deposition	No
4	-123	-80	erosion	No
5	-350	-227	erosion	No
6	-911	-592	erosion	No
7	157	102	deposition	No
8	-457	-297	erosion	No
9	325	211	deposition	No
10	-319	-208	erosion	No
11	-2,086	-1356	erosion	No
Total	-3,549	-2307	erosion	No

Conceptually, the result of "no change observed" makes sense for a budget period dominated by drought with extremely low estimated sediment supply (9.6 t/km^2/yr). This result would suggest that the channel was able to transport all of the sediment supplied to it. Even if we were to assume no error in the LiDAR dataset, and accept the calculations as is, we still only see very small amounts of change, making this a very small element in the budget. During this period, the highest flows never accessed the inner bench surface within the channel, thus providing no opportunity for significant fluvial erosion or deposition in the lower velocity environment that could persist atop of those benches. Brief in-channel observations of current sediment deposits at these types of locations suggest that the inner bench surfaces (existing at elevations higher than the bankfull elevation) would likely have sand deposition during flood events, with localized silt or gravel patches.

It appears that the LiDAR methodology is not resolute enough to accurately measure the small amount of change that may have occurred during this relatively dry budget period. Of course, the data limitations prevent conclusive statements about potential change in the low flow channel. LiDAR may however provide the resolution for changes that occur during large water years, such as Water Year 1998. However, the issue with measuring change below the water surface would still remain even if the budget period was extended to a wetter period. It is suggested that traditional surveyed cross sections and longitudinal profiles are likely the most robust method of monitoring in-channel change especially in systems where thalweg elevation change may be occurring. Additionally, the use of bathymetric LiDAR to provide data on the channel elevation in the low flow channel could be explored.

3.4. Total sediment budget

3.4.1. Uncertainties

A sediment budget for a channel system is a simple but effective mass balance for learning about the interactive processes of sediment transport and deposition that accounts for inputs, outputs, and changes in storage within a defined area and period of time. Unlike accounting for income, expenditure, and changes in savings within your bank account, in sediment budgets each input, output, and storage-change element also incorporates errors that result from natural variability of the system, sampling design and measurement errors, and challenges with extrapolation or interpolation of available data to the spatial and temporal scale required by the budget (Parker, 1988). In order to construct a sediment budget, one must account for, recognize, and quantify the transport processes, storage elements, and linkages between them (Dietrich et al., 1982). Budget elements that cannot be quantified, or are deemed small or irrelevant relative to the management questions of interest remain present but hidden within the residual. The residual term includes unknowns and the sum of errors of each term.

Linkages between budget elements are important and provide a conceptual or numeric relationship between each element within the budget (Dietrich et al., 1982). For example, where sediment enters into the channel system, or how sediment is deposited or eroded from bars or the tops of benches when considered provide improved understanding of causative mechanisms for channel form and function. This is exemplified by considering morphologic and textural features at confluences or how flood hydrographs interact with channel cross-sections. For example, bars or packages of coarse sediment may be indicators of processes than can be modified or managed. In addition, only large floods can inundate and activate transport, erosion, and depositional processes on the tops of bars or inner benches within the channel system. Unless there is visible evidence of rotational slumps or other bank alteration features, a dry weather sediment budget may not need to consider the whole channel system. Decisions about the types of processes and linkages can affect the accuracy and interpretations of channel sediment budgets.

In addition to inclusive and accurate quantification of budget elements and linkages, definition of the appropriate averaging time for sediment budgets as well as extrapolation of available data through time has been described as one of the largest challenges with developing sediment budgets (Dietrich et al., 1982; Parker 1988; Slaymaker, 2003). For example, the sediment budget presented here was developed for the period WY 2007 through 2014 based on available LiDAR data rather than for a 20 to 30 year period that will capture the larger events that tend to dominate decadal sediment supply and channel form in Bay Area and California coastal basins (e.g. Bigelow et al., 2008; Brown and Jackson, 1973). Suspended and bedload sediment flux data was available for the period WY2011 through 2015, and was extrapolated back to 2007 using annual channel flow volume as a proxy. Sediment inputs to the mainstem flood control channel from tributaries with no available flow gauging were estimated based on the erosion potential component of terrain analysis within NetMap, a method developed simply to estimate sediment supply based on slope, planform curvature (convergent, divergent), and

the size and density of vegetation. The sediment budget presented here was not immune to the issues of averaging time and extrapolation of available data.

In the context of an appropriate averaging time, another linkage to consider is the temporal disparity between the supply of coarse and fine sediment particles to the upper reaches of the channel budget area and the removal of sediment through management efforts or loss of sediment through the downstream cross section. Since coarse sediment transport is more ephemeral and can pass down a system as a wave (Whiting et al., 1988; Madej and Ozaki, 1996), sediment that comes into the system during a particular storm event may not leave for years or even decades (Bigelow et al., 2008). For example, if the budget period starts during a dry year that postdates a series of wet years during which there were large morphological changes, channel sediment transport processes or budget element linkages may be obscured as the channel relaxes and readjusts to more normal or dry climatic regimes that can persist for extended periods in semi-arid coastal California watersheds (McKee et al., 2003). Thus, the temporal disparity between the supply and loss or removal of sediment manifests as another interpretative challenge.

This brief discussion of uncertainties should help to put the results in context but shouldn't be regarded as an indication of the lack of value that a sediment budget can bring. Challenges like those described are somewhat averaged out if the budget can be developed over a sufficiently long period or if careful thought is used when interpreting the raw results of the budget. These mismatches in time are part of the challenge of developing a sediment budget and are included in the error and uncertainty element; the residual of the mass balance. Errors and uncertainties and the challenges and implications of the budget period will be discussed further below. By far, the greatest value of completing a sediment budget is the process of reconciliation between elements and linkages within the budget. This forced reconciliation and the budget that results provides an important framework for learning about how the channel may change as a result of changing climate or management regimes; an outcome that is inherently valuable.

3.4.2. Results

The sediment budget presented here has two separate, but related components. The East side budget is defined by the three gauging locations operated within this study. The West side budget extends downstream to the USGS Arroyo de la Laguna at Verona (ADLLV) gauging station. Each budget has unique elements, unknowns, errors, and residuals.

The East side sediment budget (Table 8) is comprised of five main elements. The first element is the input of total sediment load passing into the sediment budget reach at the upstream gauge stations. Input sediment from Arroyo Las Positas, as measured at the ALPL gauge station is an average annual 2,061 metric t. Input from Arroyo Mocho, as measured at the AMH gauge station is an average annual 720 metric t. The second element is sediment contributed from the ungauged tributaries. Sediment from each tributary was estimated using the erosion potential

component of NetMap (based on slope and planform curvature), calibrated to 9.6 metric t/km^2, the value derived by dividing the measured load at AMP (3,544 metric t) by the contributing drainage basin area (367.8 km^2). This produces average annual sediment estimates of 225 metric t from Cayetano Creek, 39 metric t from the Mocho "flatlands" south side tributary, 40 metric t from the Mocho "flatlands" downstream of Cayetano tributary, 150 metric t from Collier Creek, 147 metric t from Cottonwood Creek, and 80 metric t from Line G-3. The third element considered was to describe sediment that is depositing in or eroding from the channel. As discussed earlier, because errors associated with the LiDAR data sets were larger than the net average differences observed at the reach or whole system scale, no in-channel deposition or erosion was deemed observable and thus this element was reported as zero for the East side. However, we do observe in the field and in the bulk sediment analysis results (Appendix 7.6) slight changes (coarsening) of the channel bed sediments downstream from tributary confluences, suggesting that there likely is a depositional process occurring related to sediment delivery from the tributaries. The fourth element considered was the sediment removed via channel maintenance, totaling an average annual 500 metric t. The last element considered was the sediment leaving the East side, as measured at the AMP gauge. The average annual total sediment mass for this element was estimated to be 3,544 metric t. Summing all these budget elements results in a residual of -582 metric t (12.6% of the total budget); the sum of the uncertainties and errors associated with each of the budget elements and any unknown sources, sinks or losses. Because the budget residual is negative, this indicates that the budget is not accounting for an additional source of sediment. Some of this could be associated with in-channel erosion or reworking of previously deposited sediment that was not captured by the differencing methods applied to the LiDAR elevation data.

Table 8. East side sediment budget results.

East Side Sediment Budget					
Terms			Mass (metric tonnes)	Percentage	Yield (t/km2/yr)
Total sediment inputs					
	Gauged Tributaries		2,781		
		Arroyo Las Positas at North Livermore Avenue Bridge (ALPL)	2,061	59.5	14.9
		Arroyo Mocho off Stanley Boulevard between El Charro Road and Kitty Hawk Road at Hagemann Bridge (AMH)	720	20.8	5.9
	Non-gauged tributaries		681		
		Cayetano Creek	225	6.5	9.2
		Lower Mocho "Flatlands" tributary downstream of Cayetano	39	1.1	10.8
		Lower Mocho "Flatlands" south side draining Livermore	40	1.2	2.2
		Collier Creek	150	4.3	12.2
		Cottonwood Creek	147	4.2	12.7
		Line G-3	80	2.3	6.5
Total sediment exports					
	Gauged Tributaries		4,044		
		Channel Transport (Arroyo Mocho at Pleasanton at Santa Rita Road Bridge (AMP))	3,544	76.6	9.6
		Sediment removal via channel mainteance	500	10.8	-
	Channel sediment deposition/erosion		0		
		Reaches 4 through 11 (AMP up through ALPL)	0	0.0	-
Residual			-582	12.6	-

Note, all data are provided to at least two significant figures (where possible) to allow data post-processing by other researchers and do not represent a claim of relative accuracy or precision.

The West side sediment budget (Table 9) extends downstream to the ADLLV gauging station and includes elements that were not investigated during this study. This budget is comprised of seven main elements. First, the input sediment passing into the sediment budget reach, as measured at the AMP gauge station, was an average of 3,544 metric t for the period WY 2007 to 2014. Inputs of sediment were also contributed from the ungauged tributaries of Tassajara Creek (4,557 metric t), Chabot Canal (714 metric t), and Alamo Canal (5,291 metric t); these estimates were generated through calibration of the NetMap outputs. The third element was sediment removal via maintenance, which in this case was zero; Zone 7 has not removed any sediment from this area during the budget period. The fourth element describes sediment deposition or erosion in-channel (for Reaches 1-3); similar to the East side sediment budget, the analysis of net erosion/deposition using the LiDAR differencing technique could not distinguish a net change beyond errors associated with the LiDAR data, thus this element was again set to zero. The fifth element was the sediment passing the ADLLV gauging station. For the budget period, total sediment load passing through this cross section was estimated to be an annual average of 30,089 metric t. The sixth element was the sediment input from the ungauged areas, including Arroyo Del Valle tributary and the watershed area between ADLLV and Alamo Canal, but not included in one of the named tributaries. This element was an unknown, as it is unmeasured and not included in the NetMap analysis and there has been no gauging of sediment in these tributaries. The last element included in the sediment budget was the channel deposition or erosion occurring within the ADLL reach, downstream from the confluence of Arroyo Mocho and Alamo Canal and upstream from ADLLV. This again is an unknown, as it is unmeasured. The budget residual for these unquantified budget elements was -15,983 metric t per year for the budget period. Assignment of this residual will be discussed below.

Table 9. West side sediment budget results.

West Side Sediment Budget				
Terms		Mass (metric tonnes)	Percentage	Yield (t/km2/yr)
Total sediment inputs				
	Gauged Tributaries	3,544		
	Channel Transport (Arroyo Mocho at Pleasanton at Santa Rita Road Bridge (AMP))	3,544	25.1	9.6
	Non-gauged tributaries	10,562		
	Tassajara Creek	4,557	32.3	65.5
	Chabot Canal	714	5.1	51.4
	Alamo Canal	5,291	37.5	48.3
Total sediment exports				
	Gauged Tributaries	30,089		
	Channel Transport (Arroyo de la Laguna at Verona (ADLLV))	30,089	65.3	42.2
	Sediment removal via channel maintenance	0	0.0	-
	Channel sediment deposition/erosion	0		
	Reaches 1 through 3 (Confluence with Alamo Canal through AMP)	0	0.0	-
Residual (Input from Del Valle and ungauged areas, Channel deposition/erosion in ADLL Reach)		-15,983	34.7	-

Note, all data are provided to at least two significant figures (where possible) to allow data post-processing by other researchers and do not represent a claim of relative accuracy or precision.

4. Discussion

4.1. Budget justification

During the development of the sediment budget, we were surprised to see such a disparity in sediment production between the East side of the basin and the West side of the basin. We noted that sediment load passing through the AMP gauging station (3,544 metric t) was about 10-fold less for our measurement period of water years 2011 to 2015 than the USGS had measured at the ADLLV gauging station downstream (30,089 metric t). Comparing the yields (mass per unit watershed area) for each of these gauging locations gave us further cause for concern. To evaluate this disparity and provide a justification for variation in sediment budgets between the East side and the West side of the basin we went through a quality assurance analysis by carefully looking at our data in relation to answering the following three general questions. Could the disparity have occurred due to:

- Possible sampling or computational errors associated with suspended and bed sediment loads computed at the three East side gauging locations (AMH, ALPL, and AMP)?
- Possible errors associated with the measurement or reporting of discharge by Zone 7 which forms the foundation of sediment load computations?
- Possible errors associated with the USGS measurements and their report of sediment loads for the Arroyo de la Laguna at Verona gauge location?

After a thorough examination of all of these potential causes of disparity, we concluded that all of the data were robust and that the apparent disparity between sediment production and loads from East side and West side was in fact real and justifiable during this relatively dry period given the differential rainfall and water budget gradients across the watershed as a whole. More details are provided in the next few paragraphs.

First we investigated potential errors in the sediment sampling and computations. A thorough review of computations used to calculate loads at the three Zone 7 gauges was completed to see if any algebraic errors or unit conversion errors had occurred. Two independent quality assurance checks concluded that no errors were present. This triggered the elements of the sampling methodology to be reviewed and examined. We questioned if the turbidity surrogate methodology accurately represented the amount of suspended sediment transported. We looked closely at the relationships between turbidity and SSC at each site, and found them to be within the range experienced at other sampling locations around the Bay Area. A review of the SSC data for single point grab samples versus samples collected across the entire cross section showed no indication of major differences, though this dataset was not as thorough as desired. Given that the suspended load appeared to be correct, we also investigated the mass of bedload calculated for each station. Bedload was calculated as 0.8 to 22% of the total load, a proportion well within the range of load calculated for other locations reported around the Bay Area. After the review, the team concluded that the sampling methodology and results generated were sound.

Next we investigated potential errors associated with the measurement or reporting of discharge by Zone 7, but found none at the magnitude relevant to the sediment disparity. We constructed a simple water budget to see how the flow volumes measured at each gauge station compared, and how they added up moving downstream. Upon the advice of Zone 7 staff, we included flow discharged from the quarry operations at the Chain of Lakes. For the period WY 2007-2014, the flow at AMP was 26% of flow measured at ADLLV. Based upon this analysis, the patterns of flow did not appear to be unusual. We then compared unit area runoff production from basins upstream of Zone 7 gauges and basins upstream of USGS gauges, to see if there was a disparity that might suggest that the Zone 7 gauge rating curves were calculating too little discharge (Table 10). Although the unit area runoff production was lower than other gauges in the area, the results were confounded by the relative dryness of the recent time period, and thus no clear concern emerged.

Table 10. Unit area runoff production from various watershed areas, as calculated at Zone 7 and USGS gauges of interest.

	Arroyo Valle Bl Lang Cyn Nr Livermore (11176400)	**Arroyo Valle Nr Livermore (11176500)**	**Arroyo De La Laguna At Verona (11176900)**	**Alameda Ck Av Div Dam Nr Sunol (11172945)**	**Alameda Ck Nr Niles (11179000)**	**AMH (Zone 7)**	**ALPL (Zone 7)**	**AMP (Zone 7)**
Unregulated drainage area (sq miles)	130.0	17.0	254.0	33.3	348.3	55.3	52.8	145.7
	Annual runoff (in)							
2007	0.3	4.4	1.8	2.7	2.3	0.1	1.2	0.7
2008	3.4	4.2	2.9	6.0	3.0	0.6	1.5	1.0
2009	1.7	2.7	2.1	4.4	2.1	0.5	1.7	1.1
2010	2.7	13.6	3.8	6.5	3.7	1.1	2.1	1.4
2011	4.1	14.7	5.0	10.5	7.1	2.3	2.1	2.2
2012	0.2	7.3	1.9	1.6	1.6	0.3	1.2	1.2
2013	1.1	5.5	2.3	2.8	2.6	0.8	1.2	1.4
2014	0.0	2.1	1.0	0.3	1.2	0.2	0.8	0.5
Average (Years 2007-2014)	**1.7**	**6.8**	**2.6**	**4.4**	**2.9**	**0.7**	**1.5**	**1.2**

Next, the climatic variation across the budget area was examined, so that the main driver of runoff production could be better understood. Precipitation records for a number of gauges within the vicinity of Zone 7 facilities were gathered. Rainfall follows a distinct west to east and north to south gradient across the Livermore-Amador Valley and surrounding uplands (Table 11). Rainfall for the period of our measured sediment loads was much greater in the north and west side of the basin than in the east side of the basin. For example, rainfall measured in Danville was 2.5-fold greater than measured in Altamont. This variation is likely orographically driven, with most of the moisture in a storm front (that in the Bay Area typically move northwest to southeast) falling out over the Las Trampas and Pleasanton Ridges on the west side of the valley, leaving little precipitable moisture once the front reaches Livermore or the Altamont Pass area. Given the variation in rainfall, even in drought years, we would expect the

same general spatial pattern in runoff production from the West side versus the East side of the basin. Thus, we concluded that the much smaller discharges at the three Zone 7 gauges than measured at ADLLV is not only plausible, but accurate given the precipitation patterns.

Table 11. Rainfall (inches) at selected gauging locations within the vicinity of Zone 7 facilities. Stations in the table are generally organized northwest to southeast.

	Las Trampas [1]	Danville Library[2]	Dublin Fire Station[2]	Pleasanton 1.8 SSE CA US[3]	Livermore Municipal Airport CA US[3]	Altamont[1]
WY 2011	34.9	32.1	19.1	20.5	16.2	12.8
WY 2012	20.8	16.9	9.2	9.6	9.0	6.2
WY 2013	19.0	21.4	12.0	14.3	10.9	8.0
WY 2014	16.2	12.8	6.7	4.7	7.1	3.9
WY 2015	18.9	16.7	13.3	12.2	13.8	8.5
Average for 5 year period	**22.0**	**20.0**	**12.1**	**12.3**	**11.4**	**7.9**

[1] Source: RAWS; website http://www.raws.dri.edu/wraws/ccaF.html
[2] Source: CDEC; website http://cdec.water.ca.gov/snow_rain.html
[3] Source: NOAA; website http://gis.ncdc.noaa.gov/map/viewer/#app=cdo

To further check the quality of the discharge data, we then looked at historic records for the period just prior to when Zone 7 took over discharge gauging from the USGS at ALPL and AMP. For a period in the early 1980s (Water Years 1980-1983), the USGS operated many of the gauging stations in the Pleasanton-Livermore area, including the gauges measured in this study. Using the original USGS records, we looked at relationships in Water Year total discharge between gauges in the East side versus the West side for wet and dry years. The annual totals measured at the ALPL and AMP gauges in the 1980s were of the same order of magnitude as the flow measured during the budget period, giving us confidence that contemporary flow data are reliable and generally high quality. Next the proportion of total flow measured at ADLLV that was contributed by AMP, as compared to the West side tributaries was considered. AMP only contributed 22-37% of the total flow volume passing ADLLV during this period in the 1980s (Water Years 1980-1983). This helps to confirm that the West side does produce a larger flow volume, as compared to the East side. And finally, we looked at the unit area runoff at each gauge, and found that Tassajara Creek and Alamo Creek were consistently higher than Arroyo Mocho. However, the difference between Tassajara and Alamo Creeks and the eastern basin was greatest during drier years (e.g. 1981), and not as great during wetter years (e.g. 1983). For example, for WY 1983 the unit area runoff (inches) for AMP was 10.13, while the runoff for Tassajara and Alamo Creeks was 11.80 and 17.80. Data from other water years shows a similar pattern. This suggests that we should expect greater relative sediment yield potential from the

West side tributaries, particularly during dry years; however this relationship may not hold for wet years. We also looked at the relationship between stream flow and sediment load for the AMP and the ADLLV gauges to see if the West side subwatersheds are inherently more erosive than the East side subwatersheds. For dry years, the data points that create the monthly flow versus total sediment load rating curve for the two locations plot on top of each other, suggesting that there is no difference in the erosivity, and thus sediment production, between the east and west sides.

We hypothesize that the east side of the basin may produce a greater proportion of the sediment load during a period of consecutive wetter than average years that might include a rare wet year like water year 1983 (El Niño conditions) that followed the wet year of WY 1982, or the wet 1998 water year (El Niño conditions) that followed the wet water years of 1995, 1996, and 1997. The greater precipitation would likely activate hillslope mass-wasting processes, increasing the amount of sediment provided to the channels. Or alternatively, perhaps the greater precipitation provides more stream power, increasing the transport of sediment that was previously transport-limited. Unfortunately, there is presently no data to support this hypothesis. It is certainly possible that the spatial differences in sediment supply could be driven by the spatial distribution of mass wasting and channel incision processes, independent of precipitation patterns.

The next step in the quality assurance analysis was to investigate the potential errors associated with the USGS measurement and reporting of sediment loads at ADLLV. Our study team has previously worked with these data extensively during the development of a channel sediment budget for the reaches of Alameda Creek Watershed upstream from the USGS gauge in the Niles Canyon (gauge 11179000) and downstream from the USGS Alameda Creek gauge near Welch Creek (gauge 11173575) and the USGS gauge on Arroyo de la Laguna at Verona Bridge (gauge 11177000) (Bigelow et al., 2008). Despite this previous data analysis and the extensive associated field work, we again investigated the possibility of disparate measurement and reporting but this time focusing on the period of interest for the sediment budget presented here. The first check was to investigate the sediment load data at ADLLV for water years 2007 to 2014. During this period, suspended sediment loads at Verona were 60-164% of those reported at Niles and followed the general pattern of being greater than Niles during dry years and lesser than Niles during wet years. This is consistent with the previous analysis of Bigelow et al. (2008); averaged over the longer term, Verona on average passed 67% of the load passed at Niles for the period 1994-2006 despite the variable storage in that reach (the balance coming from the southern side of the basin, and channel erosion and supply from Niles Canyon tributaries). We then investigated the possibility that the bedload component of total load could have been erroneous. This was estimated from a shortened 4 year observation period from water year 2000-2003, collected at the previous gauge location on Arroyo de la Laguna (gauge 11177000). During this period, bedload made up 6-28% of the total load. On a flow-weighted basis, for these four years, bedload averaged 20%; a ratio that is very reasonable based on comparisons to other Bay Area gauge locations. We concluded that no matter how we

manipulate the possible errors associated with the extrapolation of this data to the budget period, the bedload component cannot account for the apparent disparity of sediment loads between ADLLV and AMP.

In summary, our quality assurance analysis did not turn up any egregious errors. Overall, we suggest that the suspended and bedload sampling, and loads computed by our study team for the AMP gauge, based on Zone 7 flow data, turbidity, and sampling for suspended sediment concentrations during floods and dry weather, are reliable as are the loads reported by the USGS for the ADLLV gauge. We are left asking if it reasonable to assign the missing mass between the two gauges (AMP and ADLLV) to channel erosion and contributions from other tributaries (Arroyo Del Valle and smaller unnamed tributaries) that enter the mainstem channel between the Arroyo Mocho and Alamo Canal confluence and the ADLLV gauge. To explore this, we reviewed previous work by Bigelow et al. (2008) on channel erosion around the Verona gauge and we computed the yields of sediment per unit area that would be required to balance the budget.

The West side sediment budget contained three budget elements that were not measured during this study, and thus are treated as unknowns in the budget. These three budget elements comprise the budget residual (including error from all other terms), which was -15,983 metric t for the WY 2007-2014 budget period. Despite these three budget elements being unmeasured, we can make a best estimate for each of these budget elements (Figure 10). The amount of channel deposition or erosion occurring in the ADLL reach within our budget area was unknown, but likely is significant. This 4 mi (6,500 m) length of channel is a geomorphically active reach, with historic incision causing significant bank erosion and now some deposition of sediment as the channel widens. For comparison, the 3.6 mi (5,800 m) reach that extends from ADLLV downstream to the confluence with Alameda Creek was found to be producing 14,250 (+/- 2,690) metric t/yr of sediment from bank erosion and incision, and storing 5,530 (+/- 2,140) metric t in small and large bars, the channel bed, and in the floodplain, for a net contribution downstream of 9,000 (+/- 5,000) metric t of sediment per year (Bigelow et al., 2008). The ADLL reach within our budget area likely contributes a slightly lower mass of sediment than the area downstream reported by Bigelow et al. for two reasons. Firstly, approximately 40% of the reach is upstream from Bernal Ave where there is evidence that the headcutting has been arrested (longitudinal profiles in Bigelow et al., 2008). Secondly, the period 1994-2006 was wetter than the budget period (2007-2014) that is presented here. Using data from the downstream reach, normalizing the net contribution to channel length, and applying it to the ADLL reach downstream from Bernal, and then reducing the estimate by 50% for the drier climate, our best estimate is that the reach may be producing approximately 3,126 metric t per year.

The other unknown budget element is the contribution from Arroyo Del Valle and the other ungauged tributary areas draining the Pleasanton Ridge and surrounding smaller tributaries. If we remove our estimate of channel erosion (3,126 metric t), the remaining residual is -12,857

metric t. The Arroyo Del Valle and other ungauged area together have a drainage basin area of 393 km^2 (only the unregulated area downstream of the reservoir was included in this area calculation). If we assume that this entire mass of sediment is being contributed by this area, the sediment yield would be 33 $t/km^2/yr$ (including the errors), which we consider to be very reasonable for this drier period.

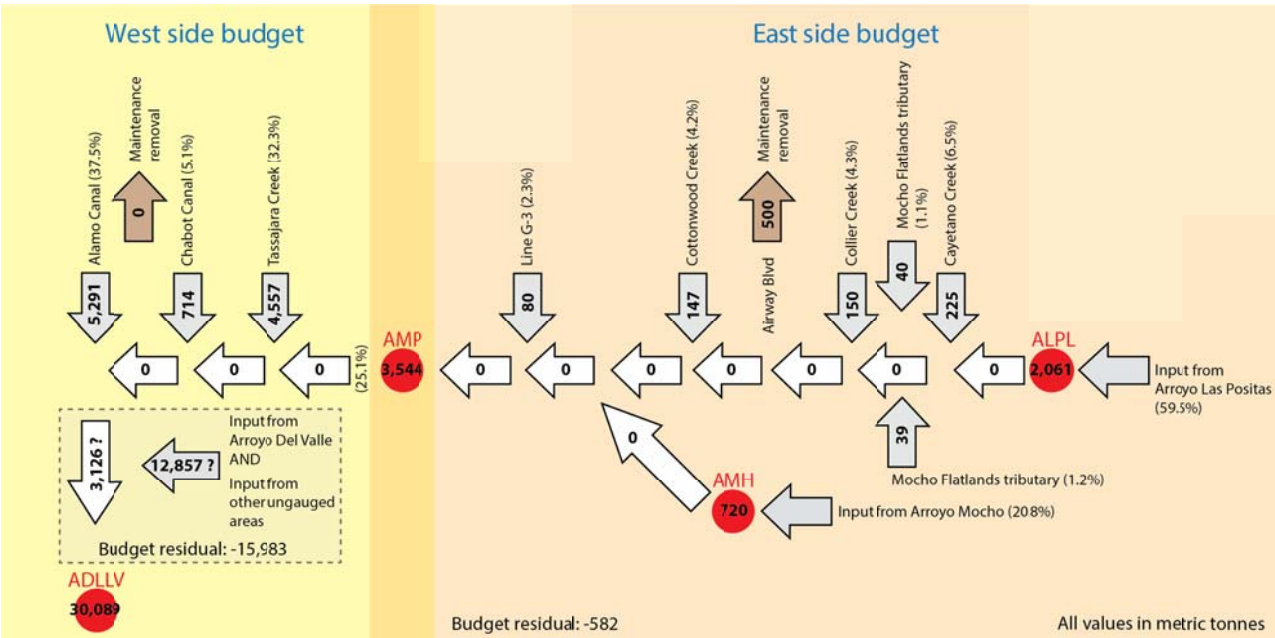


Figure 10. Zone 7 total sediment budgets (metric tonnes) for Water Years 2007-2014. Area in the shaded box in the West side budget represents the budget residual and error of all other terms. We assigned this residual to the terms representing contributions by Arroyo Del Valle and the other ungauged areas, and the ADLL reach; these values are at the hypothesis level and thus have much lower confidence. See discussion for details. Note, all data are provided to at least two significant figures (where possible) to allow data post-processing by other researchers and do not represent a claim of relative accuracy or precision. The percentage of the total sediment inputs to the channel network contributed by each tributary is shown in parentheses. Percentages for the East side and West side budgets are separate.

In conclusion, our quality assurance investigation of the budget elements verifies the original computations. Although each budget element has a level of uncertainty, there appears to be no reason to suspect any egregious sampling or computational errors associated with suspended and bed sediment loads computed at the three East side gauging locations (AMH, ALPL, and AMP). We have no reason to question the measurement or reporting of discharge by Zone 7 which forms the foundation of sediment load computations. And the sediment loads reported by the USGS for the ADLLV gauge location appear robust. Given the potential for channel

erosion in the area between the Verona gauge and Bernal Avenue and the reasonable total sediment yields from Arroyo Del Valle and other unnamed tributaries, we contend that the sediment budget presented here is reasonable and accurate for the time period presented.

4.2. How much sediment passes into the system and from where?

One of the goals of this sediment budget exercise is to provide information on the differing timing and rates of channel sediment processes, to support Zone 7 staff in managing the channel facilities and supporting the SMMP. Here we discuss the in-channel sediment supply, transport and deposition within each budget area, as it relates to channel management.

For the East side sediment budget area during dry years, we calculate an average annual 3,382 metric t of sediment being delivered to the budget reach via the mainstem Arroyo Mocho, mainstem Arroyo Las Positas, and the various tributaries (Figure 11). The Arroyo Las Positas (draining the Altamont and Arroyo Seco sub-basins) is the largest contributor of sediment. In relation to all the sediment exiting the East side budget (including the residual), an average annual 500 metric t, or 11%, was removed during the budget period. Given the location of the removal half way up the East side budget area, it actually represents a larger proportion of the sediment contributed from the upstream watersheds at that point. The majority of this mass was removed in a one-time removal at Airway Blvd that occurred in 2006. The sediment that was removed at that time was likely deposited either earlier that year (water year 2006 was a wet year) or in prior wet years. In this way there was likely a temporal mismatch; during extended dry periods, our budget would suggest that no significant sediment would be deposited. Any removal events would likely be from sediment deposited during wet years. In addition, the 500 metric t likely represents a much smaller percentage of the input sediment for the years that it was delivered and deposited.

For the budget period, 3,544 metric t passed through the downstream cross section at AMP. If we assume that the residual of -582 is erosion (a net loss from the system) such as bed incision, bank erosion, or reworking of previously deposited sediment, then the sediment export at AMP is 89% of the inputs. During these dry years, flow depths have not been high enough to spill onto the inner bench surface (at an elevation higher than the bankfull elevation) that exists for most of the length; flows have been confined to the low flow channel. Thus, attributing the residual to bed/bank erosion conceptually makes sense; flows during these drier years have been acting upon the bed and banks, modifying, reworking and transporting sediment downstream. We conducted a check to see if this was reasonable; the reach upstream from AMP to the upstream boundary of the sediment budget is 7.6 km in length, and we assume an 8 m active channel width. The -582 metric t residual equates to 425 yds^3 (325 m^3); spreading this volume evenly across the entire area of channel would require the entire reach to have eroded (bank erosion or bed incision) a total of 5 mm during the eight year budget period, a very reasonable assumption. But the residual incorporates errors from all other terms, so the amount of erosion could actually be smaller, given the error terms.

However, during wet years, when flow depths are much greater, it is possible that deposition occurs during the falling limb of the hydrograph on this bench surface, as well as upstream from channel constrictions such as the Airway Blvd crossing. Additionally, the channel is possibly prone to local sediment inputs from greater bank slumping and failure during the wet years. In general, it appears that during dry years most of the sediment supplied to the East side area is transported through the channel network mostly within the low flow channel. In contrast, during wet years, the channel could perhaps experience localized erosion and bank failure, and also much more in-channel deposition of sediment. But due to the dry budget period covered, there is no quantitative data to support these hypotheses until large events are captured in future gauging efforts.

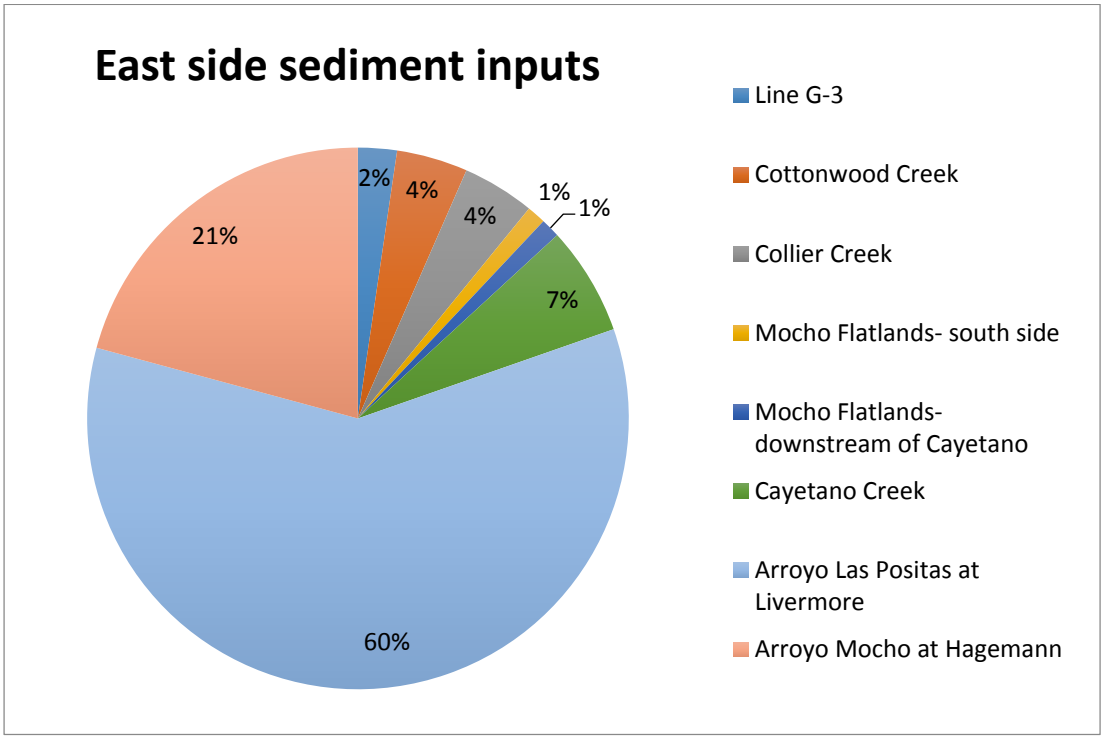


Figure 11. Sediment inputs to the East side sediment budget during Water Year 2007 to 2014 (a relatively dry period). Pie wedges correspond with the legend, starting at the top and moving clockwise.

For the West side sediment budget area during dry years, we calculate an average annual 14,106 metric t of sediment being delivered to the budget reach at the Arroyo Mocho/Alamo Canal confluence (Figure 12). And using the assumptions described in Section 4.1 about the budget residual, we could assign the remaining 12,857 metric t (43% of mass passing ADLLV) to sediment inputs from Arroyo Del Valle and other tributary area, thus significantly reducing the relative percentages for each tributary shown in Figure 12. For the West side, Zone 7 has not

conducted any sediment removals during the budget period. Thus all sediment that is contributed is either stored in-channel, or is transported out through the ADLLV cross section. Again, during these dry years, the flow depths were not high enough to cause significant in-channel deposition on inset bench surfaces. However, the west side did see more flow than the east side, and 60% of the channel length downstream from the Alamo Canal confluence is natural channel, so there is a much higher likelihood that some deposition has occurred. During wetter years, the inner bench surface in the lower reaches of Arroyo Mocho may experience sediment deposition, as well as the natural channel reach near ADLLV, particularly as that reach is adjusting and widening after earlier incision.

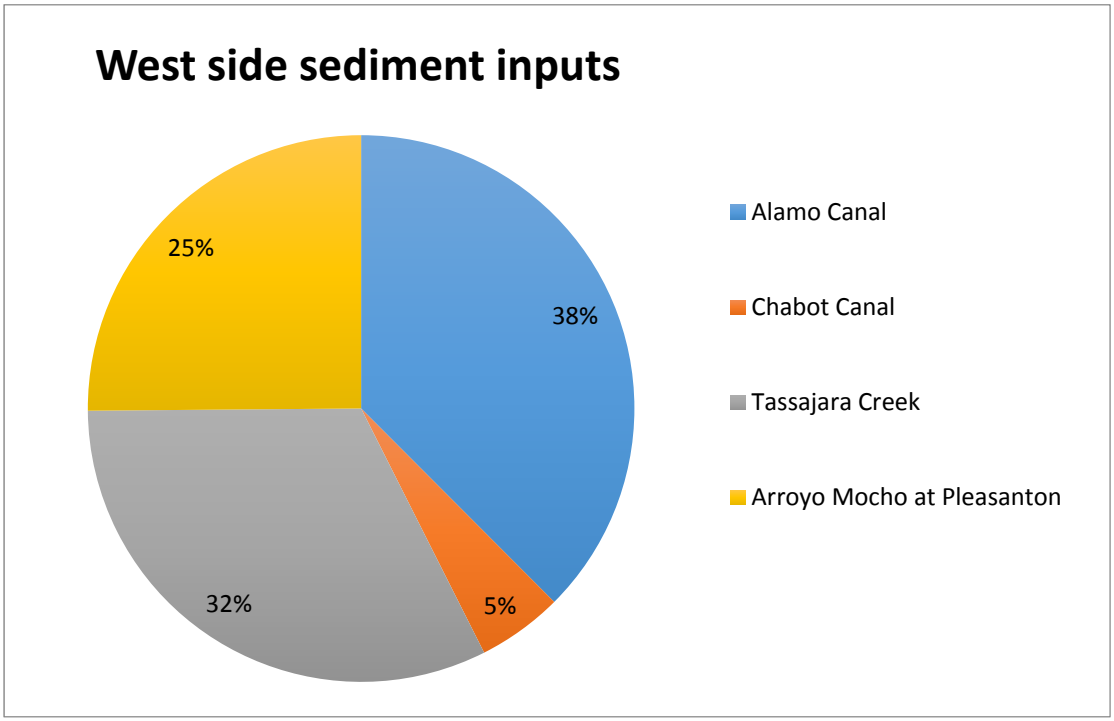


Figure 12. Sediment inputs to the West side sediment budget, upstream from the Arroyo Mocho and Alamo Canal confluence during Water Year 2007 to 2014 (a relatively dry period). Pie wedges correspond with the legend, starting at the top and moving clockwise.

In looking at the East and West side budgets together, a different pattern emerges between dry years and wet years. During dry years (e.g. WY 2007-2014), we find approximately 26% of the flow and 12% of the sediment to be sourced from the East side basin, while 74% of the flow and 88% of the sediment is sourced from the West side basin. The channel does not appear to be eroding or depositing sediment. Instead, the majority of sediment that is supplied from the watershed is efficiently transported through the channel and out the lowest cross section, with only minor reworking of the low flow channel bed and bars. The sediment supplied through the

upstream gauging locations is 10 and 11% sand, and 1 and 4% gravel for AMH and ALPL, respectively. In comparison, the current bed sediment at riffle locations (as measured via the bulk sediment sampling, see Appendix 7.6) is much coarser, on average 42% sand (ranging from 7 to 74%) and 54% gravel (ranging from 16% to 92%). This suggests that riffle locations are composed of disproportionately coarser sediment, likely sourced from the watersheds during wet years, and these coarser grains may not be transported during low velocity conditions in dry years, or may preferentially be stored in-channel.

In contrast, during wet years (e.g. 1983 or 2006) the flow contribution from the East and West sides appears to shift, with proportions of flow from the East side increasing 5-10%. And based upon our understanding of the water budget and sediment sourcing processes occurring in the upper watersheds, the relative amount of sediment input from the East side could accordingly increase 5-15% or more during wet years or wet periods of several years. During these wetter times, the depth of flow in the channel would be much greater, with the entire channel cross section engaged in sediment erosion, deposition, and transport processes. Unfortunately, no data exists on the grain size composition of sediment supplied from the upstream gauging locations during these wetter years, making it difficult to speculate on the relationship between supply and potential storage in the channel. We hypothesize that coarser sediment is sourced from the hillslopes and supplied to the channel during wetter years (reflecting hillslope mass wasting processes) and likely has a greater chance of being deposited within the channel. During large flow events, major reworking or deposition of the inner bench sediment deposit would potentially be possible. This sediment could be coarser than what is supplied during the dry period, however grain size analysis was not completed on the bench surface; this data is currently lacking. At such time, any existing in-line sediment basins may be completely inundated by a volume of sediment sourced from the many attending tributaries that is much larger than the volume of sediment supplied during the dry period of WYs 2007-2014. Taking an entire watershed scale approach to managing sediment input might be the only way to reduce the frequency of channel sedimentation problems. Managing the channel cross sectional geometry (e.g. a multi-stage channel) to encourage channel transport, rather than deposition, would also help to transport sediment downstream to the Arroyo de la Laguna reach, providing it with the vital sediment needed to re-create the appropriate channel cross section and recover from earlier major channel incision. In addition, sediment supply downstream to Alameda Creek, and eventually to the Bay margin will assist in providing the local region with the sediment needed for the salt marshes to vertically accrete and keep up with sea level rise.

In summary, during the budget period of WYs 2007 to 2014 (a relatively dry period), the majority of the sediment supply to the channel sediment budget was sourced from the western and northern portions of the basin. The majority of this sediment was transported through the low flow channel. During wetter periods, it is quite possible that a higher proportion of the water and sediment supply to the budget area would come from the eastern side of the basin potentially causing inundation of the existing sediment basins and possibly causing further deposition on the inner benches and bars of the flood control system. Data are lacking at the

present time to quantify these wet period processes. In this regard, we caution readers that inferences of sediment supply, transport, and storage patterns from dry years to wet years (where no data exists) are highly limited and of low confidence because they represent distinctly different sediment cycles and dynamics, where the majority of geomorphic work occurs during infrequent large events in California coastal basins. In general, sediment supply measured during our dry budget period is most likely dominated by low magnitude chronic bed and bank erosion within incised channels (arroyos, gullies) that are common throughout the Arroyo Mocho watershed and its tributaries. During wetter periods, supply will increase from bank erosion sources and wider areas of the basin as a result of mass wasting processes (earthflows, deep-seated and shallow landslides, debris flows) that will become active at these times. The transport and depositional processes that occur during a wetter budget period will most likely leave a legacy that ensues for years or decades until the next big event.

5. Recommendations

This sediment budget exercise, along with other work completed in the previous five years has produced and collated a substantial amount of information about channel processes and sediment loads in the Zone 7 area of interest. This information has provided a vastly improved overall understanding of the Arroyo Mocho watershed during dry weather conditions, but some questions still remain about what may occur during wetter conditions.

This study focused upon providing quantitative information in part toward the purpose of meeting requests by permitting agencies for information about the processes and rates that govern how the channel network is currently performing. The amount and location of sediment inputs to the channel network are described, and can be used in watershed-scale or smaller project planning efforts. The amount of sediment in storage in the system is addressed, which may inform decision making about regular channel maintenance activities such as de-silting or bank stabilization. The timing of sediment supply and storage, as driven by climate, is discussed and helps to inform additional data collection needs, channel maintenance activities, as well as longer-term (e.g. decadal) changes in channel form and function. This data provides a greater understanding of how processes in various channel reaches relate to each other, including channel functioning in the Arroyo de la Laguna reach, and further downstream in Alameda Creek. And lastly, the new monitoring data and sediment budget will provide input to support Zone 7's SMMP, as well as information to support interactions with various stakeholders including local Cities, Alameda County, private landowners and the general public.

Additional key data sets could provide clarity to the outstanding questions and issues. Our recommendations coalesce around three main management questions:

How much sediment passes into the system, and from where?

- Given that this sediment budget is for a relatively dry period (2007 through 2014), and that we expect quite different sediment erosion and transport processes and greater overall sediment loads as well as a different sub-basin pattern of those loads during wetter periods that are typical of semi-arid Bay Area watersheds, we recommend continued flow and sediment load gauging during future wet years at the AMP, ALPL, and AMH gauge locations. Planning to monitor during wet seasons with a greater likelihood of larger storms in the forecast, rather than monitoring continuously during all water years would potentially capture the needed data at a lower cost. With the El Niño conditions in the forecast for WY 2016 that are larger than those of 1983 and 1998 water years, there appears to be an opportunity for this coming wet season to capture this kind of data. Gauging in the Arroyo Mocho watershed this winter and subsequently revisiting the sediment budget may provide a vastly improved understanding of sediment supply and dynamics.
- Zone 7 could continue to assess channel facilities for localized pockets of sediment deposition; if the problematic areas are downstream of AMP, Zone 7 could consider reinstating the gauge stations on Tassajara Creek or Alamo Canal, to better understand sediment supply, erosion and deposition processes in this area.
- The loads calculated at ADLLV and at Alameda Creek at Niles were vitally important for developing, calibrating, and verifying this sediment budget. We recommend that the Zone 7 Water Agency continue to support or at least encourage continuation of flow and sediment data collection at these two gauge stations.

How much sediment is currently in storage, where is it being stored, and what are the primary causes for deposition?

- The LiDAR datasets are key benchmark datasets for Zone 7, and will remain important in monitoring overall change in the future. This data could become much more powerful if augmented with a limited set of surveyed monumented channel cross sections (perhaps 20-30) dispersed throughout the area of interest. These cross sections would address the issue of potential channel change under the water surface, as well as corroborate LiDAR difference findings if the measured channel change is fairly low magnitude (on the order of a centimeter to 10s of centimeters). SFEI could work together with Zone 7 Water Agency staff to identify and prioritize potential locations to establish permanent cross sections. The aim would be to maximize information gathered for the least amount of effort. We suggest that the established sections would be surveyed every five years, or after a 5-year recurrence interval flow event or greater. In addition to surveyed sections, the use of bathymetric LiDAR could also be explored.
- Zone 7 could consider collecting additional LiDAR data, along with re-surveyed cross sections, after a channel deposition event has occurred. This likely would be after a very large flood event, or perhaps after a series of two or three wet years that have

activated sediment transport from the East side of the basin. This would allow for quantification of potentially large magnitude channel change.

- Future de-silting events should include an accurate record of removal location, volume, cost, grain size, and fate of the removed sediment. Ideally this information would be available in a centralized database, rather than in project files alone.
- Building upon the findings in this sediment budget (with a calculated load from each tributary, and measured bed grain size of stored sediment in the mainstem channel), in the future, if a set of tributaries appear to be contributing volumes of sediment that cause excessive deposition, a focused geomorphic study, including further grain size analysis, could be conducted at those locations to better understand the processes and rates of sediment supply and resulting deposition patterns. Enhanced sediment budgets can be used to calculate rates of sediment supply by process (e.g. bank erosion, landslides, surface erosion, etc.) to help land managers determine what proportion of the supply is potentially controllable (e.g. see Reid and Dunne, 1996).

What mitigation opportunities are available when channel maintenance is required?

- In-channel deposition potentially could peak after wet years where sediment was activated from the East side of the basin, requiring Zone 7 to manage and remove that sediment. Understanding where and what types of mitigation opportunities are available could be a key issue for the removal project to be a success. The Historical Ecology report (Appendix 7.5) focuses upon accurately identifying both opportunities and constraints associated with strategies for stream management improvement. When mitigation is required, we recommend building upon the Historical Ecology report and convening a technical advisory group of experts (including resources agency staff, restoration engineers and ecologists) to discuss what habitat mitigation options are available and appropriate design options for implementation. In addition, the NetMap terrain analysis also provided the spatial distribution of erosion potential across the watershed at various scales; sediment mitigation efforts could also be focused on the most erosive watershed areas through outreach to local land owners and managers.

6. References

Ayres Associates, 2001. Technical Memorandum No. 5 Technical Appendix C, Zone 7 Geomorphic and Sediment Transport Evaluation. Unpublished report prepared for West Yost & Associates. September.

Benda, L., Miller, D. J., Andras, K., Bigelow, P., Reeves, G., and Michael, D. 2007. NetMap: A new tool in support of watershed science and resource management, Forest Sci., 52, 206–219.

Benda, L. and Dunne, T. 1997. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research, v.33: 2865-2880.

Bigelow, P., Pearce, S., and McKee, L. 2013. Evaluation of Sediment Sources to Don Castro Reservoir: On the magnitude, spatial distribution, and potential reduction of sediment supply in the Upper San Lorenzo Creek watershed. Prepared for the Alameda County Flood Control and Water Conservation District, Hayward, CA.

Bigelow, P., Pearce, S., McKee, L.J., 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. http://www.sfei.org/documents/sediment-budget-two-reaches-alameda-creek

Brown, W.M., and Jackson, L.E., 1973. Erosional and depositional provinces and sediment-transport in the south central San Francisco Bay region, California: San Francisco Bay Environment and Resources Planning Study, Interpretative Report 3, U.S. Department of the Interior, Geological Survey Miscellaneous Field Studies Map 515, U.S. Department of Housing and Urban Development, 3 sheets.

Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. W. H. Freeman & Company. San Francisco. 818 p.

Ellen, S. and Wieczorek, G.F., editors. 1988. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U. S. Geological Survey Professional Paper 1434.

Emmett, W.H. 2004. A historical perspective on regional channel geometry curves. Stream Notes - January. U.S. Forest Service Streams Systems Technology Center.

GMA 2007. Mad River Total Maximum Daily Loads for Sediment and Turbidity: Appendix A: Sediment Source Analysis. Prepared for the US EPA by Graham Matthews & Associates. December 21.

Griggs, G.B. 1987. The production, transport, and delivery of coarse-grained sediment by California's coastal streams. Proceedings of Coastal Sediments '87, Vol. 2. New York:American Society of Civil Engineers: 1825-1838

Hecht, B. 1993. South of the Spotted Owl - restoration strategies for episodic channels and riparian corridors in Central California: proceedings of the Society of Wetlands Scientists, Western Wetlands Conference, Davis, California, March 25-27.

Inman, D. L. and S.A. Jenkins. 1999. Climate change and the episodicity of sediment flux of small California rivers. Jour. Geology, v. 107, n. 3, p. 251-270.

Madej, M.A., and Ozaki, V., 1996. Channel response to sediment wave propagation and movement, Redwood Creek, California USA. Earth Surface Processes and Landforms, v. 21, pp. 911-927.

McKee, L.J., 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. http://www.sfei.org/documents/review-urban-runoff-processes-bay-area-existing-knowledge-conceptual-models-and-monitoring

McKee, L.J., Lewicki, M., Gangu, N.K., and Schoellhamer, D.H., 2013. Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. Special Issue: A multi-discipline approach for understanding sediment transport and geomorphic evolution in an estuarine-coastal system: San Francisco Bay (Guest editors P.L. Barnard, B.E. Jaffe, and D.H. Schoellhamer). Marine Geology 345, 47-62.

Nolan, K.M., Lisle, T.E., and Kelsey, H.M., 1987. Bankfull discharge and sediment transport in northwestern California. In: R. Beschta, T. Blinn, G. Grant, F. Swanson, and G. Ice (ed.), Erosion and Sedimentation in the Pacific Rim (Proceedings of the Corvallis Symposium, August 1987). International Association of Hydrological Sciences Pub. No. 165, p. 439-449.

NDC, 2010. San Francisquito Creek: geomorphic and sediment yield analysis. Submitted to: San Francisquito Creek Joint Powers Authority.

Reid, L.M., and Dunne, T., 1996. Rapid Evaluation of Sediment Budgets. Catena Verlag Publishers, Germany. 164 pp.

Russo, T. A., et al., 2013. Regional and local increases in storm intensity in the San Francisco Bay Area, USA, between 1890 and 2010. JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES 118: 3392–3401.

USGS, 2015a. United State Geological Survey. WaterWatch data. Annual Summery of runoff for the State of California (Water Years 1901- 2014). http://waterwatch.usgs.gov/index.php?r=18&id=statesum

Warrick, J. A., 2015. Trend analyses with river sediment rating curves. Hydrological Processes 29(6): 936-949.

Whiting, P.J., Dietrich, W.E., Leopold, L.B., Drake, T.G., and Shreve, R.L., 1988. Bedload sheets in heterogeneous sediment. Geology, v. 16, p. 105-108.

WRCC, 2015. Western Regional Climate Center. Climate data for Livermore, California. Data available for Climate Years 1904-2014. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca4997

7. Appendices

7.1. Sediment sources and sediment transport through Zone 7 channel facilities: literature and data review
7.2. Wet weather field sampling manual for suspended and bedload sediment transport in Zone 7 facilities
7.3. Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Years 2011 through 2015
7.4. Geospatial terrain mapping of sediment sources within the Arroyo Mocho watershed
7.5. Landscape scale management strategies for Arroyo Mocho and Arroyo Las Positas: process-based approaches for dynamic, multi-benefit urban channels
7.6. Arroyo Mocho bulk sediment sampling

Appendix 7.1

Sediment sources and sediment transport through Zone 7 Channel Facilities:Literature and Data review

Julie Beagle
Sarah Pearce
Alicia Gilbreath
Lester McKee

April 2012

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

Sediment sources and sediment transport through Zone 7 Channel Facilities

Task 2b: Literature and Data Review

Julie Beagle, Sarah Pearce, Alicia Gilbreath and Lester McKee

San Francisco Estuary Institute

Prepared for Zone 7 Water Agency

April 2012

Acknowledgements

Funding for this project was provided by Zone 7 Water Agency for the total amount of $200,000 under agreement number A11-45-SAN. This report and the data collection effort behind it represent 5% of the total project.

We gratefully acknowledge and thank the following Zone 7 Water Agency staff for their support of this project and sharing of data and time:

Joe Seto, Zone 7
Carol Mahoney, Zone 7
Elke Rank, Zone 7
Ryan Gromer, Zone 7
Sal Segura, Zone 7
Diana Gaines, Zone 7
Tom Rooze, Zone 7
Larry Akinsiku, Zone 7
Pamela Lung, City of Livermore
Matt Katen, Zone 7

This report can be cited as:

Beagle, J.R., Pearce, S.A., Gilbreath, A.N., and McKee, L.J., 2011. Sediment sources and sediment transport through Zone 7 Channel Facilities: Task 2b: Zone 7 Water Agency Literature and Data Review. A Technical Report of the Regional Watershed Program, prepared for Zone 7 Water Agency, Livermore, CA. San Francisco Estuary Institute, Richmond, CA. 32pp.

Table of Contents

1.0	Introduction	5
2.0	Water Flow	7
3.0	Channel Geomorphology	10
4.0	Off-Channel/Hillslope Geomorphology	14
5.0	Sediment Transport and Loads	16
6.0	Assessment of Data	17
7.0	Annotated Bibliography	23

1.0 Introduction

The San Francisco Estuary Institute is assisting Zone 7 Water Agency (Zone 7) to improve and synthesize knowledge about the transmission of water and sediment through mainstem channel facilities and to identify management and mitigation opportunities. Zone 7 has a number of questions and concerns relating to the 37 miles of channels maintained/owned by Zone 7 and the attending tributary watershed area (Figure 1). Sediment is supplied from a number of tributaries with differing timing and rates. Historically large quantities of sediment were transported by the local streams before development occurred. Currently, some of this sediment is trapped in Zone 7 facilities causing problems for flood conveyance and changes to the structure and quality of habitat. For example, Figure 2 provides an exemplary example of sedimentation challenges in the Airway Boulevard reach of the Zone 7 facilities. Zone 7 would like to know more about where this sediment comes from, how it is transported through their channel facilities, the causes, rates, and character of sedimentation, and if there are opportunities for managing the source areas or channels differently to reduce management costs. Furthermore, Zone 7 is increasingly being challenged by regulatory agencies to address stream habitat and water quality function, in addition to its ongoing flood control activities and operating procedures.

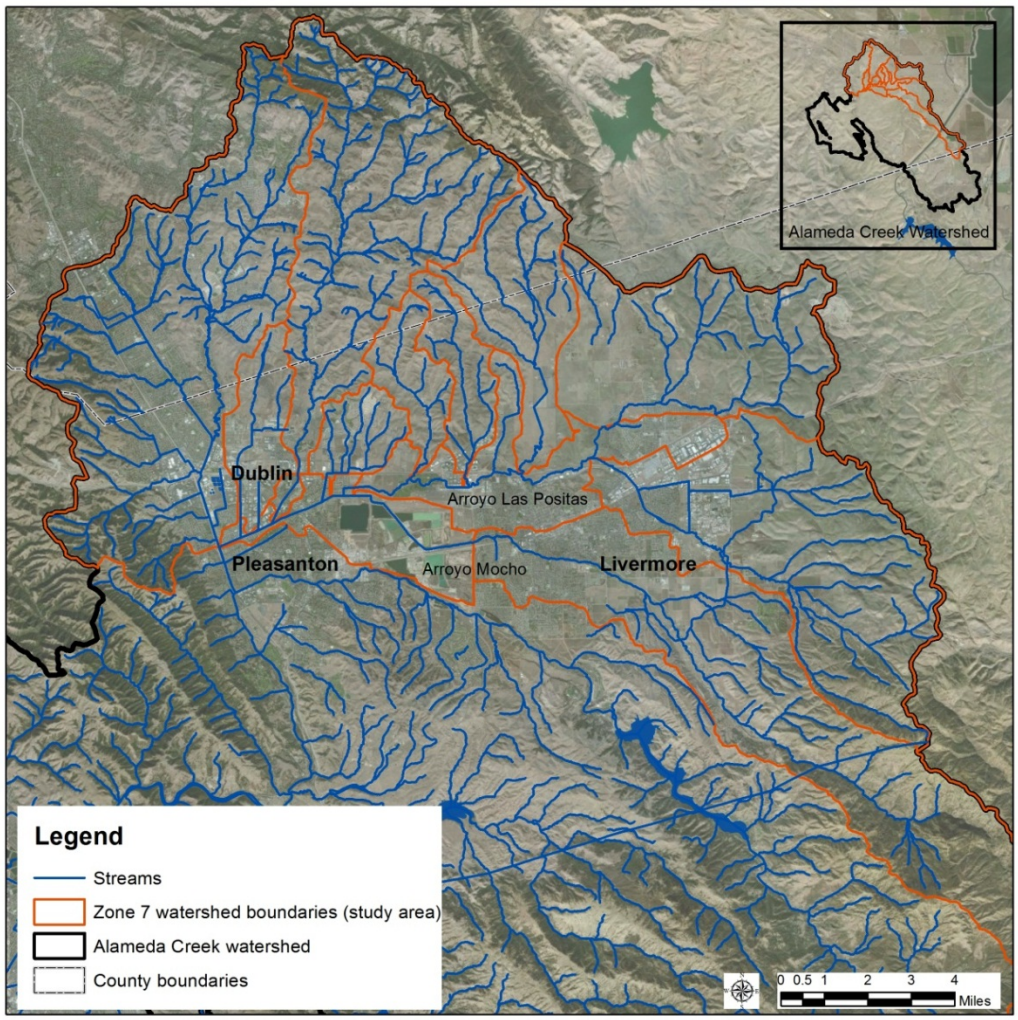


Figure 1. Zone 7 Water Agency area of influence. Upland portion of the Arroyo Mocho watershed continues further south, beyond the map extent.

Figure 2. Sedimentation and loss of channel capacity at Airway Blvd on Las Positas Creek (looking downstream).

To help address these questions and challenges, and to support Zone 7 decisions on management strategies, SFEI is in the midst of a multi-year study. The sub-objectives of this effort are to:

- Determine the flow of water and sediment into and out of mainstem Arroyo Mocho,
- Determine characteristics, rates, and causes of sedimentation in Zone 7 channel facilities,
- Develop a sediment budget for the study reach as a tool for clearly communicating the main sources and processes affecting the function of Zone 7 channels within the study area,
- Map and characterize channel modification and mitigation opportunities based on a comparison of historic and modern channel function, and
- Communicate findings primarily to Zone 7 and also to stakeholders of the Alameda Watershed Council.

Here we synthesize the existing knowledge from literature and data generated from the many previous studies. This current state of knowledge on sediment should be useful as a baseline data resource for Zone 7 modeling efforts and prioritization of key data gaps and importantly, minimized duplication of data and optimized study methods for filling those data gaps. The literature review was guided by a number of sediment-related questions developed by Zone 7 and SFEI in tandem, including:

- What is the existing knowledge in the study area for sediment supply to the channel, which would inform a sediment budget?
- Is the data sufficient, or is this a barrier?
- What are the rates and locations of sediment transport and sedimentation?
- What is the state of data quality?

The report is organized by area of investigation: water flow, channel geomorphology, off-channel hillslope processes, and sediment transport and loads. It is followed by an annotated bibliography that briefly summarizes the relevant information contained in each report or map document. The reports and data are also available on the attached CD.

2.0 Water Flow

2.1 Data was compiled relating to the flow of water through the Zone 7 channels.

The USGS has collected discharge data in the watershed from a number of locations spanning 1890 to present (Table 1). The majority of the data upstream from Verona has been collected prior to the mid-1980s and is high quality. Such data should be used with caution if trying to infer modern hydrological processes given rapidly rising populations in the tri-city areas and changing land use from rangeland to vineyards in the recent decades.

Table 1. Compiled USGS gaging records from gages in the Zone 7 jurisdiction.

Site number	Site name	Drainage area (mi^2)	Peak Flow discharge records	Peak#	Daily mean discharge records
11176100	ARROYO LAS POSITAS AB LIVERMORE CA	7.82	1/27/1972-12/26/1973	3	1971-1974
11176140	ALTAMONT C NR LIVERMORE	13.4	2/21/1979-1/13/1980	2	1978-1980
11176300	TASSAJARA C NR PLEASANTON	26.8	2/2/1915-1/24/1983	19	1914-1983
11176000	ARROYO MOCHO NR LIVERMORE CA	38.2	1/17/1913-3/4/2001	57	1912-2002
11174500	ALAMO C A DUBLIN CA	38.7	2/2/1915-3/22/1920	6	1914-1920
11174600	ALAMO CN NR PLEASANTON	40.8	1/13/1980-1/23/1983	4	1979-1983
11176090	ARROYO MOCHO A LIVERMORE CA	50.8	12/25/1983-11/8/1984	2	1983-1985
11176145	ARROYO LAS POSITAS A LIVERMORE CA	53.3	1/27/1981-2/8/1985	5	1980-1985
11176150	ARROYO LAS POSITAS NR LIVERMORE CA	64.6	1/16/1913-3/5/1930	15	1912-1930
11176180	ARROYO LAS POSITAS A ELCH RD NR PLEASANTON CA	75	1/17/1978-1/24/1983	6	1977-1983
11176400	ARROYO VALLE BL LANG CN NR LIVERMORE CA	130	1/21/1964-3/4/2009	46	1963-2911
11176200	ARROYO MOCHO NR PLEASANTON CA	142	2/1/1963-2/8/1985	23	1962-1985
11176500	ARROYO VALLE NR LIVERMORE	147	1/19/1913-5/31/2009	70	1960-1978
11176600	ARROYO VALLE A PLEASANTON CA	171	4/3/1958-2/8/1985	28	1957-1986
11176350	ARROYO DE LA LAGUNA AB AV NR PLEASANTON CA	224	NA	0	1974-1979
11176900	ARROYO DE LA LAGUNA A VERONA CA	403	1/1/2004-3/3/2009	6	1912-2011
11177000	ARROYO DE LA LAGUNA NR PLEASANTON CA	405	1/17/1913-12/16/2002	47	1912-2003
11179000	ALAMEDA C NR NILES CA	633	3/30/1892-3/4/2009	118	1891-2010
11176550	ARROYO VALLE TRIB NR LIVERMORE CA	NA	2/21/1959-1/18/1973	15	NA
11179005	ALAMEDA C TRIB NR NILES CA	NA	1959-1973	15	NA

2.2 Zone 7 surface water monitoring

Zone 7 has been operating stream gages since 1964 and took over many of the USGS gages when they were discontinued. In general Zone 7's program mirrored that of the USGS in terms of methods and data types. Documentation of rating adjustments and changes in cross-sections in relation to channel modifications and maintenance is less certain. Again, given the changes in city populations, care should be taken with respect to modeling current and future flow conditions; urbanization has potentially impacted the peak and shape of the hydrograph. Currently, Zone 7 Water Agency operates nine surface water sites and the USGS operates three surface water sites in the area (Table 2).

Table 2. Surface water sites currently operated by Zone 7 and the USGS in Livermore Valley.

Site ID	Station Name	Period of record	Operated by:
AMNL	Arroyo Mocho near Livermore	10/01/1991-present	Zone 7
AMHAG	Arroyo Mocho Hagemann	10/01/1985-present	Zone 7
AM_KB	Arroyo Mocho at Kaiser Bridge	1/30/1998-present	Zone 7
AMP	Arroyo Mocho near Pleasanton	10/01/1986-present	Zone 7
ALPL	Arroyo Las Positas at Livermore	1/02/1986-present	Zone 7
ALP_ELCH	Arroyo Las Positas at El Charro	10/01/1990-present	Zone 7
ADVP	Arroyo Valle at Pleasanton	1/01/1986-present	Zone 7
AVBLC	Arroyo Valle below Lang Canyon near Livermore	10/01/1974-present	USGS
AVNL	Arroyo Valle near Livermore	10/01/1941-present	USGS
ADLLV	Arroyo de la Laguna at Verona	1912-present	USGS
ACD	Alamo Creek at Dublin	2/2012 (expected)	Zone 7
TCD	Tassajara Creek at Dublin	2/2012 (expected)	Zone 7

2.3 Flooding history of the Zone 7

A number of floods have occurred in the system over the years (Table 3). These can be better described in terms of a recurrence interval based on the long term gage at Niles (Figure 3). Data at Niles was compiled highlighting years with the highest return intervals over the 117 year period of record (1952, 1955, 1958, 1986, and 1998). This type of analysis is possible for any of the USGS gages in the Zone 7 jurisdiction; however none have a period of record as long as the Niles Gage.

Table 3. Large flooding events noted in the literature.

Year	Source	Remarks
1862	FEMA, 1997	
1863-1888	FEMA, 1997	many small floods
1889-1910	FEMA, 1997	5 major floods, 5 smaller floods
1911	Freeman, 1912	January 15, March Flood -water depth approx. 20 ft above bed at Niles Dam
1912-1945	FEMA, 1997	2 major floods, 16 smaller floods
1952	FEMA, 1997	
1955	FEMA, 1997	December, largest storm of record (Zone 7)
1958	FEMA, 1997	Spring
1962	FEMA, 1997	
1964	FEMA, 1997	
1970	FEMA, 1997	January

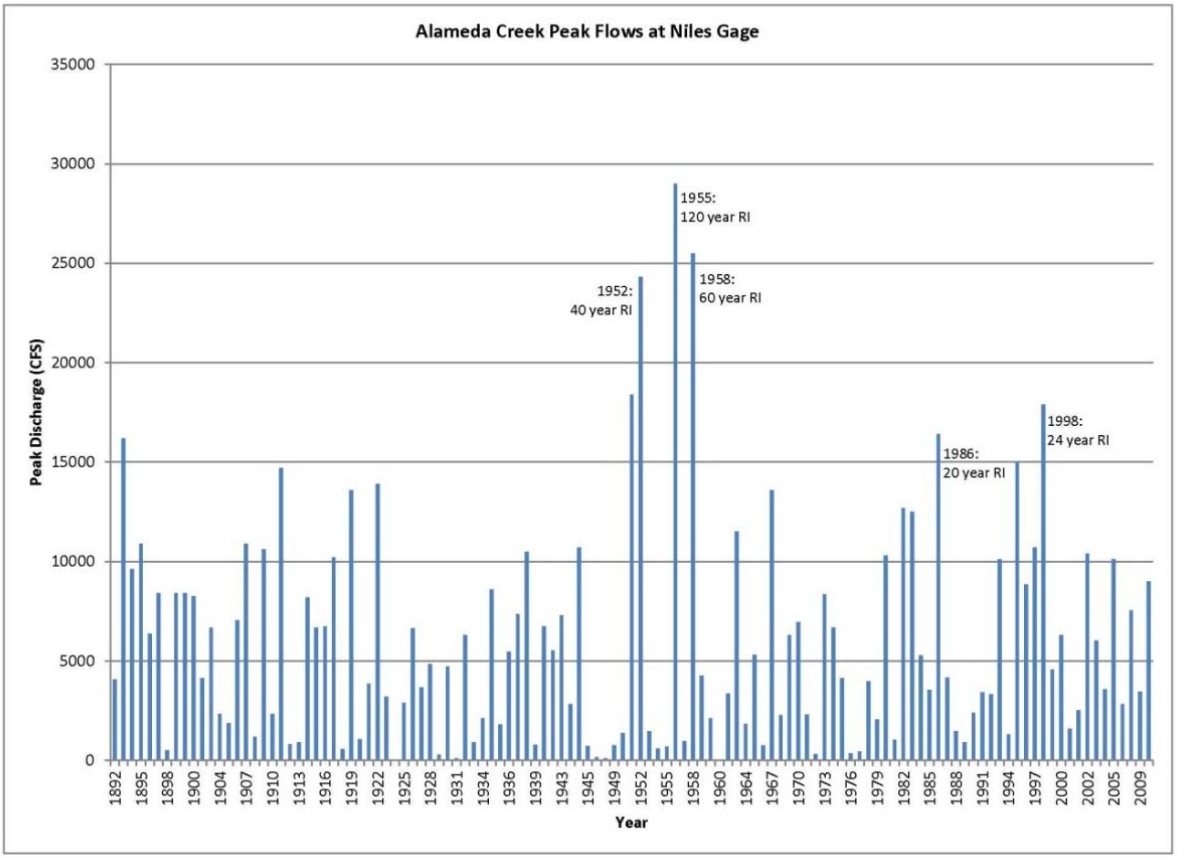


Figure 3. Alameda Creek Peak Flows at Niles Gage from 1982 to 2010.

2.4 Flow augmentation

Flow augmentation data were received from Sal Segura of Zone 7 who interfaces with the Department of Water Resources to manage the additional flows to Zone 7 facilities from the South Bay Aqueduct (SBA). Zone 7 manages releases from the SBA. Most augmentation is done when no natural flow is reaching AMP. Some augmentation occurs in ALPL and Arroyo del Valle as well. In any given rainfall event, if augmented flows are occurring (though during any significant rainfall event, artificial releases are turned off so as to not waste the purchased water), Segura estimates this augmented water comprises only 3-5% of the discharge at AMH. It is intended to recharge groundwater before reaching the AMH gage.

The gravel companies discharge water into Arroyo Mocho that eventually leaves the valley. Segura estimates that they release 8-10 cfs 90% of the time that releases occur. Annual quantities have varied significantly over time. Mining discharges have been made to Arroyo del Valle as well. The discharge point is downstream of AMH, but would affect AMP. Zone 7 staff make twice yearly calculations about how much of this artificial flow is leaving the valley, since some of the water Zone 7 releases to groundwater from the SBA often gets pumped back up by the gravel company and re-released to Arroyo Mocho, and some re-percolates. This process is described thoroughly in the Zone 7 Surface Water Annual Report 2008.

3.0 Channel Geomorphology

Geomorphic data that was collected in the watersheds within the Zone 7 service area was reviewed. Data include cross sections, longitudinal profiles and sediment size analyses. Channel morphology is important in a sediment routing study, and analyses of channel geometry changes through time facilitate a greater understanding of sediment dynamics (aggradation, degradation, etc). Interviews were conducted with key Zone 7 staff to augment physical data sources.

3.1 Channel cross sections

A number of surveys have been completed in many reaches of the Zone 7 channels during the past 6 decades (Table 4) including many engineering drawings produced when the flood control channels were built. However, the data are spotty and none can be compared over time to derive reliable sedimentation rates or provide hypotheses of climatic causes of change. Many of the drawings provide "typical cross sections" meant to represent the entire reach as it was built, but these are less useful for studying channel change over time.

Table 4. Cross sections surveyed in Zone 7 study area.

Decade	Stream	Site location	Year	Responsible party	Remarks
1960s					
	Alamo Canal	Line H	1961	Zone 7	As-built
	Arroyo De La Laguna	Line B21: ADLL through Western Pacific Railroad	1963	Zone 7	As-built
	Arroyo De La Laguna	Line B: Bernal Ave to Arroyo Mocho	1964	Zone 7	As-built
	Alamo Canal	Line F: Arroyo Mocho to Southern Pacific Railroad	1964	Zone 7	As-built
	Arroyo Las Positas	Line H	1967	Zone 7	As-built
	Pleasanton Canal	Line B5: From ADLL plus 5000ft	1967	Zone 7	As-built
	Tassajara Creek	Line K	1967	Zone 7	As-built
	Arroyo Del Valle	Line E	1969	Zone 7	As-built
1970s					
	Arroyo Mocho	Line G: Hopyard to Pleasanton Canal	1970	Zone 7	As-built
	Arroyo De La Laguna	Confluence upstream to Castlewood	1971	Zone 7	Green book survey for FEMA
1980s					
	Collier Creek	Line M	1980	Zone 7	As-built
	Arroyo Las Positas	Line H	1980	Zone 7	As-built
	Altamont Creek	Line R	1980	Zone 7	As-built
	Dublin Creek	Line T	1982	Zone 7	As-built
	Arroyo Seco	Line P	1984	Zone 7	As-built
1990s					
	Arroyo Mocho	At Pleasanton (AMP)	1991		Weir as-built

Decade	Stream	Site location	Year	Responsible party	Remarks
	Arroyo De La Laguna	Verona	1990s	USGS	Discharge measurement notes
2000s					
	Arroyo Las Positas	At Livermore (ALPL)	2003		Weir as-built
	Arroyo De La Laguna		2006	SFEI	Reoccupy six 1971 FEMA locations
	Alamo Creek		2004	Hydrologic Systems	
	Tassajara Creek	At Windemere Parkway Bridge	2004	Hydrologic Systems	
	Watershed wide	Throughout watershed	2006	West Yost & Associates	Zone 7 Stream Management Master Plan
2010s					
	Arroyo Mocho	At Pleasanton (AMP)	2011	Kier & Wright	
		At Pleasanton (AMP)	2011	SFEI	At sampling location (includes slope)
		At Hagemann (AMH)	2011	SFEI	At sampling location (includes slope)
	Arroyo Las Positas	At Livermore (ALPL)	2011	Kier & Wright	100 m upstream of sampling location
		At Livermore (ALPL)	2011	Zone 7	At sampling location

3.2 Longitudinal profiles

Longitudinal profiles have not been taken frequently in the watersheds in the Zone 7 service area; however ample data exists such that creation of a complete long profile would be feasible.

3.2.1 Existing longitudinal profiles

-Laurel Collins 2005 (downstream of Niles Canyon)

-SFEI 2011 (localized to sampling locations: ALPL, AMH, AMP)

-Arroyo De La Laguna from Verona to confluence with Alameda Creek: 1959 (RMC), 1975 (FEMA), 1998 (RMC), 2007 (SFEI)

3.2.2 Data for creating longitudinal profiles

-USGS topographic map contours are useful for estimating valley profiles and slope, but cannot be used for accurate calculations of bed profiles.

-USGS topographic quadrangles 1:24000

-Tassajara 1996, Bryon Hot Springs 1968, Dublin 1980, Livermore 1980, Altamont 1981, La Costa Valley 1996.

-Using the 2007 LiDAR data digital elevation model (DEM) and the Netmap tool, SFEI calculated a center line for the major streams in the Livermore Valley, with accurate XYZ coordinates. From this center line we use 3D analyst tools to graphically represent the long profile of the streams in the valley from the Alamo Canal to the Altamont Pass. Sources of error include noise in the LiDAR, and the fact that LiDAR scans do not read through water, so in essence, the long profile may be a water surface elevation profile, in areas with flow at the time of the LiDAR flight.

3.3 Plan-form changes in channel position and character

SFEI has undertaken several studies which broadly examine the character, form and functions of creeks in the historical period, including changes over time (Stanford et al. expected 2012, Pearce et al. 2006). From these reports, we have a broad understanding of changes to the channel plan-form in the valley, but decision-level details of timing and locations of these changes in Zone 7 channels will require more in-depth research. Our current broad understanding suggests four main periods of channel network character:

<u>Historical period (c. 1800)</u>

The network of creeks that fed and drained the wetlands varied in form across the Livermore Valley. These streams were mostly discontinuous and dried through the summer; although in many cases they maintained some connectivity through subsurface flow. Arroyo Mocho and Arroyo del Valle, in the southern valley, developed broad, braided channels that supported sycamore alluvial woodlands and were prone to flooding across the surrounding valleys. They shifted in course over thousands of years, building up broad gravelly alluvial fans that allowed for rapid percolation to groundwater. Upper Arroyo Las Positas which is now channelized through eastern Livermore Valley was historically one of many creeks to spread across the valley soils, and received its name only where a more defined channel formed at the confluence with Altamont Creek (Higley 1857, Whitney 1873, Allardt 1874, Nusbaumer 1889, Westover and Van Duyne 1910). The flow from these many discontinuous creeks drained through surface swales and subsurface flow to reach the Springtown alkali sink and Las Positas springs (Williams 1912, Coats et al. 1988; fig. yy59). The smaller northern watersheds draining towards Arroyo Las Positas and lower Arroyo Mocho (e.g., Cayetano, Altamont, Cottonwood, Collier, and Tassajara) followed narrow single-thread channels that spread and lost definition across the valley floor. The clay substrate prevented most percolation through to the underlying aquifers and held flood waters at the surface, helping support seasonal wetlands. At the western-most side of the valley was the Pleasanton lagoon, a vast wetland system which enlarged and shrunk with the rains, acting as both flood attenuation and sediment storage, upstream of Niles Canyon.

<u>Intense hydrologic modifications (1880s-1910s)</u>

Between the 1880s and the 1910s, the network of creeks and wetlands in the Livermore Valley were changed dramatically. The Pleasanton Lagoon was largely drained, and the tributaries which previously percolated into the Livermore Gravels and joined the lagoon subsurface, were now channelized creating surface hydrologic connection. For example, 1874 is recorded as possible date of ditching of Arroyo Mocho (Collins, 2003).

<u>1960s-70s</u>

Largely as a response to the severe floods in the 1950s, as well as a population boom post-World War II, the creeks and remaining wetlands in the valley were engineered throughout the 1960s and 1970s into trapezoidal flood control channels and drainage lines with levees to make way for housing development and provide flood protection. Large reservoirs were built during this period which also altered the flows and functions of the creeks. Specifically, the San Antonio Dam was completed in 1964 and the Del Valle Dam was completed in 1968 (FEMA, 1997).

Today

Today the channel network reflects its engineered past. While the locations of channels have not largely changed since the 1970s, changes in channel elevation have been observed. Channel incision is present in some reaches, largely a response to increased impervious surfaces, and the downstream effects of large dams. In other locations, channel sedimentation has become a problem, as supplies of sediment from hillslopes and upstream channel erosion have likely increased.

More detail can be found in SFEI's Historical Ecology of Alameda Creek report, due out in spring 2012. Additionally, the proposed Historical Ecology of Zone 7 project may be starting in early 2012, which would cast a more refined lens on this subject.

3.4 Reports of dredging/sediment removal

Pamela Lung at the City of Livermore presented on areas of increased deposition and sedimentation that the city monitors and dredges periodically. That presentation is included on the CD and is cited in the annotated bibliography. She notes that the areas of greatest concern are on ALPL, between Kitty Hawk and Airway Blvd, specifically at the confluence of Collier Creek and Arroyo Las Positas. Collier Creek may have been a braided channel at one point. Another point of concerns is the Holmes Street Bridge on Arroyo Mocho which is dredged often.

A sediment basin was constructed at the confluence of Arroyo Las Positas and Arroyo Mocho (at El Charro Road) in 2003/04 and was desilted once since construction, in 2007. Zone 7's Stream Management Master Plan (2006) documents areas that are eroding, and aggrading, and includes estimates of yields for the entire watershed (suspended load and bedload). Areas are highlighted that have extreme potential for either aggradation or incision and thus require maintenance

3.5 Grain size information

Grain size information and bulk sampling has not been frequently collected.

3.5.1 A report from 1959 observed grain size distributions from upper Alameda Creek to the Bay. Inderbitzen, A.L. 1959. Gravels of Alameda Creek, California. Journal of Sedimentary Petrology. 29 (2): 212-220

3.5.2 SFEI staff performed pebble counts at Arroyo Mocho at Hagemann, Arroyo Mocho at Pleasanton and Arroyo Las Positas at Livermore sampling sites, SFEI June 2011

3.6 Vegetation maintenance on Zone 7 channels

Vegetation management involves the removal of vegetation from the facilities. According to Larry Akinsiku, Zone 7 typically uses mechanical and chemical means to manage vegetation along and within the facilities.

Mechanical:

- Some vegetation is normally pruned mechanically including willows, cottonwoods, with tree pruning and mowing. Any of this could be done any time during the year except for mowing that is done between May and June.

Chemical:

- Zone 7 sprays for non-native, invasive broadleaf within the creek between March and April, for aquatic weeds within the creek between July and August and for pre-emergent vegetation on access road between December and February. LARPD has begun to use goats along parts of Arroyo Mocho.

3.7 Yearly channel maintenance

Reports, data, and information regarding yearly sloughing, erosion maintenance, and bank failure were collected from Zone 7 staff.

3.7.1 Maps of yearly bank failures were obtained from Zone 7 and are stored on the accompanying CD. Zone 7 supplied SFEI with maps of bank slump project areas from 2006-2011. These maps can potentially be used to determine if certain areas are particularly problematic year after year, or if the bank failures have been getting more severe, as well as other time lapse comparisons. The maps do not document size of the slumps, or to which storm they are associated.

3.8 GIS documentation of channels

Location of grade control structures, crossings, sewers, gas lines, and bridges were documented.
Tom Rooze and Diana Gaines are key GIS and modeling staff at Zone 7. Tom Rooze provided shapefiles of current stream layers and current surface water stations. Diana Gaines is compiling information for HEC-RAS model on Zone 7 waterways, which is slated to be done in early 2012. As far as both of them know, there are no other mapped features in GIS format in the channel such as sewers, grade control structures and gas lines. Zone 7 also recommends inquiring about data held at the cities of Livermore, Pleasanton and Dublin.

3.9 History of gravel mining (in channel)

3.9.1 Report from Division of Mines and Geology(2000) gives a brief history of mining in general in Alameda Creek
watershed.

3.9.2 One example of historical gravel mining from Echo Newspaper LHG December 20 1894 - 3:2 "In consequence of making of a large excavation in the bed of the Arroyo Mocho just below the L St. crossing to obtain gravel for use on the roads, the rapidity of the current has been greatly increased at that point and the consequent washing away of the banks and bed of the creek has made the crossing quite dangerous?"

4.0 Off-Channel/Hillslope Geomorphology

Data sources documenting off channel and hillslope processes such as channel slope, mass wasting, land use change, and flood history are essential for understanding sediment sourcing from the watershed lands. Grazing and fire regime information would also be relevant. Several data sources were gathered which contribute to a watershed-wide understanding of sediment sources and delivery mechanisms.

4.1 Aerial photos available for the study area.

4.1.1 Full coverage of watershed/county
-1940 Air Photo 28 Collection - Alameda County,
-DOQQ 1993
-1996 WAC Corps 1:24,000
-NAIP 2005, 2009, 2010

4.1.2 Valley floor coverage only
-1966 Alameda County Air Photos Scale 1:20,000
-1977 Alameda County 1:6,000 and 1:12,000
-1977 Contra Costa County 1:6,000 and 1:12,000
-1984 Walnut Creek to Pleasanton to Livermore. 1:12,000

4.2 Dominant geomorphic processes

4.2.1 Regional map of sediment producing geology (Figure 4, Adapted from Helley and Graymer, 1997). This map shows Livermore Valley with bedrock geology rated to estimate potential of

sediment production (Red is high sediment production, green is low sediment production). SFEI staff used GIS layers of bedrock geology for Alameda and Contra Costa counties as well as professional judgment, and the literature to determine lithologies most likely to produce large amounts of sediments expected to impact the channel network on the valley floor. We mapped these rankings (High, Medium, Low) along a color gradient, in order to visually express which parts of the watershed uplands might be expected to produce high amounts of sediment. This map is in draft form.

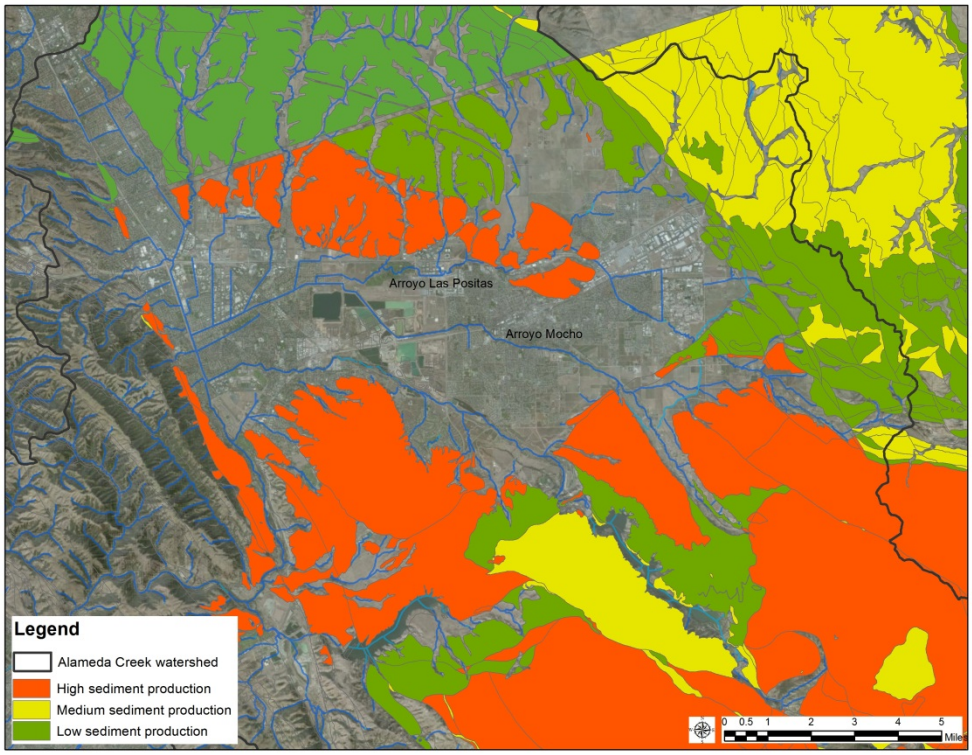


Figure 4. Regional map ranking sediment producing geology as high, medium or low

4.2.2 Landslide maps and documentation of landslides were gathered and are stored in the GIS database.

-Wentworth et al. 1997. Summary Distribution of Slides and Earth Flows in Alameda County, CA. Landslides and earth flows are slow moving, and common hazards in the SF Bay Area. They form as the result of increased water content, earthquake shaking and destabilization of slopes. This is a very general map summarizing all earth movements documented.

-Majmundar, Hasmukhrai H. 1991. Landslide Hazards in the Livermore Valley and Vicinity, Alameda and Contra Costa Counties, CA. 6 plates, map scale 1:24000. Not digitized. Information about slope stability and landslide susceptibility. Most abundant landslides are associated with the Cretaceous Cierbo and Panoche formations, Upper Miocene Neroly Sandstone, and Plio-Pleistocene Green Valley and Tassajara Formations

-Ellen et al. 1997. Map showing Principal Debris Flow source areas in Alameda County, CA. Debris flows were calculated from a 30 m grid using slope and curvature as parameters, as well as historical maps of debris flows.

4.3 Digital Elevation Data

4.3.1 The LiDAR hillshade and Digital Elevation Model (DEM) were created by loading bare earth

points from the county LiDAR flight in 2007 into a terrain model in a GIS database. The terrain was then converted into a raster DEM.

4.3.2 DEM data quality from LiDAR flight is considered good, but with some error. The bare earth points were cleaned, but sources of error include noise, or unwanted data points, left in the LiDAR layers, water in the channel, which the LiDAR cannot read through, as well as an issue of trees in canyons.

5.0 Sediment Transport and Loads

In order to understand sediment dynamics in the watershed, an understanding of the mass balance of input and output of water and sediment must be thoroughly studied.

5.1 SFEI sediment monitoring

Results of data analysis from WY 2010-2011 sediment monitoring on Arroyo Las Positas and Arroyo Mocho are shown in the year one report on this CD.

5.2 USGS sediment gaging records

USGS records for Alameda Creek at Niles include suspended sediment loads WY 1957-59: Annual sum only; WY 1960-73; 2000-06: Daily for wet season based on rating; WY 2007-present: 15 minute and daily for wet season based on turbidity surrogate; Bedload records include WY 2000-present: Daily for wet season based on rating; USGS records for Arroyo De La Laguna near Pleasanton (11177000) and at Verona (11176900); WY 2000-03: Daily for wet season based on rating; WY 2007-present: 15 minute and daily for wet season based on turbidity surrogate. Bedload is only available for the "near Pleasanton site due to the Verona site being unsuitable for measurements; WY 2000-03: Daily for wet season based on rating.

5.3 No other entity is currently monitoring sediment in the study watersheds

5.4 Historical sediment transport data from USGS

Suspended sediment and bedload data collected for the Bay Area region can be plotted in wet season load (tons) against peak flows (Figure 5). Several trends start to emerge with regards to the sediment production of watersheds throughout the Bay Area. Zone 7 watersheds are not remarkably different as shown by generalized log-log scale, but the SFEI WY 2010 data do continue to support the hypothesis that each sub-watershed area feeding into Zone 7 facilities shows a unique transport relation – ALPL with lower sediment load and some of the other tributaries with high sediment load.

5.5 Consulting reports

5.5.1 RMC sediment appendix for the Zone 7 Stream Management Master Plan (2006) estimates sediment loads, current and predicted, as well as documenting areas of aggradation and degradation in the channels.

5.5.2 Hydrologic Systems estimated and models sediment transport rates and yields for Alamo Creek and Tassajara Creek driven by protecting a restoration project from head cutting, as well as a bridge crossing.

5.5.3 SFEI conducted a low-flow turbidity study (2008) which documented the spatio-temporal variability of turbidity in Alameda Creek watershed from August-December 2007.

6.0 Assessment of data in the context of study objectives

In gathering these data and reports, SFEI found that many datasets have been or are being collected to support the current and future needs of Zone 7. However, a number of key pieces of information or data are lacking. Below, we categorize the data available for each of the project's sub-goals, highlighting the information that is needed in future work plans to answer Zone 7 questions.

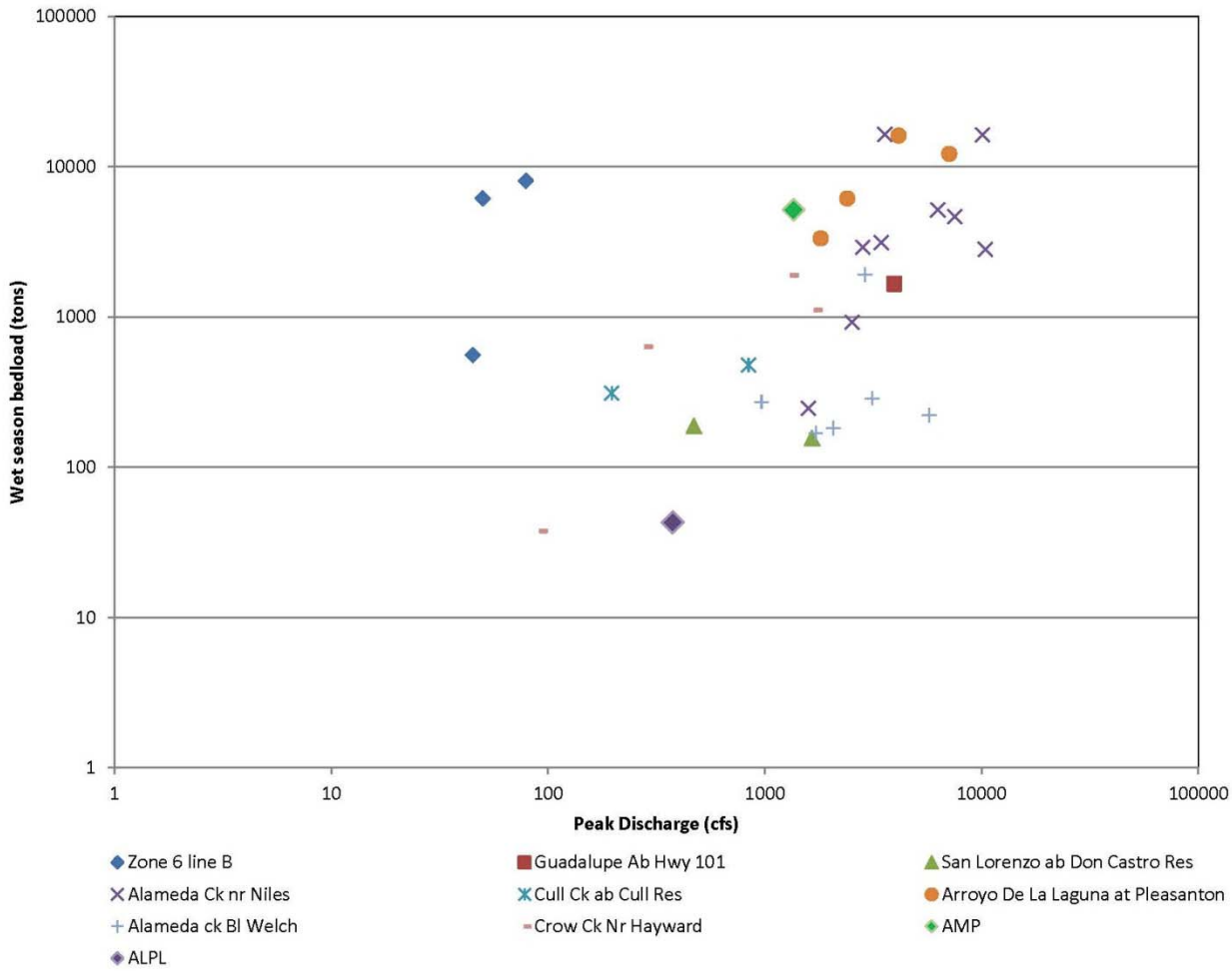


Figure 5. A comparison of bed sediment loads in Zone 7 facilities to loads measured by USGS at other Bay Area locations. WY 2011 sampling of Zone 7 streams at Arroyo Mocho at Pleasanton (AMP) and Arroyo Las Positas at Livermore (ALPL) are shown as purple and green diamonds and fit within the general regional relation although AMP is in the upper area indicating bed load is relatively high and ALPL is in the lower area indicating lower supply.

6.1 Determine the sediment flux into and through Zone 7 facilities

Determination of sediment fluxes into and through Zone 7 facilities could be achieved in three fundamental ways: 1. Using regional rating relationships based on nearby measurements in watersheds of similar size and geology, 2. modeling using some kind of terrain based model, or 3. measurements at strategic field locations.

Given Zone 7's questions and long term visions for improved dynamic modeling to support channel management, they have concluded, and we concur, that the appropriate method at this time is field observation on the larger upstream channels and at the downstream boundary. We recommend coupling this field effort with terrain mapping to estimate sediment loads from the smaller tributaries to the north of the channel. Prior to the initiation of SFEI study in October 2010, there had been no measurements of suspended sediment concentration or bedload rates sufficient to determine fluxes. USGS gaging at Verona on Arroyo de la Laguna and further downstream, although certainly suitable for developing a regional rating relationship that might be applied to the lower mainstem Arroyo Mocho, does not provide the detail needed to constrain a sediment budget for Zone 7 facilities given many geologically unique tributaries with specific suspended and bedload characteristics. Zone 7's systematic measurement of flow at Arroyo Mocho at Pleasanton (AMP) and Hagemann (AMH) and Arroyo Las Positas at Livermore (ALPL) are suitable to support suspended sediment and bedload records. However, flow and suspended sediment and bedload data are lacking for the creeks that flow in from the uplands to the north of the Arroyo Mocho Flood Control Channel including Line G3, Tassajara Creek, and into Arroyo Las Positas, including Cottonwood Creek, Collier Creek, and Cayetano Creek. Given that the creeks north of the channel facilities are underlain by a variety of geologic formations (Miocene sandstones, Plio/Pleistocene Livermore gravels, and Holocene/Pliocene surficial deposits) and exhibit a variable set of sediment producing processes (channel bed and bank erosion, headward extension, shallow landslides, earth flows and gullying), the terrain mapping methodology is being utilized to estimate sediment flux from these watershed areas. Initial development of the terrain model has begun and has been successful, though a refining of the data inputs is necessary to address the unique topography of the arroyos in question (Bigelow et al. in prep). Initial results suggest that the northern tributaries have similar dominant sediment sourcing processes, namely erosion of the channel bed and banks. However a large amount of variability exists between tributaries in how connected the sediment supply from other hillslope processes (e.g. shallow earth flows and landslides) is to the channel network due to the presence of wide valley flat surfaces.

During Water Year 2011, the SFEI field crew began measurements of suspended sediment concentrations and bedload flux at Arroyo Mocho at Pleasanton (AMP) and Hagemann (AMH) and Arroyo Las Positas at Livermore (ALPL). Although there were some improvements recommended to the program (See WY 2011 report for details; Beagle et al., 2011), the following study plan is recommended for accurate quantification of sediment fluxes (**SF**) in the context of Zone 7 questions and dynamic modeling ambitions:

SF-1 Carry out suspended sediment and bedload measurements at Arroyo Mocho at Pleasanton (AMP) and Hagemann (AMH) and Arroyo Las Positas at Livermore (ALPL) for a period of 4 wet seasons (October 1st to April 30th) using a combination of automated and manual methods (see Beagle et al., 2011 for details). The objective of the 3 years of observation is to capture storms of a reasonable size (at least a 5 year recurrence interval would be ideal) and capture a variety of bedload conditions given bed load tends to move through systems in slugs and in relation to climatic anomalies in a less systematic way then suspended sediments. At the end of 4 years, the data should be reassessed to determine if further data are still needed and if a modified approach to sampling is preferred (e.g. large storm only or some other data capture structure).

SF-2 Given the expense of completing sediment gaging on all five northern tributaries, we recommend modeling sediment loads using terrain mapping software calibrated with suspended sediment and bedload data collected on the mainstem. Initial development of the model to-date has been positive but weaknesses (discussed above) have been identified. As such we recommend continued support to improve the accuracy of output supplied from the model by adding explicit quantification of arroyo processes and more explicit storage components. This effort would remove supply from watershed areas that are disconnected from the channel network (due to deposition on the valley floor), thus producing more accurate relative estimates of erosion potential from areas that have been observed as active. At the completion of the terrain model, it is possible that we might

recommend strategic measurements of suspended sediment concentrations and bedload fluxes on one or more of the five northern tributaries where there is strong evidence of disproportionate sediment supply to the mainstem.

6.2 Determine characteristics, rates, and causes of sedimentation in Zone 7 channel facilities

Sediment storage in channels is one of the three important components of a sediment budget (inputs, storage, outputs) and directly impacts capacity, habitat quality and distribution and ultimately maintenance costs. Reliable discharge measurements are also an integral part of the equation to determine rates of sedimentation, because the majority of sediment is supplied and transported during, and potentially deposited on the falling stage of large flood events. There have been many reconnaissance level studies throughout Zone 7 channels; however there has not been a comprehensive study of in-channel conditions. Furthermore, as with most watersheds in California, many stream flow gages were abandoned in the mid-1980s. While there are a few gages with long-term records, such as Tassajara Creek near Pleasanton, Arroyo Mocho near Livermore, Arroyo Valle near Livermore, and others with over 80 years of discharge records, many areas in the watershed have flow data that only captures a few years of data. In addition to the USGS gages, Zone 7 operates nine surface water stream gages, and inputs from the delta and quarries are well documented. Flooding history is well documented by Zone 7, and long term gages at the downstream end of the watershed indicate major flood years. Zone 7 staff provided useful reporting on maintenance practices and locations in flood control channels, however comprehensive data on channel geomorphology over time is lacking. There are spotty cross sectional surveys, but none that can be compared over time. Reports of bank failures and maintenance are complete but lack spatial accuracy. In-channel geomorphic mapping has not been completed, nor has a comprehensive grain size analysis along the channel both import data for modeling channel processes. The following study plan is recommended to address further data collection relating to characteristics, rates and causes (**CRC**) of sedimentation in Zone 7 channel facilities:

CRC-1 Conduct a geomorphic assessment of channel character and sedimentation. Collect a suite of basic geomorphic data (e.g. monumented cross sections, longitudinal profiles, deposit volumes) to allow for quantification of sediment storage (volume, location, grain size, cause) presently in Zone 7 channel facilities, and to allow for analysis of change through time (using existing earlier data, and using this data as a baseline for future analysis). This assessment should include:

- Mapping of aggrading and degrading reaches
- Quantification of grain size along channel length
- Locations of grade control structures and other hardened locations
- Documenting yearly bank failures using a GPS system, so trends over time can be assessed.
- GIS based maps of grade controls, crossings, sewer, water, gas etc do not exist and would help guide a full sediment analysis.
- Completion of a single set of stationing (Zone 7 is in the process of this)

CRC-2 Prioritize consistent and reliable discharge measurements at all Zone 7 managed surface water sites. We recommend adding a stage monitoring component to SFEI's turbidity threshold data loggers at ALPL, AMP and AMH in order to gain a less error-prone relationship between discharge and sediment.

CRC-3 Additional focused investigation of locations within the northern tributaries identified by GIS terrain mapping as large sources of sediment to the channel network. This study would aim to document the process, rate, and cause of sediment supply, and make recommendations for controlling supply for the specific location.

6.3 Develop a sediment budget for the study reach as a tool for clearly communicating the main sources and processes affecting the function of Zone 7 channels within the study area

A sediment budget requires measurements or estimates of sediment being supplied to the system, sediment processes and deposition within the system, and sediment transport out of the system. Currently data is being measured to address some of these budget terms, for example, sediment gaging at three channel locations. Basic reconnaissance-level assessment has been completed for the entire Zone 7 watershed area (completed by RMC and Zone 7 as part of the Stream Management Master Plan) which estimated relative sediment yields and sediment-related problem locations. In addition, Hydrologic Systems (Burke and colleagues) estimated sediment yields from project areas on Alamo and Tassajara Creeks. Arroyo Mocho at Pleasanton is the furthest downstream site at which SFEI is currently gaging sediment (WY 11 and WY 12). Despite these watershed-specific estimates previously made, a full quantitative sediment budget has not been conducted for the full Zone 7 watersheds. Such a budget would allow for better communications across Zone 7 staff and its Board members and support decision-making by Zone 7 regarding its maintenance, operations, and long-term vision for its channel facilities, as well as for focusing effort on portions of the watershed to potentially control sediment supply to the channel network.

Typically estimates of sediment supply to the system from various geomorphic processes have error bars around the estimated averages, but that error can be reduced with more complete data. The value in a sediment budget is that it forces reconciliation of those errors. For example, upslope, large scale mass wasting is an important component of sediment supply in Bay Area watersheds. In the watersheds within the Zone 7 service area, some large scale landslide mapping has been completed, including Majmundar (1991), Wentworth (1997) and others, however there has been no comprehensive information on erosion rates, lowering rates, landslide connectivity or delivery to channels in the watershed. Understanding the key sediment input sources within the watershed, assessing the existing data (quality and spatial coverage), and prioritizing which data sets are most important to collect, will be an important step towards an accurate sediment budget.

By continuing to collect a complete record of sediment yields at Arroyo Mocho at Pleasanton (sediment output budget term), sediment yields at Arroyo Mocho at Hagemann and Arroyo Los Positas at Livermore (sediment input budget term), the terrain mapping in the northern tributaries being undertaken by SFEI (see section 1) (sediment input budget term), and the history of deposition and erosion rates in the channel facilities, a reasonable sediment budget could be calculated. The following long term planning should be put in place for future years, to ensure that appropriate data exists to compile a sediment budget (**SB**).

SB-1 Over the next two years, we recommend focusing the study plan on gathering the data necessary to complete a quantitative sediment budget. This includes data that addresses sediment inputs, storage, outputs, timing, and grain size. Such a sediment budget would provide Zone 7 with important information for making decisions with regards to sediment maintenance activities, source management, and mitigation opportunities.

6.4 Map and characterize channel modification and mitigation opportunities based on a comparison of historical and modern channel function

The provision of the most up-to-date spatial datasets, spanning historical time to the present, will be an important basis for assessing patterns and trends in geomorphic and biological function over the past five decades. These data will help to direct management decisions and provide important support for identifying mitigation opportunities. An understanding of how the watershed has changed through time requires accurate

mapping of the historical and modern channel network, and riparian and wetland habitats. This is best accomplished and communicated in a geographic information system (GIS) so that data can be used by Zone 7 staff or consultants in the future to support decisions or modeling channel form and function.

A general understanding of the historical conditions of the Livermore Valley has been compiled by SFEI in the Alameda Creek Historical Ecology report (in prep). This study produced a historical habitat map of the Livermore Valley, Sunol Valley, and Niles Cone in a GIS database. Additional data collection and analysis specific to the Arroyo Mocho and Arroyo Las Positas watersheds would provide more detail and utility for Zone 7 staff than the prior report which had a much larger geographic scope. The additional study would address a number of specific Zone 7 questions that will contribute directly to the Stream Management Master Plan (SMMP). For example, exploring what reaches of Arroyo Mocho had a broad distributary character, what reaches were historically perennial or intermittent and why, historical riparian vegetation patterns, and further understanding historical patterns of sediment deposition and erosion.

As a complement to the historical data, and to allow for accurate assessment of change through time, present-day data on the channel network and surrounding ecology should be gathered in GIS. For example, with the advancements of LiDAR and aerial photography, basic landscape level data is available. The LiDAR datasets provide a very clear picture of the current land surface features, and have been extremely helpful for understanding baseline conditions and for current geomorphic assessment work in process by SFEI and others. There exists a good understanding of bedrock and surficial geology, and faults, mostly with respect to Lawrence Livermore Lab and its environs. Presently, Zone 7's GIS library is limited, however, GIS data gathered for Zone 7 (presented on the accompanying CD) can augment current holdings. The GIS data includes: aerial photos, elevations, geology, hazards, soils, streams, USGS topographic quadrangles, vegetation cover, and watershed boundaries.

The following recommendations aim to help synthesize mapping and characterizing (**MC**) of channel modification and mitigation opportunities with the acknowledgment that Zone 7 is currently in the process of completing some of the recommendations:

MC-1 We recommend organizing and managing a GIS database, including collection of Contra Costa County and Santa Clara County LiDAR data to complete a 1m grid DEM of the Alameda Creek Watershed.

MC-2 We recommend completing a Zone 7 Historical Ecology study to expand the initial data set and analysis (discussed above) to focus on the Arroyo Mocho and Arroyo Las Positas channel reaches. This study should collect and synthesize additional historical data for these reaches in order to develop a more detailed understanding of pre-Euro-American modification conditions, and channel modification history to inform the SMMP and other activities. This will aid in development of alternative management strategies, including opportunities for environmental enhancement, channel modification, and/or mitigation. Specific topics that should be addressed include (to the extent that data are available):

- Historical extent, type, and character of riparian habitat of different kinds,
- Seasonal and perennial wetland habitats and riparian vegetation
- Extent of perennial and intermittent stream reaches
- Changes in channel plan form alignment and channel cross-section
- Changes in reach land uses
- Other related characteristics of the fluvial, riparian, and wetland systems.

7.0 Annotated Bibliography

Zone 7 literature including peer reviewed papers, and consultant reports documenting projects and processes in the Zone 7 watersheds:

Key words: *Alameda creek (tri-valley), sediment, erosion, incision, faults*

ACCWP. 2004. Watershed Management Integration Report. Prepared for Alameda Countywide Clean Water Program by The Alameda County Public Works Agency, with the assistance of EOA, Inc. February 18, 2004

This report provides an overview of the program's watershed management and assessment activities. It includes: background description on watershed management approaches in general, key characteristics of Alameda County watersheds and their relation to major Program elements, watersheds relevant to individual member agencies (Permittees) and ACCWP's activities and priorities for scheduling watershed assessment. It also reviews recent and current activities by the ACCWP's General Program and its member agencies to implement watershed management approaches and summarizes the current status and identifies needs and issues for future activities.

Alger, C.S. 1991. Debris flows and the morphogenesis of hollows near Sunol, Alameda County, California (Master's Thesis). Paper 224. http://scholarworks.sjsu.edu/etd_theses/224

This study examines a 6 km^2 area in Sunol and focuses on zero-order basins near the Calaveras fault. The purpose of the study was to better understand the relationship between debris flows and the development of hollows. Various field mapping and field surveys in the late 1980s and an eight time enlargement (1:3,000) of the USGS 1:24,000-sclae La Costa Valley 7.5-minute quadrangle was used as a base map for field observations of geomorphic features. He concludes that debris flows are the dominant form of erosion on hillslopes in this area and that debris flows occur more commonly within the hollows rather than on planar slopes and spurs. He estimates that rates of removal of slope material suggest that debris flows are sufficient to have carved the hollows within the Holocene, without significant contribution from other hillslope processes.

Beagle, J.R., Eads, R., Pearce, S., Gilbreath, A.N., Gluchowski, D.C., and McKee, L.J., 2011. Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Year 2011. A Watershed Program report of the San Francisco Estuary Institute prepared for Zone 7 Water Agency, Livermore, CA. San Francisco Estuary Institute, Oakland, CA. 38pp.

This report described methods and results for suspended sediment and bedload measurements made at three locations within ZONE 7 facilities; Arroyo Mocho at Pleasanton (AMP) and Hagemann (AMH) and Arroyo Las Positas at Livermore (ALPL). The report also includes a detailed set of recommendations for improvement to both Zone 7S discharge measurement program as well as the sediment program.

Bigelow et al. (in prep) Terrain mapping in Zone 7 channels. A Watershed Program report of the San Francisco Estuary Institute prepared for Zone 7 Water Agency, Livermore, CA. San Francisco Estuary Institute, Oakland, CA. XXpp.

Terrain mapping (Netmap) is a computer modeling program that develops regional scale terrain databases in support of watershed science and resource management, and provides tools for

interpreting watershed-level controls on aquatic systems. Netmap analyses were performed on the Arroyo Mocho watershed and were verified and analyzed in a reconnaissance field study to observe geomorphic processes, scales and magnitudes, channel characteristics, and collect selected geomorphic data. The reconnaissance aimed to refine the initial hypotheses about sediment supply generated by the terrain mapping. The Netmap program produces maps of erosion potential from the watersheds, allowing the user to identify locations where erosion may be greatest, locations of certain erosional processes, and cumulative sediment production from discreet areas (e.g. tributary basins). This technique was used in the Arroyo Mocho watershed to predict sediment supply from ungaged tributary basins. The estimates can then be used for future focused investigation, or as an input term in a sediment budget.

Carpenter, D.W., Sweeney, J.J., Kasameyer, P.W., Burkhard, N.R., Knauss, K.G., and R.J. Shelton. 1984. Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas. Lawrence Livermore National Laboratory, Livermore, CA. UCRL-53316

This report examines the geologic, hydrologic, and seismologic setting of the Lawrence Livermore National Laboratory (LLNL) and its nearby areas through a literature review, photographic studies, geologic mapping, geophysical surveys, geologic exploration, subsurface studies, and soil dating. The Livermore Valley is a seismically active region with two major regional faults (San Andreas and Hayward) as well as several other local faults. LLNL is underlain by a thick (>1km) sequence of late Tertiary and Quaternary alluvial deposits overlying a basement of Mesozoic metamorphic rocks of the Franciscan Assemblage and late Mesozoic and Tertiary marine sedimentary rocks. The late Tertiary and Quaternary alluvial deposits include lacustrine, alluvial fan, and stream channel deposits that accumulated in a continental environment. Soil liquefaction at LLNL is deemed improbable and land sliding at the site is prevented by lack of slopes. Erosion and sloughing can occur along drainage ditch and stream channel banks, and sheet flooding could occur at Arroyo Seco during major storms.

Collins, L. and K. Leising. 2003. Draft Alameda Creek Sediment Budget and Sediment Source Analysis: 2003 Progress Report.

This report provides general information on the Alameda Creek Watershed, as well as findings and a progress report on the first year goals for the Alameda Creek Sediment Budget and Sediment Source Analysis (SBSSA). The tasks performed include: 1) Become familiar with the watershed and its multitude of land use operations that influence supply, transport and storage of water and sediment by conducting interviews, field reconnaissance and literature review. 2) Start to develop a variety of approaches and associated methodologies that together will provide reliable lines of evidence for quantification and extrapolation of former and future rates of sediment supply, transport, and storage. 3) From the information gathered to date, develop initial hypotheses that lead to interpreting the influence of land use versus natural processes on routing sediment to the ACFCC so that strategies for further investigation and/or remediation can be developed in years hence.

Collins, L. 2005. Alameda Creek Longitudinal Profiles (PowerPoint)

Graph showing the longitudinal thalweg profiles of Alameda Creek Flood Control Channel and the Historic “Old” Alameda Creek Downstream of Niles Canyon. Another graph shows the sedimentation rates and location of dredging activities along the longitudinal thalweg profile of Alameda Creek Flood Control Channel.

Collins, L. 2005. Significant Fluvial Geomorphic Alterations in the Alameda Creek Watershed and Preliminary Sediment Budget of the Alameda Creek Flood Control Channel (PowerPoint).

This PowerPoint presentation includes a number of historic and modern maps and photographs showcasing the Alameda Creek watershed. It describes the historic water management and channelization practices during the late 1880s through present times. The sediment storage dynamics of the watershed are also discussed and a conceptual semi-quantitative sediment budget is presented.

Ellen, Stephen D. Robert K Mark, Gerald F Wieczorek, Carl M. Wentworth, David W Ramsey and Thomas E May. 1997. Map showing principal debris flow source areas in Alameda County, CA. USGS OF 97-745

This map from 1997 predicts occurrences of debris flows from a 30 m DEM using slope and curvature as parameters for likelihood of debris flow. The map was also calibrated using historical debris flows mapped in the area.

Federal Emergency Management Agency, 1981 (revised 1997). Flood Insurance Study for Alameda County, California unincorporated areas, volume 1 of 2.

The hydrologic and hydraulic analyses for this study were completed in March 1976. Analyses reflect 1975 levels of urban development. The study includes Arroyo De La Laguna. Section 2.2 has a fair setting/description. The design capacity of the Alameda Flood Control channel is 51,000 cfs from the mouth of Niles Canyon to Dry Creek, and 52,000 downstream of Dry Creek. The study used a previous COE study, USGS gage records (84 yrs) at Niles, gage records from Verona and Arroyo Mocho at Livermore to derive unit hydrographs. Then a peak flow frequency curve was created for each location. For the hydraulic analysis, they used existing maps and cross-sections, with additional field surveys. The channel invert (bed elevation) and bank profiles were plotted, and then water-surface profiles for each event were calculated. "Channel cross sections used to define the flood water-surface profiles are delineated on the Flood Boundary and Floodway Map (Exhibit 2). Locations of selected cross sections used in the hydraulic analyses are shown of the Flood Profiles (Exhibit 1)." The study defines both a "Floodway" and a "Floodway Fringe" within the 100-year flood plain. Revisions include hydraulic analyses for Arroyo Mocho and Arroyo Las Positas reflecting 1997 development.

Ferriz, H. 2001. Groundwater resources of Northern California - An overview: in Ferriz, H., Anderson, R., (eds.), Engineering Geology Practice in Northern California: Association of Engineering Geologists Special Publication 12 and California Division of Mines and Geology Bulletin 210.

This paper is an introduction to the hydrogeology of the major groundwater basins of Northern California, organized loosely by geologic province. There is a section on the Livermore groundwater basin that describes the stratigraphy, hydrogeology, and water quality of the region. The Livermore groundwater basin has a surface area of ~100 square miles, with ~65 mi^2 underlain by Quaternary alluvium and ~35 mi^2 underlain by Livermore Foundation. Four distinct gravel aquifers can be recognized in the Livermore basin, to an average depth of 400 feet.

Freeman, J.R., 1912. On the proposed use of a portion of the Hetch Hetchy, Eleanor and Cherry Valleys within and near to the boundaries of the Stanislaus U.S. National Forest Reserve and the Yosemite National Park as reservoirs for impounding Tuolumne River flood waters and appurtenant works for the water supply of San Francisco, California and neighboring cities. A report to James Rolph, Jr., Mayor of San Francisco and Percy Long, city attorney. Published by the Board of Supervisors.

We only have Appendix 4: The dependable additional water supply to cities from Alameda Creek. This is Freeman's evidence to support his statement that “Of lands owned by Spring Valley Water Company, reservoirs on Calaveras, San Antonio and Arroyo Valle plus additional wells upstream of Pleasanton are of noteworthy importance for increasing the water supply to SF”. In dry years, the watershed could supply an additional 25 to 30 million gallons, above what is already being used. He says that the total yield from the Alameda Creek watershed is 30 to 50 million gallons per day, of which 15 million per day is already being used. He used gage records from 1889 to 1908 (Niles Canyon), giving an average of 132 million gallons per day of flow.
There are errors in the discharge record. The original estimate of 141 million gallons a day is too high because of backwater effects during flood. With correction, the discharge should be ~99 to 106 million gallons a day, (130 million is used later). The report discusses why measurements at the dams were inaccurate, and has a series of photos of the dam sites and channel up and downstream. The bed has a lot of boulders, which I presume is provided by the local adjacent hillslopes, and are not transported from upstream. The last page has a table with rainfall and runoff for the years 1889 to 1911.

Graymer, R.W., Jones, D.L., and E.E. Brabb. 1996. Preliminary geologic map emphasizing bedrock formations in Alameda County, California: A digital database. USGS Open-File Report: 96-252

This report describes and maps the geologic formations, especially the bedrock formations, in Alameda County. There are nine different stratigraphic assemblages in Alameda County. In general, in Alameda County the Tertiary strata rest with angular unconformity on two complexly deformed Mesozoic rock complexes. The faults of Alameda County are characterized by both strike-slip and dip-slip components of displacement. There are four major fault systems that display large right-lateral offsets, the Hayward, the Stonybrook-Palomares-Miller Creek-Moraga, the Calaveras, and the Greenville.

Inderbitzen, A.L. 1959. Gravels of Alameda Creek, California. Journal of Sedimentary Petrology. 29 (2): 212-220

This paper examines gravel and boulder size in Alameda Creek over a stretch of 18 miles, from the headwaters on Valpe Ridge to the town of Niles. Size, rock-type, roundness, and sphericity of the maximum sized boulder were determined. At several stations, pebble counts of 200 rocks were conducted to determine gravel size distribution. It was found that the maximum boulder size fluctuates throughout the length of the stream, but generally decreases as distance from the headwaters increases. They conclude that the fluctuations are due to constrictions in the channel width and changes in the stream gradient. The sediments are well sorted. The sphericity of maximum-sized boulders increases while roundness decreases as the distance from the headwaters.

Knudsen, K.L., Sowers, J.M., Witter, R.C., Wentworth, C.C., and E.J. Helley. 2000. Description of Mapping of Quaternary Deposits and Liquefaction Susceptibility, Nine-County San Francisco Bay Region, California. USGS Open File Report 00-444: Version 1.0 (Part 3)

This report describes a map of Quaternary deposits and liquefaction susceptibility for the nine county San Francisco Bay region since the 1970s. The maps are in the form of a digital database, produced from original 1:24,000- and 1:100,000-scale geologic mapping. This report identifies the geologic materials most susceptible to liquefaction as the Holocene stream channel deposits, Holocene beach deposits, and artificial fill overlying Bay Mud; these deposits are widely present in the wider region.

Lung, Pamela. 2008. Power point: Sediment and Hydraulic Challenges in the City of Livermore December 11, 2008. Presentation to Sediment Forum of Alameda Creek Watershed.

This presentation describes sedimentation problems experienced on Arroyo Mocho and Arroyo Las Positas, their locations and gives examples of projects aimed to control the sedimentation and erosion problem in the Livermore Valley Creeks.

Mahacek, V. 2007. Arroyo de la Laguna Initial Geomorphology Investigation Draft Report. Prepared for West Yost Associates by Virginia Mahacek, Valley and Mountain Consulting, August 1, 2007.

This report focuses on the geomorphology of Arroyo de la Laguna (ADLL) from Arroyo Mocho to Alameda Creek. The initial investigation included a review of available reports, documents, maps, and hydraulic monitoring provided by WYA and Zone 7, as well as a field assessment of geomorphic conditions. A review of base maps, aerial photography, and prior hydraulic models was also performed. Channel stage, channel bed conditions, channel capacity/constriction, and bank stability are all examined. In general the ADLL channel has experienced vertical and lateral channel instability during the historic period of record. Channel instability and associated bank erosion, property loss, and sedimentation issues are a concern throughout the study area.

Majmundar, Hasmukhrai H. 1991. Landslide Hazards in the Livermore Valley and Vicinity, Alameda and Contra Costa Counties, CA. 6 plates, map scale 1:24000.

Not digitized. Information about slope stability and landslide susceptibility. Most abundant landslides are associated with the Cretaceous Cierbo and Panoche formations, Upper Miocene Neroly Sandstone, and Plio-Pleistocene Green Valley and Tassajara Formations.

Mikesell, L.R., Weissmann, G.S., and J.A. Karachewski. 2010. Stream capture and piracy recorded by provenance in fluvial fan strata. Geomorphology. 115: 267-277

This study examines fluvial fan stratigraphy beneath the Lawrence Livermore National Lab (LLNL). Geomorphic evidence for this stream capture include: (1) the Arroyo Seco enters the basin from the south through an uplifted fault block, (2) south of this fault block lies an abandoned Arroyo Seco fluvial fan, (3) north of the fault block, in the Livermore Basin, Arroyo Seco built a 7- km^2 fluvial fan, apparently forcing the Arroyo Las Positas, a smaller stream that enters the basin from the east, northward around the Arroyo Seco fan, and (4) a knickpoint exists near the point of capture on Arroyo Seco. A provenance study of 215 gravel units from 34 boreholes spaced evenly over the 2.6 km^2 LLNL site was conducted. These results indicate that the Arroyo Seco flowed north and deposited sediments at the LLNL site, then was later absent from the basin at which time it formed a fan south of the fault block. During this absence of the Arroyo Seco, the Arroyo Las Positas, a westerly flowing stream, dominated the sediment supply at the LLNL site. The Arroyo Seco was then captured by a gully headwardly eroding through the uplifted fault block, redirecting the Arroyo Seco into the basin once again. This history of multiple stream captures created three stratigraphic units with alternating overall channel and paleoflow orientations.

Montgomery, D.R., and D.L. Jones. 1992. How wide is the Calaveras fault zone- Evidence for distributed shear along a major fault in central California. Geology 20: 55-58

This report looks at the Calaveras faulting zone and tries to determine how wide the zone is. They examine the basement rocks and stratigraphy in the Sunol Regional Park, on the eastern side of the Calaveras fault. They also examine the Quaternary and Holocene faulting, as well as the alluvial terraces on Alameda Creek. They conclude that there are many active faults in the region that are not recognized in current (1992) seismic hazard assessments.

Roberts, S., Roberts, A., and E.M. Brennan. 1999. Landslides in Alameda County, California, A Digital Database Extracted From Preliminary Photointerpretation Maps of Surficial Deposits By T.H. Nilsen In USGS Open File Report 75-277. USGS Open-File Report 99-504: Version 1.1

All or part of 25 7.5-minute quadrangles identifying 8465 landslides—largely slow-moving slides and earth flows—in Alameda County, California, have been converted to a digital-map database, compiled at 1:24,000 scale and plotted at 1:62,500 scale. Information on the hazard is incomplete; no slope failures since 1966 are shown. The first reproduces excerpts from T.H. Nilsen's explanatory text printed on the source maps. Part II describes compilation of the source maps as a digital database and the conventions adopted in encoding the landslide information in a geographic information system (GIS). The final section describes details of the digital-map database, its constituent data files, and their computer formats.

Sowers, Janet M. 2003. Historical Geomorphology of Arroyo Valle and Arroyo Mocho with notes on steelhead migration, Livermore-Amador Valley. Prepared for Zone 7 Water Agency by Janet M. Sowers, William Lettis & Associates. November 26, 2003.

This study examines the historical geomorphology of Arroyo Valle and Arroyo Mocho in the Livermore Valley in order to shed light on the likelihood that either stream support steelhead passage and suitable habitat. The author concludes that while both streams most likely provided suitable habitat for steelhead in their headwaters, because the streams did not connect to the historical lagoon that occupied the town of Pleasanton, historically passage from the lagoon up these two creeks would not have been likely except in wet years. Arroyo Valle would have been more likely, because of its bigger watershed, to connect with the lagoon and provide passage. Channelization of the waterways of Livermore Valley possibly increased the likelihood of fish passage, which may explain the increase in steelhead sightings after the major hydromodification of the tributaries of Alameda Creek.

Unruh, J and K. Krug. 2007. Assessment and Documentation of Transpressional Structures, Northeastern Diablo Range, for the Quaternary Fault Map Database: Collaborative Research with William Lettis & Associates, Inc., and the U.S. Geological Survey. USGS National Earthquake hazards Reduction Program. Award Number 06HQGR0139.

This report presents a digital map compilation of Quaternary faults and folds in the northeastern Diablo Range and northwestern San Joaquin Valley. The goal was to analyze and compile digital point and line data on the locations of Quaternary folds, thrust and reverse faults (including blind faults), and strike-slip faults along the boundary between the northern Diablo Range and northwestern San Joaquin Valley for incorporation into the Northern California Quaternary Fault Map Database (NCQFMD). Geologic mapping of Quaternary faults and folds in the study region was compiled at the largest available scale and, where necessary, digitized and georeferenced. Vectorized maps and acquired digital files were compiled at a map scale of 1:24,000.

Vickery, F.P. 1925. The structural dynamics of the Livermore region. The Journal of Geology. 33 (6): 608-628

This paper describes the faults and folds that are present in the Livermore region (defined as the Pleasanton, Tesla, San Jose, and Mount Hamilton quadrangles). He determines that north-northwesterly dominant faults, west-northwesterly branch faults, and northwesterly folds are present. Franciscan and Lower Miocene strata are present on both sides of the fault along Alameda Creek, but the Cretaceous series is present on the western side, but not the eastern side.

Wentworth Carl M., Scott E. Graham, Richard J. Pike, Gregg S. Beukelman, David W Ramsey, Andrew D. Barron. 1997. Summary Distribution of Slides and Earth Flows in Alameda County, CA. USGS OF 97-745.

Landslides and earth flows are slow moving, and common hazards in the SF Bay Area. They form as the result of increased water content, earthquake shaking and destabilization of slopes. This is a very general map summarizing all earth movements documented.

Williams, Cyril. 1912. Report on the water supply of Alameda Creek watershed with particular reference to the Livermore Valley underground supply. Prepared at the request of Percy V Long by Cyril Williams. San Francisco, March 1912.

This comprehensive report describes the water supply from Alameda Creek for the City of San Francisco including a history of water supply and key dates of constructions of dams and groundwater recharge and pumping. Geology, groundwater supply, and valley form are all explored in depth. The report includes many cross sections, and long profiles which have the potential to be reoccupied.

Studies done in the watershed

Burke et al. 2003. Alamo Creek. Creek Stabilization Structures Review of Alternative Structures. Prepared for ENGEO INC by HSI Hydrologic Systems project 1172. November 2003.

The report summarizes alternatives for a stabilization project on Alamo Creek just North of the Alameda Contra Costa county line at the Dougherty Road bridge and downstream of the Windemere restoration project. This section of the creek experiences vertical and lateral scour with several large headcuts which may eventually undermine the restoration project site. The report details several alternatives including additional grade control structures, change of channel gradient or creek alignment, vortex weir drop structures and other options in order to slow or stop the incision from continuing to move upstream. HSI used a series of cross sections and HEC-RAS to test each option.

Burke et al. 2004. Lower Alamo Creek Restoration Project Design Information. Prepared for ENGEO INC by HSI Hydrologic Systems project 1172. May 2004

This report summarizes the preliminary design alternative chosen for the restoration of Lower Alamo creek. The goals of the restoration projects are to stabilize the existing vertical incision levels, restore an active natural floodplain, remove cattle from the riparian corridor, revegetate the creek banks, and provide elements of geomorphic heterogeneity that would provide for a dynamic equilibrium within the channel. HEC RAS was used to model the restoration design. Section 2.4 focuses on the sediment yield from Alamo creek watershed, and dominant hillslope processes, followed by a sediment routing analysis for the project area based on the SAM SED model developed by USACE.

Burke et al. 2008. Alamo Creek Watershed Analysis. Prepared for FarWest Restoration Engineering by HSI Hydrologic Systems project 1252. July 2008.

This report aimed to develop recurrent discharge data for a creek restoration project in the lower portion of the watershed that is experiencing erosion, and destabilization of several grade control structures that were installed in the 1980s. The goal of this study was to develop runoff characteristics for the 5, 10, 25, and 100 year storm for Alamo creek at the Alameda-Contra Costa County line. HSI used historical precipitation gages, soil type distribution, an assumption of lag time and other inputs to create a watershed and flow routing model.

Burke T and Martin Trso. 2002. Gale Ranch Sewer Bridge Scour Evaluation. Prepared for ENGEO INC by HSI Hydrologic Systems project 1155. December 2002.

This study was conducted to determine the potential scour that might occur in Alamo Creek at Gale Ranch Sewer Bridge Crossing. The goal was to estimate an Erosion Hazard Zone Width (EHZW) to ensure that the bridge is not impacted by ongoing incision or erosion in the channel. To evaluate the stream morphology, stratigraphic, historic, and geomorphic analyses of the eroded banks were conducted. The study used a meander belt assessment to determine hazard width, as well as HEC RAS model as implemented by the Army Corps of Engineers SAM model.

Burke T. 2002. Gale Ranch Sewer Bridge Scour Evaluation. Volume II Sediment Transport and Yield Model Output. Prepared for ENGEO INC by HSI Hydrologic Systems project 1155. December 2002.

This report details the outputs from the sediment transport analysis for each of the stations surveyed in the study area using SAM.

Burke T. 2005. Windemere Parkway over Tassajara Creek: Channel Scour Analysis. Prepared for ENGEO INC by HSI Hydrologic Systems project 1158. May 2005.

This study was conducted to determine the potential scour that might occur in Tassajara Creek at the Windemere Parkway Bridge Crossing. The goal was to estimate an Erosion Hazard Zone Width (EHZW) to ensure that the bridge is not impacted by ongoing incision or erosion in the channel. To evaluate the stream morphology, stratigraphic, historic, and geomorphic analyses of the eroded banks were conducted. The study used a meander belt assessment to determine hazard width over time, as well as HEC RAS model as implemented by the Army Corps of Engineers SAM model.

Burke T. 2005. Windemere Parkway over Tassajara Creek: Channel Scour Analysis Volume II-Appendix 1-Sediment Transport Model Output. Prepared for ENGEO INC by HSI Hydrologic Systems project 1158. May 2005.

This report details the outputs from the sediment transport analysis for each of the stations surveyed in the study area using SAM.

West Yost and Associates. 2001. Zone 7 Water Agency Geomorphic and Sediment Transport Evaluation. Prepared by Ayres Associates. Ayres Associates Project Number 33-0144.00, December 11, 2001

Zone 7 contracted a geomorphic evaluation of sediment supply, in-channel storage, and channel stability in their channels. They used an Incised Channel Evolution Model (ICEM) to judge the degree to which the channels have incised and/or widened. West Yost used the "Present Sediment Yield Rate Maps" from the NRCS to determine a sediment yield estimate, which sums surface geology, soils, climate, runoff, topography, groundcover, land use, upland erosion and channel erosion. They found no high watershed sediment yield rates (see pg 11). However, the highest yields were in the northern drainages. West Yost and Associates recommend a series of sediment management tools including grade control structures and active sediment removal in certain locations, as well as sediment traps, but calls for the need for sediment transport modeling.

Philip Williams and Associates, 1999, Arroyo Mocho and Arroyo Las Positas management plans: initial findings and recommendations, phase 1 supplemental report, draft July 27, 1999.
**exists, but can't find

McWilliams, Michael; Mark R Tompkins; Robert L. Street; G. Mathias Kondolf; Peter K. Kitanidis. 2010. Assessment of the Effectiveness of a Constructed Compound Channel River Restoration Project on an Incised Stream. Journal of Hydraulic Engineering Dec 2010 p 1042-1052

This report evaluated the effectiveness of using a compound channel restoration design on Tassajara Creek as a case study. Compound channels are often constructed in restoration projects on rivers and streams that have been channelized or are deeply incised. This design allows for flow over a wider cross-sectional area during high flows and is expected to reduce both flow velocities and bed-shear stresses in the channel during high flows. On-going post project appraisals seem to confirm that the compound channel approach to incised streams reduces velocities, and improves channel stability while still providing conveyance capacity for flood flows. Cross sections over several years have been done by multiple teams of students and researchers.

Gilbreath, A.N, and McKee, L.J, 2008. Spatiotemporal variation of turbidity in Alameda Creek and selected tributaries: August through December 2007. A Technical Report of the Regional Watershed Program prepared for Alameda Flood Control and Water Conservation District (AFC&WCD): SFEI Contribution 547. San Francisco Estuary Institute, Oakland, CA. 53 pp.

The objective of this study was to carry out a pilot study and measure turbidity in Alameda Creek and selected tributaries and relate the spatiotemporal distribution of turbidity to the quality of habitat for anadromous juvenile fish. We measured turbidity on a weekly basis from August to December 2007 at numerous sites throughout the watershed under primarily low flow conditions. Since suspended sediment concentrations and flow were not measured, no estimates could be made of fine sediment loads. Some reaches exhibited maximum turbidity >50 NTU with temporal patterns that may indicate point sources. None of the stream reaches targeted for good rearing habitat had elevated turbidity

Zone 7 Stream Management Master Plan. Prepared by RMC August 2006.

In 2002, recognizing regulatory changes and different funding opportunities, Zone 7 and several other stakeholders convened to create a stream management master plan which addresses flood protection, drainage issues, as well as water quality, and environmental concerns associated with managing

streams. The goal was to provide a multi-benefit regional plan that would be implemented by individual cities as well as Zone 7.

The report highlights areas in Zone 7 that are aggrading, degrading and providing sediment sources or sediment sinks. The sediment appendix to the report gives a watershed-wide assessment of sediment sources and yields based on a mass balance equation of hillslope erosion rates and flow calculated using the PSIAC method and was estimated to be 184,000 cubic yards per year. Grain size distribution in the channel and channel geometry and geomorphic equations (Wilcock and Meyer-Peter Muller) were used to estimate bedload yield. The report includes reach based assessments with cross sections.

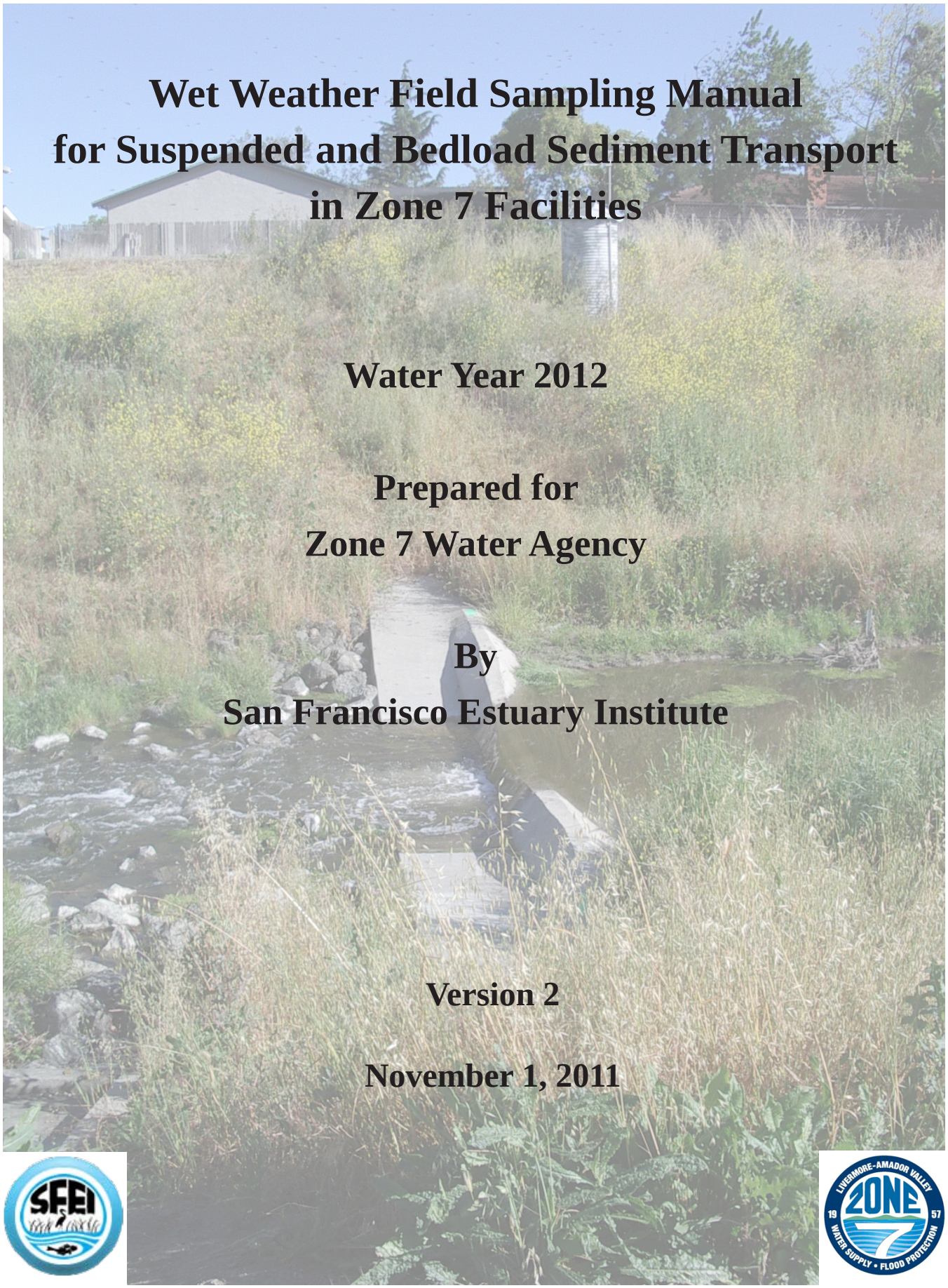
Appendix 7.2

Wet Weather Field Sampling Manual for Suspended and Bedload Sediment Transport in Zone 7 Facilities

San Francisco Estuary Institute

November 2011

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER



Wet Weather Field Sampling Manual for Suspended and Bedload Sediment Transport in Zone 7 Facilities

Water Year 2012

Prepared for

Zone 7 Water Agency

By

San Francisco Estuary Institute

Version 2

November 1, 2011

Acknowledgements

The majority of the information contained in this field manual was derived from published field manuals developed by the USGS over the last 40 years. In addition, the section on maintenance of automated sampling equipment was derived from field manual put together by RiverMetrics Inc.

The interested reader can obtain more detail by referring to the original references:

Edwards, Thomas K and G. Douglas Glysson. 1999. Field Methods for Measurement of Fluvial Sediment. Techniques of Water-Resources Investigations of the U.S. Geological Survey in Book 3, Applications of Hydraulics. Virginia 1999. Revised from "Field Methods for Measurement of Fluvial Sediment," by Harold P. Guy and Vernon W. Norman, U.S. Geological Survey Techniques of Water-Resources Investigations, 'Book 3, Chapter C2, published in 1970.

Lewis, Jack, and Rand Eads. 2008. Implementation guide for turbidity threshold sampling: principles, procedures, and analysis. Gen. Tech. Rep. PSW-GTR-212. Arcata, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Oct 2008.

Contents

Acknowledgements	2
Introduction	4
Section 1. Preparing for the field	6
Section 2. Sampling equipment and equipment operation	9
Section 3: Collecting a suspended sediment concentration (SSC) sample	12
Section 4. Collecting a bedload sample	15
Section 5: Maintaining the ISCO sampler	19
References	29
Appendix A. SSC field form	30
Appendix B. Bedload sampling field form	31
Appendix C. ISCO servicing field form	32
Appendix D. Sampling sites maps, directions and resources	33

Introduction

Zone 7 Water Agency (the DISTRICT) provides potable water and flood protection to the tri-cities of Livermore, Dublin and Pleasanton as well as for 3500 acres of farm land. In recent years, DISTRICT facilities have experienced a loss of flood capacity, and sedimentation. The problem is largely due to population growth and land use changes, in the form of increased urbanization, and a change from non-irrigated range land to irrigated and controlled drainage viticulture. This project aims to understand sediment transport characteristics within the DISTRICT facilities to support ongoing management and maintenance.

Individual tasks include:

- Determining the flow of water and sediment into and out of mainstem Arroyo Mocho,
- Determining the characteristics, rates, and causes of sedimentation in DISTRICT channel facilities, and
- Developing a sediment budget for the study reach as a tool for clearly communicating the main sources and processes affecting the function of DISTRICT channels within the study area,
- Mapping and characterizing channel modification and mitigation opportunities based on a comparison of historic and modern channel function
- Communicating the findings primarily to the DISTRICT and also to stakeholders within the Alameda Watershed Council

In this the first year of study, the focus is on the first of these tasks and preparing for subsequent tasks that will likely be implemented in future project phases. The objective of this manual is to provide guidance to DISTRICT staff who will be working with SFEI staff over the wet season performing water and bed sediment sampling during floods and maintenance activities on automated sampling equipment. The sediment field program is enabled by the existing reliable DISTRICT measurements of discharge at each field location. Without the measurement of water flow, sediment discharge could not be computed.

In general, over 95% of sediment transport occurs during wet season months in rivers and creeks in the Bay Area. As such, field programs usually run from October 1st through to April 30th. During this the first year of the program, a later than preferred start date has occurred due in part to contracting and in part to a protracted period of equipment purchasing. In future years, the DISTRICT should aim to install equipment during the latter half of September. While the methods described in this manual could be applied to any sampling location, this year, the DISTRICT has decided to sample three locations (Arroyo Mocho at Pleasanton, Arroyo Mocho at Hagemann, and Arroyo Las Positas at Livermore) (Figure 1) using a combination of manual and automated techniques.

This manual is divided into five sections.

Section 1 provides guidance on how to prepare for field work and generally what conditions DISTRICT staff can expect to face while in the field.
Section 2 provides an overview of sampling equipment and general guidance on how it is operated.
Section 3 provides instructions for taking a suspended sediment concentration sample.
Section 4 provides instructions for collecting a bedload sample.
Section 5 provides detailed instructions for maintaining the automated sampling equipment

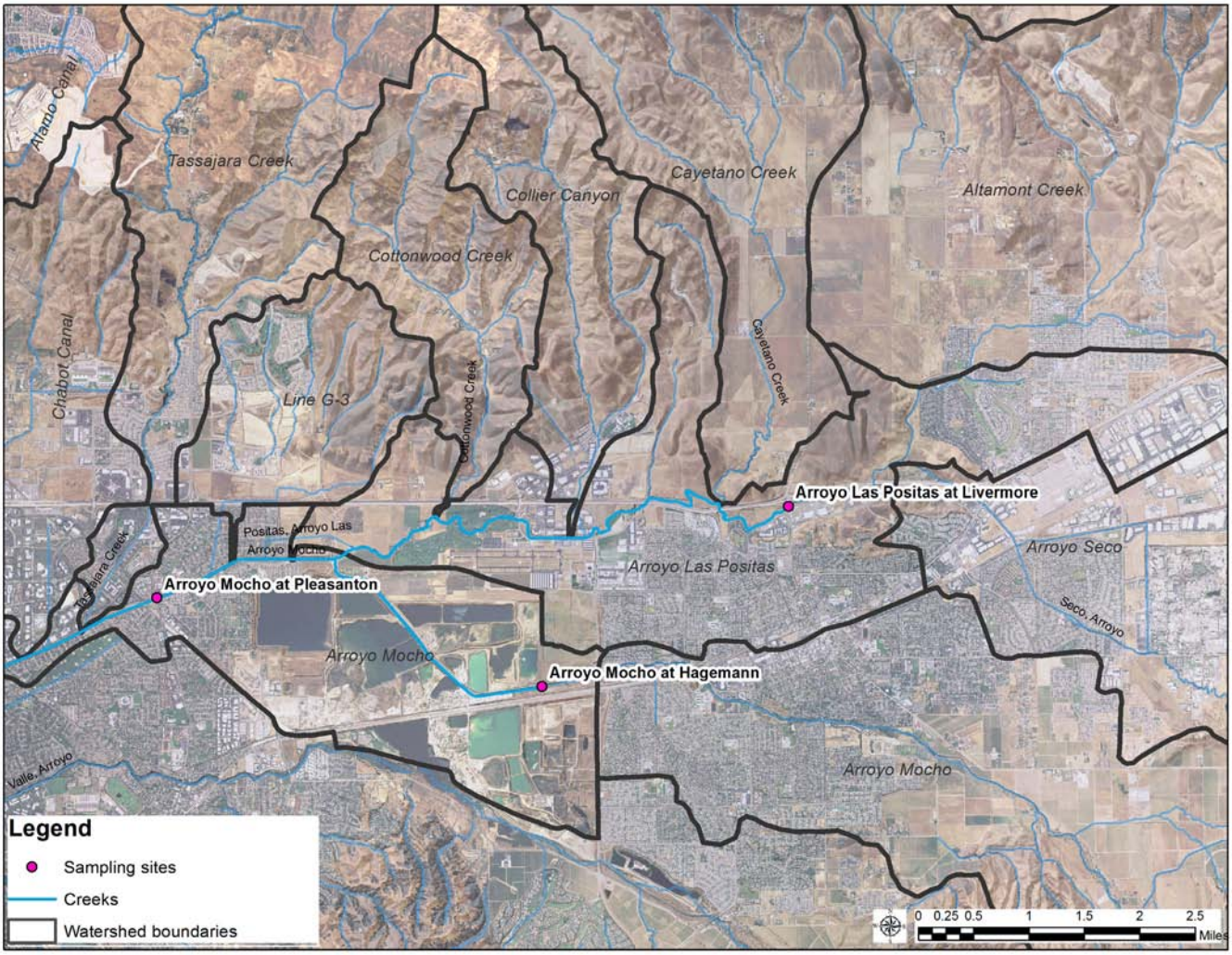


Figure 1. Location of sampling sites

Section 1. Preparing for the field

Introduction

A field program like this one that aims to measure suspended and bed load sediment transport requires a large team that is well coordinated and dedicated. Sampling at each of the three field locations will entail working as part of a team of 2 people anytime of the day or night and on weekends during rain storms whenever they occur. Given the size of the watershed, we anticipate storm flow will peak approximately 5-8 hours after the peak in rainfall at the Pleasanton location and that the peak will be wide. The other two gage locations will peak faster, perhaps in the range of 4-6 hours, and the peaks will be narrower. Field observations this year will refine these estimates substantially. Staff deployment is specific for each site and will likely range from 8-12 hours. The primary participants in this program and their roles are described briefly in Table 1. DISTRICT staff working as part of the team should primarily direct all their communications to Joe Seto and Alicia Gilbreath during office hours and dry weather. During wet weather, communications should be directed towards the assigned event field lead for that particular event.

Table 1. Team structure and important phone numbers.

Title	Role	Name	Office	Cell
DISTRICT Project Co-Manager	Oversees entire project for DISTRICT.	Carol Mahoney	925 454 5064	925 980 1464
DISTRCT Project Co-Manager	Oversees entire project for DISTRICT.	Joe Seto	925 454 5085	925 519 1728
Senior Scientist / Field Lead	Oversees entire project for SFEI. Assists in trouble shooting and reviews procedures and products.	Lester McKee	510 746 7363	415 847 5095
Project Manager / Field Lead	Coordinates field team; manages day-to-day project activities. Manages budget. Coordinates with the DISTRICT.	Alicia Gilbreath	510 746 7308	530 400 3950
Senior Geomorphologist / Field Lead	Implements the field program makes day-to-day decisions coordinating with the Senor Scientist, Project Manager, and Field Scientist.	Sarah Pearce	510 746 7354	510 847 3976
Field Scientist / Field Lead	Works closely with the Senior Geomorphologist to implement the field program.	Julie Beagle	510 746 7312	510 316 6765

Field Locations

Samples will be taken at or near the three district gages. At Arroyo Mocho at Hagemann Bridge (AMHag) and Arroyo Las Positas (ALPL) sampling locations are on bridges at the gage site. In the case of Arroyo Mocho at Pleasanton (AMP), the sampling site will be about 350 m downstream of the gage and the nearest bridge.

Arroyo Las Positas (ALPL)

Nearest Medical Facility (Distance=5.3 mi)
Valley Memorial Hospital
1111 East Stanley Blvd
Livermore, CA 94550

Legend for all location maps

X Sampling Location
Parking Location
H Hospital direction

Arroyo Mocho at Pleasanton (AMP)

Nearest Medical Facility (Distance=0.3 mi)
Valley Care Health System
5555 W Las Positas Blvd
Pleasanton, CA

Arroyo Mocho at Hagemann (AMHAG)

Nearest Medical Facility (Distance=2 mi)
Valley Memorial Hospital
1111 East Stanley Blvd
Livermore, CA 94550

Preparing to sample a storm event

Preparing thoroughly for a storm event is important for setting each sampling effort up for success. Field leads track the weather throughout the entire season and make the call about when to mobilize for a sampling event. The normal course of planning occurs in the following order:

1. Field leads track the weather using the following on-line weather resources:
   a. NOAA 7-day Forecast for Livermore, CA: This website enables you to see a 7-day forecast for a given location as well as provides links for different information about the same location. These links are in the bottom right of the webpage and will direct you to the Forecast Discussion and Hourly Weather Graph (discussed below). http://forecast.weather.gov/MapClick
   php?CityName=Livermore&state=CA&site=MTR&textField1=37.6819&textField2=-121.767
   b. NOAA Area Forecast Discussion: This link provides greater meteorological detail about a predicted storm and its current progress. We typically watch this closely to see how the forecast evolves. This forcast is reisssued approximately every 6 hours beginning at 3:15am.
   http://forecast.weather.gov/productphp?site=NWS&issuedby=MTR&product=AFD&format=CI&version=1&glossary=1
   c. NOAA Hourly Weather Graph: The primary graph that we look at is the rain graph, which indicates the predicted amount of precipitation over a given period of time. http://forecast.weather.gov/MapClick.php?CityName=Livermore&state=CA&site=MTR&textField1=37.6819&textField2=-121.767&FcstType=graphical
2. Starting about 4-6 days prior to a predicted storm event, an event field lead is assigned and this person contacts potential SFEI and DISTRICT field staff and inquires about availability.
3. 2-3 days prior to a storm event, the event field lead organizes the event sampling team and communicates the team's meeting location.
4. The event field lead continues to communicate with the sampling team each day as the forecast becomes more certain.
5. As the storm approaches, the event field lead organizes all of the sampling equipment and the sampling team remains on-call. A check-list of the personal field clothing and equipment is provided below.
6. The event field lead determines when it is time to mobilize for sampling and communicates that to the event sampling team.

Appropriate field clothing

All members of the event sampling team should wear appropriate clothing, including:

- Warm underlayers
- Raincoat and pants
- Rubber boots

Each member of the sampling team should also bring:

- Head lamp
- Food and water
- Extra socks (recommended)
- Hat (recommended)
- Gloves (recommended)

At least one member should have waders and appropriate footwear for sampling during wadeable stages.

Section 2. Sampling equipment and equipment operation

Sampling equipment checklist

Boom truck and crane
B-reel
Counter weights
D74
D74 sampling bottles
D74 Nozzle
250 ml wide-mouth pre-labelled sample bottles
BL84
BL84 200 micron mesh and fastener
BL84 cotton sample bags
Keys and/or sampling permits
Field Notebook
Clipboard
Extra labels
Short pencils (for field sheets)/Sharpies (for bottle caps and plastic bags)
ISCO replacement bottles
Field computer to download data
Orange traffic safety cones
Reflective vests
Empty coolers for samples
Towel (1-2)
Hach 2100p turbidimeter, plus spare batteries
Paper towels for cleaning turbidimeter sample bottles
Waders (at least one team member)

Basic Equipment Operation and Safety Points

Pre-sampling Safety Protocols

- Event field lead should facilitate a short conversation about site safety (e.g. are there any medical concerns for any of the event sampling team members, what happens in the event of an emergency such as an injury or if someone falls into the creek, where are a cell phone and truck keys located, etc.).
- Place the safety bag in an accessible location.
- Place traffic cones near the equipment if needed and near the edge of the sidewalk if sampling occurs close to traffic.
- Wear reflective vests.

Unloading the equipment

- Use two people for all heavy equipment.
- Communicate clearly when working with others to lift equipment in a coordinated manner.
- Lift with the legs, not the back!

Setting up the equipment

1. Place boom truck in position such that the mounting plate is creek-side.
2. Attach the crane to the boom truck:
    a. Remove nuts from the mounting plate.
    b. As one field member holds the mounting plate forward, another field member places the crane on the mounting plate and screws on the nuts to hold it in place.
    c. Secure the plate on the crane to the arm at the back boom truck.
    d. Fold the arm on the crane at the lower front of the boom truck back towards the rear and secure it to the back plate by squeezing it together and fitting the bolts into the holes.
    e. Latch the two final front pieces by securing the rods into the grooves (2 separate actions).
    f. Place counterweights on the back of the boom truck.
    g. Attach the b-reel winch onto the crane with the 4 screws. Hold winch in place while screwing it on. String the wire through the wheels on the crane and screw on the winch handle.
    h. Load the D74 (or BL84) onto the end of the winch wire coordinating with a second event team member to ensure the cable and winch is ready to take the load.

Safety Point: While setting up, there are many opportunities to pinch your finger as the crane folds upon itself. Be careful to keep your fingers away from pinch points. Communicate clearly with other team members while setting up the equipment to avoid injury.

Figure 2. Set-up of crane and boom truck (SFEI)

Operating the b-reel winch

Field staff should be properly trained to utilize the lock and break features of the winch prior to operating the winch during storm sampling.

The locking mechanism is located on the lower right-hand side of the reel and determines the mode of the reel.

1. The default mode is with the locking mechanism unlatched. In this mode, the reel does not un wind freely. You may wind up the reel by rotating the handle forward. You may allow the reel to “free-drop” by rotating the handle backward. To end a free-drop, pull the handle forward again. This mode is generally used when the reel is resting, or when an experienced team member is using the free-drop option.
2. When the locking mechanism is latched, the reel will unwind freely and should be controlled with an operator on the handle. This mode enables the operator to lower the reel with control and is generally used for lowering and raising the D74 or BL84 when sampling.

Note: The counter is on the left-hand side of the reel. Counter measurements are in feet. Once the equipment is set up, the counter should be zeroed on the creek bottom. This enables the sampling team to avoid touching the bottom of the creek when sampling for SSC. To zero the counter, lower the sampler to the creek bottom making sure there is no slack in the line. Pull out the handle on the counter and rotate it to zero. Note that the number in the counter window changes with every ten feet.

Safety Point A: Be careful to avoid getting fingers or other body parts caught in any portion of the reel while operating.

Safety Point B: In general the winch assemble is a safe environment if used properly. The highest level of safety is attained by an event field team member who communicates before each change in operation and makes small and deliberate adjustments to the position of the winch handle and break mechanisms. Fast or reactive operation of this equipment or operation by two people at once is considered DANGEROUS and should be avoided.

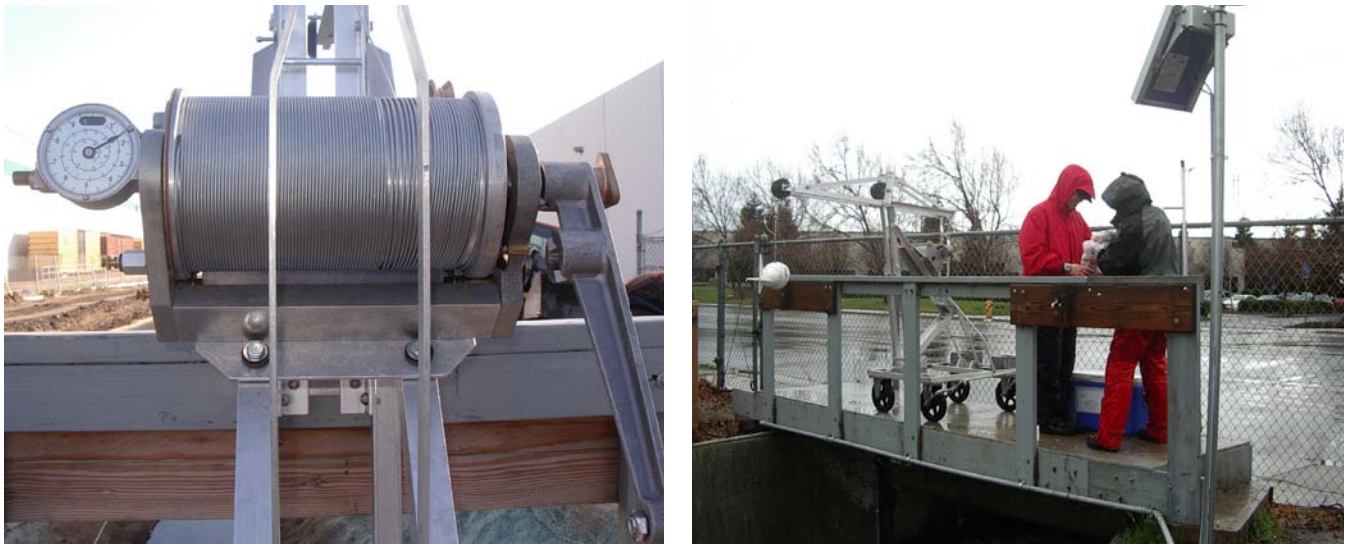


Figure 3. SFEI photos of b-reel and assembly of equipment on bridge

Sediment transport background

We distinguish two types of sediment transport: suspended sediment and bedload sediment. Bedload and suspended sediment: The stream usually transports sediment by maintaining the finer particles in suspension with turbulent currents and by rolling or skipping, (or saltating) the coarser particles along the streambed.

Generally, the fine suspended particles move downstream at about the same velocity as the flow of water, whereas the coarser bedload sediment particles may move continuously or only intermittently and remain at rest much of the time. Bedload particles generally move much slower than the mean velocity of the stream.

However, bedload, suspended material, and bed material are closely interrelated. Bedload in transport may stop moving and become bed material, or may be suspended briefly or continuously, in certain reaches of a given channel. For these reasons, bedload and suspended sampling must account for spatial and temporal variation in types and rates of sediment transport.

Section 3: Collecting a suspended sediment concentration (SSC) sample

Introduction

The purpose of suspended sediment sampling is to determine the average suspended-sediment concentration at a cross section. The majority of samples taken manually during the WY 2011 field season will be single point vertically depth integrated samples sent to the laboratory for analysis of suspended sediment concentration. In addition, a smaller number of single equal width increment (SEWI) samples will be taken at 10 points across the section to determine x-sectional variation under lower, medium and high flow conditions. Such suspended sediment concentrations will be combined with water discharge to compute the measured suspended "instantaneous" sediment discharge during a 15 minute interval and used to develop a daily record for the entire wet season.

Description and function of the equipment

The DH48 is a handheld sampler used for collecting suspended sediment sampling when safe wading conditions occur. The sampler is 13" long, made of aluminum which encloses a glass pint milk bottle shaped container. A ¼ inch intake nozzle extends horizontally from the sampler body. The sampler is attached to a ½ in diameter rod which is held vertically by the field technician. The instrument can sample to within 3½ inches of the streambed

The D74 is a 30-pound sampler which is attached to a suspension cable, reel and crane and can be used in stream depths up to 5.5 meters. The nozzle size can vary depending on expected stream velocities. The head of the sampler is hinged to load and unload the sample container, a pint sized milk bottle. Tail vanes at the back of the instrument orient the sampler into the stream flow.

Taking a sample

Suspended sediment samples will be collected over a variety of stages (height of the water from the creek bottom). When the stage is low, an event field team member may wade into the creek to collect a sample using a D48. When stages are higher, or whenever wading into the creek is considered unsafe, event field team members will utilize the boom truck/crane/winch to lower the sample bottles into the creek using a D74.

Maximum safe wading depths depend on the size of the event field team member collecting the sample, the velocity of the water, and the streambed material. Generally, creek stages less than 1.25 ft are considered wadeable for most field staff, but it may be lower and event field team members should constantly evaluate the safety of wading. When deemed safe, the event field team member wearing waders will enter the creek and utilize the handheld DH48 to collect a sample in the following steps:

Wading stages DH-48 sampler

1. Load clean sample bottle into instrument
2. Enter the channel in a manner that ensures no bed disturbance upstream from the sampling point.
3. Sampler is lowered into the channel horizontally, at a uniform rate with the nozzle opening pointing upstream.
4. As soon as the sampler reaches the bottom (without disturbing any bottom sediment material), it should instantly be raised again to the water surface at a uniform rate.

Note:

-Sampler should approach the desired sampling location and position their body maximizing stability. Sampler should stand sideways to flow, slightly bend the upstream knee, and lean into the flow to maximize stability.

-Samples should be depth-integrated along the single-vertical line of the thalweg (the line of maximum depth in a creek). A "depth-integrated" sample has approximately the same amount of water from each position of the water column. Sample bottles should not touch the bottom of the creek. This avoids stirring up creek bottom sediments and confounding the sample results. The sounding reel counter may be used to avoid touching the bottom.

-Sample water should fill the bottle to approximately 2/3s capacity. If the sample is overfull (>90%), discard and begin again with a clean bottle. If the sample is not full enough (<60%), lower it back into the water and repeat the depth-integration at least as fast as first round.

Figure 4. DH48 sampler (sources: http://www.rickly.com/ss/depth-integrating-samplers.htm, http://fisp.wes.army.mil/Instructions%20US%20DH-48%20001010.PDF)

4. Mark sample bottles to indicate the unique sample number and secure a sample label with appropriate sample detail recorded.
5. Record the required information on the sampling field sheet.

Non-wading stages – D74 sampling:

When stages are not safe for wading, staff will utilize a D74 for collection. The D74 is suspended from the hanger bar of a crane via a stainless steel cable. It is lowered into the creek using the sounding reel mounted on the crane.

1. Lower the D74 into the creek to determine water depth (zero the counter). Raise it back to the bridge level again. You are now ready to take a sample.
2. Load a clean sampling bottle into the D74 with the air hole pointing upwards and the nozzle pointing downwards.
3. Lower the D74 using the crane to the water surface and allow the tail vane of the fish to orient the sample bottle pointing upstream.
4. Once oriented in the proper direction, lower the bottle and collect a depth-integrated sample. Lower the bottle at a uniform rate while watching the sounding reel.
5. When the sounding reel counter reaches zero, immediately reverse the sample and pull it back up (at a uniform rate) to the water surface.
6. Repeat across the wetted with in pre-determined vertical bins (usually 10).
7. Label samples according to the vertical in which they were collected. Each complete samples will consist of ~10 jars.

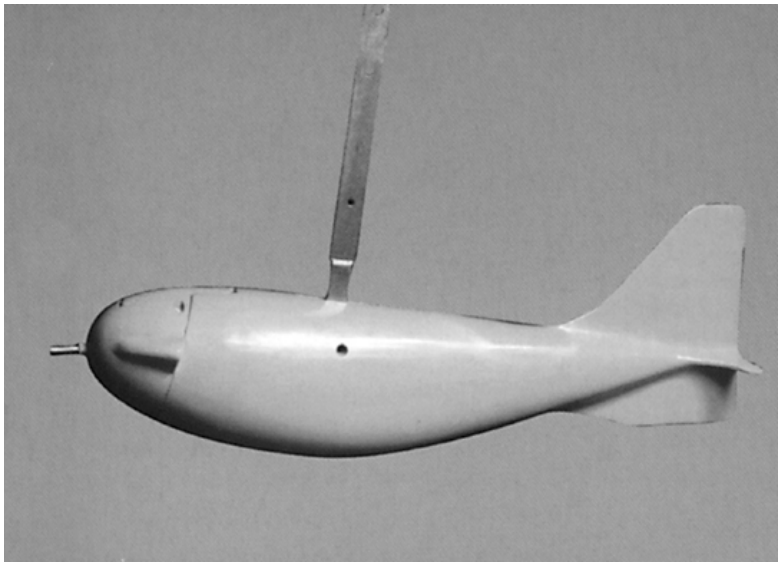


Figure 5. Image of D74 (Source: http://www.rickly.com/ss/images/D_74.JPG)

Sampling records

For each sampling event, fill out the sampling sheet completely. This includes a record of the sampling location, date, time, unique sample ID, event field team members, stage at time of sample collection, sample volume, and any pertinent notes or comments. See Appendix A for field sheet.

Sample preservation and shipping samples to the laboratory

Sample integrity will be preserved by keeping the samples in a cool and dark location until shipment to the laboratory. Considerable care should be taken while packaging samples to avoid breakage during transit.

Section 4. Collecting a bedload sample

Introduction

The purpose of bed load sediment sampling is to determine the average rate of bed load movement in a cross section. All samples with be taken manually during the WY 2011 field season. The single equal width increment (SEWI) method will be used to determine cross-sectional variation under lower, medium and high flow conditions. The samples will be composited from a single pass across 10 equal width sampling points. Bed load flow rates will be combined with water discharge to compute "instantaneous" bedload discharge and used to develop a daily record for the entire wet season.

Description and function of the equipment

BL84-Bedload sampler is a 64 lb-cable suspended sampler with a 3" x 3" opening, and a 200 micron bag for collection. The sampler design enables collection of particle sizes up to 1.5 inches at mean velocities up to 10 ft/sec. The sampler must be supported by a steel cable and b-reel connected to a 4-wheel boom truck to be lowered into a river or stream for taking a bedload sample. When the sampler is submerged and sitting on the streambed with the nozzle pointed into the flow, the water sediment mixture flows through the opening into the bag. The mesh openings in the bag allow water and fine sediment to flow through the bag while trapping the coarse sediment.

Taking a sample

Setting up equipment

1. Connect b-reel to 4-wheel boom truck (as described in equipment operation section)
2. Connect sampler to the suspension cable and b-reel. Suspension cable diameter should be 1/8 or less, as bulky equipment increases the chance of the sampler to be pulled downstream.
3. Attach the sample bag to the sampler by loosening retention clips on either side of the nozzle. Stretch the opening of the sample bag over the nozzle so that it fits in a groove at the rear of the nozzle. Tighten the retention clips. Attach the retention spring found at the front of the tail, to the metal grommet found in the rear of the sample bag.

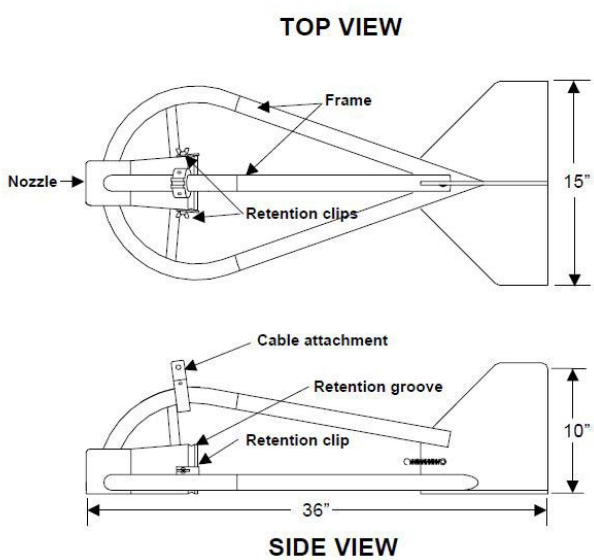


Figure 6. Image of BL84 (Source: FISP and SFEI photo)

Single Equal Width Increment (SEWI) method

Staff will use the USGS Single Equal Width Increment (SEWI) method to collect depth integrated samples at multiple verticals across the stream. (see side panel).

Staff will decide on a suitable distance for sample spacing for each cross section, in order to account for spatial and temporal variation in bed mobility (see side panel), and will mark these verticals and sampling locations on a bridge rail prior to the field season.

1. Starting at one bank and proceeding to the other, the event field team will collect one sub-sample per vertical at 10 evenly spaced verticals in the cross section. After the sampling time has elapsed (e.g. 30 seconds), the BL84 is raised and the process is repeated at the next vertical. All bedload collected in one pass is added to a single sediment sample bag to make one composite sample. The process is then immediately repeated in reverse again sampling each of the 10 verticals while returning to the starting point, making a second composite sample. Each composite sample is labeled discretely with a single sample number and an "a" and "b" indicating they are separate but collected sequentially only minutes apart.

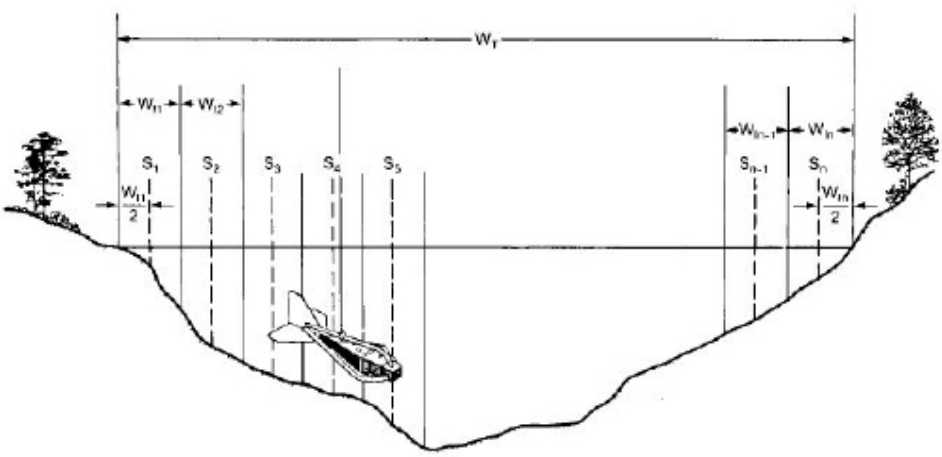


Figure. 7 Diagram of Single Equal Width Increment sampling method (USGS_d)

Single Equal Width Increment background:

The spatial or cross-channel variations in bed load transport rates are significant. Most bed load transport occurs in the narrow part of the total width of channel, or the thalweg. However, the thalweg can shift laterally with changes in hydraulic conditions or sediment characteristics and deposition (Emmett 1981).

At least 10-20 equally spaced sampling stations are necessary to ensure that zones of both maximum and minimum transport are adequately sampled across the full width of the channel. Sections should not more than 15 m apart, and seems to be no need for spacing sections closer than 0.5 m (Emmett 1981).

Temporal variation:
Variation over time is also important in measuring sediment transport. The USGS method of accounting for changes over time is to conduct two passes of the stream (back and forth) at each cross section and to sample at least 10-20 verticals at each pass. The spatial factor is covered by the 10-20 sections; the temporal factor is covered because of the time lag between the first and second passes at each vertical.

At each vertical:

Lower the sampler at an even rate through the water column until it touches the streambed and use a stopwatch to measure the time interval during which the sampler is on the streambed. The sampling-time interval should be the same for each vertical sampled in the cross section and by default will be set at 30 seconds.The time the sampler is left on the bottom should be equal for all verticals in a given cross section, but each cross section sampled may require different sampling times and distances (see side panel).

It is not unlikely that the time of deployment in each vertical will be related to stage (small times for high stage) and specific for each location.

The samples are collected at the midpoint of the equal width increments.

Note on sample compositing:

A bedload sample is the material collected during one sampling time. Individual bedload samples can be analyzed individually, or combined into one or more composite samples for analysis. Only samples collected with equal sampling times and width increments may be composited. The more samples one composites, the less one learns about variability in space and time.

Discussion of sample time at each cross section

Because of the temporal variations in bedload transport rates, there is no easy way to determine the appropriate sampling time. Several test samples may be needed in order to estimate the proper sampling-time interval to be used. The sample time should be short enough to allow for the collection of a sample from the section with the highest transport rate in the cross section, without filling the sample bag more than about half full. The sample bag may be filled to 40 percent full with sediment coarser than the mesh size of the bag without reducing the hydraulic efficiency of the sampler.

Figure 8. SFEI photo of BL84 in water

Sampling records and field forms

The following data should be recorded on a field note sheet for each cross-section sample:

Station name/number
Date
Name of person collecting sample
Cross-section sample starting and ending times
Gage height at the start and end of sample collection
Total width of the cross section including stations of both banks
Width between verticals sampled (SEWI method)
Time sampler was on the bottom at each vertical
Type of sampler used

Sample field sheets are shown in Appendix B.

Preservation:

Sample integrity will be preserved by keeping the samples in a cool and dark location. Samples will first be brought back to SFEI's offices where they will be hung and air-dried before being sent to the laboratory.

Note:

1. Disturbing the bed (especially during higher flows) can impact bedload measurements more than other measurements we make. Disturbances mostly move downstream but can also move upstream.
2. If the bedload sampler is undermined and tilts then the sample is no longer valid
3. The BL-84 sampler should not be used when there is an extremely irregular channel bed. The sampling opening must be flush with the channel bed, or close.

Section 5: Maintaining the ISCO sampler

Each monitoring station has an automated ISCO sampler that is triggered to collect a sample when pre-determined thresholds of turbidity are crossed. A turbidity probe is installed within the creek at each location. The turbidity probe and ISCO sampler are connected to a battery and datalogger, both located within the same housing as the ISCO. Every 14 days the data must be downloaded at each location because the datalogger has a limited amount of memory. This section of the manual takes the user step-by-step through downloading the data, servicing the site, and troubleshooting the most common problems experienced with the ISCO equipment. The following section is an adaptation of the Turbidity Threshold Sampling Field Manual written by Rand Eads (RiverMetrics LLC, 2005, revised on 10/01/2008). Field sheet for ISCO maintenance is shown in Appendix C.

5.1. Observing and recording station information

5.1.1. On the field form record the Date, Time, Observer initials.

5.1.2. Note the presence of sediment and/or debris that is in the channel or obstructing the turbidity probe (to be cleared later) and read the stage (but only record within 5 minutes of data logger wakeup).

5.1.3. Observe current ISCO pumping sampler displays and check the samples. Do not disturb the ISCO pumping samplers within +/-2 minutes a wakeup. If sample volumes are too high or too low, go to Troubleshooting.

5.1.4. Prepare to change the ISCO pumping sampler bottles if needed and perform routine station maintenance.

5.2. Connecting to the data logger and starting LoggerNet

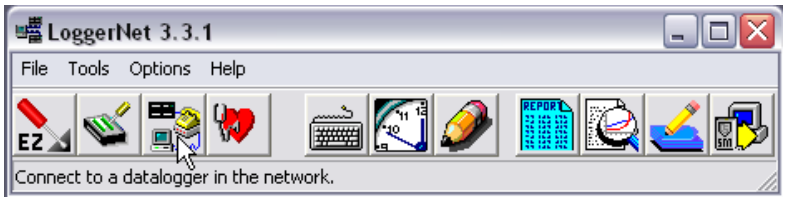
5.2.1. Connect the communications cable between the laptop and the data logger.

5.2.2. Open the laptop and turn it on.

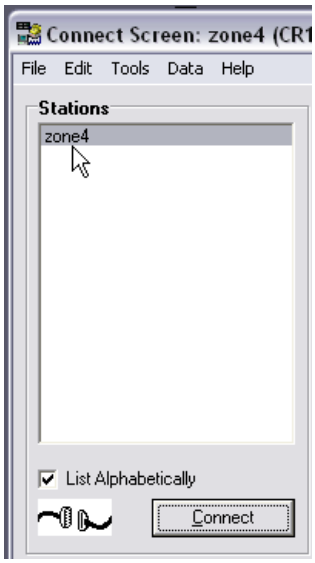
5.2.3. Click on the LoggerNet icon:

5.3. Establishing communications between the laptop and data logger

5.3.1. Click on the Connect icon.

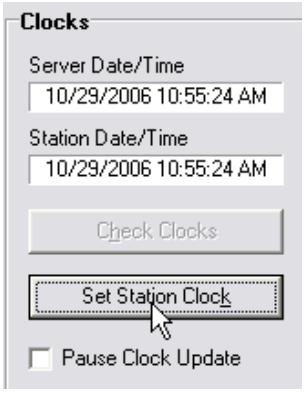


5.3.2. Select the Station Name:



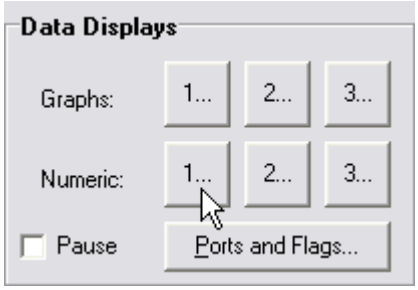
5.3.3. Click on the Connect Button:

5.3.4. Make sure the laptop's clock is accurately set to the telephone time recording before setting the data logger's clock. Then compare the data logger clock (station date/time) to the laptop clock (server date/time). If the error is greater than 30 seconds, adjust the clock after you transfer the data.

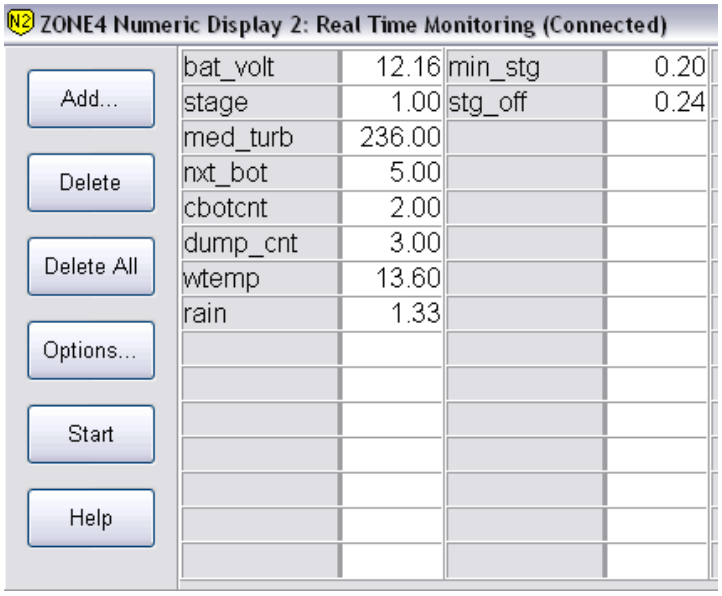


5.4. Viewing, observing, and recording information

5.4.1. Click on the **Numeric 1** button, to open the window:



The station **Numeric** window displays the values from the most recent wake-up.



5.4.2. Record current time and information from the following fields in the station **Numeric** window, onto the field form:

- ***bat_volt*** (battery voltage): if voltage is less than 12.0, notify the project supervisor.
- ***stage*** (electronic stage): Compare this value with the observed stage from the staff plate reading. If the stage differs by more than .02 feet, make note, view plot, and take further action as necessary, after collecting the data.
- ***med_turb*** (turbidity): Value is valid when stage is above minimum stage.
- ***nxt_bot*** (next sample number): Compare this value with the value on the ISCO pumping sampler display. If sample numbers differ, go to Troubleshooting after collecting the data.
- ***dump_cnt*** (data dump number): Compare this value with the dump number from the previous field form. If the number displayed on the data logger is incorrect, change it now.
- ***wtemp*** (water temperature). The DTS-12 must be fully submerged for this temperature to be valid.

- ***rain*** (rainfall during previous interval). One tip is equal to 0.01" of rainfall.
- ***min_stg*** (minimum stage). Both the turbidity sensor and ISCO pumping sampler intake are adequately submerged above this stage. To modify the value double-right click on the current value, then type the new value and press [Enter].
- ***stg_off*** (stage offset). Enter a value to make the electronic stage agree with the staff plate. Avoid making changes during high flows or when it is difficult to obtain an accurate staff plate reading.

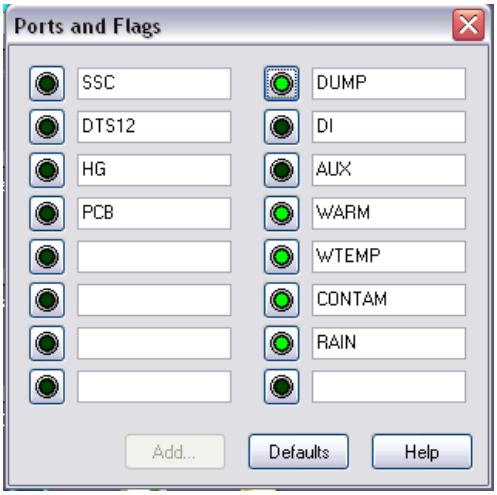
5.5. Dumping the data

NOTE: The sequence and timing of each activity is important for post-processing programs to work correctly.

5.5.1. If a wake up has occurred since your initial observation of the Numeric window, re-examine the values in the station Numeric window AND the next bottle number on the ISCO pumping sampler display. Update any changes into the station notebook noting the new time.

5.5.2. A sample *may* be collected at the next wakeup. Be sure to allow yourself a full wakeup interval to service the ISCO pumping sampler and bring it back online before that next wakeup occurs.

5.5.3. Be sure that the next wakeup is at least 3 minutes away, then click on the box next to **DUMP** (in the **Ports / Flags)** window to select the Dump flag:

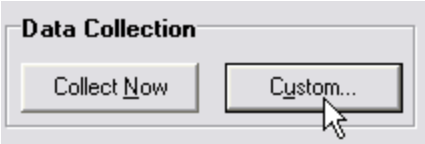


The *dump_cnt* value displayed in the Numeric window and written to each record in the file will increment by one at the next wake up.

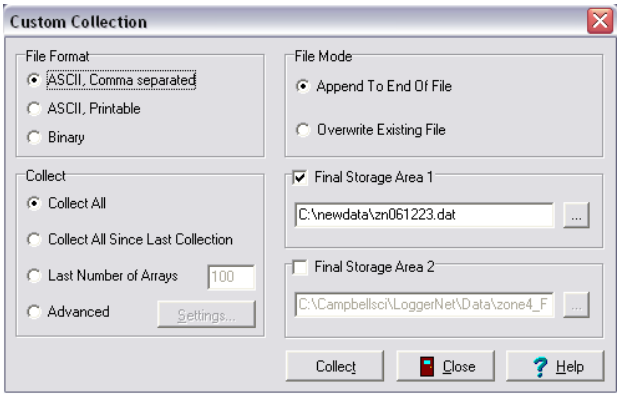
NOTE: You can click again on the box to deselect it if you made a mistake. Do not select or deselect any other DUMP, DI, or AUX.

5.5.4. Change ISCO pumping sampler bottles and perform the station maintenance tasks, noting times and details in station notebook.

5.5.5. Click on the **Data Collection** button labeled **Custom**.



5.5.6. Edit the date within **filename** to reflect today's date—leave the remainder of the path as it is displayed. Always use the directory structure: C/:newdata/znyymmdd (where zn are two letters of the station, yy is the year, mm is the month, and dd is the day, chose .dat as the extension).



CAUTION! If this station was dumped earlier on today's date, this naming convention will result in duplicate filenames!

Instead, the new file name is: ssyyddnn.dat (where: yy is hydrologic year and nn is the *dump_cnt*)

5.5.7. Follow the file transfer in the **% Collected** bar until it displays 100% and disappears from the screen:

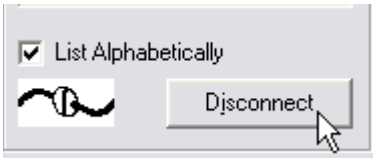
When file transfer is complete, the program will automatically deselect the Dump flag at the next wake up.

5.5.8. If you need to correct the data logger clock, do so now after verifying that the laptop time is correct and that the time discrepancy does not straddle a wakeup (for example: 10:18:30 = data logger clock and 10:20:30 = PC clock.) Click on **Set Datalogger Clock**. If the PC clock is incorrect, first correct it by selecting **Settings** from the **Start** menu.

5.5.9. If you need to change these values in the Numeric window: *min_stg*, (minimum stage), *stg_off* (stage offset), do so now by following the directions in that section.

5.5.10. Close the **Ports / Flags** window by clicking on the **x** in the upper right corner.

5.5.11. Click on the **Disconnect** button:



5.5.12. Close the **LoggerNet** window by clicking on the **x** in the upper right corner.

5.5.13. Disconnect the communications cable from the data logger.

5.6. Changing the ISCO pumping sampler bottles

5.6.1. Prepare replacement bottles:

6.1.1. Label each bottle "ss – nn", where

- "ss" is the two-letter gaging station ID, and
- "nn" is the sequential bottle number (01 to 24)

1.1.1. Remove the caps.

5.6.2. Unfasten the bale latches on the sampler, and lift the controller section on the support arms.

5.6.3. Tightly cap each bottle containing a sample before removing the bottle from the base.

5.6.4. Place the samples on the designated level shelf.

5.6.5. Insert the empty, uncapped replacement bottles being sure that the entire sampler is full of bottles.

5.6.6. Re-assemble the ISCO pumping samplers.

5.6.7. **RESET SAMPLER** to bottle position 1 by:

Press red stop button

Press [↑] to scroll up until the "RUN PROGRAM" is blinking

Press the enter key

The ISCO pumping sampler will display "BOTTLE 1 AFTER 1 PULSE"

5.6.8. Write the data dump number, *dd*, on each label in front of the station letters.

5.6.9. On bottle 01, within parentheses, write the number of samples (*x*) that were removed.

Label Format for bottle 1: *dd-ss-nn (x)*

5.7. Maintaining the station

Perform station maintenance tasks:

5.7.1. Service the turbidity probe and sampling boom between wakeups:

- Removing debris from housing and leading edge of the boom, and
- Remove sediment from inside housing by rapidly pushing the boom up and down stream, and
- During *non-storm* visits, clean the optics if necessary using a soft toothbrush (and mild soap if necessary).

5.7.2. Service the measurement section between wakeups:

- Remove branches and debris
- Read and record the staff plate a second time after clearing measurement section.

5.7.3. Check/replace system batteries as needed by following these steps:

- If the 12V battery is <12.0 volts **only replace the battery while the solar panel is supplying power (at least some sun on the panel) or else all the counters and flags will be reset to the default conditions**.
- Turn off **ALL** the ISCO pumping samplers.
- Set the replacement battery (if one is available) next to the battery being removed and quickly remove first the battery ground clip and attach it to the new battery's ground terminal, then do the same with the positive battery clip. **Make sure to keep the polarity correct (Red to positive +)!**
- Turn ISCO pumping sampler back on.
- Check the data dump number to make sure it is correct, if not edit the value in the numeric window. If the dump number reverts to "1" it means that power was lost.

5.7.4. Replace desiccants when the lowest circle on the moisture card inside the enclosure turns pink.

5.7.5. Adjust/troubleshoot/replace equipment as needed

5.8. Complete the field form

5.8.1. Fill out or strike-through ALL fields on the field form.

5.8.2. Use the appropriate letter designation for the bottle status of each of the 24 sample bottles.

5.8.3. Make notes on the bottom of the form. Be thorough and make concise comments on what was done and observed during this visit. Use the back of the form if you need more space. Note any conditions that may affect the data quality. Make a list of supplies needed at the next site visit.

5.9. Changing values in the Numeric window

Explanation: Program parameters in the Numeric window may be changed to temporarily update the TTS program on the data logger.

CAUTION: Changing a value in the Numeric window modifies the program operation on the data logger but not the actual code on the data logger, laptop, memory sticks, etc. If the TTS program is reloaded, the changes made in the Numeric window will be lost.

5.9.1. Place the mouse pointer in the field you wish to change and double-click on the value

5.9.2. Press the backspace key to erase the old value

5.9.3. Type the new value.

5.9.4. Press [ENTER] for the new value to take effect.

5.9.5. Exit the Numeric window and PC400 software now, or wait until the next wakeup to see that your change has taken effect.

5.10. Viewing the data file

5.10.1. Navigate to the C:/**newdata** directory.

5.10.2. Open the current file by right-clicking on it and choosing "Send To NotePad".

Here is the data format:

Site ID,Year,Julian day,Time,Dump Number,Bottle Number,Threshold Code, Sample Code,Stage,Turbidity,Water Temp,Rain,Contaminate bottle number

5.10.3. Click on **Exit**.

5.10.4. Choose **No** to **Save Changes** prompt.

5.11. Troubleshooting

If possible, retrieve the data before attempting to troubleshoot.

Record everything: symptoms, actions, and results.

Identify, repair, and replace malfunctioning equipment.

5.11.1. Diagnostics Programs

Note: The following diagnostic programs enable repeated tests of a data logger function over a short time frame. The TTS program performs these same functions but only at 10- or 15-minute intervals. Ideally, the test programs are run from a spare data logger and thus station data is not compromised. To load and run one of these programs, see section 16.0 Loading a new program revision:

- INWTEST.CSI – Reports mean stage from pressure transducer at 10-second intervals
- DTS12TEST.CSI – records DTS-12 turbidity statistics at 60-second intervals using C2
- ISCO PUMPING SAMPLER_C1.CSI – Tests the SSC ISCO pumping sampler relay circuit using Port 1 (C1), runs at 15-second intervals

5.11.2. Problem: Data logger not connecting or dropping connection

11.2.1. Check cables between data logger and laptop. Be sure to check ALL connections.

11.2.2. Check Battery voltages with voltmeter. Either gel cell or 9V must be at least 9 volts. Replace any low batteries.

5.11.3. Problem: Station Numeric window does not contain necessary variables or values

11.3.1. If the variable names are present but the values are blank, you have not successfully

connected to the station data logger. (see above)

11.3.2. If the variable names in the Numeric window = "Inloc_1", "Inloc_2",…"Inloc_10" then the laptop is not setup correctly for this station.

a) Confirm that you have selected the correct "associated program file name".

b) At the bottom of the Numeric window, click on [ADD]. A second window will open on the left showing all the variables. This window is titled "InLoc list". Scroll down the list and drag and drop the designated variables (*dump_cnt*, *stage*, …) into the Numeric window using the graphic in the appendix as your guide. The values for each variable should appear as they are dropped on the Numeric window.

c) Close the "Inloc List" window.

11.3.3. If the variable names appear, but the values are equal to zero, the data logger is in "Cold Start" Mode. The values should fill at the second wakeup. Wait and see. You may have to update some parameters (*stg_off*, etc.) if they were not current in the program. See Changing values in the Numeric window, Section 15.

5.11.4. **Problem: *Dump_cnt* is incorrect**

Note: The *dump_cnt* reverts to 1 at a "cold start" (after loading a new program revision or after a power loss). To correct the *dump_cnt* See changing values in the Numeric window, Section 15. The station notebook and fieldform program track dump numbers.

5.11.5. **Problem: Displayed *stage* is not correct within acceptable limits**

NOTE: During the first storm flow of the season, the electronic (Campbell) stage is frequently off and the transducer index (*stg_off*) needs to be adjusted. If a stage error is noted after an initial seasonal adjustment has been done, additional troubleshooting should be done.

11.5.1. To adjust the *stg_off* in the Numeric window:

a) Do a data dump.

b) Re-open the Numeric window

c) Offset correction = staff plate – elec. Stage

d) Add this correction to the current value of the *stg_off*

e) Wait for the next wake-up and confirm that the electronic stage agrees with your *current* observer stages.

f) Be sure to record the change on the station note sheet and in the field form.

11.5.2. Check the previous field forms and station status sheet to determine if changes were made to the *stg_off*. The offset may have been set incorrectly or reverted to a previous value.

11.5.3. Verify that the transducer is secured. If you suspect it has moved, re-secure the transducer and reset offset.

11.5.4. Inspect the transducer cable for damage.

11.5.5. If the stage plot indicates drifting or erratic stage over time suspect a failing pressure

transducer. Replace the pressure transducer.

11.5.6. If the stage error occurs after a high sediment event, check for debris and flush the intake if clogged. Note action, extent of obstruction, and post-cleaning stage on Field Form.

11.5.7. If the transducer has been replaced and the problem persists, suspect data logger.

5.11.6. **Problem: ISCO pumping sampler bottle volumes too low (empty) or too high**

Volumes may be low when ISCO pumping sampler intake is marginally submerged. Avoid calibrating sampler at stages very near to the station minimum stage.

Ideal sample volume is 1/3 of bottle capacity (~330ml). Minimum is 1" depth.

11.6.1. Check station status sheet and ISCO pumping sampler controller for proper settings.

11.6.2. Inspect for cracked and leaking ISCO pumping sampler bottles.

11.6.3. Check intake tubing for leaks or kinks. Make sure connections are tight.

11.6.4. Check inside ISCO pumping sampler pump housing for worn pump tubing.

11.6.5. Inspect ISCO pumping sampler intake for obstruction (if stage permits).

11.6.6. Overflowing bottles in an ISCO pumping sampler may indicate a failure of the "liquid detector".

a) Enter the configuration mode and select the following:
   - Disable "Liquid detector"
   - Calibrate sample volume.

5.11.7. **Problem: ISCO pumping sampler over-sprays or water in base of sampler**

11.7.1. Adjust distribution tube-end to extend 1/16" beyond the distributor arm.

11.7.2. Inspect distributor arm for loose connections, binding, or twisted tube.

11.7.3. Check for cracked and leaking bottles.

11.7.4. Overflowing bottles in an ISCO pumping sampler 3700 may indicate a failure of the "liquid detector".

a) Enter the configuration mode and select the following:
   - Disable "Liquid detector"
   - Calibrate sample volume.

For any problem that cannot be resolved by the attending technician, please call one of the following SFEI staff members:

Alicia Gilbreath (SFEI): 510-746-7308
Julie Beagle (SFEI): 510-746-7312

If you cannot reach Alicia or Julie, please make as many notes as you can on the field form about the problem. Record exactly the message in the display window of the ISCO. Open the ISCO control panel and look at the C-flex tubing to ensure that it is correctly positioned and in one piece. Note if all cords are correctly secured between the ISCO, datalogger, and battery power source. Note if any of the equipment appears damaged in any way. Please leave a message with Alicia and/or Julie about any problems encountered and email any pertinent notes to them so that issues can be resolved immediately and data loss can be minimized.

References

Edwards, Thomas K and G. Douglas Glysson. 1999. Field Methods for Measurement of Fluvial Sediment. Techniques of Water-Resources Investigations of the U.S. Geological Survey in Book 3, Applications of Hydraulics. Virginia 1999. Revised from "Field Methods for Measurement of Fluvial Sediment," by Harold P. Guy and Vernon W. Norman, U.S. Geological Survey Techniques of Water-Resources Investigations, 'Book 3, Chapter C2, published in 1970.

Emmett, Williams W. 1981. Measurement of bedload in rivers. Erosion and Sediment Transport Measurement (Proceedings of the Florence Symposium, June 1981). IAHS Publ. no. 133.

Lewis, Jack, and Rand Eads. 2008. Implementation guide for turbidity threshold sampling: principles, procedures, and analysis. Gen. Tech. Rep. PSW-GTR-212. Arcata, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Oct 2008.

Appendix A. SSC field form

Gaging Stations:
Arroyo Las Positas (ALPL), Arroyo Mocho at Hagemann Bridge (AMHag), Arroyo Mocho at Pleasanton (AMP)
Livermore and Pleasanton, CA
Sample Collection Log
Project 5075, Task 02A

Sample #	Parameter	Time Start	Time End	Stage (ft)	Quantity	Comment/Notes
	SSC					
Date	Turbidity					
	Turbidity					
Observers	Turbidity					
	Turbidity					
	Turbidity					

Sample #	Parameter	Time Start	Time End	Stage (ft)	Quantity	Comment/Notes
	SSC					
Date	Turbidity					
	Turbidity					
Observers	Turbidity					
	Turbidity					
	Turbidity					

Appendix B. Bedload sampling field form

Zone 7 Bedload Sampling Data Sheet

Site:	
Date:	
Sample Name:	

Field Technicians:
Weather Conditions:

Bedload Sample Yes_____ No_____

Stage (ft) _____

Time start:		Time finish:	Mean time:

Pass (A or B)	Time start	Time end	Mean time	Time on bottom at each vert	No. of containers	Stations

Remarks: _____

_____

_____

_____

Appendix C. ISCO servicing field form

Location: _____ Date: _____

Observer Initials: _____ Time: _____

Numeric Window Record

Battery Voltage:	Next Bottle:
Stage:	Dump Count:
Turbidity:	Comment:

Data Dump

____ Data Collected (check when completed)

File Name: _____

Staff Plate reading: _____ Time of Staff Plate reading: _____

ISCO Bottles

Time Replaced: _____ Number of Bottles: _____

____ Dump Count Changed (check when completed)

Comment on status of samples (Bottle full? Any problems?): _____

_____

Post Flood Maintenance

Debris/sediment obstructing probe? Y/N (comment if yes) _____ _____

_____

____ Probe checked and cleaned (check when completed)

____ Channel cross section cleared of large debris (check when completed)

Notes pertinent to data quality: _____

_____

Any supplies needed during next site visit? _____

Date of Next Download:

Appendix D. Sampling sites maps, directions and resources

Directions from SFEI to Zone 7 Sampling Sites and Zone 7

To Zone 7
1. Head **northeast** on **Central Ave** toward **Rydin Rd…**……...0.2 mi
3. Turn right to merge on to **I-580 E** towards **Oakland**……..1.1 mi
4. Merge onto **I-80 W** …….3.8 mi
5. Continue onto **I-580 E/I-880 S** (signs for **Hayward/Stockton**)…….0.3 mi
6. Take exit **50** for **Airway Blvd/CA-84** toward **Collier Canyon Rd**…….31.3 mi
7. Turn left at **Airway Blvd**…….0.3 mi
8. Take the 1st right onto **N Canyons Pkwy** Destination will be on the right……..0.7 mi

Zone 7 Water Agency
100 N Canyons Pkwy
Livermore, CA 94551

Arroyo Las Positas at Livermore (ALP)
1. Head **northeast** on **Central Ave** toward **Rydin Rd…**……...0.2 mi
3. Turn right to merge on to **I-580 E** towards **Oakland**……..1.1 mi
4. Merge onto **I-80 W** …….3.8 mi
5. Continue onto **I-580 E/I-880 S** (signs for **Hayward/Stockton**)…….0.3 mi
6. Take exit **52B** for **N Livermore Ave** toward **Livermore**……...0.3 mi
7. Turn right at **N Livermore** Ave……..0.1 mi
8. Make a U-turn. Destination will be on the right…….308 ft

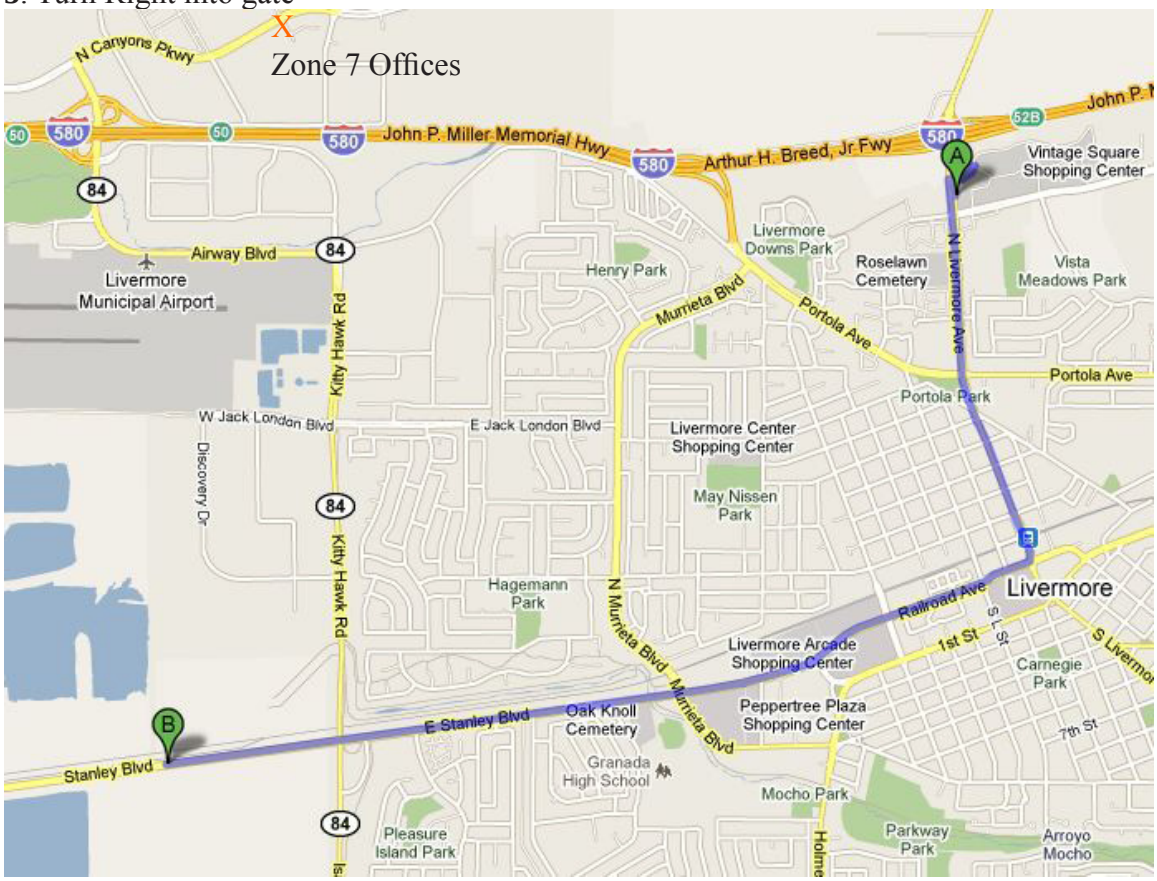
Arroyo Mocho at Hagemann (AMH)
1. Head **northeast** on **Central Ave** toward **Rydin Rd…**……...0.2 mi
3. Turn right to merge on to **I-580 E** towards **Oakland**……..1.1 mi
4. Merge onto **I-80 W** …….3.8 mi
5. Continue onto **I-580 E/I-880 S** (signs for **Hayward/Stockton**)…….0.3 mi
6. Take exit **50** for **Airway Blvd/CA-84** toward **Collier Canyon** Rd……0.2 mi
7. Turn right at **CA-84 E/Airway** Blvd……...0.9 mi
8. Turn right at **Kitty Hawk** Rd……1.3 mi
9. Continue onto **Isabel** Ave……..0.3 mi
10. Turn left toward **E Stanley** Blvd……...0.2 mi
11. Turn left at **E Stanley** Blvd……...0.6 mi
12. Turn right into Zone 7 gate

Arroyo Mocho at Pleasanton (AMP)
1. Head **northeast** on **Central Ave** toward **Rydin Rd…**……...0.2 mi
3. Turn right to merge on to **I-580 E** towards **Oakland**……..1.1 mi
4. Merge onto **I-80 W** …….3.8 mi
5. Continue onto **I-580 E/I-880 S** (signs for **Hayward/Stockton**)…….0.3 mi
8. Take exit **47** for **Santa Rita Rd** toward **Tassajara Rd**……..0.2 mi
9. Keep right at the fork, follow signs for Downtown…….289 ft
10. Turn right at **Santa Rita Rd**……..1.0 mi
11. Make a U-turn at **Stoneridge Dr**. Destination will be on the right……...0.1 mi

Directions between Sampling Sites

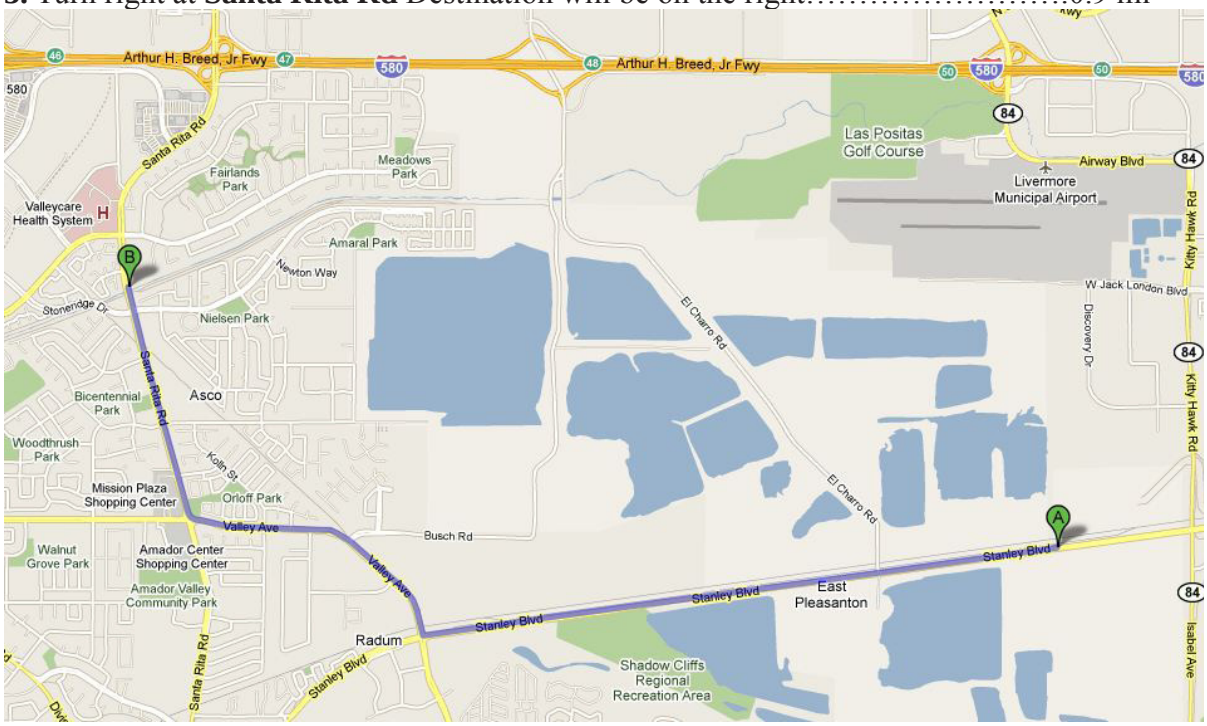
From APL to AMH

1. Turn left at **N Livermore Ave (away from freeway)**…… 1.1 mi
2. Turn right at **Railroad** Ave……0.1 mi
3. Keep left at the fork……0.6 mi
4. Continue onto **E Stanley Blvd**……1.9 mi
5. Turn Right into gate



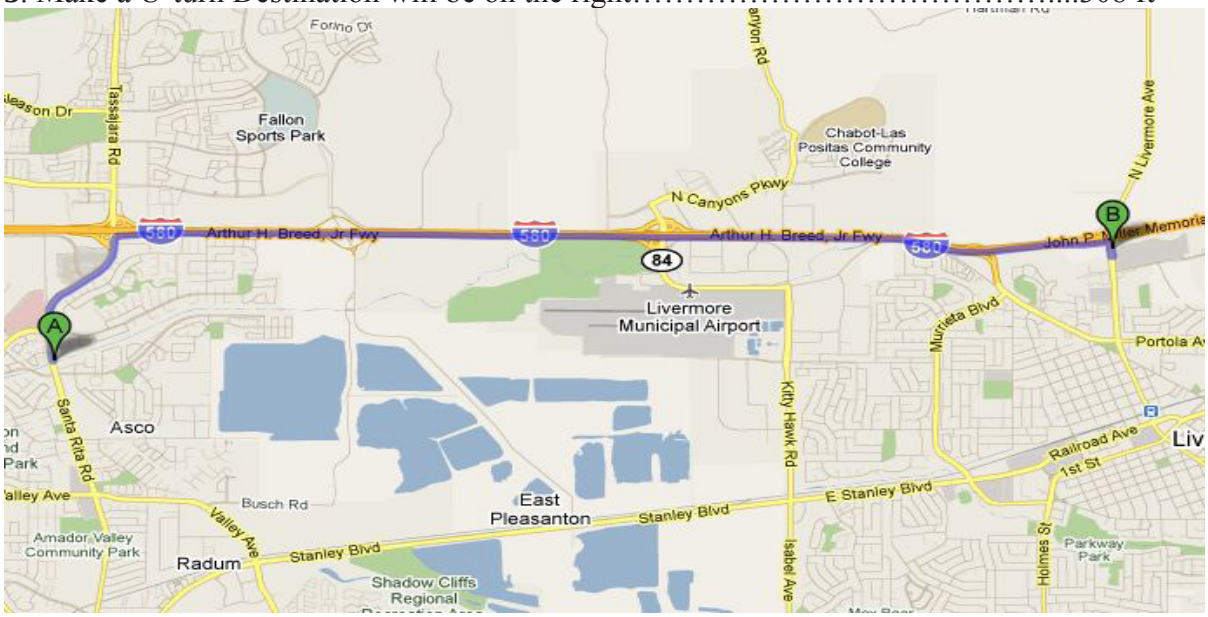
From AMHAG to AMP

1. Head **west** on **Stanley Blvd** toward **El Charro Rd**……2.4 mi
2. Turn right at **Valley Ave** ……1.1 mi
3. Turn right at **Santa Rita Rd** Destination will be on the right……0.9 mi

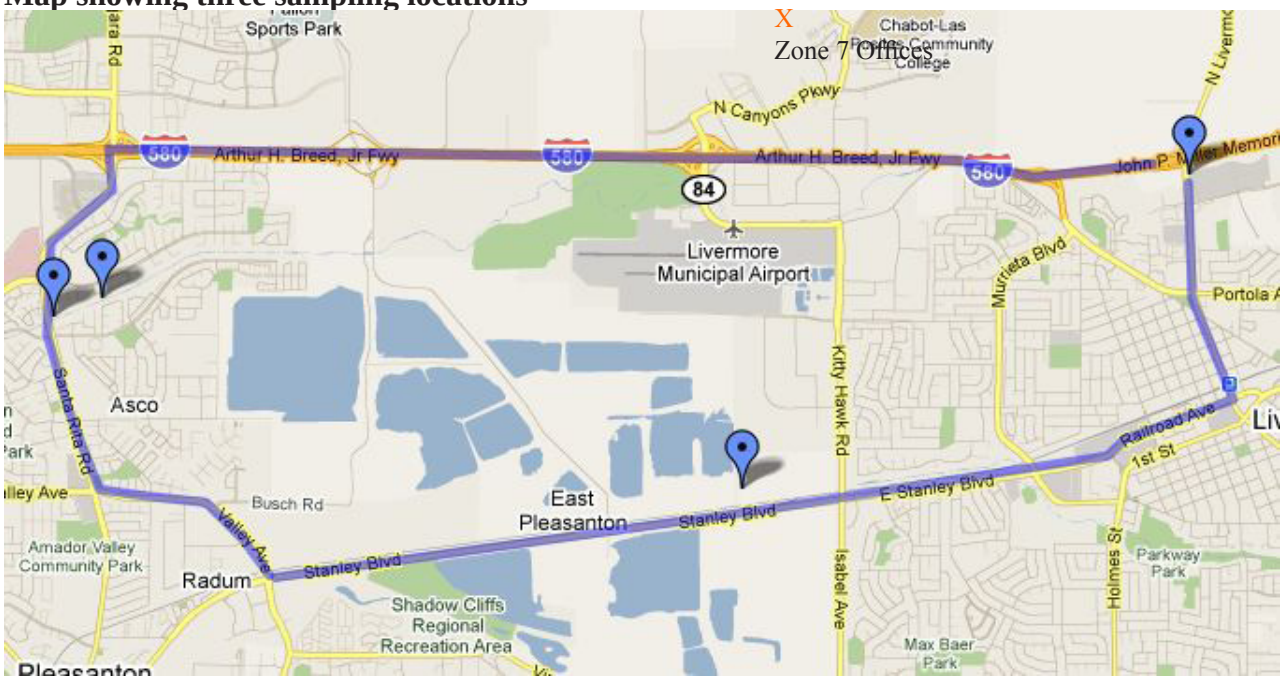


From AMP to APL

1. Head **north** on **Santa Rita Rd** toward **Navajo** Ct……0.9 mi
2. Merge onto **I-580 E** via the ramp to **Stockton**…….....5.1 mi
3. Take exit **52B** for **N Livermore Ave** toward **Livermore**……...…0.3 mi
4. Turn right at **N Livermore Ave** ……0.1 mi
5. Make a U-turn Destination will be on the right……....308 ft



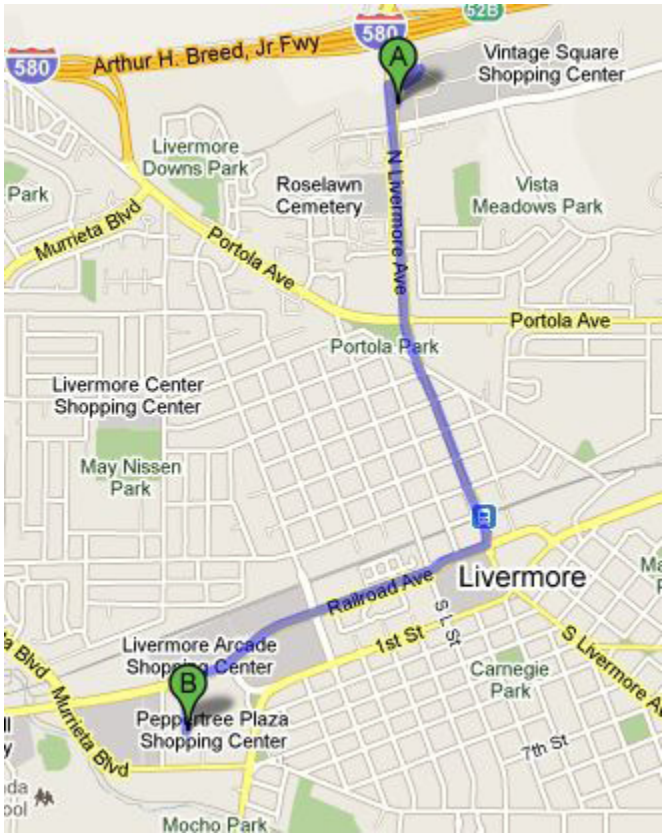
Map showing three sampling locations



Directions from Sampling Sites to Nearest Emergency Services

Arroyo Las Positas at Livermore to Valley Memorial Hospital
1. Head **South** on **N Livermore Ave (away from freeway)**……1.1 mi
2. Turn right at **Railroad Ave**……0.1 mi
3. Keep left at the fork……0.7 mi
4. Turn left at **Fenton St**. Destination will be on the left……0.1 mi

Valley Memorial Hospital
1111 East Stanley Boulevard
Livermore, CA 94550

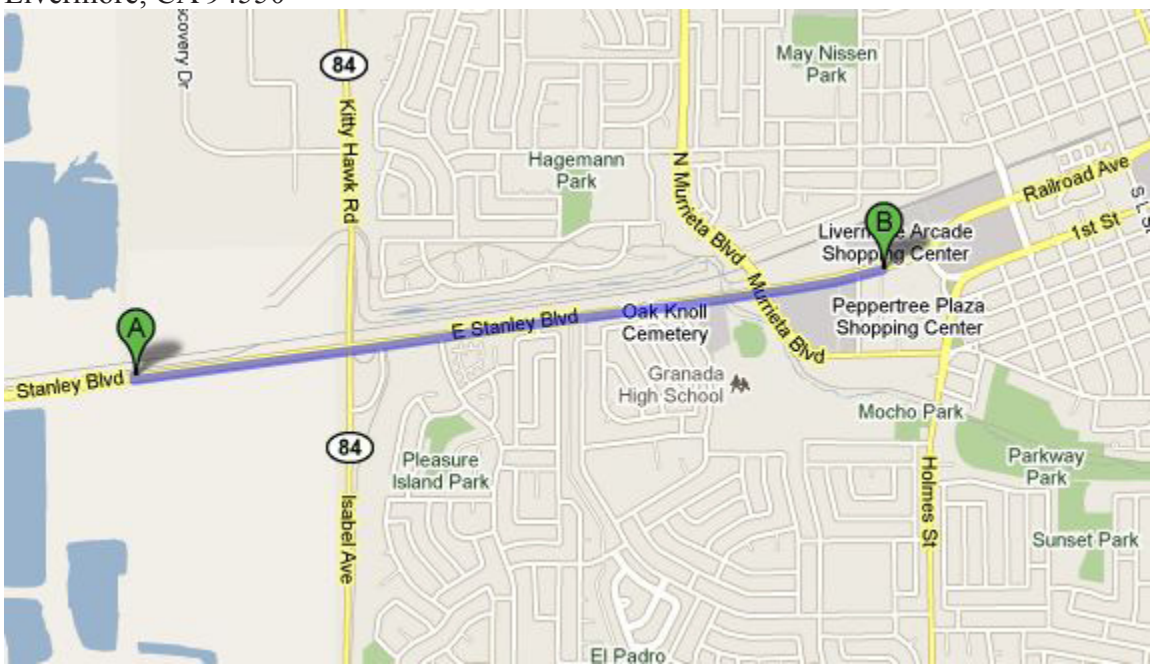


Livermore Police Department (925) 371-4900
Alameda County Sheriff Department (510) 667-7721

Arroyo Mocho at Hagemann (AMHAG) to Valley Memorial Hospital

1. Turn left at **Stanley Blvd**……1.8 mi
2. Destination will be on right.

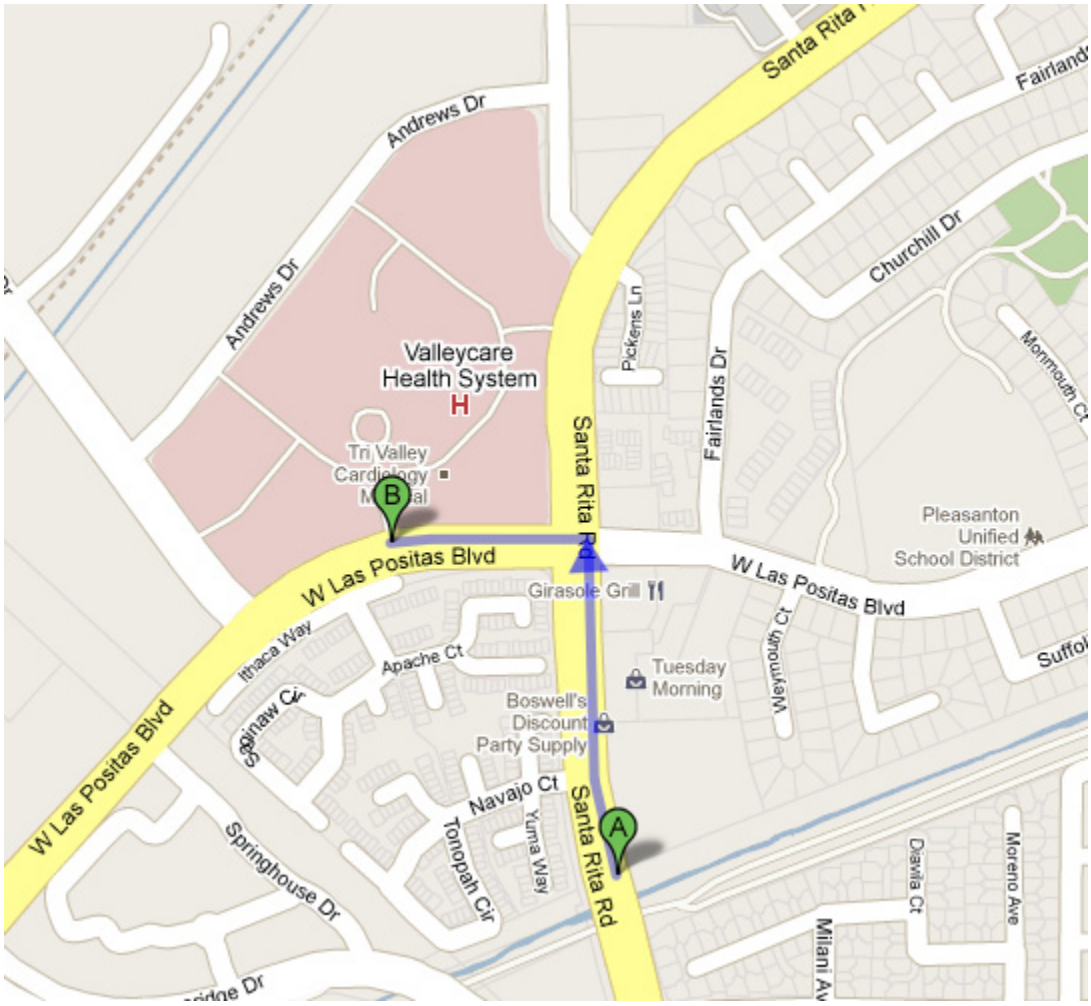
Valley Memorial Hospital
1111 E Stanley Blvd
Livermore, CA 94550



<u>Livermore Police Department</u> (925) 371-4900

Arroyo Mocho at Pleasanton to Valley Care Health System
1. Head **north** on **Santa Rita Rd** toward **Navajo** Ct……..0.2 mi
2. Turn left at **W Las Positas Blvd** Destination will be on the right……..0.1 mi

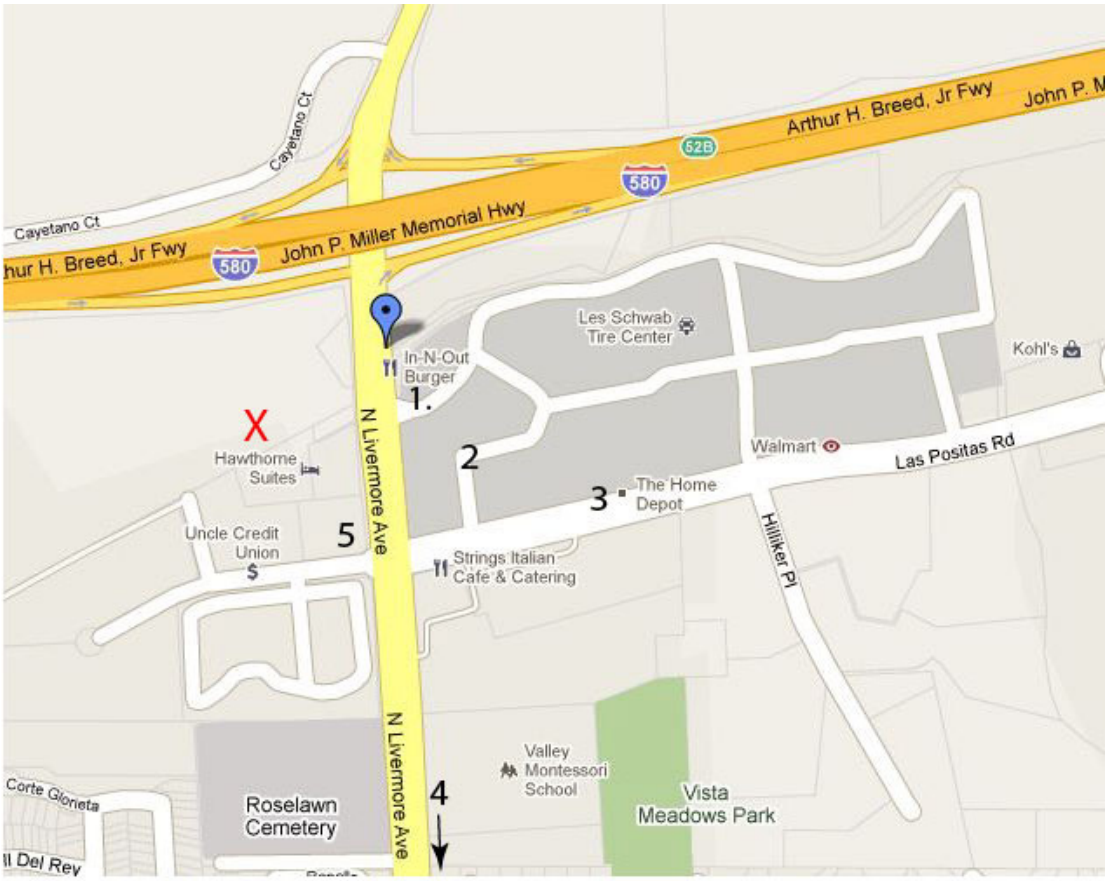
Valley Care Health System
5555 W Las Positas Blvd
Pleasanton, CA 94588



Pleasanton Police Department (925) 931-5100

Nearby gas, coffee shops and cheap restaurants

Arroyo Las Positas at Livermore (APL)



X Hawthorne Suites
1700 North Livermore Ave
Livermore, CA 94551
(925) 606-6060

1. In N Out Burger
1881 North Livermore Ave
Livermore, CA 94550

2. Lanna Thai
2270 Las Positas Road
Livermore, CA 94551

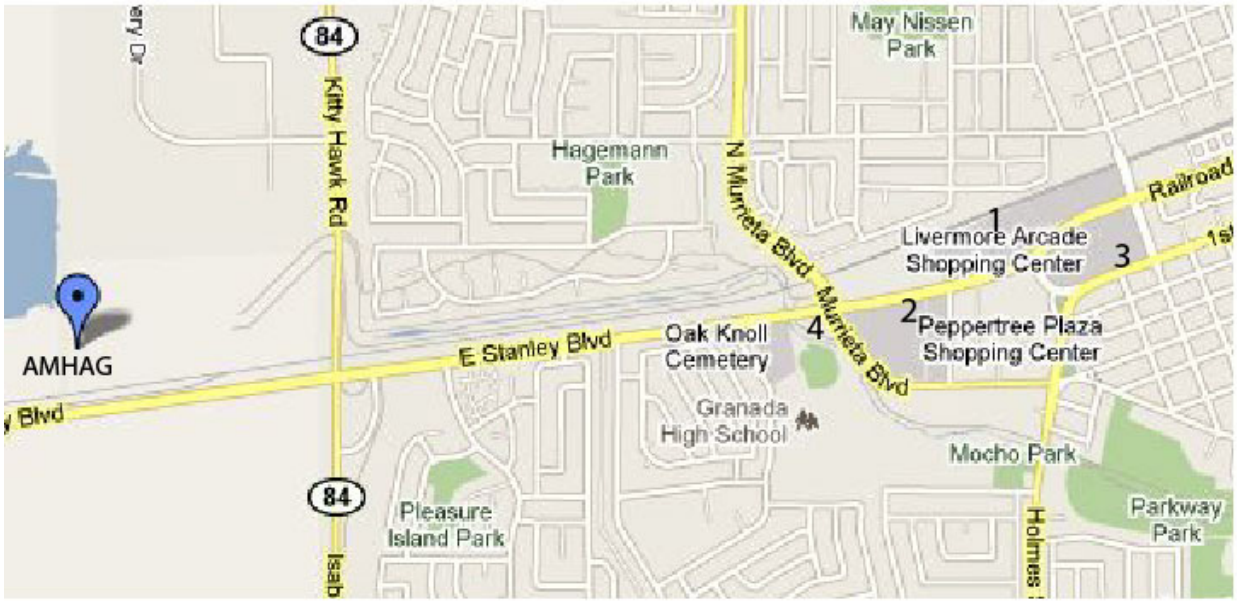
3. Quizno's
2476 Las Positas Rd
Livermore, CA 94551

4. Starbucks
2050 Portola Ave
Livermore, CA 94550

GAS
5. Chevron
2186 Las Positas Court
Livermore, CA 94551

Arroyo Mocho at Hagemann (AMHAG)

1. Trader Joe's
1122 East Stanley Boulevard
Livermore, CA 94550-

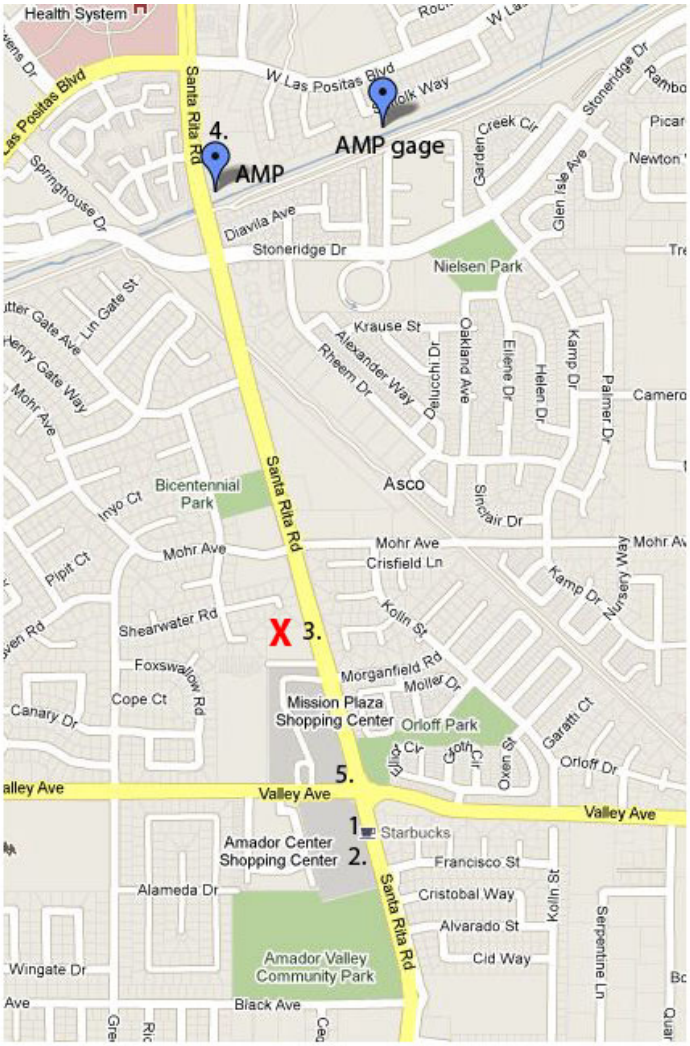


GAS
4. AM PM
785 East Stanley Boulevard
Livermore, CA 94550

2. Subway
969 East Stanley Boulevard
Livermore, CA 94550

3. Starbucks
1472 1st Street
Livermore, CA 94550

Arroyo Mocho at Pleasanton (AMP)



4. Togo's
3120 Santa Rita Rd # D
Pleasanton, CA 94566

Tri Valley Inn and Suites
2025 Santa Rita Road
Pleasanton, CA
(925) 846-2742

3. Royal Tofu House
2025 Santa Rita Road
Pleasanton, CA 94566

5. Pleasanton Shell
1801 Santa Rita Road
Pleasanton, CA 94566

1. Starbucks
1701 Santa Rita Rd
Pleasanton, CA 94566

2. Noahs Bagels
1737 Santa Rita Rd Ste 400
Pleasanton, CA 94566

Parking and Sampling Locations

Arroyo Las Positas at Livermore (APL)

Arroyo Las Positas @ Livermore

X Sampling Location

Parking Location

Nearest Medical Facility: Valley Memorial Hospital
1111 East Stanley Boulevard,
Livermore, CA 94550
Distance= 5.3 mi

Arroyo Mocho at Hagemann (AMHAG)

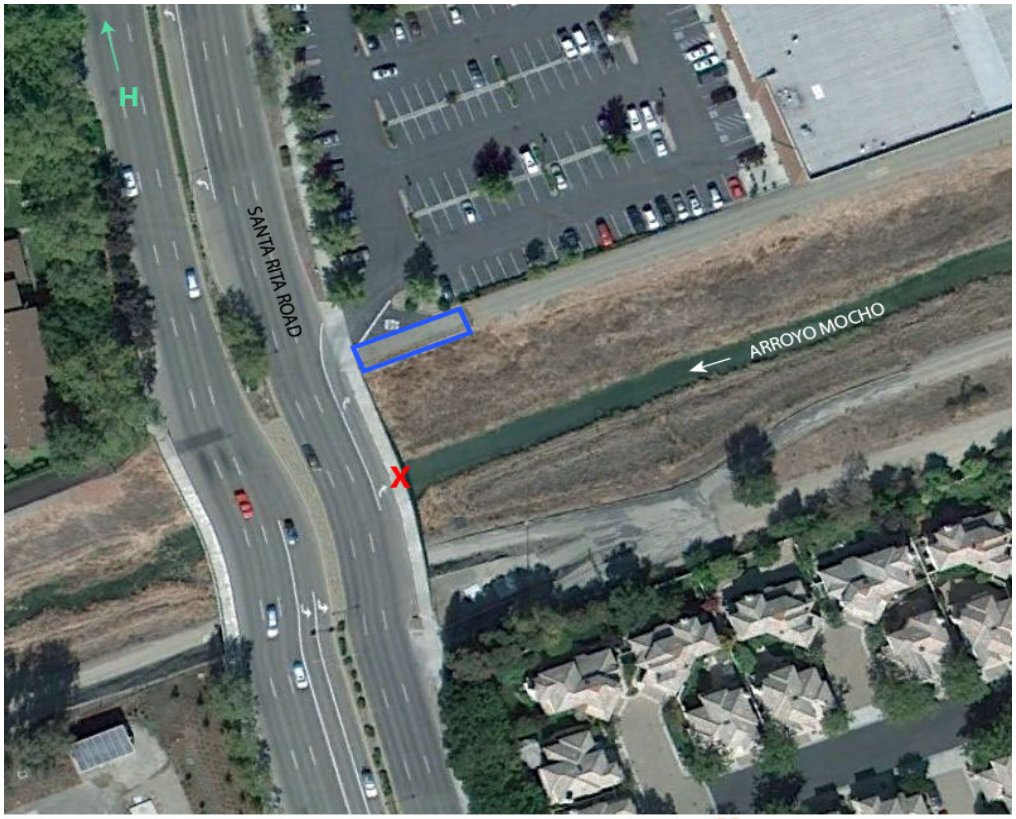
Arroyo Las Positas @ Livermore

X Sampling Location

Parking Location

Nearest Medical Facility: Valley Memorial Hospital
1111 East Stanley Boulevard,
Livermore, CA 94550
Distance= 2 mi

Arroyo Mocho At Pleasanton (AMP)



Arroyo Mocho @ Pleasanton

X Sampling Location

Parking Location

Nearest Medical Facility: Valley Care Health System
5555 W Las Positas Blvd
Pleasanton, CA 94588
Distance= 0.3 mi

Appendix 7.3

Suspended and Bed Sediment Transport in Arroyo Mocho and Arroyo Las Positas during Water Years 2011 through 2015

Alicia Gilbreath
Sarah Pearce
Julie Beagle
Lester McKee

November 2015

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Years 2011 through 2015

Gilbreath, A.N., Pearce, S., Beagle, J.R., and McKee, L.J.
November 2015

Prepared for Zone 7 Water Agency, Livermore, CA

A report of the Watershed Loadings Focus Area of the Clean Water Program
San Francisco Estuary Institute
Richmond, CA

Acknowledgements
Funding for this project was provided by Alameda County Flood Control and Water Conservation District, Zone 7 Water Agency for the total amount of $398,000, under agreement numbers A11-45-SAN and A13-50-SAN. This report and the data collection effort behind it represent 50% of the total project.

We gratefully acknowledge and thank the following people for their support of this project, invaluable guidance and comment, and sharing of data and time:

Joe Seto, Zone 7 Water Agency
Brad Ledesma, Zone 7 Water Agency
Carol Mahoney, Zone 7 Water Agency
Larry Akinsiku, Zone 7 Water Agency
Sal Segura, Zone 7 Water Agency
Ryan Gromer, Zone 7 Water Agency
Jeff Tang, Zone 7 Water Agency
Matt Katen, Zone 7 Water Agency

This report should be cited as:
Gilbreath, A.N., Pearce, S., Beagle, J.R., and McKee, L.J., 2015. Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Years 2011 through 2015. A report of the Watershed Loadings Focus Area of the Clean Water Program, San Francisco Estuary Institute, Richmond, CA prepared for Zone 7 Water Agency, Livermore, CA. San Francisco Estuary Institute, Richmond, CA. 68 pp.

Contents

Summary 4
1.0 Introduction 4
2.0 Methods 5
2.1 Study area overview 5
2.2 Sampling locations 6
2.3 Suspended sediment sampling and loads analysis methods 6
2.3.1 Automated suspended sediment sampling 7
2.3.2 Manual suspended sediment sampling 9
2.3.3 Suspended sediment load calculations 9
2.4 Bedload 10
2.4.1 Equipment and sampling protocol 10
2.4.2 Bedload calculations 10
2.5 Other sources of data 11
2.6 Quality assurance 11
3.0 Results 12
3.1 Period of record, rainfall and recurrence intervals 12
3.2 Results for water years 2011-2015 14
3.2.1 Results of Arroyo Las Positas at Livermore (ALPL) 14
3.2.2 Results of Arroyo Mocho at Hagemann (AMH) 16
3.2.3 Results of Arroyo Mocho at Pleasanton (AMP) 20
4.0 Discussion 22
4.1 Dry climatic conditions during study period 22
4.2 Field observations and sediment load record by site 22
5.0 References 25
Appendix A: Selected Supporting Figures 26
ALPL Model Summaries 27
AMH Model Summaries 34
AMP Model Summaries 42
Appendix B: Suspended Sediment Sample Data 51
Appendix C: Bedload Sample Data 63
Appendix D: Pebble Count Sample Data 67

Summary

San Francisco Estuary Institute was funded to assist Zone 7 Water Agency in the improvement and synthesis of knowledge about the transmission of water and sediment through mainstem channel facilities. The program spanned Water Years (WY) 2011 through 2015 and measured suspended load and bedload during high flow events, and maintained continuous turbidity measurements and auto-sampling equipment during the wet seasons when the majority of sediment is transported in the system. This program augmented Zone 7's existing stage-discharge measurements. Rainfall during the study period included a record-low 3-year cumulative total (WYs 2012-2014) bounded by more average wet seasons, and therefore does not include characterization of any very large events. Nevertheless, most large storm events and peaks during the 5-year study period were sampled, and thus we have high confidence in the loadings estimates for the five years presented here. The results of this study serve as key inputs into Section 3.1.1 (Total sediment inputs from gauged tributaries) of the larger sediment budget for this study area (this report: Pearce et al, 2015).

1.0 Introduction

Zone 7 Water Agency, covering an area of 425 square miles, is charged with providing a reliable supply of potable water for the residents of the cities of Dublin, Pleasanton, and Livermore, and untreated water for about 3500 acres of agricultural land. In addition, since its inception in 1957, Zone 7 has provided flood protection for Livermore-Amador Valley residents, largely abating the flooding which was common place prior to the 1960s. Today Zone 7 maintains 37 miles of channels that receive and convey urban drainage from the tri-cities and runoff and eroded sediment from the watersheds of Arroyo Mocho, Arroyo Las Positas and tributaries to the north. In the recent decades, the population has doubled from 99,000 in 1980 to 197,000 in 2010 (US Census Bureau), and agriculture has been shifting in the Valley from non-irrigated rangeland to irrigated and controlled drainage viticulture. As a result, the water quantity and sediment flux has continued to evolve. Modeling carried out by Zone 7 now indicates that, in some reaches, a combination of loss of capacity from sedimentation coupled with increased peak flows has led to channels that may not pass design flows. In recent years, the role of the Zone 7 Water Agency is changing, as they increasingly must consider and include improved stream habitat and water quality function, in concert with ongoing flood control activities and operating procedures.

In the broader context, because of expected sea level rise, understanding the Bay's sediment budget is important for wetland restoration, maintaining shipping channels, and understanding contaminant processes. For example, millions of dollars have been spent on salt pond restoration and rebuilding tidal marsh, which require certain sediment inputs. Thus, although sediment can be a nuisance to watershed agencies that include flood control as part of their mission such as Zone 7, local tributary loads are also a resource and are important for allowing tidal marshes to establish and keep pace with sea level rise (Mudd, 2011). However, it is both expensive to dredge sediment from the channel and get it to where it is needed, and increasingly difficult given requirements of resource agencies with regulatory responsibilities (e.g. NOAA, DFW, Region 2 Water Quality Control Board, NMFS, USACE).

Several studies have quantified the suspended sediment yields from the Livermore and Amador Valleys and estimated suspended sediment loads passing through Niles Canyon before entering the San Francisco Bay (West Yost and Associates, 2001; PWA 2005, Bigelow et al, 2008). A previous sediment source assessment study (Bigelow et al, 2008) found that about 63% of the sediment load in the Alameda Creek Watershed is sourced from upstream of the Verona gage on Arroyo de la Laguna, which partly underlies the motivation of this study. However, prior to this study, no empirical suspended sediment or bedload data have been developed for a multi-year period for Arroyo Mocho or Arroyo Las Positas within Zone 7's primary management area. These issues caused Zone 7 to embark upon a 5-year sediment sampling program to

directly support design and compliance purposes and decisions about future operations and maintenance of its facilities focusing on the mainstem of Arroyo Mocho from Alamo Canal upstream to the gage at Hageman, and Arroyo Las Positas (altogether comprising the study area).

2.0 Methods

2.1 Study area overview

The Arroyo Mocho and Arroyo Las Positas watersheds (the focus study area) drain the northern and eastern portions of the Alameda Creek Watershed (Figure 1). The Alameda Creek watershed is the largest local watershed draining to the San Francisco Bay, encompassing an area of 642 mi^2 near the Bay margin and 633 mi^2 at the U.S. Geological Survey (USGS) flow gage in Niles Canyon. The watershed ranges in elevation from sea level at San Francisco Bay to 4400 ft. at the top of Mt. Hamilton. The Mediterranean climate of the watershed is characterized by dry warm to hot summers and moderate temperature winter rainfall with a mean annual precipitation of 13.9 inches measured at Livermore (WRCC, 2015). The majority of rain falls between October and May during an average of 60 rain days >0.01 inch. Mean annual rainfall varies in the watershed in response to elevation and aspect ranging from 24 in/yr at Mission Peak to 11 in/yr in Altamont Pass (Collins and Leising 2003).

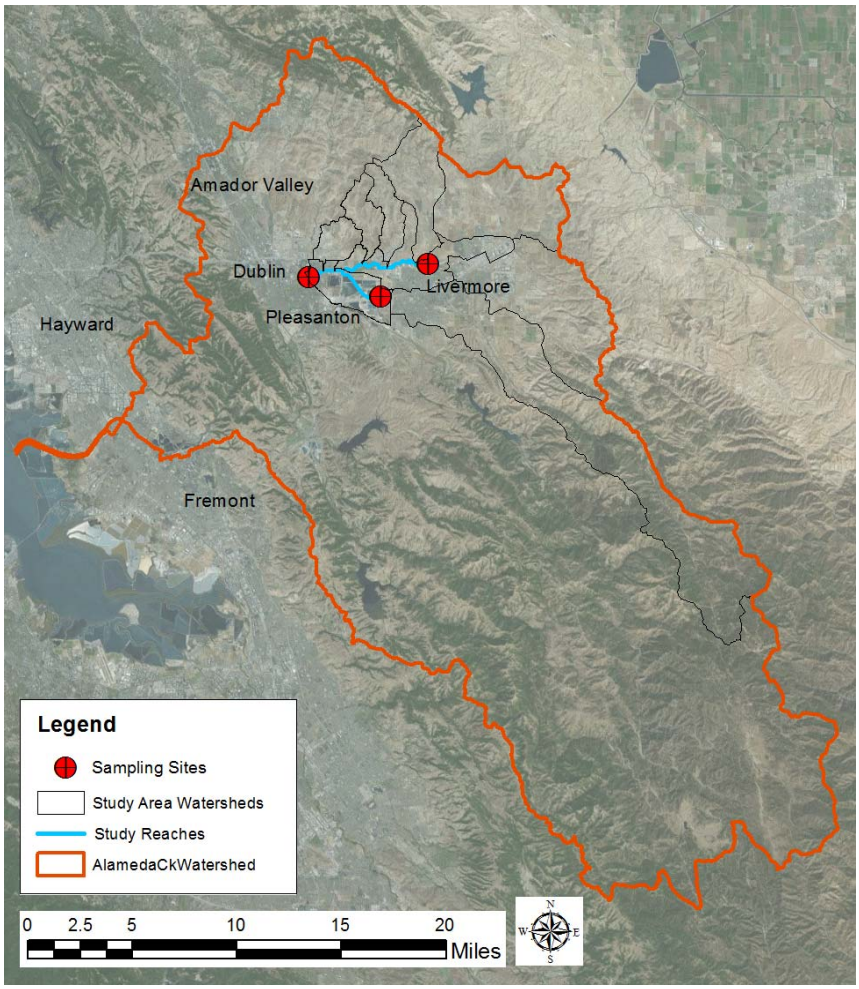


Figure 1. Alameda Creek watershed, study reaches, sampling locations and nearby cities indicated.

The study area includes approximately 120 miles of channels located in the northern and eastern portion of Alameda Creek Watershed, of which about 37 miles are owned and maintained by Zone 7. Both the natural and constructed channels within Zone 7 experience erosion and deposition. Upstream erosional processes, channel incision and bank failures have increased downstream aggradation, exacerbating Zone 7 management of flow and sediment. Many channels within the Livermore Valley were historically intermittent and experienced flow directly related to the timing and totals of rainfall or the season. However, due to the historical ditching, construction of the Zone 7 channels, regulation provided by the large municipal dams, increased urbanization, quarry releases, and inputs from the Delta, the current urban hydrology sustains increased connectivity and year round base flows to most of the streams (Sowers, 2003). In addition to significant changes in flow, the watershed has also experienced changes in sediment supply, largely related to changes in land use. Historically, the dominant supply of coarse sediment came from the upper watersheds, which created the alluvial fans of Arroyo Mocho and Arroyo Del Valle. Today, landslides and debris flows, as well as channel incision and stream bank failures likely account for the major sources of sediment flux (Bigelow et al, 2008).

2.2 Sampling locations

During the rainy season of each monitored WY, SFEI and Zone 7 staff collected suspended sediment and bedload samples during high flows at three sites in the Arroyo Mocho watershed: Arroyo Las Positas at North Livermore Avenue Bridge (ALPL), Arroyo Mocho off Stanley Boulevard between El Charro Road and Murrieta Blvd at Hagemann Bridge (AMH), and Arroyo Mocho at Pleasanton at Santa Rita Road Bridge (AMP) (Figure 2). These sites were chosen because they are at or near existing Zone 7 automated flow gages.

Arroyo Las Positas (ALPL) is the most upstream site in the study. It drains 49 mi^2 of the eastern Livermore hills including inputs from Arroyo Seco and Altamont Creek. The subwatershed is underlain by Holocene and Pliocene surficial deposits, and Plio/Pleistocene Livermore gravels. Arroyo Mocho at Hagemann (AMH) drains 51 mi^2 of the large Arroyo Mocho watershed. The Arroyo Mocho subwatershed is underlain by Jurrasic/Cretaceous sheared metamorphosed mudstones, Franciscan melange, and serpentinite. Arroyo Mocho at Pleasanton (AMP) is the most downstream sampling site, draining approximately 140 mi^2. This site captures flow and sediment loads from Arroyo Las Positas, Arroyo Mocho and creeks that flow in from the ridge to the north of the Zone 7 Flood Control Channel including Line G3, Cottonwood Creek, Collier Creek, and Cayetano Creek. The creeks to the north of the channel facilities are underlain by Miocene sandstones, Plio/Pleistocene Livermore gravels, and Holocene/Pliocene surficial deposits.

2.3 Suspended sediment sampling and loads analysis methods

The goal of the suspended sediment sampling program was to provide a suitable data set for characterizing concentration change in relation to flow, particularly during rain events when erosion and sediment transport is greater. Suitable, in this context, means empirical measurements at the scale of variability necessary for accurate calculations of flux (the mass or “load” of material passing through a cross-section per unit of time). To achieve this, water samples for suspended sediment analysis were collected using both automated and manual sampling protocols as described in the field manual prepared for the 2010/2011 study (Beagle et al., 2010). The sampling equipment for each of the three gauging stations was identical, as were the auto- and manual field sampling protocols (See Table 1 for equipment specifications). Stage and discharge data were measured by instrumentation previously installed and maintained by Zone 7. Real-time stage data was not available to inform automatic sampling decisions.

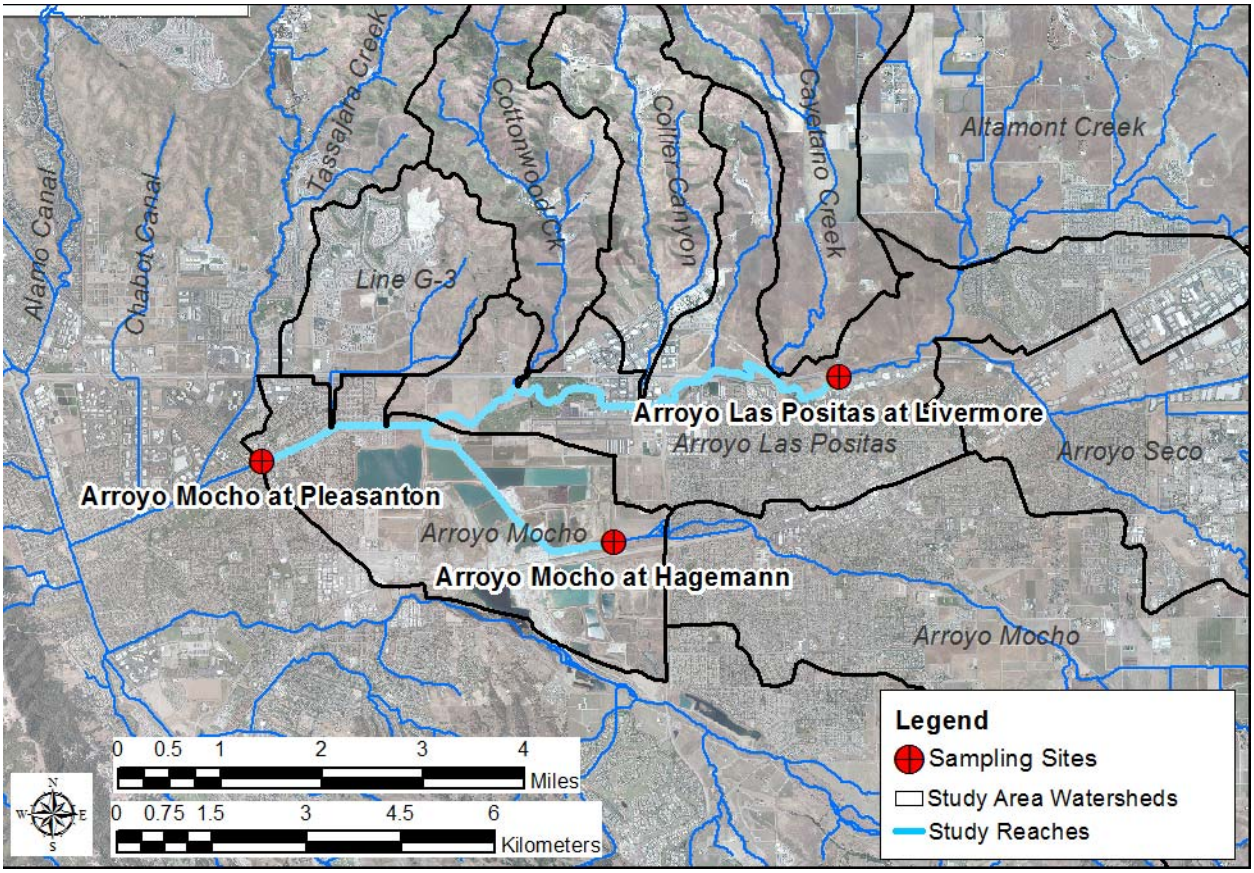


Figure 2: Study area within the Arroyo Mocho Watershed. Sampling locations are shown with dots, and the mainstem channel reaches downstream from these locations are shown in light blue.

2.3.1 Automated suspended sediment sampling

A CR850 Campbell Scientific Inc. data logger was installed to control the automatic collection of suspended sediment samples. The data logger received a real-time turbidity measurement every 15 minutes, and based on the program parameters, determined if an automatic suspended sediment sample should be collected. The data logger activated sampling by sending a signal to a pumping sampler, which in turn collected discrete samples of approximately 300 ml. The record of sample collection, turbidity, and temperature measurements were retained in the data logger's memory and periodically retrieved by a field crew using a flash drive. The data logger was accessed by the field crew via a built-in keyboard and display to update parameters. The data logger and pumping sampler were powered by a battery and solar panel.

At each sample location an FTS DTS-12 turbidity sensor was deployed to measure in-stream turbidity. This sensor uses a mechanical wiper to clean the optical surface thereby removing contamination that might otherwise cause erroneous measurements. These sensors have a nominal range of 0 to 1600 FNU. These sensors also measured water temperature when fully submerged (although they were optimally positioned in the channel for evaluation of suspended sediment concentrations and not permanently shaded for temperature measurements in relation to biological resources). These sensors use the SDI-12 communication protocol (digital) that eliminates external electronic noise and errors from cable length common to analog sensors. The sensors were mounted on a depth-proportional aluminum sampling boom inside of a protective housing. The pumping sampler intake opening was mounted near the sensor to facilitate the best possible comparison

between SSC and turbidity. Each boom was mounted near the thalweg and pivoted on anchors driven into the bed. A float on the downstream end of each boom provided the necessary buoyancy to maintain a constant 0.6 flow depth (Eads and Thomas, 1983). The design was effective for positioning the sensor correctly, shedding organic debris, and discouraging vandalism.

Suspended sediment samples were automatically collected under the control of the software called Turbidity Threshold Sampling (TTS) (Lewis, 1996) that was modified for use at the Zone 7 field sites. Under the control of the TTS software loaded in the CR850 data loggers, samples were collected over the range of rising and falling turbidities with the aim of sampling all significant turbidity peaks in relation to changes in discharge (Lewis and Eads, 2001). An ISCO 6712 automatic pumping sampler, fitted with 24 samples bottles, was used to collect one discrete sample for each turbidity threshold that was exceeded. The pumping sampler was programmed to purge the intake line before each sample, first with air, then with water.

Table 1. Summary of equipment used for suspended sediment and bedload sampling WY 2011.

Controlling system	Crane, Type A, Type A 4 Wheel Truck
	B-Reel, Sndg, B-56, Eng, .100
	Counterweight, Crane, Type A/E
Suspended sediment sampling	**Automated sampling**
	Knaack box (Jobmaster)
	Interstate Sealed Lead Acid Battery 12V, 33Ah, Flag Posts
	Solar panel 10W regulated, 20 ft cable
	FTS DTS-12 Turbidity Sensor
	Depth-proportional aluminum sampling boom
	Campbell Scientific CR850 Data Logger
	Campbell Scientific SC115 Flash Memory Drive, USB to RS-232 interface
	Teledyne ISCO 6712 compact sampler
	24-500 ml poly wedge shaped bottles
	Bulk 3/8" vinyl intake tubing, 100 ft rolls
	Extra 500 ml poly wedge sample bottles, set of 24
	Extra bottle carriers
	Manual sampling
	Sampler, Reel Type, US D-74
	Container, Sample, Glass, Qt. 12/pack
Bedload Sampling	**Manual sampling**
	Sampler, Suspended, BL-84 Stl
	200-micron mesh sample bag
	7"x12.5" Hubco Protexo bags

After each sample was collected, the ISCO sampler was programmed to purge any remaining water in the intake line with air. ISCO samplers use a sensor to detect the volume entering the sample bottle thereby eliminating volume discrepancies from fluctuating river stage. Under control of the software program, the ISCO samplers collected samples based on user-specified turbidity thresholds which were modified throughout the sampling season to ensure that an adequate number of suspended sediment concentration (SSC) samples were distributed over the range of site specific turbidities. After each flood event, and routinely during maintenance visits, the sample bottles were manually exchanged by the field crew. During large storm events, field crews carried out maintenance as necessary when each ISCO had collected near, or

in excess of, the 24 bottle capacity. In addition, during large events, when the turbidity sensor's range was exceeded the program collected samples at fixed-time intervals of 45 minutes initially and later decreased to 30 minute intervals, thus ensuring adequate data density to estimate annual loads for each site.

2.3.2 Manual suspended sediment sampling

Water samples for analysis of suspended sediment were also collected manually to determine the average instantaneous sediment concentration at a cross section using an isokentic sampler (water and sediment entering the sampler is proportional to the stream velocity and unbiased). A Federal Interagency Sediment Program (FISP) D74 sampler, weighing 64 lbs., was attached to a sounding reel and cable mounted to a 4-wheel boom track (crane). The sampler was manually deployed from the bridge at each sampling site during the high flow events. For each sample, the equal width increment (EWI) method was used to divide the cross-section into 10 equal widths to determine the cross-sectional variation (Edwards and Glysson, 1999). A single pass was made from one side of the channel to the other, with each vertical sample collected in a separate sample bottle, which were later composited. The sampling goal was to collect samples within each of three flow regimes; below "bankfull," above "bankfull," and above high "bankfull." These data were to be used to correct possible cross-sectional sampling bias in the automated point samples[a].

2.3.3 Suspended sediment load calculations

Relationships between continuous turbidity and flow and discrete grab samples analyzed for SSC form the basis for estimating a continuous time series of suspended sediment (SS) load. The use of a turbidity surrogate methodology (e.g. Lewis, 1996; Minella et al., 2008) to collect SSC samples across a wide range of turbidity conditions provides data to support loads calculations with high accuracy and precision. Suspended sediment grab samples and concurrent turbidity and discharge measurements were used to compute loads following the recently evolved USGS protocols for turbidity surrogate methodology as described in Rasmussen et al. (2009) for each study location. The protocol includes developing a simple linear regression model for SSC and turbidity pairs on untransformed or log-log transformed data, and in cases where a simple linear model does not meet a minimum standard (model standard percentage error (MSPE) < 20%), a multiple linear model including both turbidity and flow is evaluated.

Turbidity is an optical measurement and it is affected to some extent by the color, size, and shape of the sediment particles in the water column. Although turbidity dominated by fines and turbidity dominated by sands can both be well-related to SSC, those relations can vary by multiple factors from one another. If the sediment source changes over time, for instance from bed material to bank failure material, the resulting turbidity-SSC relation may exhibit increased scatter. Therefore, stratification of the data prior to regression may be warranted. Multiple stratification methods were explored for each dataset to identify reliable predictors of environmental processes leading to variable relations, including stratification by WY, season, rising versus falling stage, and varying temporal relationships between peak discharge and peak turbidity.

After selecting the best regression model for the calibration dataset (stratified when warranted) at each site, a continuous time series of SSC was calculated. When the turbidity was above the sensor's range, all SSC samples collected were analyzed and linear interpolation between these real measured samples was used to

[a] Note, the manual suspended sediment data collected across the cross section of each sampling location were too few in number to conclusively justify an adjustment of the automated samples taken in the thalweg. This was the case because the field teams primarily focused their manual sampling effort on bedload collection. After careful review of the samples that were collected, no adjustment was made. Nevertheless, bias corrections of this sort are common; the lack of sufficient data to make adjustments is an area of uncertainty that should be addressed if the field program is continued.

estimate SSC. Using the resulting continuous SSC time series, SS load was computed as the product of concentration and discharge measurements, and summed for each day, month, and for the monitored season as a whole.

2.4 Bedload

2.4.1 Equipment and sampling protocol

Similar to suspended sediment sampling, the goal of bedload sampling is to determine the average rate of bedload transport at a cross section at a time scale as close as practical to the variability of flux that occurred in response to the combination of changes supply and in the energy in the channel system represented by changes in flow. All bedload samples were collected manually during sampled storm events. A FISP BL84-Bedload sampler was used, which is a 32 lb-cable suspended sampler with a 3 inch x 3 inch opening (76.2 mm), with a 200-micron sample bag attached to the rear (down current) of the opening. The sampler was supported by a cable and b-reel connected to a 4-wheel truck and that was manually lowered and raised. When the sampler is submerged and sitting on the streambed, with the opening pointed into the flow, the water sediment mixture flows through the opening into the bag. The mesh openings in the bag allow water and fine sediment to flow through the bag while trapping the coarse sediment. Thus, the sampler design achieves a representation of bedload ranging between 0.2 mm and about 38 mm (50% of the opening). Given the grain size observed in the bed at each sampling site during reconnaissance and planning prior to the wet season, this specification was deemed appropriate.

The single equal width increment (SEWI) method was used to adequately sample the cross section at each site. The field team collected one sample per vertical for each of 8-10 evenly spaced verticals in the cross section of each sampling location depending on the active width of the channel. Each vertical sample was added to a single bag to make one composite sample. The amount of time the sampler is positioned on the streambed, and the sediment collected, when combined with discharge, determined the transport rate for that vertical. The time the sampler rested on the bed ranged from 5-180 seconds, and was the same for each vertical within a composite sample, but varied between composite samples depending on sediment transport characteristics. Unlike suspended sediment, two passes (back and forth once across the channel) were carried out per composite sample in order to account for the temporal and spatial variability of bedload. Each composite sample within the resulting pair was labeled discretely with a single sample number and the letter “a” or “b” indicating they were separate but collected sequentially only minutes apart.

2.4.2 Bedload calculations

Following USGS protocol for relating discharge to bedload, a sediment rating curve was developed using the measured samples, in the form of a power equation: $Q_s = aQ^b$, where Q_s is the bedload discharge per day. The measured sediment samples were converted from kg/min to sediment load in units of metric tons per day, integrating active width of the channel with bed movement and size of sampler opening, in this case, 0.25 ft (Dunne and Leopold, 1978; Edwards and Glysson, 1999).

*Bedload Discharge (metric tons/day) = [average active bed width (ft) * sample dry weight (gm) * 86,400[b] (sec)]/ [sampler width (ft) * sampling time (sec) *1, 000,000[c] (gm)] (Edwards and Glysson, 1999).*

The discharge (cfs) was plotted against bedload in metric tons/day and a power model was used to create a relationship for each sampling location. The equation describing this relation was used to estimate bedload at

[b] Seconds per day
[c] Grams per metric ton

the same interval as discharge measurement, from which a seasonal total was calculated. The threshold of bedload initiation was determined based on observations of no, and low, bedload movement.

2.5 Other sources of data

Zone 7 provided 15-minute discharge data from pressure transducers or bubblers deployed at the three sampling locations. SFEI staff made cross-sectional pebble counts at each site using the Wolman method (Wolman, 1954; see Appendix D for pebble count data).

2.6 Quality assurance

SFEI staff used standard Quality Assurance (QA) procedures during data collection, including verifying labels on samples and data sheets in the field and in the office after each storm. All sampling was done from a bridge, which avoids hydraulic interference by the field staff when wading. Data verification is the process by which the completeness of the records are checked and documented, and any obvious instrumentation problems are identified and corrected. This typically involves plotting the data to visually note if the data appears reasonable and whether the continuous records (stage/discharge and turbidity) corroborate one another (e.g. does turbidity rise and fall in relation to stage?). As continuous data was downloaded by either SFEI or Zone 7 staff and then sent to SFEI, the continuous datasets were verified throughout the season and in a final step at the end of the season.

Quality of the continuous datasets were further validated and corrected as necessary. Flow data collection and QA of data was provided by Zone 7, and assessed by SFEI based on the relationship between it and monthly rainfall collected at the Livermore Airport. A comparison of total flow volume between the three Zone 7 gages and the USGS operated Arroyo De La Laguna at Verona gage also served to quality assure the flow data from Zone 7. No flow data were corrected by SFEI, however, flow at AMH was rejected for WY 2011 (a decision detailed in the Results section for the AMH).

Turbidity is both important and challenging to QA due to the potentially real rapid changes in turbidity during a storm, the potential variability of turbidity in the cross section of the creek, frequent opportunities for debris to accumulate near the sensor, the potential for fouling, and the potential for the sensor to read the bottom of the creek bed during low flows. With these challenges in mind, we closely assessed the continuous turbidity record by plotting with continuous discharge and reviewing all low flow and storm flow periods. Periods in which the sensor recorded at its maximum were flagged. Using best professional judgement, data was de-spiked using interpolation (only gaps with short time intervals were filled by interpolation). Periods of fouling in which debris likely built up on the sampling boom were also interpolated. After all data corrections have been made, the data were re-plotted with discharge to verify that data look reasonable and no errors were made during the correction process.

The use of the turbidity surrogate method for suspended sediment provides a very high quality check on field measurements of suspended sediment. Samples that do not conform with our conceptual model of systematic progressive change in concentration in response to changes in sources and transport energy are easily identified and flagged for scrutiny.

3.0 Results

3.1 Period of record, rainfall and recurrence intervals

The targeted period for automated monitoring and manual sampling during each WY was October 1 through May 31. The actual period of record each year was influenced by runoff conditions in the creeks; the instrumentation was more exposed to potential vandalism if left in a dry creek bed and therefore installation was withheld each year until significant flows initiated and removed towards the end of the season as the creeks went dry. The actual period of record for the continuous data at each site during each WY is provided in Table 2. These periods represent the periods for which loads of suspended sediment and bedload were calculated, as well as the total discharges reported.

Rainfall during the study period ranged from 49% to 117% of mean annual for the Livermore Airport (Table 3), and included a record-low 3-year cumulative total rainfall (WYs 2012-2014). A total of 10 storm events were manually sampled during the 5-year study period, including most of the largest storm events and peaks (Figure 3). All other storm events were sampled for turbidity only. Based on approximately a 30-year partial duration series record of discharges >400 cfs at AMP, the four largest sampled storm events (one at the end of WY 2011, two in the early part of WY 2013, and one in the early part of WY 2015) had estimated return intervals between 2 and 4 years.

Table 2. Period of record for the continuous datasets collected at each site during each WY.

Water Year	Period of Record		
	ALPL	AMH	AMP
WY 2011	12/8/2010 - 3/27/2011	12/8/2010 - 3/31/2011	12/8/2010 - 3/31/2011
WY 2012	11/1/2011 - 4/30/2012	11/1/2011 - 4/30/2012	11/1/2011 - 4/30/2012
WY 2013	10/30/2012 - 5/13/2013	10/30/2012 - 5/10/2013	10/30/2012 - 5/10/2013
WY 2014	12/2/2013 - 6/10/2014	11/26/2013 - 6/10/2014	11/27/2013 - 6/11/2014
WY 2015	10/22/2014 - 5/12/2015	10/21/2014 - 5/14/2015	10/21/2014 - 5/7/2015

Table 3a. Rainfall at Livermore Airport and total discharge at each of the monitoring locations for each WY.

Water Year	Total Rainfall (in) (% mean annual)	Rainfall During Monitored Period (in)	Total Discharge (Acre-feet)		
			ALPL	AMH	AMP
WY 2011	16.2 (117%)	11.4	2,672	-	8,899
WY 2012	8.8 (63%)	7.6	1,920	585	5,864
WY 2013	10.7 (77%)	10.1	2,715	1,760	8,715
WY 2014	6.8 (49%)	5.3	1,448	200	2,158
WY 2015	13.1 (94%)	12.5	3,238	965	6,617

Table 3b. Instantaneous peak flow discharge at each of the monitoring locations for each WY.

	ALPL			AMH			AMP		
	DateTime	Peak Discharge (CFS)	Peak Stage (ft)	DateTime	Peak Discharge (CFS)	Peak Stage (ft)	DateTime	Peak Discharge (CFS)	Peak Stage (ft)
WY 2011	12/19/2010 8:15	376	4.1	-	-	-	3/24/2011 22:30	1,358	8.6
WY 2012	1/21/2012 1:20	204	3.4	1/21/2012 0:30	416	4.5	1/21/2012 2:40	481	6.5
WY 2013	12/2/2012 10:15	661	4.2	12/24/2012 0:15	1,730	6.8	12/2/2012 11:15	1,240	7.8
WY 2014	2/28/2014 6:15	429	3.6	2/28/2014 4:45	227	4.1	2/28/2014 8:15	463	6.2
WY 2015	12/12/2014 1:00	863	4.7	12/12/2014 0:30	557	4.8	12/12/2014 2:00	1,382	8.5

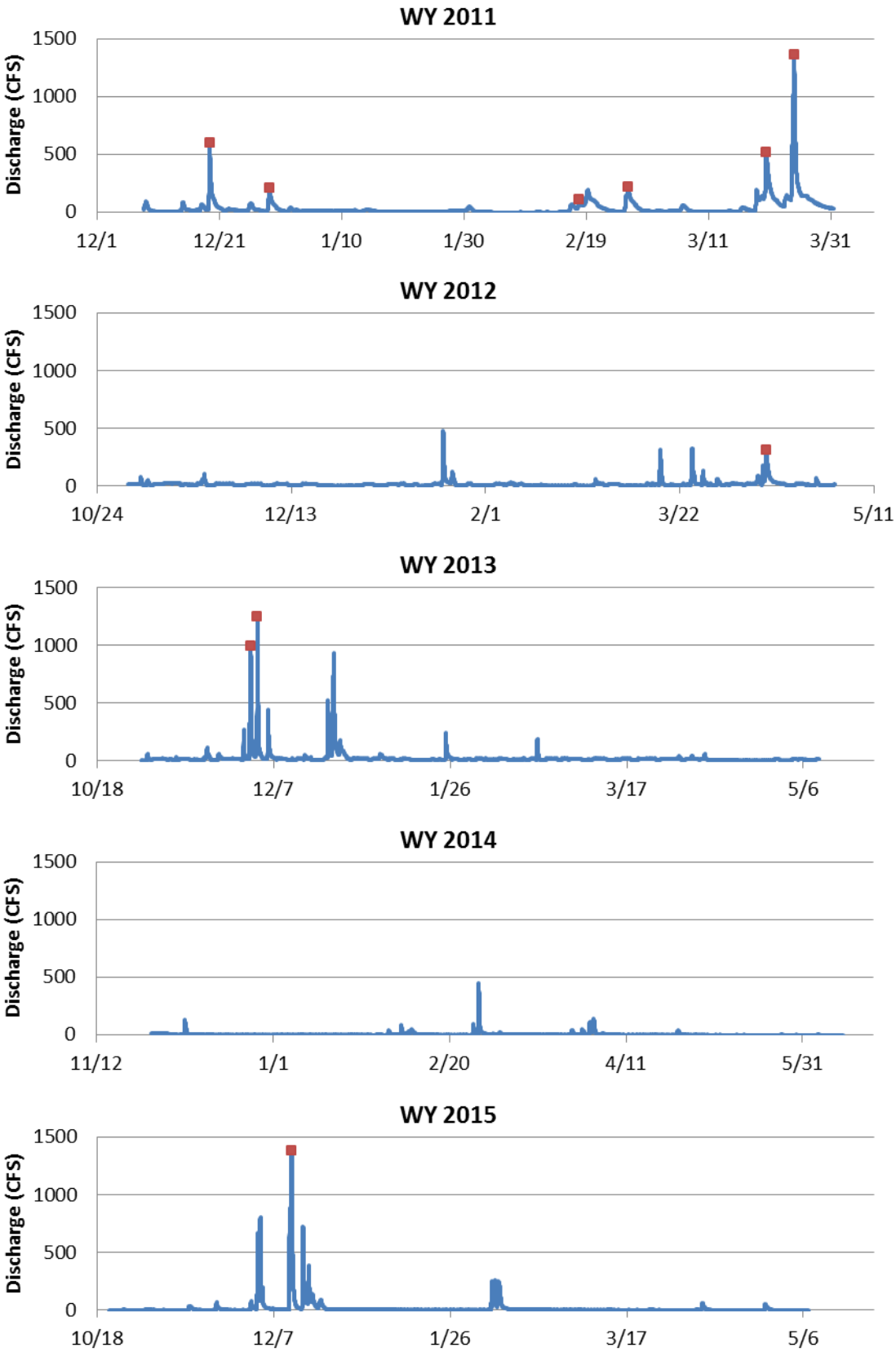


Figure 3. Discharge records for each WY at Arroyo Mocho at Pleasanton (AMP). Storms sampled manually (at all sites, AMP flow shown here just as an example) are indicated as red dots on the peak of each event. All y-axes held constant for comparison between WYs.

3.2 Results for water years 2011-2015

During the study period, turbidity was measured at 15 minute increments during WYs 2011, 2013 and 2014, at 10 minute increments during WY 2012, and at 5 minute increments during WY 2015. Discharge measurements were also made at 15 minute intervals by Zone 7. Throughout the study period, several thousand suspended sediment samples were collected automatically using the turbidity threshold sampling program and 422 of these were selected to be analyzed at the laboratory. At each location, SSC samples for analysis were selected to represent and characterize the range of discharges and turbidities in order to form a strong calibration dataset for estimating continuous SSC. The broadest range of turbidity and flow occurred during the small window of time each season when storm-associated runoff drives sediment transport, thus the samples well-represent the top 10% of flows and turbidities during the sampling period (Figure 4). Ten storms were manually sampled for bedload, during which a total of 127 bedload samples over the range of discharges were collected. Of these sampling efforts, 103 samples occurred when flow was beyond the threshold for bedload transport and therefore a sample was actually captured and sent to the lab. Conversely, twenty four bedload sampling attempts were made when no bedload was captured.

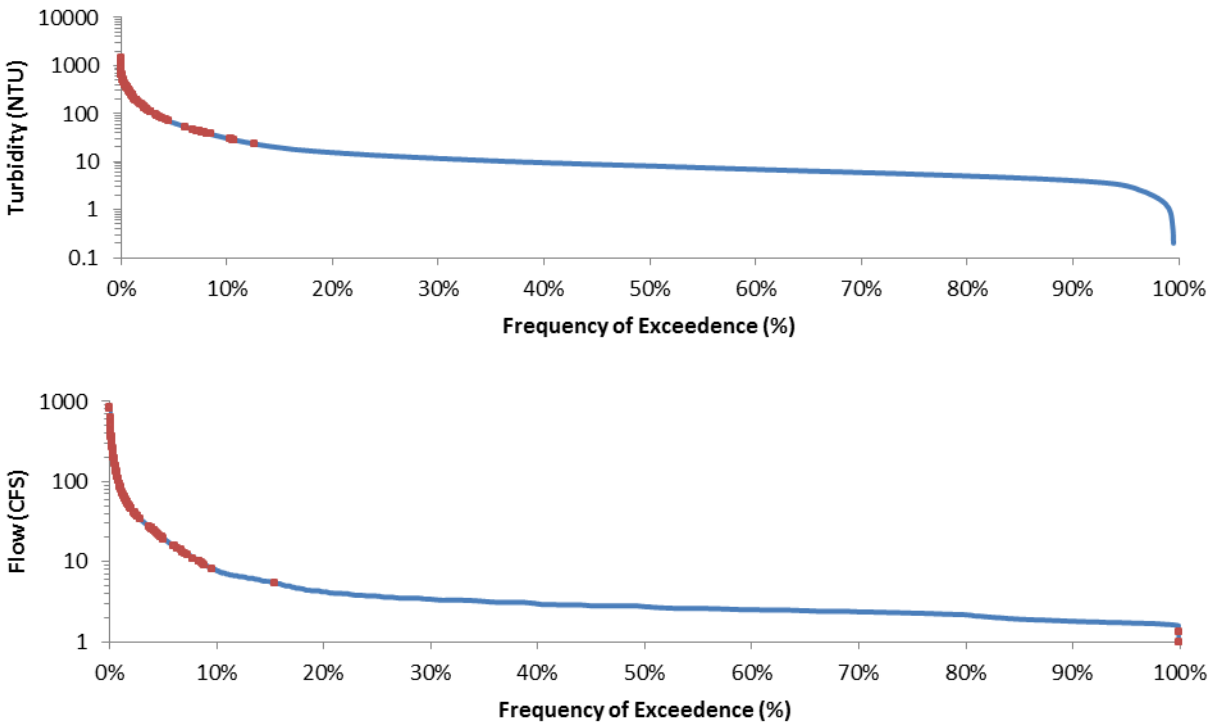


Figure 4. Duration curves for turbidity and flow at ALPL, with SSC sample points noted as red dots.

3.2.1 Results of Arroyo Las Positas at Livermore (ALPL)

Total discharge for the study period each WY at ALPL ranged between 1,448 and 3,238 acre-feet (Table 3). The largest flow event at this site over the 5 years occurred on 12/12/2014, with discharge peaking above 850 cfs, corresponding to approximately a 5-year event at ALPL (a 3-4 year event at the downstream AMP gage). The SSC calibration dataset for regression model development to estimate continuous suspended sediment loads comprised a total of 130 samples measuring between 21 and 1,974 mg/L. These samples were collected across a range of flows (between 1 and 836 cfs) and turbidities (between 23 and 1,418 NTU). Forty SSC samples were analyzed for sand fraction for an average of 6.6% sand, and with a range of 0.9% to 16.5% sand. The complete model calibration dataset is provided in Appendix B, Table B1.

The initial plot of SSC versus turbidity data pairs indicated correlation between the two, but that stratification should be investigated. The data pairs generally indicated a 2:1 slope between SSC and turbidity, but some of the data across multiple water years had a slope closer to 1:1. The temporal relationship between the turbidity and hydrograph peaks distinguished these two groupings. Typically, turbidity at ALPL peaked very near the hydrograph peak. When SSC was sampled during this typical scenario, the relationship between SSC and turbidity was approximately 2:1 (represented by blue squares in Figure 5). Occasionally turbidity had a second peak on the recession limb of the hydrograph (see example in Figure 6), when the relationship of SSC to turbidity was closer to 1:1 (represented by red squares in Figure 5). Based on this temporal relationship of turbidity to hydrograph peak, the calibration dataset was stratified and two models were developed and applied to the continuous time series (see Appendix A for model summaries).

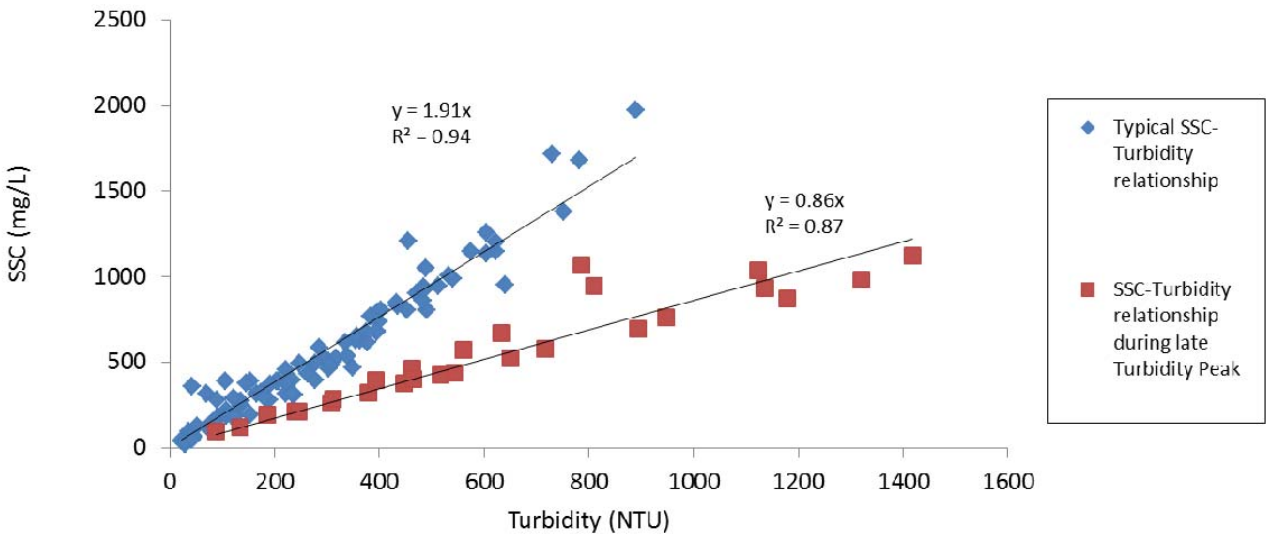


Figure 5. Initial SSC versus turbidity plot using the ALPL calibration dataset. The two distinct categories are shown as different colored markers.

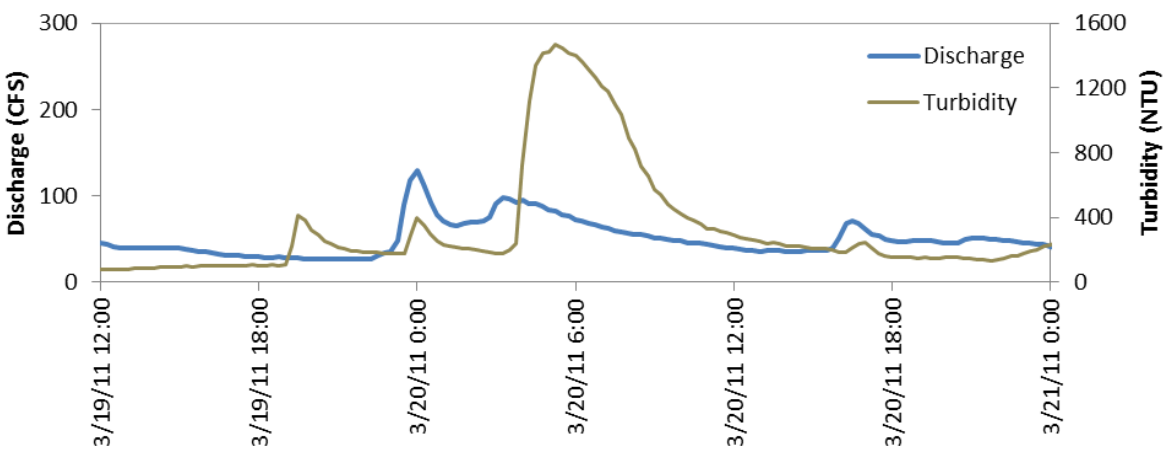


Figure 6. Hydrograph plot with turbidity peak on recession limb to illustrate identification of time periods when application of secondary model was indicated.

Throughout the period of study, a total of 52 bedload samples were collected at ALPL, 45 of which were above the threshold for bedload movement. The average D_{50} of the ALPL bedload samples was 6.4 mm (pebble). ALPL samples contained on average 38% sand mass and up to a maximum of 92%; the proportion

of sand correlated inversely with discharge. A power model using discharge and the bedload sample results ($y = 1.26E\text{-}04x^{2.27}$, $R^2=0.73$) was used to estimate seasonal load (Appendix A Figure A1d). Using the graphical relation and observations of no bedload movement, initial bedload movement for this reach was attributed to be 60 cfs. In total each WY, bedload was estimated to be between 9 and 216 metric tons, representing between 4 and 15% of the total sediment load past this monitoring location. Of the total sediment load passing through ALPL, approximately 83% is silt, 11% is sand and 5% is gravel (Figure 7). Monthly loads and discharges from ALPL are provided in Table 4.

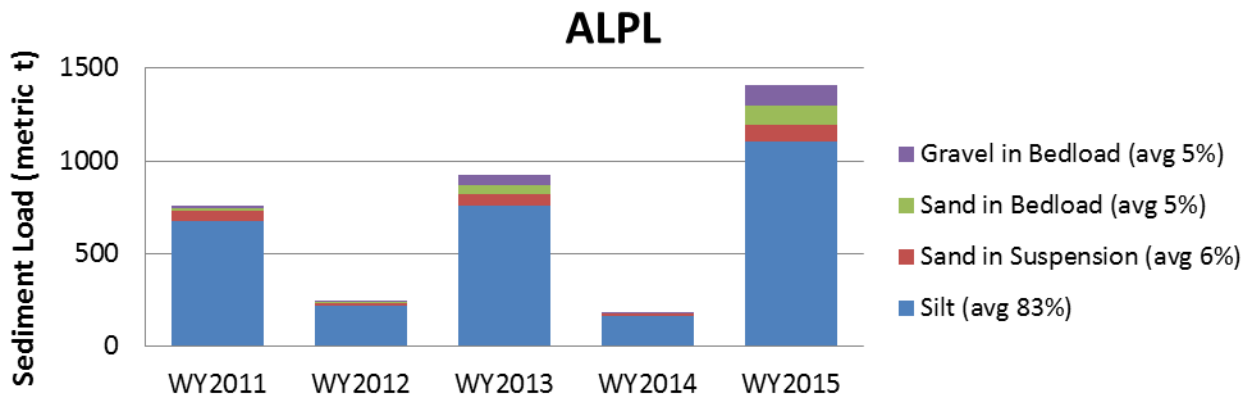


Figure 7. Grain size of total sediment load passing through ALPL during each year monitored. Load unit is metric tons.

3.2.2 Results of Arroyo Mocho at Hagemann (AMH)

Total flow volume through Arroyo Mocho at Hagemann was lowest in WY 2014 (200 acre feet) and greatest in WY 2013 (1,552 acre feet). Discharge records for WY 2011 at this site were poor overall and deemed unusable. This conclusion was based on the unreasonable relationship between rainfall and runoff relative to the other WYs and the illogical relationships between flow at the AMH gage and at the ALPL and AMP gages[d]. Consequently, loads of sediment could not be determined for this WY. During the four WYs for which loads were estimated, turbidity exceeded the sensor maximum during only one event on December 23rd and 24th, 2012 (Appendix Figure A2a). During the measurement period, a total of 145 SSC samples were analyzed, which formed the basis for turbidity surrogate regression analysis and computation of suspended sediment loads. A total of 61 SSC samples were analyzed for sand fraction for an average of 7.2% sand and a range of 0%-34.5%.

[d] The entire discharge record at AMH for WY 2011 was rejected. Several discharge peaks were missing in the AMH data that year due to the malfunction of the pressure transducer during the last two weeks of March. This was further evidenced by the peaks logged by the AMH pressure transducer during the March storm series which were reported as two orders of magnitude above the gage at AMP. In order to verify that the AMH discharge data was flawed, we compared monthly rainfall records for WY2011 measured at the Livermore Airport, with runoff coefficients calculated from drainage area and monthly discharge totals at each of the three sites. Sites ALPL and AMP were calculated to have a monthly runoff coefficient which ranges between 6% and 16%, whereas AMH showed a much wider variation (1%-30%) which is inconsistent with the watershed characteristics. We also calculated a simple water budget, basing this on assumptions that the combined flow of AMH and ALPL (taking into account routing times) can never be more than the flow at AMP during storms, as this site also has inputs from the northern tributaries. We assumed a 4 hour lag between ALPL and AMP, which is representative of most storms during the water year. Over 30% of 15 minute periods in the wet season did not agree with the water balance, which we interpreted to indicate that AMH discharges were too high. These inaccuracies occurred all season, and were not only present during the March storm series and therefore the entire discharge record for AMH was rejected as erroneous.

Table 4. Monthly discharge, suspended sediment and bedload loads (metric t) at Arroyo Las Positas at Livermore (ALPL).

	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Wet season total
WY2011	Discharge (acre-ft)	NA	NA	776	358	632	906	NA	NA	NA	2672
	Suspended Sediment (t)	NA	NA	229	8	83	411	NA	NA	NA	732
	Bedload (t)	NA	NA	13	0	2	14	NA	NA	NA	29
	Total Sediment (t)	NA	NA	242	8	85	425	NA	NA	NA	760
WY2012	Discharge (acre-ft)	NA	347	168	331	189	432	453	NA	NA	1920
	Suspended Sediment (t)	NA	15	0	77	3	87	54	NA	NA	236
	Bedload (t)	NA	0	0	3	0	5	2	NA	NA	10
	Total Sediment (t)	NA	15	0	80	3	93	56	NA	NA	247
WY2013	Discharge (acre-ft)	6	573	1109	342	227	194	200	63	NA	2715
	Suspended Sediment (t)	0	239	493	51	20	3	12	1	NA	820
	Bedload (t)	0	46	53	2	0	0	0	0	NA	102
	Total Sediment (t)	0	286	546	52	21	3	12	NA	NA	921
WY2014	Discharge (acre-ft)	NA	NA	232	155	409	263	230	120	38	1448
	Suspended Sediment (t)	NA	NA	14	1	131	20	11	1	0	177
	Bedload (t)	NA	NA	0	0	8	0	0	0	0	9
	Total Sediment (t)	NA	NA	14	1	139	21	11	1	0	186
WY2015	Discharge (acre-ft)	37	197	2144	168	334	150	169	41	NA	3238
	Suspended Sediment (t)	3	38	1081	0	59	1	10	0	NA	1192
	Bedload (t)	0	0	235	0	2	0	0	0	NA	237
	Total Sediment (t)	3	39	1316	0	61	1	10	0	NA	1429

The relationship between SSC and turbidity varied inter-annually. Therefore, a unique regression model was developed and applied to each WY. Water Year 2012 was best represented by a multiple linear regression model on untransformed data using turbidity and discharge to predict SSC (see Appendix A for model summaries). WYs 2013 through 2015 were best represented by a simple linear regression on untransformed data using turbidity only as a surrogate predictor of SSC. While most WYs utilized only data collected during that WY to develop the regressions, because no samples were collected in WY 2014, a model using input data from all other WYs was applied. The total estimated suspended sediment load for each WY ranged two orders of magnitude, between 16 and 1,552 metric tons (Table 5). The complete model calibration dataset is provided in Appendix B.

During seven storms, a total of 24 bedload samples were collected, half of which were collected during WY 2011 when the discharge record was rejected and therefore could not be used to develop a relationship between discharge and bedload. In WY 2013, 12 more bedload samples were collected during two large storm events at the end of November and early December, all of which were sampled while bedload was undergoing active transport (Appendix A Figure A2f; Appendix C Table C3). The average D_{50} of the AMH bedload samples was 7.5 mm (pebble), with a maximum of 25.9 mm, which is the largest D50 sampled from the three locations. This was similar to the results from the pebble count taken at this site, which resulted in a 16mm D_{50} on the bed surface. In total each WY, bedload was estimated to be between 0.12 and 143 metric tons (Table 5), representing between 1 and 9% of the total sediment load past this monitoring location. Of the total sediment load passing through AMH, approximately 83% is silt, 10% is sand and 6% is gravel (Figure 8).

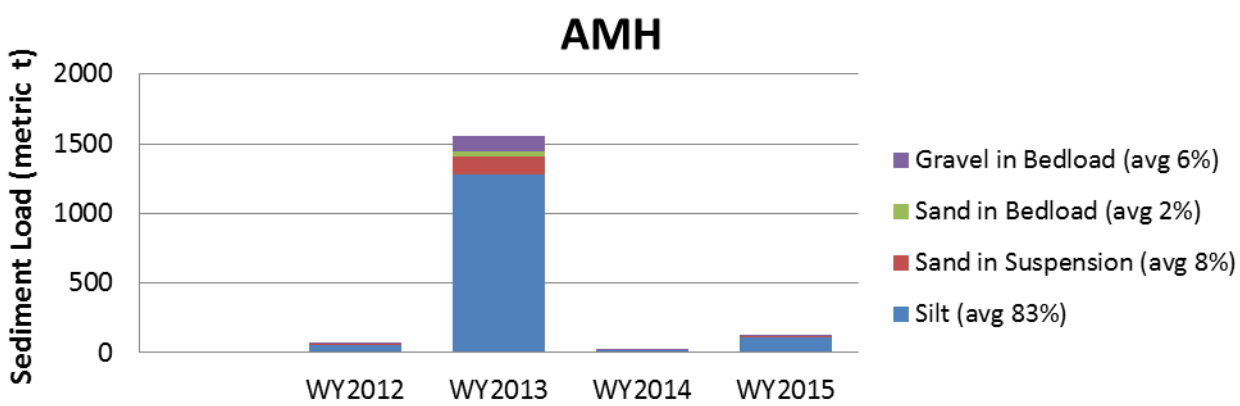


Figure 8. Grain size of total sediment load passing through AMH during each year monitored.

Table 5. Monthly discharge, suspended sediment and bedload loads (metric t) at Arroyo Mocho at Hagemann (AMH).

	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Wet season total
WY2012	Discharge (acre-ft)	NA	17.0	0.0	77.8	0.3	239.6	250.6	NA	NA	585
	Suspended Sediment (t)	NA	0.6	0.0	20.3	0.0	23.1	19.1	NA	NA	63
	Bedload (t)	NA	0.0	0.0	0.6	0.0	0.3	0.1	NA	NA	1
	Total Sediment (t)	NA	0.6	0.0	20.9	0.0	23.5	19.2	NA	NA	64
WY2013	Discharge (acre-ft)	1.4	210.9	1272.8	53.5	31.1	43.1	128.7	18.8	NA	1760
	Suspended Sediment (t)	0.0	20.3	1384.3	2.3	1.5	0.1	0.8	0.1	NA	1409
	Bedload (t)	0.0	1.6	141.5	0.0	0.0	0.0	0.0	0.0	NA	143
	Total Sediment (t)	0.0	21.9	1525.8	2.3	1.5	0.1	0.8	0.1	NA	1553
WY2014	Discharge (acre-ft)	NA	22.0	64.7	1.8	79.4	17.6	14.8	0.0	0.0	200
	Suspended Sediment (t)	NA	0.0	1.8	0.0	10.7	2.0	1.1	0.0	0.0	16
	Bedload (t)	NA	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0
	Total Sediment (t)	NA	0.0	1.8	0.0	10.8	2.0	1.1	0.0	0.0	16
WY2015	Discharge (acre-ft)	0.0	9.3	915.0	0.0	40.3	0.0	0.0	0.0	NA	965
	Suspended Sediment (t)	0.0	1.2	117.6	0.0	2.9	0.0	0.0	0.0	NA	122
	Bedload (t)	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	NA	5
	Total Sediment (t)	0.0	1.2	122.2	0.0	2.9	0.0	0.0	0.0	NA	126

3.2.3 Results of Arroyo Mocho at Pleasanton (AMP)

Total discharge over the period of the study at AMP ranged from 2,158 acre feet (WY 2014) to 8,899 acre feet (WY 2011). The December 11-12, 2014 storm event resulted in the peak discharge for the 5-year study period at 1,382 cfs (Table 6). A total of 147 suspended sediment concentration samples collected during the measurement period were analyzed to create a calibration dataset for regression model development. These samples were distributed throughout storm flows and across the turbidity range. During the two largest storms in WY 2011, turbidity exceeded the sensor range and SSC had to be interpolated linearly using real measured datapoints; SSC samples from these storm events were disproportionately selected for analysis in order to serve this purpose and derive a continuous SSC record through this period with high confidence. A total of 56 SSC samples were analyzed for sand fraction for an average of 8.8% sand and a range of 0%-45.4% sand.

Similar to AMH, the relationship between SSC and turbidity varied between WYs and so an annual regression model was developed and applied to each WY (see Appendix A for model summaries). Water Years 2011, 2012 and 2015 were best represented by a power model for a simple linear regression between SSC and turbidity. The power model for WY 2013 was improved by using discharge in addition to turbidity. For WY 2014, no SSC samples were analyzed and therefore a WY-specific model could not be developed. Instead, a power model using both turbidity and discharge as explanatory variables was selected. The total estimated suspended sediment load for each WY ranged between 533 and 5,755 metric tons (Table 6). The complete model calibration dataset is provided in Appendix B Table B3.

Bedload sampling was attempted during 12 storm events, during which 51 samples were collected, 41 of which were taken at a discharge greater than the initiation energy for bedload transport at this gage site (Appendix C Table C3). Bedload samples for AMP had finer grain sizes than the other two locations; the D_{50} at AMP averaged 3.1 mm (granule). A power equation estimating bedload discharge rate on the basis of streamflow discharge rate ($y = 1.20E\text{-}03x^{1.66}$) with an $R^2 = 0.42$ (poor compared to the other two sites) was derived from the data (Appendix A Figure A3g). Based on visual inspection of the discharge versus bedload rate plot, the threshold for bedload movement was set at 90 cfs. Seasonal estimates of bedload discharge at AMP ranged between 7 and 201 metric tons, comprising between 1 and 5% of the total sediment load past the AMP gage location. Of the total sediment load passing through AMP, approximately 90% is silt, 9% is sand and 2% is gravel (Figure 9).

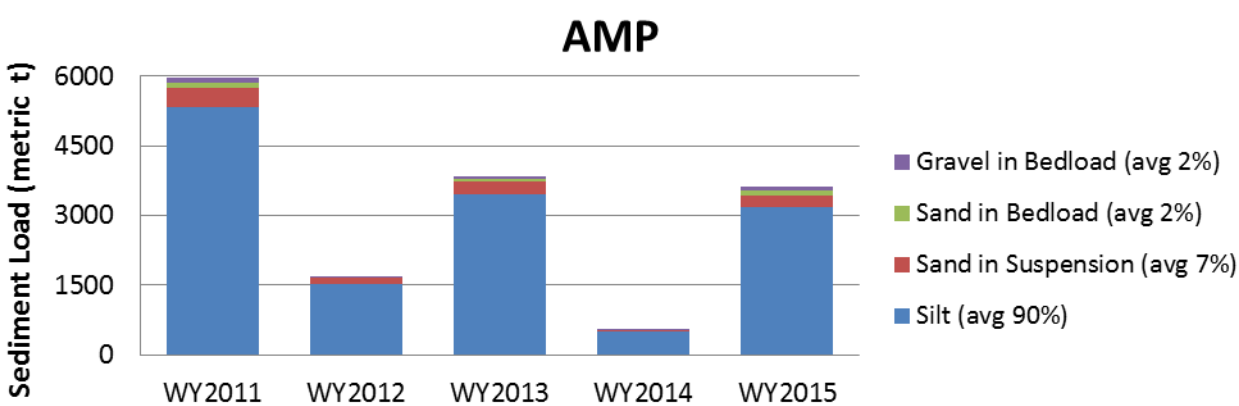


Figure 9. Grain size of total sediment load passing through AMP during each year monitored.

Table 6. Monthly discharge, suspended sediment and bedload loads (metric t) at Arroyo Mocho at Pleasanton (AMP).

	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Wet season total
WY2011	Discharge (acre-ft)	NA	NA	1788	833	1595	4684	NA	NA	NA	8899
	Suspended Sediment (t)	NA	NA	467	50	417	4820	NA	NA	NA	5755
	Bedload (t)	NA	NA	72	0	13	116	NA	NA	NA	201
	Total Sediment (t)	NA	NA	540	50	430	4936	NA	NA	NA	5956
WY2012	Discharge (acre-ft)	NA	968	602	1108	468	1236	1482	NA	NA	5864
	Suspended Sediment (t)	NA	128	65	465	46	560	387	NA	NA	1650
	Bedload (t)	NA	0	0	9	0	9	9	NA	NA	28
	Total Sediment (t)	NA	128	65	473	46	569	396	NA	NA	1678
WY2013	Discharge (acre-ft)	5	1832	3729	897	787	833	429	203	NA	8715
	Suspended Sediment (t)	0	1022	2578	64	39	20	11	1	NA	3736
	Bedload (t)	0	34	83	2	1	0	0	0	NA	120
	Total Sediment (t)	0	1056	2662	65	40	20	11	1	NA	3856
WY2014	Discharge (acre-ft)	NA	114	320	151	704	391	357	92	29	2158
	Suspended Sediment (t)	NA	11	56	7	353	54	49	2	1	533
	Bedload (t)	NA	0	1	0	6	0	1	0	0	7
	Total Sediment (t)	NA	11	57	7	359	55	49	2	1	541
WY2015	Discharge (acre-ft)	31	283	4823	157	937	138	234	16	NA	6617
	Suspended Sediment (t)	1	25	3065	4	330	3	14	0	NA	3443
	Bedload (t)	0	0	168	0	11	0	0	0	NA	179
	Total Sediment (t)	1	25	3233	4	341	3	14	0	NA	3622

4.0 Discussion

4.1 Dry climatic conditions during study period

The climatic conditions during which a study is conducted can have a large impact on the sediment loads observed. Ideally, sediment transport should be studied in a system for many years, including average wet years as well as rare large events and dry periods. Typically, monitoring programs span a shorter time period with the objective of sampling a sufficiently broad spectrum of variability to make inferences from a smaller dataset. Conceptually, watersheds like the ones studied, that have very high inter annual rainfall variability, that are more pervious, and larger in area have large inter-annual variability in sediment production. Larger storm events on the order of a 10-year return or greater, occur infrequently and yet these types of events usually transport most of the sediment load over the long term.

Unfortunately, during the five year study, the winter seasons were mostly very dry relative to average annual conditions with all observations made during years of between 49-117% mean annual precipitation and the largest flows at AMP having a return interval of approximately 3.5 years (March 24, 2011 and December 11-12, 2014)[e]. Loads of sediment for the period were disproportionately transported during these largest events of the study period; for example, AMP passed 56% of the entire suspended load for WY 2011 during just the two days of March 24th and 25th, and similarly ALPL passed 54% of its WY 2015 suspended sediment load during the two days of December 11th and 12th, 2014. However, despite these moderate-sized individual storm events, the overall drought conditions persisting during the study and leading to benign flow production, sediment erosion, and transport conditions overall likely resulted in loads that are biased low relative to loads during more average climatic periods. With that said, our estimates reflect the best interpretations of the data collected during a dry period.

4.2 Field observations and sediment load record by site

Arroyo Las Positas at Livermore (ALPL) drains 49 square miles of lower elevation rolling hills. The geology of this watershed includes relatively low producing surficial deposits of the Holocene and Pliocene (Figure 10). Throughout the study period, ALPL had a consistent supply of sand migrating through the reach; during typical high flow conditions, this site had high sand content and low turbidity. Occasionally, a different process occurred in which a second turbidity peak occurred on the recession limb of the hydrograph, and during these conditions, turbidity was very high relative to sand and SSC. These conditions may have been explained by silt-dominated bank failures.

Arroyo Mocho at Hagemann (AMH) drains Arroyo Mocho's upper watershed, which is composed of metamorphosed mudstones, Franciscan melange, and serpentinite. These geologic units likely produce coarser and higher loads of sediment perhaps of similar magnitude to the northern tributaries which contribute sediment from underlying Miocene sandstone geology. Indeed, AMH has the coarsest bed. AMH is an intermittent reach, with a weir showing signs of upstream aggradation and slight incision at the bridge footers. Although we hypothesize that AMH may pass coarser and greater sediment loads than ALPL during wet years, this was not the case during the dry period monitored. In fact, during the driest year, WY 2014, AMH passed a total of only 16 metric tons of sediment downstream.

Arroyo Mocho at Pleasanton (AMP) is a trapezoidal flood control channel with an inner depositional bench. This gage had the most unpredictable sediment-discharge relationships of the three locations, likely the results of being located downstream from both ALPL and AMH, as well as other relatively

[e] These return intervals are based on approximately a 30-year partial duration series record of discharges >400 cfs at AMP.

near field contributions from the tributaries that flow in from the ridge to the north of the Zone 7 Flood Control Channel (including Line G3, Cottonwood Creek, Collier Creek, and Cayetano Creek). The sediment rating was more challenging to interpret than the other two sites and exemplifies the complex nature of sediment transport. Nevertheless, given that both bedload and SSC samples were collected over a broad range of flows and turbidity, well-characterizing the highest 10% of discharges and turbidities, we have relatively high confidence in the loads estimated for the study period.

Total sediment loads from ALPL and AMH combined comprised between 19 and 64% of the sediment load passing through AMP (excluding WY 2011, not reported because no loading estimate could be calculated for WY 2011). AMH comprised only 3-4% during WYs 2012, 2014 and 2015, but 40% during WY 2013 when this location also reached its greatest peak discharge of the monitoring period (1730 cfs). Similarly, ALPL's greatest contribution was in WY 2015 when it comprised 39% of the total load at AMP, a year in which it also had its greatest peak discharge of the study (1382 cfs). The varying degree of contribution to the AMP sediment load from AMH versus ALPL likely was caused by geographic-specific rainfall, where the AMH watershed received disproportionately more rainfall in the November-December 2012 storms, and the ALPL watershed received disproportionately more rainfall during the December 11-12, 2014 storm. Overall, total sediment loads at each location correlated relatively well with total discharge (Figure 11).

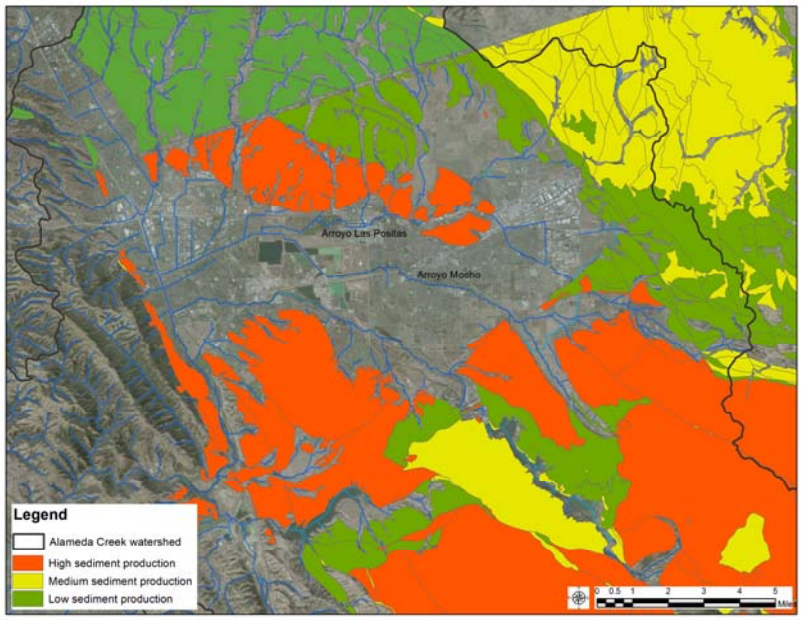


Figure 10. Regional map of sediment producing geology (Adapted from Helley and Graymer, 1997). This map shows Livermore Valley with bedrock geology rated to estimate potential of sediment production (red is high sediment production, green is low sediment production).

Table 7. Summary of discharge and sediment loads measured at each location during the study period.

	ALPL				AMH				AMP			
	Discharge (acre-feet)	Suspended load (tons)	Bedload (tons)	Total Sediment Load (tons)	Discharge (acre-feet)	Suspended load (tons)	Bedload (tons)	Total Sediment Load (tons)	Discharge (acre-feet)	Suspended load (tons)	Bedload (tons)	Total Sediment Load (tons)
WY 2011	2,672	732	29	760	-	-	-	-	8,899	5,755	201	5,956
WY 2012	1,920	236	10	247	585	63.1	1.1	64	5,864	1,650	28	1,678
WY 2013	2,715	820	102	922	1,760	1,409	143	1,552	8,715	3,736	120	3,856
WY 2014	1,448	177	9.0	186	200	15.6	0.12	16	2,158	533	7.3	541
WY 2015	3,238	1,192	237	1,429	965	122	4.6	126	6,617	3,443	179	3,622

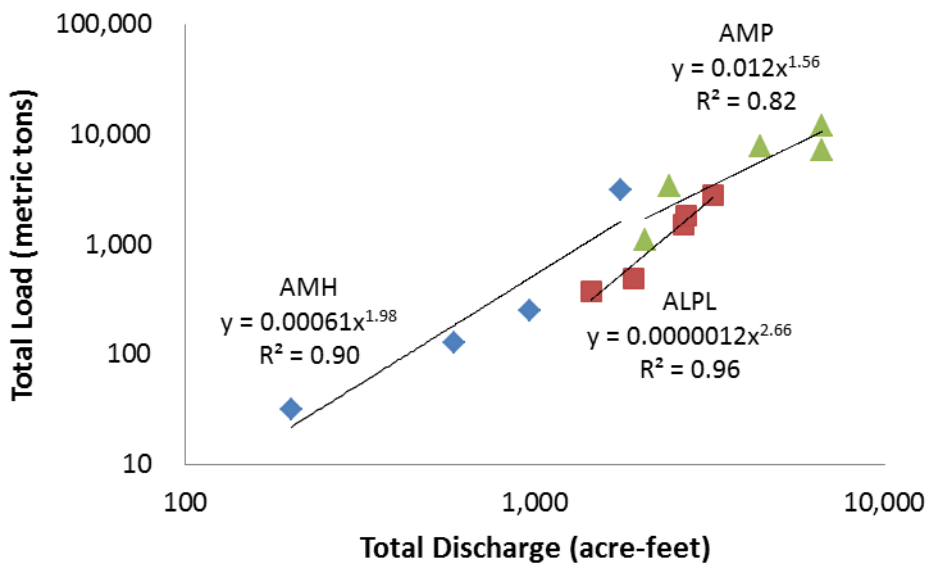


Figure 11. Plot of total seasonal sediment load as a function of total seasonal discharge at each of the three monitoring locations.

5.0 References

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.

Dunne, T. and Luna Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

Eads, R. E., Thomas, R.B., 1983. Evaluation a depth proportional intake device for automatic pumping samplers. Water Resources Bulletin 19(2), 289-292.

Edwards, Thomas K and G. Douglas Glysson. 1999. Field Methods for Measurement of Fluvial Sediment. Techniques of Water-Resources Investigations of the U.S. Geological Survey in Book 3, Applications of Hydraulics. Virginia 1999. Revised from "Field Methods for Measurement of Fluvial Sediment," by Harold P. Guy and Vernon W. Norman, U.S. Geological Survey Techniques of Water-Resources Investigations, 'Book 3, Chapter C2, published in 1970.

Helley, E.J., and Graymer, R.W., 1997, Quaternary geology of Alameda County, and parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, California: A digital database: U.S. Geological Survey Open-File Report 97-0097.

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

Lewis, J, Eads, R.E., 2001. Turbidity threshold sampling for suspended sediment load estimation. In: Proceedings, 7th Federal Agency Sediment Conference, 25-29 Mar 2001, Reno, Nevada.

Minella, J.P.G., Merten, G.H., Reichert, J.M., and Clarke, R.T., 2008. Estimating suspended sediment concentrations from turbidity measurements and the calibration problem. Hydrological Processes 22, 1819-1830.

Mudd, Simon. 2011. The life and death of salt marshes in response to anthropogenic disturbance of sediment supply. Geological Society of America. May 2011. V. 39; no 5. p 511-512

Sowers, Janet M. 2003. Historical Geomorphology of Arroyo Valle and Arroyo Mocho with notes on steelhead migration, Livermore-Amador Valley. Prepared for Zone 7 Water Agency by Janet M. Sowers, William Lettis & Associates. November 26, 2003.

West Yost and Associates. 2001. Zone 7 Water Agency Geomorphic and Sediment Transport Evaluation. Prepared by Ayres Associates. Ayres Associates Project Number 33-0144.00 December 11, 2001

Wolman, M.G., 1954, A method of sampling coarse river-bed material: Transactions of the American Geophysical Union (EOS), v. 35, p. 951-956.

Appendix A: Selected Supporting Figures

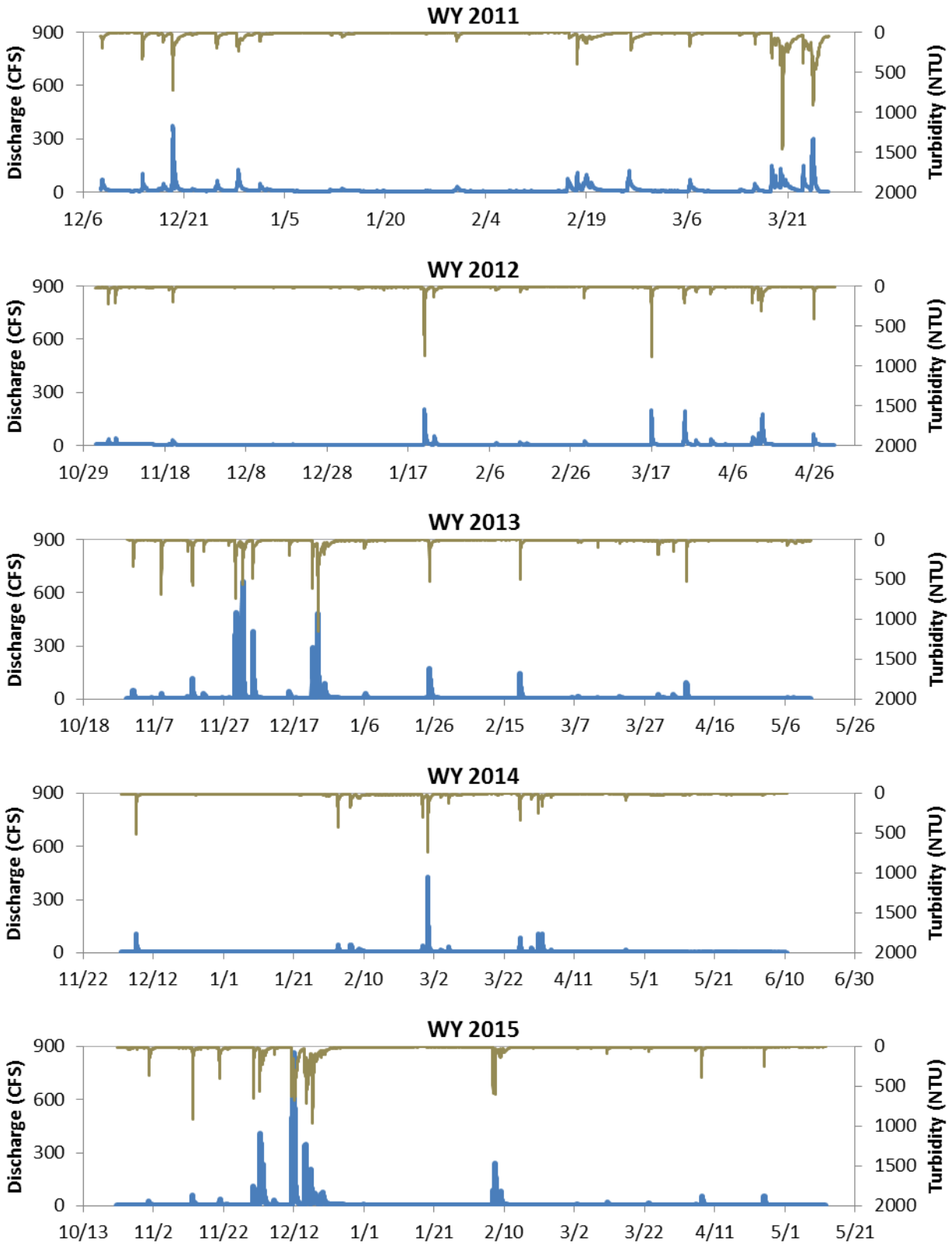


Figure A1a. Turbidity and discharge on Arroyo Las Positas at North Livermore Avenue Bridge (ALPL) as measured during the study period. All measurements were within the range of the sensor.

ALPL Model Summaries

ALPL during Typical Conditions (turbidity peak simultaneous with discharge peak)

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. The simple linear model on utransformed data for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The regression and residual plot of the selected model is provided in Figure A1b.

The final model for ALPL during typical conditions is:

$$SSC = 1.95774(Turb) - 20.41672$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 95
Root-mean-squared error (RMSE) = 96.1
Model standard percentage error (MSPE) = +/-17.9%
Adjusted coefficient of determination (R^2_a) = 0.94
p-value = <2.2e-16

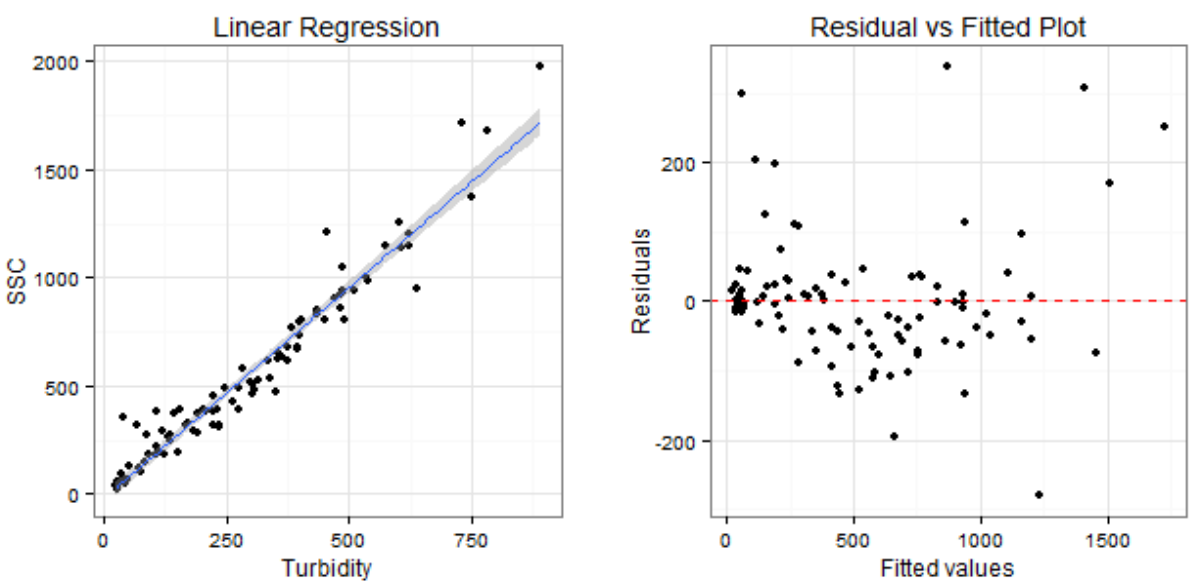


Figure A1b. Regression and residual plots of suspended sediment concentration as a function of turbidity during the study period on Arroyo Las Positas at North Livermore Avenue Bridge (ALPL) under typical conditions.

ALPL when Turbidity Peak occurs on Recession Limb

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A $\log_{10}$-transformed data model for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The regression and residual plot of the selected model is provided in Figure A1c.

The final model for ALPL during typical conditions is:

$$\log_{10}(SSC) = 0.92966 \log_{10}(Turb) + 0.13714$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 35
Root-mean-squared error (RMSE) = 0.059
Model standard percentage error (MSPE) = -12.66% to 14.5%
Adjusted coefficient of determination (R^2_a) = 0.95
p-value = <2.2e-16
Duan bias correction factor = 1.385

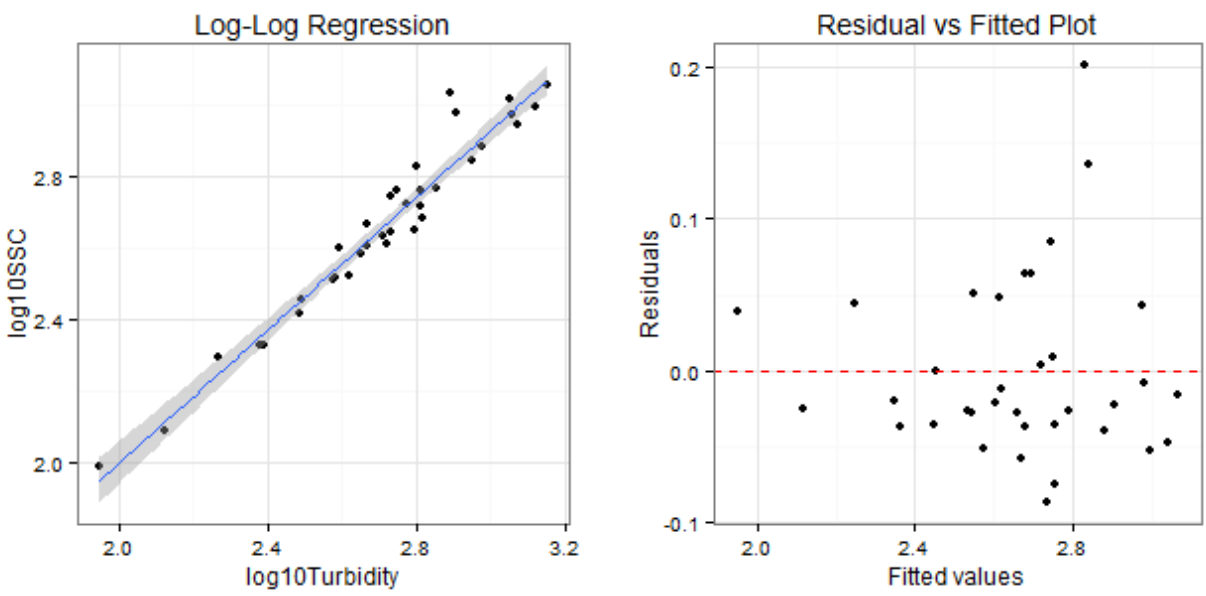


Figure A1c. Regression and residual plots of suspended sediment concentration as a function of turbidity during the study period on Arroyo Las Positas at North Livermore Avenue Bridge (ALPL) during atypical conditions when the turbidity peak occurred on the recession limb of the hydrograph.

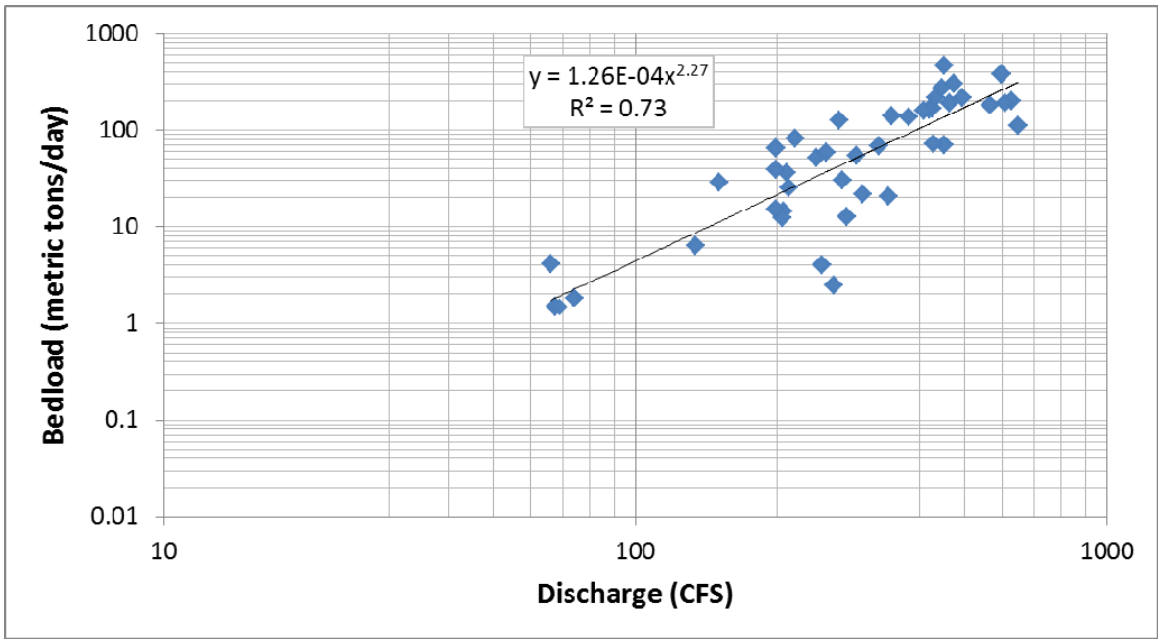


Figure A1d. Arroyo Las Positas (ALPL) bedload samples with power equation.

Tables A1. Daily results from monitoring at Arroyo Las Positas at Livermore (ALPL) for each WY.

WY 2011 Daily Results

	DECEMBER				JANUARY				FEBRUARY				MARCH			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	*NA*	*NA*	*NA*	*NA*	18.70	41.92	2.81	0.00	4.17	0.19	0.00	0.00	4.30	3.77	0.04	0.00
2	*NA*	*NA*	*NA*	*NA*	12.64	18.45	0.59	0.00	3.24	0.00	0.00	0.00	5.25	4.20	0.07	0.00
3	*NA*	*NA*	*NA*	*NA*	7.46	6.42	0.13	0.00	3.77	0.00	0.00	0.00	4.18	2.19	0.02	0.00
4	*NA*	*NA*	*NA*	*NA*	5.77	1.12	0.02	0.00	3.73	0.00	0.00	0.00	4.44	1.37	0.01	0.00
5	*NA*	*NA*	*NA*	*NA*	5.13	0.00	0.00	0.00	3.67	0.00	0.00	0.00	3.73	0.14	0.00	0.00
6	*NA*	*NA*	*NA*	*NA*	4.88	0.00	0.00	0.00	3.75	0.00	0.00	0.00	26.40	64.49	6.62	0.07
7	*NA*	*NA*	*NA*	*NA*	4.34	0.00	0.00	0.00	4.06	0.00	0.00	0.00	11.09	13.63	0.42	0.00
8	38.06 *P*	149.39 *P*	7.35 *P*	0.09 *P*	4.17	0.00	0.00	0.00	4.11	0.00	0.00	0.00	5.62	5.00	0.08	0.00
9	16.61	36.91	2.06	0.00	4.03	0.00	0.00	0.00	4.02	0.00	0.00	0.00	3.89	1.12	0.01	0.00
10	6.13	0.38	0.01	0.00	3.57	0.00	0.00	0.00	3.79	0.29	0.00	0.00	3.56	0.00	0.00	0.00
11	5.12	0.00	0.00	0.00	5.34	7.38	0.16	0.00	3.96	0.00	0.00	0.00	3.25	0.00	0.00	0.00
12	4.82	0.00	0.00	0.00	6.32	6.14	0.11	0.00	3.97	0.00	0.00	0.00	3.27	0.00	0.00	0.00
13	5.29	0.00	0.00	0.00	10.02	36.44	1.16	0.00	4.02	0.00	0.00	0.00	4.98	5.28	0.15	0.00
14	18.39	72.64	12.82	0.28	7.85	22.86	0.44	0.00	4.28	0.00	0.00	0.00	6.64	5.81	0.15	0.00
15	16.14	48.13	2.70	0.00	5.52	11.19	0.16	0.00	4.36	0.00	0.00	0.00	4.19	0.45	0.01	0.00
16	5.29	0.86	0.01	0.00	4.49	0.34	0.00	0.00	34.91	*94.61 P*	*10.10 P*	0.24	19.28	41.60	3.03	0.00
17	16.46	39.09	2.86	0.00	4.30	0.00	0.00	0.00	26.13	117.27	14.48	0.24	4.45	0.04	0.00	0.00
18	15.81	46.54	2.25	0.00	4.19	0.00	0.00	0.00	33.33	102.22	9.86	0.19	39.17	126.08	29.87	1.44
19	109.44	330.17	154.61	11.36	4.34	0.02	0.00	0.00	44.73	122.56	15.03	0.48	39.84	220.25	21.70	0.24
20	14.67	96.77	3.94	0.00	3.80	0.00	0.00	0.00	17.51	90.95	4.03	0.00	57.61	568.64	90.01	0.97
21	7.51	25.31	0.48	0.00	3.77	0.00	0.00	0.00	8.84	47.86	1.08	0.00	24.44	268.98	17.65	0.00
22	11.20	26.10	0.79	0.00	3.72	0.00	0.00	0.00	6.34	22.10	0.35	0.00	10.15	101.74	2.73	0.00
23	5.74	3.13	0.05	0.00	3.53	0.00	0.00	0.00	5.41	4.42	0.06	0.00	43.44	226.92	33.91	0.94
24	4.88	0.00	0.00	0.00	3.75	0.00	0.00	0.00	4.91	*0.85 P*	*0.01 P*	0.00	99.92	528.09	176.58	9.80
25	13.14	52.82	5.09	0.03	3.73	0.00	0.00	0.00	48.33	*188.90 P*	*23.23 P*	0.71	23.18	368.97	27.67	0.33
26	16.56	63.13	3.44	0.00	4.36	3.23	0.04	0.00	15.79	102.46	4.16	0.00	0.31	106.98	0.09	0.00
27	6.08	9.68	0.16	0.00	3.87	0.00	0.00	0.00	7.51	42.45	0.81	0.00	0.00 *P*	86.62 *P*	0.00 *P*	0.00 *P*
28	12.44	31.10	3.57	0.00	3.79	0.00	0.00	0.00	5.84	12.25	0.18	0.00	*NA*	*NA*	*NA*	*NA*
29	46.24	178.79	25.35	1.09	4.04	0.00	0.00	0.00	-	-	-	-	*NA*	*NA*	*NA*	*NA*
30	10.44	53.61	1.44	0.00	12.83	43.66	2.16	0.00	-	-	-	-	*NA*	*NA*	*NA*	*NA*
31	6.35	22.37	0.37	0.00	6.49	15.17	0.35	0.00	-	-	-	-	*NA*	*NA*	*NA*	*NA*
Total			222.01	12.76			8.13	0			83.38	1.86			410.84	13.79

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2012 Daily Results

DAY	NOVEMBER Q(cfs) avg	NOVEMBER Mean SS Conc	NOVEMBER SS Load (tons)	NOVEMBER Bedload (tons)	DECEMBER Q(cfs) avg	DECEMBER Mean SS Conc	DECEMBER SS Load (tons)	DECEMBER Bedload (tons)	JANUARY Q(cfs) avg	JANUARY Mean SS Conc	JANUARY SS Load (tons)	JANUARY Bedload (tons)	FEBRUARY Q(cfs) avg	FEBRUARY Mean SS Conc	FEBRUARY SS Load (tons)	FEBRUARY Bedload (tons)	MARCH Q(cfs) avg	MARCH Mean SS Conc	MARCH SS Load (tons)	MARCH Bedload (tons)	APRIL Q(cfs) avg	APRIL Mean SS Conc	APRIL SS Load (tons)	APRIL Bedload (tons)
1	7.01	16.00	0.28	0.00	2.85	0.00	0.00	0.00	2.40	1.30	0.01	0.00	2.66	0.00	0.00	0.00	3.34	6.34	0.06	0.00	7.83	16.43	0.45	0.00
2	6.64	16.22	0.26	0.00	3.00	0.00	0.00	0.00	2.40	0.91	0.01	0.00	2.61	0.00	0.00	0.00	2.70	0.03	0.00	0.00	3.50	1.47	0.01	0.00
3	7.05	15.26	0.27	0.00	2.91	0.00	0.00	0.00	2.56	4.65	0.03	0.00	2.63	0.00	0.00	0.00	2.56	0.00	0.00	0.00	3.22	0.00	0.00	0.00
4	14.46	84.60	4.36	0.00	2.80	0.00	0.00	0.00	2.83	13.69	0.11	0.00	2.60	0.00	0.00	0.00	2.55	0.00	0.00	0.00	4.16	2.60	0.04	0.00
5	10.42	43.03	3.00	0.00	2.92	0.35	0.00	0.00	2.50	5.65	0.03	0.00	2.58	0.00	0.00	0.00	2.50	0.00	0.00	0.00	2.84	0.00	0.00	0.00
6	14.47	43.40	2.46	0.00	3.51	0.09	0.00	0.00	2.46	2.15	0.01	0.00	2.72	0.20	0.00	0.00	2.85	0.13	0.00	0.00	2.91	0.00	0.00	0.00
7	6.67	9.37	0.15	0.00	3.21	0.15	0.00	0.00	2.47	4.11	0.02	0.00	6.57	26.07	0.62	0.00	2.56	0.00	0.00	0.00	2.88	0.00	0.00	0.00
8	6.43	4.89	0.08	0.00	3.08	0.00	0.00	0.00	2.41	2.08	0.01	0.00	3.56	20.14	0.20	0.00	2.50	0.06	0.00	0.00	2.86	0.00	0.00	0.00
9	6.00	6.41	0.09	0.00	2.96	0.06	0.00	0.00	2.42	2.06	0.01	0.00	2.80	1.73	0.01	0.00	2.51	0.09	0.00	0.00	2.83	0.00	0.00	0.00
10	6.34	7.11	0.11	0.00	3.03	0.00	0.00	0.00	2.63	6.82	0.05	0.00	2.88	0.00	0.00	0.00	2.50	0.09	0.00	0.00	11.52	39.44	3.47	0.00
11	6.30	7.79	0.12	0.00	2.96	0.12	0.00	0.00	2.51	7.63	0.05	0.00	2.89	0.02	0.00	0.00	2.50	0.19	0.00	0.00	16.32	34.49	1.92	0.00
12	6.46	6.53	0.10	0.00	2.90	0.00	0.00	0.00	2.47	4.52	0.03	0.00	2.77	0.00	0.00	0.00	2.49	0.56	0.00	0.00	21.05	75.53	6.96	0.12
13	6.44	8.92	0.14	0.00	2.73	0.03	0.00	0.00	2.42	4.34	0.03	0.00	5.42	22.16	0.52	0.00	2.51	0.34	0.00	0.00	61.41	169.21	33.20	2.18
14	6.85	11.04	0.19	0.00	2.84	2.12	0.02	0.00	2.43	3.62	0.02	0.00	3.89	11.03	0.12	0.00	2.50	2.08	0.01	0.00	7.87	31.69	0.71	0.00
15	4.71	3.67	0.06	0.00	2.96	0.16	0.00	0.00	2.46	2.66	0.02	0.00	4.52	8.50	0.14	0.00	2.52	6.33	0.04	0.00	4.91	5.35	0.07	0.00
16	3.48	0.00	0.00	0.00	2.92	0.87	0.01	0.00	2.42	2.44	0.01	0.00	2.84	*0.02*	*0.00*	0.00	23.04	117.97	38.43	1.53	4.03	0.79	0.01	0.00
17	3.29	0.00	0.00	0.00	2.62	1.32	0.01	0.00	2.44	1.21	0.01	0.00	2.66	0.00	0.00	0.00	26.33	93.14	12.11	0.53	3.70	0.00	0.00	0.00
18	3.64	0.50	0.01	0.00	2.60	0.19	0.00	0.00	2.52	0.78	0.00	0.00	2.80	0.00	0.00	0.00	4.18	9.01	0.10	0.00	3.55	0.00	0.00	0.00
19	5.81	25.30	0.49	0.00	2.94	6.99	0.06	0.00	2.74	1.21	0.01	0.00	2.74	0.00	0.00	0.00	2.99	1.68	0.01	0.00	3.39	0.00	0.00	0.00
20	10.84	58.66	2.64	0.00	2.51	1.21	0.01	0.00	7.76	96.09	8.93	0.05	2.68	0.00	0.00	0.00	2.82	0.13	0.00	0.00	3.40	0.24	0.00	0.00
21	3.40	0.76	0.01	0.00	2.46	0.04	0.00	0.00	59.07	210.28	61.75	2.86	2.80	0.00	0.00	0.00	2.72	0.52	0.00	0.00	3.36	0.04	0.00	0.00
22	2.99	0.00	0.00	0.00	2.37	1.35	0.01	0.00	5.29	12.41	0.18	0.00	2.75	0.00	0.00	0.00	2.69	0.63	0.00	0.00	3.23	1.56	0.01	0.00
23	3.10	0.00	0.00	0.00	2.22	0.51	0.00	0.00	21.83	66.88	4.93	0.00	2.68	0.00	0.00	0.00	2.65	0.33	0.00	0.00	3.18	0.33	0.00	0.00
24	3.45	0.00	0.00	0.00	2.33	0.00	0.00	0.00	4.86	20.82	0.29	0.00	2.57	*0.00*	*0.00*	0.00	9.50	34.44	3.37	0.02	3.14	0.01	0.00	0.00
25	3.19	0.00	0.00	0.00	2.37	0.31	0.00	0.00	3.49	6.23	0.05	0.00	2.56	*0.00*	*0.00*	0.00	59.57	118.07	29.43	3.13	10.39	42.09	5.31	0.04
26	3.12	0.01	0.00	0.00	2.38	1.09	0.01	0.00	3.24	0.15	0.00	0.00	2.56	0.15	0.00	0.00	5.17	9.07	0.13	0.00	16.48	30.32	1.83	0.00
27	2.93	0.00	0.00	0.00	2.43	1.16	0.01	0.00	2.89	0.07	0.00	0.00	2.55	0.00	0.00	0.00	7.39	14.34	0.79	0.00	4.14	2.70	0.03	0.00
28	2.94	0.00	0.00	0.00	2.48	2.34	0.01	0.00	2.82	0.00	0.00	0.00	2.58	0.00	0.00	0.00	8.77	19.78	0.63	0.00	3.55	0.20	0.00	0.00
29	3.44	0.00	0.00	0.00	2.50	1.43	0.01	0.00	2.80	0.00	0.00	0.00	9.18	43.26	1.60	0.00	3.66	1.80	0.02	0.00	3.41	0.64	0.01	0.00
30	3.31	0.00	0.00	0.00	2.53	3.22	0.02	0.00	2.80	0.00	0.00	0.00	-	-	-	-	3.33	0.01	0.00	0.00	3.23	0.63	0.01	0.00
31	-	-	-	-	2.44	5.40	0.03	0.00	2.75	0.00	0.00	0.00	-	-	-	-	13.69	36.40	2.15	0.00	-	-	-	-
Total			14.81	0.00			0.20	0.00			76.62	2.91			3.20	0.00			87.31	5.22			54.04	2.35

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2013 Daily Results

DAY	OCTOBER Q(cfs) avg	OCTOBER Mean SS Conc	OCTOBER SS Load (tons)	OCTOBER Bedload (tons)	NOVEMBER Q(cfs) avg	NOVEMBER Mean SS Conc	NOVEMBER SS Load (tons)	NOVEMBER Bedload (tons)	DECEMBER Q(cfs) avg	DECEMBER Mean SS Conc	DECEMBER SS Load (tons)	DECEMBER Bedload (tons)	JANUARY Q(cfs) avg	JANUARY Mean SS Conc	JANUARY SS Load (tons)	JANUARY Bedload (tons)	FEBRUARY Q(cfs) avg	FEBRUARY Mean SS Conc	FEBRUARY SS Load (tons)	FEBRUARY Bedload (tons)	MARCH Q(cfs) avg	MARCH Mean SS Conc	MARCH SS Load (tons)	MARCH Bedload (tons)	APRIL Q(cfs) avg	APRIL Mean SS Conc	APRIL SS Load (tons)	APRIL Bedload (tons)	MAY Q(cfs) avg	MAY Mean SS Conc	MAY SS Load (tons)	MAY Bedload (tons)
1	*NA*	*NA*	*NA*	*NA*	14.82	134.08	8.52	0.00	12.20	61.96	2.41	0.00	3.56	0.70	0.01	0.00	3.30	0.00	0.00	0.00	2.93	0.00	0.00	0.00	5.62	22.70	0.35	0.00	2.24	3.34	0.02	0.00
2	*NA*	*NA*	*NA*	*NA*	2.85	1.95	0.02	0.00	134.80	259.02	187.66	28.71	3.48	1.37	0.01	0.00	3.30	0.00	0.00	0.00	3.04	0.00	0.00	0.00	3.06	8.18	0.06	0.00	2.45	3.80	0.02	0.00
3	*NA*	*NA*	*NA*	*NA*	2.41	0.00	0.00	0.00	10.08	79.68	2.74	0.00	3.37	5.11	0.04	0.00	3.32	0.00	0.00	0.00	2.94	0.00	0.00	0.00	2.82	5.89	0.04	0.00	2.11	2.17	0.01	0.00
4	*NA*	*NA*	*NA*	*NA*	2.28	0.00	0.00	0.00	4.57	6.20	0.08	0.00	3.30	2.98	0.02	0.00	3.24	0.00	0.00	0.00	2.88	0.01	0.00	0.00	8.38	50.35	1.60	0.00	2.05	1.91	0.01	0.00
5	*NA*	*NA*	*NA*	*NA*	2.13	0.00	0.00	0.00	64.78	160.64	60.71	5.68	3.66	5.64	0.10	0.00	3.21	0.00	0.00	0.00	2.79	0.00	0.00	0.00	3.31	9.14	0.08	0.00	2.23	2.58	0.01	0.00
6	*NA*	*NA*	*NA*	*NA*	2.36	1.02	0.01	0.00	10.33	62.91	1.90	0.00	15.64	64.92	2.83	0.00	3.10	0.00	0.00	0.00	3.38	0.00	0.00	0.00	2.80	6.11	0.04	0.00	2.99	26.42	0.32	0.00
7	*NA*	*NA*	*NA*	*NA*	2.50	0.85	0.01	0.00	4.90	12.00	0.15	0.00	4.91	10.47	0.14	0.00	3.11	0.00	0.00	0.00	2.96	0.00	0.00	0.00	2.95	14.23	0.13	0.00	2.60	21.94	0.14	0.00
8	*NA*	*NA*	*NA*	*NA*	2.36	0.08	0.00	0.00	4.15	0.05	0.00	0.00	3.76	1.64	0.01	0.00	3.24	0.00	0.00	0.00	5.02	28.12	0.34	0.00	14.57	102.50	9.65	0.10	3.73	31.67	0.31	0.00
9	*NA*	*NA*	*NA*	*NA*	9.49	135.40	6.15	0.00	3.64	0.00	0.00	0.00	3.46	2.13	0.02	0.00	3.09	0.00	0.00	0.00	2.93	19.36	0.14	0.00	3.16	7.67	0.06	0.00	2.75	19.75	0.16	0.00
10	*NA*	*NA*	*NA*	*NA*	2.98	6.75	0.06	0.00	3.49	0.00	0.00	0.00	3.29	0.73	0.01	0.00	2.95	0.00	0.00	0.00	2.59	0.04	0.00	0.00	2.74	4.45	0.03	0.00	2.31	7.03	0.04	0.00
11	*NA*	*NA*	*NA*	*NA*	2.54	0.37	0.00	0.00	3.52	0.00	0.00	0.00	3.16	0.53	0.00	0.00	2.94	0.05	0.00	0.00	2.57	0.00	0.00	0.00	2.84	2.10	0.01	0.00	3.03	15.90	0.14	0.00
12	*NA*	*NA*	*NA*	*NA*	2.50	0.06	0.00	0.00	3.47	0.00	0.00	0.00	3.11	0.36	0.00	0.00	3.01	0.00	0.00	0.00	2.82	0.01	0.00	0.00	2.80	2.90	0.02	0.00	2.30	8.93	0.05	0.00
13	*NA*	*NA*	*NA*	*NA*	2.49	0.25	0.00	0.00	3.24	0.00	0.00	0.00	2.92	0.00	0.00	0.00	2.90	0.00	0.00	0.00	3.08	23.84	0.19	0.00	2.76	3.29	0.02	0.00	2.45 *P*	16.26 *P*	0.04 *P*	0.00 *P*
14	*NA*	*NA*	*NA*	*NA*	2.50	0.01	0.00	0.00	3.10	0.00	0.00	0.00	2.93	0.13	0.00	0.00	2.90	0.00	0.00	0.00	2.81	0.16	0.00	0.00	2.71	3.41	0.02	0.00	*NA*	*NA*	*NA*	*NA*
15	*NA*	*NA*	*NA*	*NA*	2.49	0.00	0.00	0.00	7.98	43.82	2.55	0.00	2.90	0.00	0.00	0.00	2.93	0.00	0.00	0.00	2.79	0.18	0.00	0.00	2.76	1.88	0.01	0.00	*NA*	*NA*	*NA*	*NA*
16	*NA*	*NA*	*NA*	*NA*	3.81	30.60	0.57	0.00	6.26	20.37	0.52	0.00	2.90	0.00	0.00	0.00	3.08	*0.00*	*0.00*	0.00	2.78	0.43	0.00	0.00	2.66	1.69	0.01	0.00	*NA*	*NA*	*NA*	*NA*
17	*NA*	*NA*	*NA*	*NA*	5.96	51.38	0.80	0.00	3.93	1.06	0.01	0.00	2.94	0.00	0.00	0.00	3.00	0.00	0.00	0.00	2.74	0.48	0.00	0.00	2.48	0.49	0.00	0.00	*NA*	*NA*	*NA*	*NA*
18	*NA*	*NA*	*NA*	*NA*	24.33	159.67	23.16	0.31	3.43	3.98	0.04	0.00	2.86	0.00	0.00	0.00	2.84	0.00	0.00	0.00	2.87	1.50	0.01	0.00	2.54	0.58	0.00	0.00	*NA*	*NA*	*NA*	*NA*
19	*NA*	*NA*	*NA*	*NA*	3.23	3.27	0.03	0.00	2.95	0.00	0.00	0.00	2.80	0.00	0.00	0.00	25.58	108.87	19.37	0.42	3.58	5.78	0.12	0.00	2.56	0.35	0.00	0.00	*NA*	*NA*	*NA*	*NA*
20	*NA*	*NA*	*NA*	*NA*	2.84	0.14	0.00	0.00	2.89	0.00	0.00	0.00	2.80	0.00	0.00	0.00	7.34	34.41	0.88	0.00	4.86	15.15	0.20	0.00	2.60	0.75	0.00	0.00	*NA*	*NA*	*NA*	*NA*
21	*NA*	*NA*	*NA*	*NA*	11.93	58.11	2.64	0.00	3.29	1.55	0.02	0.00	2.80	0.00	0.00	0.00	3.74	0.55	0.01	0.00	2.99	4.27	0.03	0.00	2.59	2.36	0.02	0.00	*NA*	*NA*	*NA*	*NA*
22	*NA*	*NA*	*NA*	*NA*	3.60	9.19	0.10	0.00	76.31	181.03	69.27	6.41	2.89	0.00	0.00	0.00	3.48	0.00	0.00	0.00	2.78	3.40	0.02	0.00	2.56	1.05	0.01	0.00	*NA*	*NA*	*NA*	*NA*
23	*NA*	*NA*	*NA*	*NA*	2.74	0.01	0.00	0.00	86.41	287.42	122.19	11.69	3.24	0.06	0.00	0.00	3.30	0.00	0.00	0.00	2.84	3.66	0.03	0.00	2.54	1.02	0.01	0.00	*NA*	*NA*	*NA*	*NA*
24	*NA*	*NA*	*NA*	*NA*	2.59	0.00	0.00	0.00	36.94	272.60	30.22	0.60	40.25	158.35	42.47	1.84	3.15	*0.00*	*0.00*	0.00	2.59	3.62	0.02	0.00	2.53	0.94	0.01	0.00	*NA*	*NA*	*NA*	*NA*
25	*NA*	*NA*	*NA*	*NA*	2.55	0.00	0.00	0.00	16.93	111.53	6.07	0.09	21.98	65.62	4.63	0.00	3.11	*0.00*	*0.00*	0.00	2.85	3.76	0.03	0.00	2.54	1.70	0.01	0.00	*NA*	*NA*	*NA*	*NA*
26	*NA*	*NA*	*NA*	*NA*	2.64	0.03	0.00	0.00	20.47	98.71	4.49	0.00	5.74	16.94	0.25	0.00	3.09	0.00	0.00	0.00	2.96	6.37	0.05	0.00	2.45	1.17	0.01	0.00	*NA*	*NA*	*NA*	*NA*
27	*NA*	*NA*	*NA*	*NA*	2.50	0.00	0.00	0.00	7.57	82.52	1.64	0.00	4.12	3.30	0.04	0.00	3.06	0.00	0.00	0.00	2.73	6.45	0.04	0.00	2.31	2.11	0.01	0.00	*NA*	*NA*	*NA*	*NA*
28	*NA*	*NA*	*NA*	*NA*	3.55	11.57	0.14	0.00	5.01	25.97	0.32	0.00	3.66	0.00	0.00	0.00	3.01	0.00	0.00	0.00	2.69	6.32	0.04	0.00	2.31	2.23	0.01	0.00	*NA*	*NA*	*NA*	*NA*
29	*NA*	*NA*	*NA*	*NA*	2.96	5.55	0.05	0.00	4.96	7.79	0.10	0.00	3.46	0.00	0.00	0.00	-	-	-	-	2.67	7.37	0.05	0.00	2.30	1.86	0.01	0.00	*NA*	*NA*	*NA*	*NA*
30	1.94 *P*	0.00 *P*	0.00 *P*	0.00 *P*	156.75	303.67	197.18	46.18	4.06	3.59	0.03	0.00	3.46	0.00	0.00	0.00	-	-	-	-	4.03	28.81	0.98	0.00	2.44	2.10	0.01	0.00	*NA*	*NA*	*NA*	*NA*
31	2.09	0.00	0.00	0.00	-	-	-	-	3.68	4.80	0.04	0.00	3.30	0.00	0.00	0.00	-	-	-	-	6.43	52.41	1.05	0.00	-	-	-	-	*NA*	*NA*	*NA*	*NA*
Total			0.00	0.00			239.45	46.49			493.15	53.18			50.58	1.84			20.25	0.42			3.35	0.00			12.27	0.10			1.23	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2014 Daily Results

DAY	DECEMBER Q(cfs) avg	DECEMBER Mean SS Conc	DECEMBER SS Load (tons)	DECEMBER Bedload (tons)	JANUARY Q(cfs) avg	JANUARY Mean SS Conc	JANUARY SS Load (tons)	JANUARY Bedload (tons)	FEBRUARY Q(cfs) avg	FEBRUARY Mean SS Conc	FEBRUARY SS Load (tons)	FEBRUARY Bedload (tons)
1	*NA*	*NA*	*NA*	*NA*	3.20	0.00	0.00	0.00	2.35	3.92	0.02	0.00
2	3.37 *P*	0.00 *P*	0.00 *P*	0.00 *P*	3.19	0.00	0.00	0.00	12.73	110.55	7.18	0.00
3	3.35	0.00	0.00	0.00	2.92	0.00	0.00	0.00	6.10	29.92	0.66	0.00
4	3.32	0.00	0.00	0.00	2.41	0.00	0.00	0.00	2.53	4.04	0.03	0.00
5	3.33	0.01	0.00	0.00	2.45	0.10	0.00	0.00	2.40	2.06	0.01	0.00
6	3.47	0.00	0.00	0.00	2.33	0.04	0.00	0.00	20.61	86.56	6.37	0.00
7	22.21	111.64	13.47	0.20	2.32	0.11	0.00	0.00	4.86	23.36	0.28	0.00
8	4.38	5.26	0.06	0.00	2.41	0.02	0.00	0.00	10.16	62.01	1.64	0.00
9	3.79	0.14	0.00	0.00	2.38	0.29	0.00	0.00	8.79	30.82	0.71	0.00
10	3.62	0.01	0.00	0.00	2.36	1.08	0.01	0.00	4.64	15.83	0.20	0.00
11	3.55	0.00	0.00	0.00	2.41	0.51	0.00	0.00	3.12	10.48	0.08	0.00
12	3.48	0.00	0.00	0.00	2.36	0.88	0.01	0.00	2.84	9.67	0.07	0.00
13	3.57	0.00	0.00	0.00	2.26	0.50	0.00	0.00	2.74	9.14	0.06	0.00
14	3.33	0.00	0.00	0.00	2.27	0.51	0.00	0.00	2.75	10.70	0.07	0.00
15	3.27	0.18	0.00	0.00	2.32	0.50	0.00	0.00	2.82	12.00	0.08	0.00
16	3.25	0.00	0.00	0.00	2.31	0.43	0.00	0.00	2.86	*10.78*	*0.08*	0.00
17	3.28	0.00	0.00	0.00	2.33	1.26	0.01	0.00	2.71	11.23	0.08	0.00
18	3.30	0.00	0.00	0.00	2.32	0.69	0.00	0.00	2.62	10.16	0.07	0.00
19	3.22	0.00	0.00	0.00	2.31	0.54	0.00	0.00	2.83	12.43	0.09	0.00
20	3.09	0.00	0.00	0.00	2.28	0.35	0.00	0.00	2.57	6.70	0.04	0.00
21	3.04	0.00	0.00	0.00	2.27	0.41	0.00	0.00	2.48	5.70	0.03	0.00
22	3.18	0.00	0.00	0.00	2.54	5.04	0.03	0.00	2.44	6.09	0.04	0.00
23	3.39	1.00	0.01	0.00	2.36	3.21	0.02	0.00	2.51	6.03	0.04	0.00
24	3.26	2.34	0.02	0.00	2.32	1.94	0.01	0.00	2.40	*5.38*	*0.03*	0.00
25	3.22	0.01	0.00	0.00	2.28	2.52	0.01	0.00	2.38	*5.66*	*0.03*	0.00
26	3.25	0.14	0.00	0.00	2.30	2.49	0.01	0.00	9.29	82.06	3.73	0.00
27	3.21	0.00	0.00	0.00	2.33	2.15	0.01	0.00	10.69	46.99	1.54	0.00
28	3.22	0.00	0.00	0.00	2.50	3.50	0.02	0.00	70.87	244.67	107.93	8.28
29	3.22	0.00	0.00	0.00	2.88	4.62	0.03	0.00	-	-	-	-
30	3.23	0.00	0.00	0.00	4.33	20.20	0.23	0.00	-	-	-	-
31	3.19	0.00	0.00	0.00	3.11	8.04	0.07	0.00	-	-	-	-
Total			13.56	0.20			0.51	0.00			131.20	8.28

DAY	MARCH Q(cfs) avg	MARCH Mean SS Conc	MARCH SS Load (tons)	MARCH Bedload (tons)	APRIL Q(cfs) avg	APRIL Mean SS Conc	APRIL SS Load (tons)	APRIL Bedload (tons)	MAY Q(cfs) avg	MAY Mean SS Conc	MAY SS Load (tons)	MAY Bedload (tons)	JUNE Q(cfs) avg	JUNE Mean SS Conc	JUNE SS Load (tons)	JUNE Bedload (tons)
1	5.62	29.12	0.50	0.00	25.91	78.23	7.64	0.28	2.24	0.08	0.00	0.00	2.02	0.00	0.00	0.00
2	3.51	3.65	0.03	0.00	12.21	37.99	1.60	0.00	2.05	5.54	0.03	0.00	1.81	0.00	0.00	0.00
3	3.26	2.29	0.02	0.00	3.62	8.18	0.08	0.00	2.00	16.35	0.08	0.00	3.54	5.65	0.06	0.00
4	6.26	21.73	0.41	0.00	6.31	20.17	0.38	0.00	2.01	15.47	0.08	0.00	2.35	0.85	0.01	0.00
5	3.14	4.58	0.04	0.00	3.47	3.45	0.03	0.00	1.98	19.27	0.09	0.00	1.83	0.00	0.00	0.00
6	9.30	47.52	1.70	0.00	2.92	0.65	0.00	0.00	1.99	15.01	0.07	0.00	1.72	0.00	0.00	0.00
7	3.21	7.16	0.06	0.00	2.81	0.12	0.00	0.00	1.87	3.42	0.02	0.00	1.68	0.00	0.00	0.00
8	2.80	13.18	0.09	0.00	2.69	0.06	0.00	0.00	1.88	0.68	0.00	0.00	1.70	0.00	0.00	0.00
9	2.66	21.41	0.14	0.00	2.56	0.00	0.00	0.00	1.94	4.29	0.02	0.00	1.66	0.00	0.00	0.00
10	2.83	1.48	0.01	0.00	2.50	0.06	0.00	0.00	1.92	8.23	0.04	0.00	1.65 *P*	0.00 *P*	0.00 *P*	0.00 *P*
11	2.65	3.23	0.02	0.00	2.50	0.12	0.00	0.00	1.92	12.21	0.06	0.00	*NA*	*NA*	*NA*	*NA*
12	2.50	7.66	0.05	0.00	2.46	0.00	0.00	0.00	1.97	11.26	0.05	0.00	*NA*	*NA*	*NA*	*NA*
13	2.45	5.93	0.04	0.00	2.40	0.00	0.00	0.00	1.81	1.48	0.01	0.00	*NA*	*NA*	*NA*	*NA*
14	2.47	0.01	0.00	0.00	2.35	0.00	0.00	0.00	1.70	0.77	0.00	0.00	*NA*	*NA*	*NA*	*NA*
15	2.43	0.00	0.00	0.00	2.37	0.00	0.00	0.00	1.69	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
16	2.38	0.00	0.00	0.00	2.36	0.00	0.00	0.00	1.75	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
17	2.32	0.00	0.00	0.00	2.29	0.00	0.00	0.00	1.78	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
18	2.28	0.00	0.00	0.00	2.25	0.00	0.00	0.00	1.77	0.01	0.00	0.00	*NA*	*NA*	*NA*	*NA*
19	2.58	0.84	0.01	0.00	1.92	0.00	0.00	0.00	1.76	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
20	2.38	8.07	0.05	0.00	1.84	0.00	0.00	0.00	1.71	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
21	2.33	0.01	0.00	0.00	1.80	0.00	0.00	0.00	1.79	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
22	2.31	0.00	0.00	0.00	1.83	0.18	0.00	0.00	1.78	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
23	2.28	0.00	0.00	0.00	1.96	0.00	0.00	0.00	1.99	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
24	2.27	0.00	0.00	0.00	1.88	0.00	0.00	0.00	3.12	5.02	0.05	0.00	*NA*	*NA*	*NA*	*NA*
25	2.64	2.86	0.02	0.00	5.05	30.05	0.61	0.00	2.12	4.21	0.02	0.00	*NA*	*NA*	*NA*	*NA*
26	16.62	99.58	8.10	0.08	4.91	16.70	0.24	0.00	1.89	3.09	0.01	0.00	*NA*	*NA*	*NA*	*NA*
27	4.66	22.06	0.34	0.00	2.65	1.55	0.01	0.00	1.76	0.05	0.00	0.00	*NA*	*NA*	*NA*	*NA*
28	2.62	2.07	0.01	0.00	2.41	0.00	0.00	0.00	2.47	0.23	0.00	0.00	*NA*	*NA*	*NA*	*NA*
29	7.75	23.31	0.93	0.00	2.27	0.00	0.00	0.00	2.08	1.01	0.01	0.00	*NA*	*NA*	*NA*	*NA*
30	6.58	17.37	0.37	0.00	3.24	3.15	0.03	0.00	1.84	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
31	15.28	60.92	7.51	0.19	-	-	-	-	2.14	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
Total			20.43	0.26			10.64	0.28			0.64	0.00			0.07	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2015 Daily Results

DAY	OCTOBER Q(cfs) avg	OCTOBER Mean SS Conc	OCTOBER SS Load (tons)	OCTOBER Bedload (tons)	NOVEMBER Q(cfs) avg	NOVEMBER Mean SS Conc	NOVEMBER SS Load (tons)	NOVEMBER Bedload (tons)	DECEMBER Q(cfs) avg	DECEMBER Mean SS Conc	DECEMBER SS Load (tons)	DECEMBER Bedload (tons)
1	NA	NA	NA	NA	4.55	67.13	0.84	0.00	5.45	30.01	0.48	0.00
2	NA	NA	NA	NA	2.16	10.49	0.06	0.00	128.73	251.68	140.74	21.27
3	NA	NA	NA	NA	1.83	2.09	0.01	0.00	64.80	144.24	32.84	3.46
4	NA	NA	NA	NA	1.76	1.09	0.00	0.00	9.68	56.55	1.71	0.00
5	NA	NA	NA	NA	1.70	1.07	0.00	0.00	3.75	11.99	0.12	0.00
6	NA	NA	NA	NA	1.66	2.49	0.01	0.00	8.29	31.46	1.09	0.00
7	NA	NA	NA	NA	1.69	2.11	0.01	0.00	3.72	7.46	0.08	0.00
8	NA	NA	NA	NA	1.73	1.43	0.01	0.00	2.98	2.16	0.02	0.00
9	NA	NA	NA	NA	1.74	2.31	0.01	0.00	2.59	0.00	0.00	0.00
10	NA	NA	NA	NA	1.69	3.31	0.01	0.00	2.49	0.00	0.00	0.00
11	NA	NA	NA	NA	1.70	3.69	0.02	0.00	245.04	262.77	291.76	92.34
12	NA	NA	NA	NA	1.73	2.30	0.01	0.00	236.85	510.89	348.60	102.70
13	NA	NA	NA	NA	13.51	172.49	11.67	0.00	14.03	162.60	6.23	0.00
14	NA	NA	NA	NA	3.00	22.03	0.17	0.00	6.36	52.41	0.84	0.00
15	NA	NA	NA	NA	1.89	5.73	0.03	0.00	122.44	460.83	146.94	13.18
16	NA	NA	NA	NA	1.74	1.99	0.01	0.00	35.38	323.97	34.58	1.28
17	NA	NA	NA	NA	1.68	0.56	0.00	0.00	43.62	455.53	43.73	0.46
18	NA	NA	NA	NA	1.67	0.12	0.00	0.00	28.57	189.90	13.52	0.00
19	NA	NA	NA	NA	1.76	0.32	0.00	0.00	18.37	114.53	5.77	0.02
20	NA	NA	NA	NA	6.16	88.56	4.01	0.00	37.95	100.67	9.56	0.19
21	NA	NA	NA	NA	6.74	70.00	1.37	0.00	12.04	62.70	1.95	0.00
22	1.67 *P*	0.79 *P*	0.00 *P*	0.00 *P*	2.80	17.60	0.12	0.00	7.03	22.02	0.39	0.00
23	1.67	2.28	0.01	0.00	3.11	20.89	0.19	0.00	5.80	12.52	0.18	0.00
24	1.64	2.31	0.01	0.00	2.01	3.01	0.02	0.00	5.80	7.53	0.11	0.00
25	1.99	10.79	0.06	0.00	1.92	0.46	0.00	0.00	5.38	5.82	0.08	0.00
26	2.02	13.72	0.07	0.00	1.83	0.03	0.00	0.00	4.36	2.67	0.03	0.00
27	1.74	4.85	0.02	0.00	1.77	0.01	0.00	0.00	4.10	0.01	0.00	0.00
28	1.70	1.03	0.00	0.00	1.75	0.05	0.00	0.00	3.93	0.01	0.00	0.00
29	1.65	1.74	0.01	0.00	1.72	0.00	0.00	0.00	3.82	0.00	0.00	0.00
30	1.65	2.10	0.01	0.00	20.25	139.04	19.89	0.27	3.88	0.00	0.00	0.00
31	3.73	108.29	2.57	0.00	-	-	-		3.78	0.00	0.00	0.00
Total			2.75	0.00			38.49	0.27			1081.34	234.90

DAY	JANUARY Q(cfs) avg	JANUARY Mean SS Conc	JANUARY SS Load (tons)	JANUARY Bedload (tons)	FEBRUARY Q(cfs) avg	FEBRUARY Mean SS Conc	FEBRUARY SS Load (tons)	FEBRUARY Bedload (tons)	MARCH Q(cfs) avg	MARCH Mean SS Conc	MARCH SS Load (tons)	MARCH Bedload (tons)
1	3.57	0.00	0.00	0.00	2.28	0.00	0.00	0.00	2.36	0.00	0.00	0.00
2	3.52	0.00	0.00	0.00	2.38	0.02	0.00	0.00	2.78	1.28	0.01	0.00
3	3.51	0.00	0.00	0.00	2.29	0.00	0.00	0.00	2.76	2.21	0.02	0.00
4	3.43	0.00	0.00	0.00	2.22	0.00	0.00	0.00	2.42	0.02	0.00	0.00
5	3.35	0.00	0.00	0.00	2.21	0.01	0.00	0.00	2.37	0.00	0.00	0.00
6	3.31	0.00	0.00	0.00	18.36	97.76	15.01	0.43	2.32	0.90	0.01	0.00
7	3.25	0.00	0.00	0.00	40.15	152.13	33.64	1.30	2.28	0.03	0.00	0.00
8	3.11	0.00	0.00	0.00	24.95	68.88	5.34	0.06	2.29	0.06	0.00	0.00
9	3.06	0.00	0.00	0.00	18.50	69.67	3.86	0.09	2.28	0.06	0.00	0.00
10	2.77	0.00	0.00	0.00	5.21	71.74	0.97	0.00	2.24	0.07	0.00	0.00
11	2.65	0.00	0.00	0.00	3.81	12.93	0.13	0.00	5.16	26.94	0.55	0.00
12	2.59	0.00	0.00	0.00	3.35	2.13	0.02	0.00	2.83	2.92	0.02	0.00
13	2.58	0.00	0.00	0.00	3.12	0.46	0.00	0.00	2.37	0.19	0.00	0.00
14	2.54	0.00	0.00	0.00	2.96	0.01	0.00	0.00	2.32	0.01	0.00	0.00
15	2.61	0.00	0.00	0.00	2.85	0.00	0.00	0.00	2.24	0.17	0.00	0.00
16	2.64	0.00	0.00	0.00	2.79	*0.00*	0.00	0.00	2.28	0.67	0.00	0.00
17	2.65	0.00	0.00	0.00	2.81	0.01	0.00	0.00	2.24	0.93	0.01	0.00
18	2.59	0.00	0.00	0.00	2.71	0.05	0.00	0.00	2.19	1.25	0.01	0.00
19	2.54	0.00	0.00	0.00	2.88	0.00	0.00	0.00	2.22	1.07	0.01	0.00
20	2.53	0.00	0.00	0.00	2.74	0.05	0.00	0.00	2.18	0.55	0.00	0.00
21	2.50	0.00	0.00	0.00	2.62	0.00	0.00	0.00	2.19	0.74	0.00	0.00
22	2.38	0.00	0.00	0.00	2.56	0.03	0.00	0.00	2.15	0.42	0.00	0.00
23	2.34	0.00	0.00	0.00	2.47	0.04	0.00	0.00	4.42	18.35	0.24	0.00
24	2.37	0.00	0.00	0.00	2.45	0.00	0.00	0.00	2.40	2.09	0.01	0.00
25	2.37	0.00	0.00	0.00	2.47	0.00	0.00	0.00	2.14	0.40	0.00	0.00
26	2.37	0.00	0.00	0.00	2.42	0.00	0.00	0.00	2.06	0.12	0.00	0.00
27	2.32	0.00	0.00	0.00	2.44	0.00	0.00	0.00	2.01	0.35	0.00	0.00
28	2.30	0.00	0.00	0.00	2.37	0.00	0.00	0.00	2.03	0.54	0.00	0.00
29	2.30	0.00	0.00	0.00	-	-	-	-	1.99	0.64	0.00	0.00
30	2.32	0.00	0.00	0.00	-	-	-	-	1.92	0.12	0.00	0.00
31	2.27	0.00	0.00	0.00	-	-	-	-	1.93	0.15	0.00	0.00
Total			0.00	0.00			58.97	1.88			0.91	0.00

DAY	APRIL Q(cfs) avg	APRIL Mean SS Conc	APRIL SS Load (tons)	APRIL Bedload (tons)	MAY Q(cfs) avg	MAY Mean SS Conc	MAY SS Load (tons)	MAY Bedload (tons)
1	1.89	0.53	0.00	0.00	1.74	0.00	0.00	0.00
2	1.88	0.23	0.00	0.00	1.74	0.00	0.00	0.00
3	1.88	0.21	0.00	0.00	1.76	0.00	0.00	0.00
4	1.89	0.28	0.00	0.00	1.73	0.00	0.00	0.00
5	2.72	13.61	0.14	0.00	1.72	0.00	0.00	0.00
6	2.62	5.51	0.04	0.00	1.74	0.00	0.00	0.00
7	15.92	79.31	6.15	0.00	1.78	0.01	0.00	0.00
8	3.56	10.48	0.12	0.00	1.91	0.00	0.00	0.00
9	2.33	0.96	0.01	0.00	1.79	0.00	0.00	0.00
10	2.21	0.00	0.00	0.00	1.73	0.00	0.00	0.00
11	2.02	0.00	0.00	0.00	1.72	0.04	0.00	0.00
12	1.88	0.00	0.00	0.00	1.71	0.00	0.00	0.00
13	1.82	0.00	0.00	0.00	1.96	15.58	2.76	0.00
14	1.87	0.00	0.00	0.00	1.67	0.79	0.00	0.00
15	1.85	0.01	0.00	0.00	1.67	2.28	0.01	0.00
16	1.83	0.07	0.00	0.00	1.64	2.31	0.01	0.00
17	1.83	0.01	0.00	0.00	1.99	10.79	0.06	0.00
18	1.80	0.23	0.00	0.00	2.02	13.72	0.07	0.00
19	1.85	0.06	0.00	0.00	1.74	4.85	0.02	0.00
20	1.89	0.01	0.00	0.00	1.70	1.03	0.00	0.00
21	1.88	0.00	0.00	0.00	1.65	1.74	0.01	0.00
22	1.88	0.03	0.00	0.00	1.65	2.10	0.01	0.00
23	1.80	0.00	0.00	0.00	3.37 *P*	108.29 *P*	2.57 *P*	0.00 *P*
24	1.77	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
25	12.23	42.84	3.08	0.00	*NA*	*NA*	*NA*	*NA*
26	2.49	2.18	0.02	0.00	*NA*	*NA*	*NA*	*NA*
27	2.00	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
28	1.87	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
29	1.81	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
30	1.77	0.00	0.00	0.00	*NA*	*NA*	*NA*	*NA*
31	-	-	-	-	*NA*	*NA*	*NA*	*NA*
Total			9.56	0.00			2.94	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

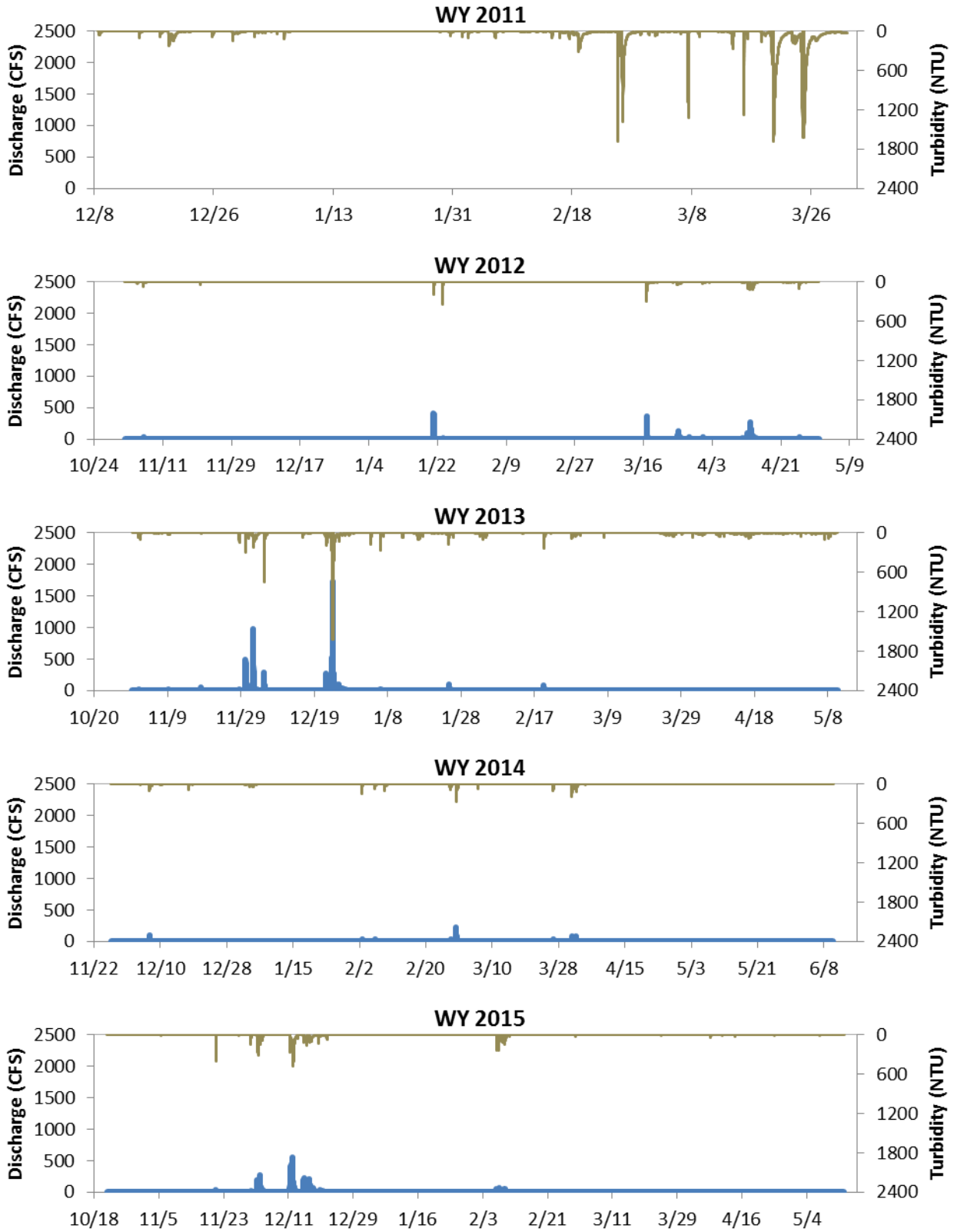


Figure A2a. Turbidity and discharge on Arroyo Mocho at Hagemann (AMH) as measured during the study period (WY 2011 discharge was rejected and therefore not shown). The turbidity sensor went out of range and is plotted at the sensor maximum during the storms on 3/20/2011, 3/24/2011, and 12/23-24/2012.

AMH Model Summaries

AMH - WY 2012

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that both potential explanatory variables correlated to SSC. Regression analysis was performed in R. Simple and multi-linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A multi-linear regression model on untransformed data was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The predicted/fitted versus observed and standardized residual plot of the selected model is provided in Figure A2b.

The final model for AMH WY 2012 is:

$$SSC = 1.20182(Turb) + 0.33754(Q) + 0.32350$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU
Q = discharge in cubic feet per second

Model information:

Number of Measurements = 43
Root-mean-squared error (RMSE) = 13.63
Model standard percentage error (MSPE) = +/-34.1%
Adjusted coefficient of determination (R^2_a) = 0.98
p-value = <2.2e-16

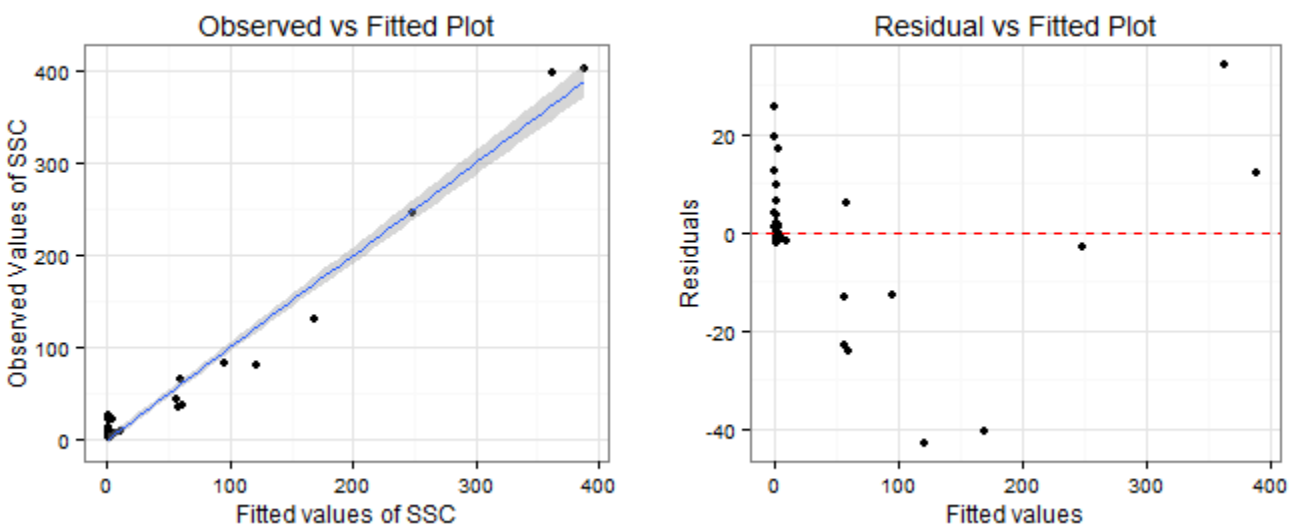


Figure A2b. Observed versus fitted values and standardized residual plot s of suspended sediment concentration as a function of turbidity and discharge during WY 2012 on Arroyo Mocho at Hagemann (AMH).

AMH - WY 2013

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. The simple linear model on utransformed data for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The regression and residual plot of the selected model is provided in Figure A2c.

The final model for AMH WY 2013 is:

$$SSC = 0.77037(Turb)$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 17
Root-mean-squared error (RMSE) = 92.2
Model standard percentage error (MSPE) = +/-17.2%
Adjusted coefficient of determination (R^2_a) = 0.98
p-value = 9.702e-16

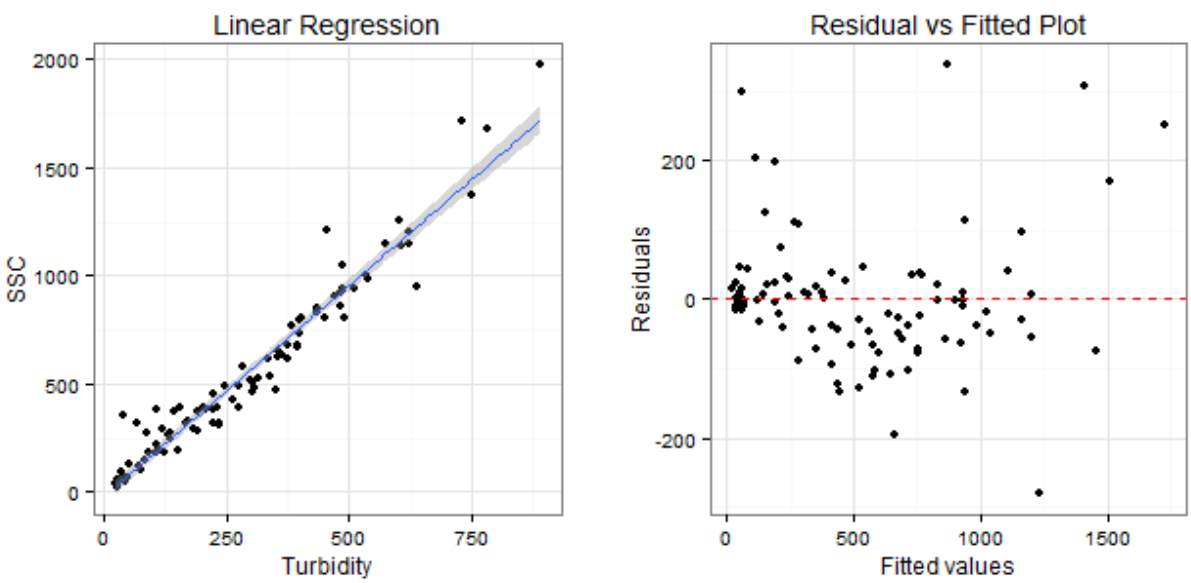


Figure A2c. Regression and residual plots of suspended sediment concentration as a function of turbidity during the WY 2013 on Arroyo Mocho at Hagemann (AMH).

AMH - All WYs combined (used to estimate WY 2014)

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. The simple linear model on utransformed data for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The regression and residual plot of the selected model is provided in Figure A2d.

The final model for ALPL during typical conditions is:

$$SSC = 0.96748(Turb)$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 125
Root-mean-squared error (RMSE) = 111.26
Model standard percentage error (MSPE) = +/-29%
Adjusted coefficient of determination (R^2_a) = 0.96
p-value = <2.2e-16

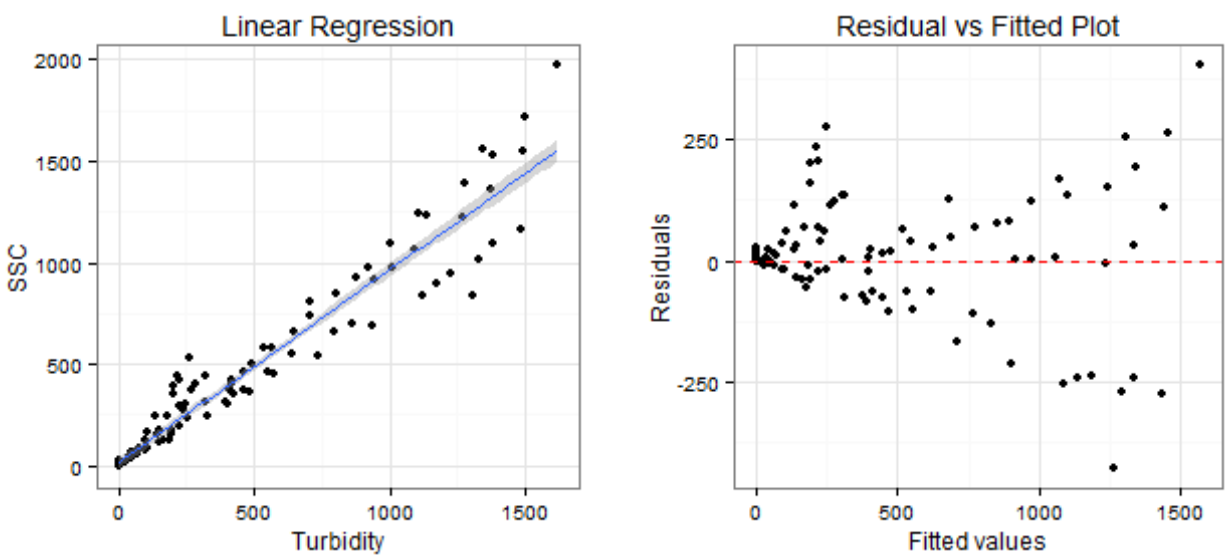


Figure A2d. Regression and residual plots of suspended sediment concentration as a function of turbidity during the entire period of study (WYs 2011 – 2015) on Arroyo Mocho at Hagemann (AMH). Because no samples were collected during WY 2014, this dataset was used to develop the relationship between SSC and turbidity for application to the WY 2014 continuous turbidity record.

AMH - WY 2015

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. The simple linear model on utransformed data for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The regression and residual plot of the selected model is provided in Figure A2e.

The final model for ALPL during typical conditions is:

$$SSC = 0.9827(Turb)$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 6
Root-mean-squared error (RMSE) = 30.8
Model standard percentage error (MSPE) = +/-8.9
Adjusted coefficient of determination (R^2_a) = 0.99
p-value = 1.709e-06

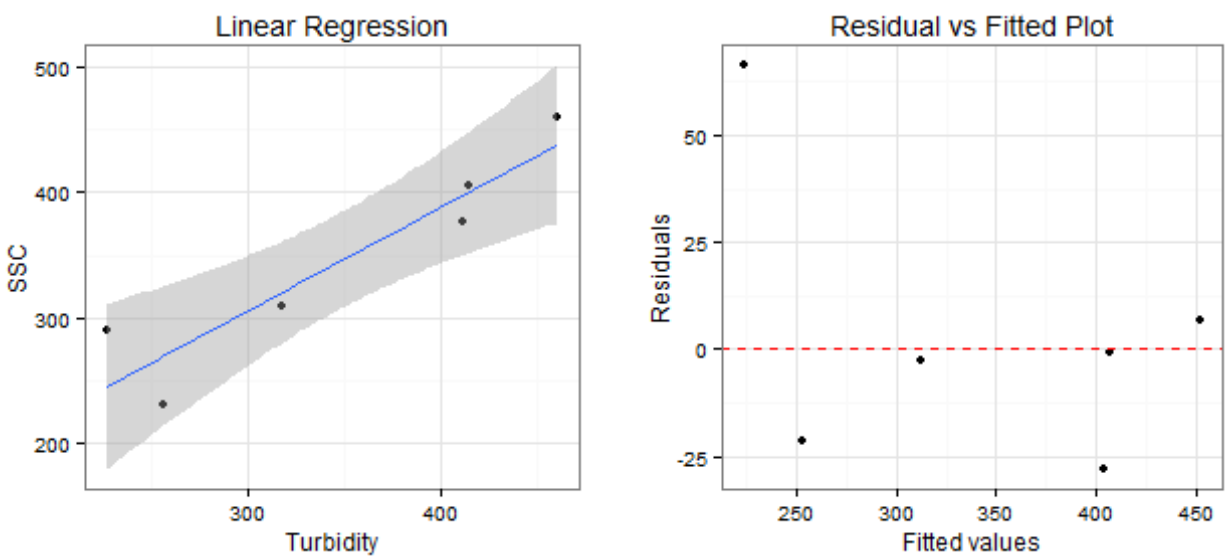


Figure A2e. Regression and residual plots of suspended sediment concentration as a function of turbidity during the WY 2015 on Arroyo Mocho at Hagemann (AMH).

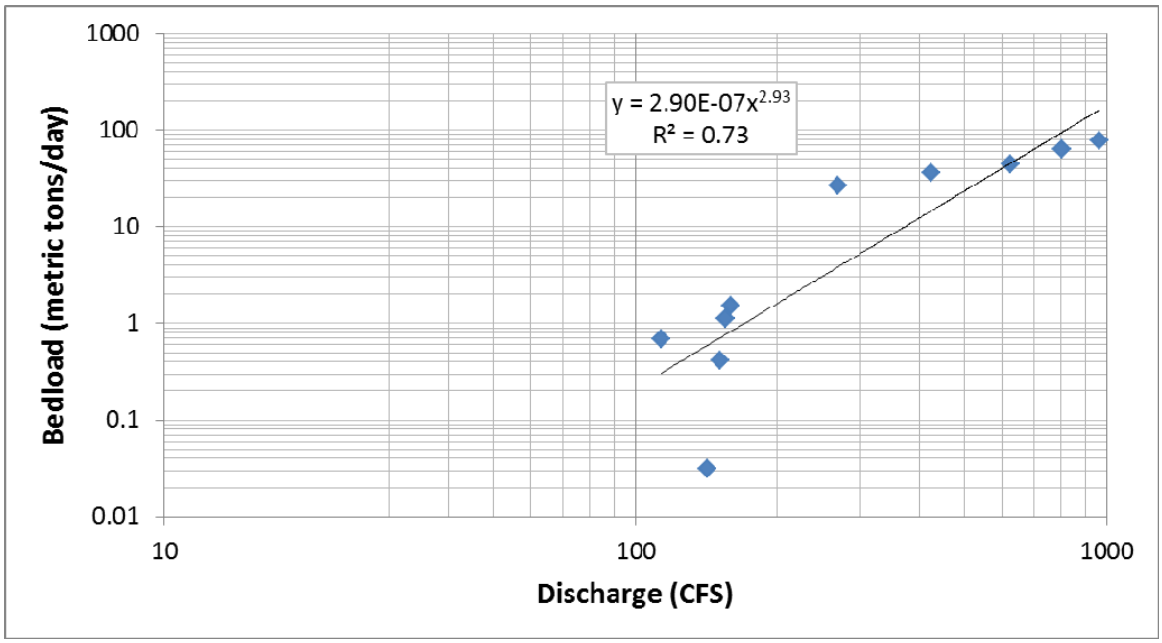


Figure A2f. Relationship between discharge and bedload transport rates at the Arroyo Mocho at Hagemann (AMH) gage location.

Tables A2. Daily results from monitoring at Arroyo Mocho at Hagemann (AMH) for each WY.

WY 2012 Daily Results at AMH

	NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	0.98	1.19	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.80	0.00	0.00	2.05	2.73	0.01	0.00	1.04	5.17	0.03	0.00
2	0.21	0.67	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.80	0.00	0.00	1.81	3.32	0.01	0.00	0.74	3.39	0.01	0.00
3	0.04	0.68	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.80	0.00	0.00	1.21	2.86	0.01	0.00	0.20	0.61	0.00	0.00
4	1.59	10.20	0.06	0.00	0.00	0.70	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.80	0.00	0.00	1.24	2.50	0.01	0.00	0.17	0.62	0.00	0.00
5	3.07	8.60	0.45	0.00	0.00	0.76	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.80	0.00	0.00	1.20	2.12	0.01	0.00	0.31	0.67	0.00	0.00
6	2.06	10.72	0.10	0.00	0.00	0.73	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.73	0.00	0.00	1.25	1.77	0.01	0.00	0.21	0.63	0.00	0.00
7	0.13	0.63	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.68	0.00	0.00	0.91	1.29	0.00	0.00	0.56	0.88	0.00	0.00
8	0.00	0.63	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.68	0.00	0.00	0.00	1.08	0.00	0.00	0.43	0.91	0.00	0.00
9	0.00	0.62	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.68	0.00	0.00	2.90	2.40	0.02	0.00	0.48	1.02	0.00	0.00
10	0.00	0.63	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.68	0.00	0.00	2.88	2.73	0.02	0.00	2.88	6.35	0.13	0.00
11	0.00	0.61	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.68	0.00	0.00	3.10	3.14	0.02	0.00	3.11	8.57	0.09	0.00
12	0.00	0.56	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.68	0.00	0.00	1.96	3.07	0.02	0.00	15.72	25.87	3.92	0.04
13	0.00	0.57	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.68	0.00	0.00	0.50	2.88	0.00	0.00	50.37	81.79	12.68	0.11
14	0.00	0.56	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.68	0.00	0.00	0.07	3.02	0.00	0.00	17.26	22.00	1.19	0.00
15	0.00	0.58	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.62	0.00	0.00	0.02	3.31	0.00	0.00	6.18	5.83	0.09	0.00
16	0.00	0.58	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.56	0.00	0.00	25.16	32.05	15.75	0.30	3.21	4.30	0.03	0.00
17	0.00	0.55	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.56	0.00	0.00	6.92	24.07	0.71	0.00	1.30	3.97	0.01	0.00
18	0.00	0.57	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.56	0.00	0.00	2.83	8.34	0.06	0.00	1.05	3.35	0.01	0.00
19	0.00	0.57	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.56	0.00	0.00	1.28	4.65	0.01	0.00	0.93	2.41	0.01	0.00
20	0.47	4.79	0.02	0.00	0.00	0.61	0.00	0.00	3.11	5.58	1.88	0.02	0.00	0.56	0.00	0.00	0.00	4.76	0.00	0.00	0.87	1.51	0.00	0.00
21	0.00	0.62	0.00	0.00	0.00	0.59	0.00	0.00	32.87	36.56	17.97	0.58	0.00	0.56	0.00	0.00	0.00	5.04	0.00	0.00	1.10	2.43	0.01	0.00
22	0.00	0.74	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.56	0.00	0.00	1.62	5.15	0.02	0.00	1.06	5.18	0.01	0.00
23	0.00	0.77	0.00	0.00	0.00	0.62	0.00	0.00	3.23	18.53	0.45	0.00	0.00	0.56	0.00	0.00	5.31	6.05	0.08	0.00	1.09	4.02	0.01	0.00
24	0.00	0.77	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.52	0.00	0.00	11.10	13.28	0.76	0.00	1.28	4.33	0.01	0.00
25	0.00	0.79	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.44	0.00	0.00	30.85	39.63	5.01	0.04	5.15	12.41	0.60	0.00
26	0.00	0.76	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.44	0.00	0.00	3.87	5.00	0.05	0.00	4.35	9.93	0.16	0.00
27	0.00	0.74	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.44	0.00	0.00	4.16	3.45	0.11	0.00	1.60	4.60	0.02	0.00
28	0.00	0.76	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.44	0.00	0.00	0.87	0.95	0.01	0.00	1.43	4.50	0.02	0.00
29	0.00	0.73	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.80	0.00	0.00	0.18	0.96	0.00	0.00	0.00	0.57	0.00	0.00	1.31	4.94	0.02	0.00
30	0.00	0.72	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.80	0.00	0.00	-	-	-	-	0.35	1.88	0.00	0.00	0.96	4.66	0.01	0.00
31	-	-	-	-	0.00	0.64	0.00	0.00	0.00	0.80	0.00	0.00	-	-	-	-	5.37	12.97	0.40	0.00	-	-	-	-
Total			0.64	0.00			0.00	0.00			20.30	0.60			0.00	0.00			23.12	0.34			19.06	0.14

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2013 Daily Results at AMH

	October				November				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	4.41	9.77	0.33	0.00	1.81	8.04	0.12	0.00	0.00	0.17	0.00	0.00	0.87	3.83	0.01	0.00	0.22	3.64	0.00	0.00	1.13	2.90	0.01	0.00	0.07	0.52	0.00	0.00
2	NA	NA	NA	NA	0.18	0.30	0.00	0.00	95.86	58.79	32.20	18.63	0.00	0.19	0.00	0.00	0.59	24.04	0.03	0.00	0.22	0.45	0.00	0.00	1.97	8.86	0.04	0.00	1.39	2.98	0.01	0.00
3	NA	NA	NA	NA	0.10	0.27	0.00	0.00	9.32	29.03	0.83	0.00	1.66	5.80	0.04	0.00	0.53	28.16	0.04	0.00	0.09	0.21	0.00	0.00	1.81	14.49	0.06	0.00	1.20	3.60	0.01	0.00
4	NA	NA	NA	NA	0.02	0.24	0.00	0.00	0.18	1.05	0.00	0.00	0.01	0.15	0.00	0.00	0.43	2.60	0.00	0.00	0.00	0.12	0.00	0.00	1.88	5.27	0.05	0.00	1.20	3.94	0.01	0.00
5	NA	NA	NA	NA	0.03	0.60	0.00	0.00	24.16	38.91	5.13	0.35	0.00	0.15	0.00	0.00	0.23	0.38	0.00	0.00	0.10	0.08	0.00	0.00	0.27	0.14	0.00	0.00	1.11	3.65	0.01	0.00
6	NA	NA	NA	NA	1.47	2.17	0.01	0.00	0.25	3.68	0.01	0.00	3.94	16.63	0.27	0.00	0.15	0.21	0.00	0.00	0.00	0.12	0.00	0.00	0.38	0.16	0.00	0.00	1.17	3.63	0.01	0.00
7	NA	NA	NA	NA	1.27	0.62	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.20	0.00	0.00	0.11	0.20	0.00	0.00	0.61	0.69	0.00	0.00	0.46	2.30	0.00	0.00	0.45	4.84	0.01	0.00
8	NA	NA	NA	NA	0.77	0.54	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.18	0.00	0.00	0.20	0.24	0.00	0.00	2.20	0.27	0.00	0.00	2.12	8.86	0.08	0.00	0.67	6.90	0.01	0.00
9	NA	NA	NA	NA	2.77	5.81	0.11	0.00	0.00	0.24	0.00	0.00	0.00	0.21	0.00	0.00	0.16	0.24	0.00	0.00	0.75	0.05	0.00	0.00	1.44	4.06	0.02	0.00	1.37	4.64	0.01	0.00
10	NA	NA	NA	NA	0.00	0.27	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.24	0.00	0.00	0.17	0.23	0.00	0.00	0.58	0.05	0.00	0.00	0.00	0.15	0.00	0.00	1.31 *P*	2.80 *P*	0.01 *P*	0.00 *P*
11	NA	NA	NA	NA	0.00	0.30	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.25	0.00	0.00	0.16	0.20	0.00	0.00	0.52	0.04	0.00	0.00	1.19	3.03	0.01	0.00	NA	NA	NA	NA
12	NA	NA	NA	NA	0.00	0.21	0.00	0.00	0.00	0.24	0.00	0.00	0.44	9.32	0.03	0.00	0.10	0.19	0.00	0.00	0.38	0.04	0.00	0.00	2.23	4.67	0.03	0.00	NA	NA	NA	NA
13	NA	NA	NA	NA	0.00	0.11	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.20	0.00	0.00	0.37	1.63	0.00	0.00	0.29	0.03	0.00	0.00	1.93	5.24	0.02	0.00	NA	NA	NA	NA
14	NA	NA	NA	NA	0.00	0.11	0.00	0.00	0.79	1.40	0.00	0.00	0.00	0.23	0.00	0.00	0.31	0.72	0.00	0.00	0.01	0.03	0.00	0.00	1.29	5.72	0.02	0.00	NA	NA	NA	NA
15	NA	NA	NA	NA	0.00	0.11	0.00	0.00	0.60	4.58	0.04	0.00	0.43	3.26	0.00	0.00	0.23	0.31	0.00	0.00	0.00	0.03	0.00	0.00	0.73	13.70	0.02	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	0.00	0.16	0.00	0.00	0.84	7.13	0.01	0.00	0.16	29.50	0.01	0.00	0.24	0.20	0.00	0.00	0.00	0.04	0.00	0.00	0.56	6.30	0.01	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	0.00	0.71	0.00	0.00	2.23	5.09	0.03	0.00	0.10	1.60	0.00	0.00	0.24	0.20	0.00	0.00	0.00	0.06	0.00	0.00	1.84	9.05	0.04	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	5.70	0.82	0.02	0.00	0.39	1.41	0.00	0.00	0.02	0.37	0.00	0.00	0.24	0.22	0.00	0.00	0.00	0.07	0.00	0.00	3.84	4.34	0.04	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	0.00	0.19	0.00	0.00	0.20	0.42	0.00	0.00	0.00	0.20	0.00	0.00	9.35	15.22	1.36	0.01	0.09	0.12	0.00	0.00	3.73	3.61	0.03	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	0.00	0.09	0.00	0.00	0.14	0.28	0.00	0.00	0.90	4.56	0.01	0.00	0.06	1.82	0.00	0.00	1.44	0.28	0.00	0.00	3.67	3.52	0.03	0.00	NA	NA	NA	NA
21	NA	NA	NA	NA	0.00	0.06	0.00	0.00	0.77	3.49	0.03	0.00	0.98	4.08	0.01	0.00	0.00	0.27	0.00	0.00	0.82	0.26	0.00	0.00	3.65	3.41	0.03	0.00	NA	NA	NA	NA
22	NA	NA	NA	NA	0.00	0.05	0.00	0.00	32.07	38.47	6.02	0.47	0.84	4.30	0.01	0.00	0.00	0.24	0.00	0.00	0.00	0.14	0.00	0.00	3.79	3.76	0.04	0.00	NA	NA	NA	NA
23	NA	NA	NA	NA	0.00	0.11	0.00	0.00	120.60	240.77	361.08	24.69	0.35	4.19	0.00	0.00	0.00	0.24	0.00	0.00	2.28	3.26	0.02	0.00	4.02	3.38	0.03	0.00	NA	NA	NA	NA
24	NA	NA	NA	NA	1.22	0.11	0.00	0.00	266.30	503.40	974.01	97.33	11.84	22.79	1.76	0.03	0.00	0.24	0.00	0.00	2.29	5.38	0.03	0.00	4.16	3.60	0.04	0.00	NA	NA	NA	NA
25	NA	NA	NA	NA	0.56	0.10	0.00	0.00	31.45	30.82	2.79	0.02	4.20	14.39	0.14	0.00	0.00	0.23	0.00	0.00	1.45	3.05	0.02	0.00	4.40	4.08	0.04	0.00	NA	NA	NA	NA
26	NA	NA	NA	NA	0.86	0.15	0.00	0.00	27.25	18.40	1.28	0.00	0.17	0.31	0.00	0.00	0.29	1.80	0.00	0.00	2.38	9.19	0.04	0.00	4.52	4.24	0.05	0.00	NA	NA	NA	NA
27	NA	NA	NA	NA	1.84	0.29	0.00	0.00	15.82	13.86	0.53	0.00	0.00	0.17	0.00	0.00	0.37	16.28	0.01	0.00	1.39	2.28	0.01	0.00	2.53	3.38	0.02	0.00	NA	NA	NA	NA
28	NA	NA	NA	NA	3.21	15.51	0.47	0.00	6.38	11.31	0.17	0.00	0.00	0.20	0.00	0.00	0.30	9.51	0.01	0.00	1.12	0.27	0.00	0.00	2.31	3.47	0.02	0.00	NA	NA	NA	NA
29	NA	NA	NA	NA	0.00	0.28	0.00	0.00	4.02	3.65	0.04	0.00	0.00	0.20	0.00	0.00	-	-	-	-	0.92	0.62	0.00	0.00	2.00	3.55	0.02	0.00	NA	NA	NA	NA
30	0.54 *P*	0.21 *P*	0.00 *P*	0.00 *P*	81.88	46.22	19.34	1.59	0.31	0.24	0.00	0.00	0.00	0.20	0.00	0.00	-	-	-	-	0.84	0.23	0.00	0.00	1.07	3.46	0.01	0.00	NA	NA	NA	NA
31	0.43	0.20	0.00	0.00	-	-	-	-	0.00	0.15	0.00	0.00	0.92	2.45	0.01	0.00	-	-	-	-	0.75	0.16	0.00	0.00	-	-	-	-	NA	NA	NA	NA
Total			0.00	0.00			20.28	1.59			1384.33	141.50			2.30	0.03			1.47	0.01			0.13	0.00			0.82	0.00			0.09	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2014 Daily Results at AMH

	NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May				June			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	2.05	1.20	0.01	0.00	0.08	0.89	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.22	0.00	0.00	7.14	20.40	1.07	0.00	0.00	0.21	0.00	0.00	0.00	0.28	0.00	0.00
2	NA	NA	NA	NA	2.15	1.35	0.01	0.00	0.34	3.46	0.00	0.00	2.97	11.34	0.46	0.00	0.00	0.32	0.00	0.00	0.34	7.80	0.03	0.00	0.00	0.24	0.00	0.00	0.00	0.33	0.00	0.00
3	NA	NA	NA	NA	2.12	1.09	0.01	0.00	0.20	5.33	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.32	0.00	0.00
4	NA	NA	NA	NA	2.21	1.50	0.01	0.00	0.18	6.35	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.34	0.00	0.00
5	NA	NA	NA	NA	2.36	1.23	0.01	0.00	0.12	1.02	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.29	0.00	0.00
6	NA	NA	NA	NA	1.91	0.98	0.00	0.00	0.00	0.34	0.00	0.00	6.62	10.14	0.42	0.00	0.12	4.51	0.01	0.00	0.00	0.31	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.30	0.00	0.00
7	NA	NA	NA	NA	9.75	25.76	1.69	0.00	0.00	0.45	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.30	0.00	0.00
8	NA	NA	NA	NA	0.01	0.43	0.00	0.00	0.00	0.41	0.00	0.00	0.46	5.86	0.04	0.00	0.00	0.29	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.24	0.00	0.00
9	NA	NA	NA	NA	0.33	1.91	0.01	0.00	0.00	0.37	0.00	0.00	0.15	3.62	0.01	0.00	0.00	0.29	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00
10	NA	NA	NA	NA	2.89	4.00	0.03	0.00	0.00	0.29	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.27	0.00	0.00	0.00 *P*	0.29 *P*	0.00 *P*	0.00 *P*
11	NA	NA	NA	NA	1.04	1.66	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.26	0.00	0.00	NA	NA	NA	NA
12	NA	NA	NA	NA	0.82	1.71	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.24	0.00	0.00	NA	NA	NA	NA
13	NA	NA	NA	NA	3.62	2.67	0.03	0.00	0.00	0.28	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.22	0.00	0.00	NA	NA	NA	NA
14	NA	NA	NA	NA	0.10	0.46	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.20	0.00	0.00	NA	NA	NA	NA
15	NA	NA	NA	NA	0.00	0.39	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.22	0.00	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	0.00	0.45	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.25	0.00	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	0.18	3.84	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.28	0.00	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	0.32	0.69	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.29	0.00	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	0.27	0.66	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.30	0.00	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	0.19	1.23	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.29	0.00	0.00	NA	NA	NA	NA
21	NA	NA	NA	NA	0.17	0.79	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.27	0.00	0.00	NA	NA	NA	NA
22	NA	NA	NA	NA	0.10	0.53	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.26	0.00	0.00	NA	NA	NA	NA
23	NA	NA	NA	NA	0.04	0.37	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.25	0.00	0.00	NA	NA	NA	NA
24	NA	NA	NA	NA	0.02	0.34	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.25	0.00	0.00	NA	NA	NA	NA
25	NA	NA	NA	NA	0.00	0.36	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.26	0.00	0.00	NA	NA	NA	NA
26	2.87 *P*	1.37 *P*	0.00 *P*	0.00 *P*	0.00	0.44	0.00	0.00	0.00	0.31	0.00	0.00	4.70	14.73	0.53	0.00	2.62	15.26	0.47	0.00	0.00	0.28	0.00	0.00	0.00	0.26	0.00	0.00	NA	NA	NA	NA
27	2.87	1.33	0.01	0.00	0.00	0.48	0.00	0.00	0.00	0.33	0.00	0.00	0.96	6.81	0.05	0.00	0.00	0.26	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.35	0.00	0.00	NA	NA	NA	NA
28	2.63	1.37	0.01	0.00	0.00	0.46	0.00	0.00	0.00	0.31	0.00	0.00	24.19	57.39	9.20	0.12	0.00	0.30	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.43	0.00	0.00	NA	NA	NA	NA
29	2.33	1.27	0.01	0.00	0.00	0.44	0.00	0.00	0.00	0.35	0.00	0.00					0.00	0.33	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.40	0.00	0.00	NA	NA	NA	NA
30	2.20	1.71	0.01	0.00	0.00	0.47	0.00	0.00	0.00	0.31	0.00	0.00					0.00	0.37	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.37	0.00	0.00	NA	NA	NA	NA
31	-	-	-	-	0.00	0.51	0.00	0.00	0.00	0.32	0.00	0.00					6.13	19.70	1.50	0.00					0.00	0.29	0.00	0.00	-	-	-	-
Total			0.03	0.00			1.81	0.00			0.01	0.00			10.70	0.12			1.98	0.00			1.10	0.00			0.00	0.00			0.00	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2015 Daily Results at AMH

	October				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	0.00	0.37	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.47	0.00	0.00
2	NA	NA	NA	NA	0.00	0.37	0.00	0.00	34.50	34.39	6.57	0.09	0.00	0.56	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.48	0.00	0.00
3	NA	NA	NA	NA	0.00	0.37	0.00	0.00	26.08	28.59	5.29	0.13	0.00	0.56	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.52	0.00	0.00
4	NA	NA	NA	NA	0.00	0.37	0.00	0.00	0.01	0.70	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.78	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.53	0.00	0.00
5	NA	NA	NA	NA	0.00	0.36	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.51	0.00	0.00
6	NA	NA	NA	NA	0.00	0.35	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.40	0.00	0.00	5.24	12.32	0.85	0.00	0.00	0.51	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.52	0.00	0.00
7	NA	NA	NA	NA	0.00	0.34	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.42	0.00	0.00	4.17	21.68	1.14	0.00	0.00	0.50	0.00	0.00	0.00	1.19	0.00	0.00	0.00	0.66	0.00	0.00
8	NA	NA	NA	NA	0.00	0.33	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.84	0.00	0.00	4.95	10.91	0.40	0.00	0.00	0.50	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.53	0.00	0.00
9	NA	NA	NA	NA	0.00	0.34	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.86	0.00	0.00	5.65	13.69	0.45	0.00	0.00	0.51	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.55	0.00	0.00
10	NA	NA	NA	NA	0.00	0.34	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.81	0.00	0.00	0.32	2.83	0.01	0.00	0.00	0.55	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.20	0.00	0.00
11	NA	NA	NA	NA	0.00	0.36	0.00	0.00	125.11	45.73	27.77	2.17	0.00	0.79	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.09	0.00	0.00
12	NA	NA	NA	NA	0.00	0.37	0.00	0.00	122.12	179.16	62.62	2.04	0.00	0.79	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.07	0.00	0.00
13	NA	NA	NA	NA	0.00	0.31	0.00	0.00	5.16	15.77	0.36	0.00	0.00	0.68	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.07	0.00	0.00
14	NA	NA	NA	NA	0.00	0.33	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.70	0.00	0.00	0.00 *P*	0.09 *P*	0.00 *P*	0.00 *P*
15	NA	NA	NA	NA	0.00	0.35	0.00	0.00	39.44	39.57	5.30	0.13	0.00	0.61	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.53	0.00	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	0.00	0.37	0.00	0.00	36.67	29.81	4.08	0.06	0.00	0.64	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.46	0.00	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	0.00	0.35	0.00	0.00	37.62	47.00	4.58	0.00	0.00	0.64	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.47	0.00	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	0.00	0.37	0.00	0.00	13.06	10.87	0.38	0.00	0.00	0.65	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	0.00	0.37	0.00	0.00	6.12	12.30	0.29	0.00	0.00	0.80	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	3.04	16.81	0.98	0.00	11.61	10.17	0.29	0.00	0.00	0.71	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.51	0.00	0.00	NA	NA	NA	NA
21	0.00 *P*	0.37 *P*	0.00 *P*	0.00 *P*	0.03	0.19	0.00	0.00	3.82	4.87	0.05	0.00	0.00	0.70	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.52	0.00	0.00	NA	NA	NA	NA
22	0.00	0.29	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
23	0.00	0.32	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.49	0.00	0.00	NA	NA	NA	NA
24	0.00	0.29	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
25	0.00	0.33	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.77	0.00	0.00	NA	NA	NA	NA
26	0.00	0.34	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
27	0.00	0.36	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.46	0.00	0.00	NA	NA	NA	NA
28	0.00	0.36	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.77	0.00	0.00	NA	NA	NA	NA
29	0.00	0.37	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.67	0.00	0.00	-	-	-	-	0.00	0.53	0.00	0.00	0.00	0.48	0.00	0.00	NA	NA	NA	NA
30	0.00	0.33	0.00	0.00	1.61	6.45	0.22	0.00	0.00	0.56	0.00	0.00	0.00	0.71	0.00	0.00	-	-	-	-	0.00	0.55	0.00	0.00	0.00	0.45	0.00	0.00	NA	NA	NA	NA
31	0.00	0.36	0.00	0.00	-	-	-	-	0.00	0.56	0.00	0.00	0.00	0.70	0.00	0.00	-	-	-	-	0.00	0.49	0.00	0.00	-	-	-	-	NA	NA	NA	NA
Total			0.00	0.00			1.21	0.00			117.58	4.62			0.00	0.00			2.85	0.00			0.00	0.00			0.00	0.00			0.00	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

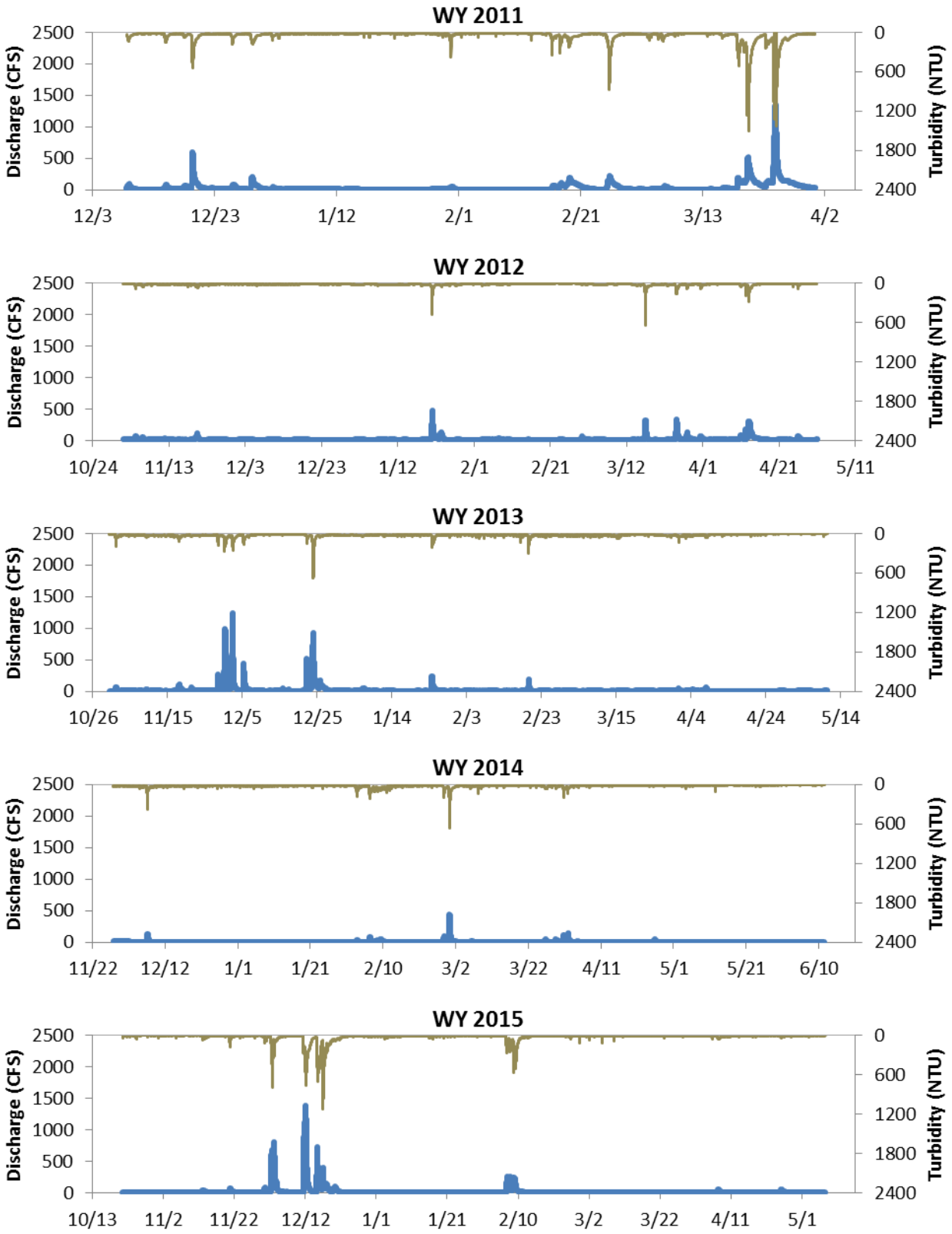


Figure A3a. Turbidity and discharge on Arroyo Mocho at Pleasanton (AMP) as measured during the study period. The turbidity sensor went out of range and is plotted at the sensor maximum during the storms on 3/20/2011 and 3/24/2011.

AMP Model Summaries

AMP - WY 2011

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that both correlated to SSC but the p-value for discharge was larger than 0.025 and so only turbidity was used. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A $\log_{10}$-transformed data model for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The regression and residual plot of the selected model is provided in Figure A3b.

The final model for AMP WY 2011 is:

$$\log_{10}(SSC) = 0.99133 \log_{10}(Turb) + 0.13354$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 52
Root-mean-squared error (RMSE) = 0.17736
Model standard percentage error (MSPE) = -33.5 to +50.4%
Adjusted coefficient of determination (R^2_a) = 0.90
p-value = < 2.2e-16
Duan bias correction factor = 1.398

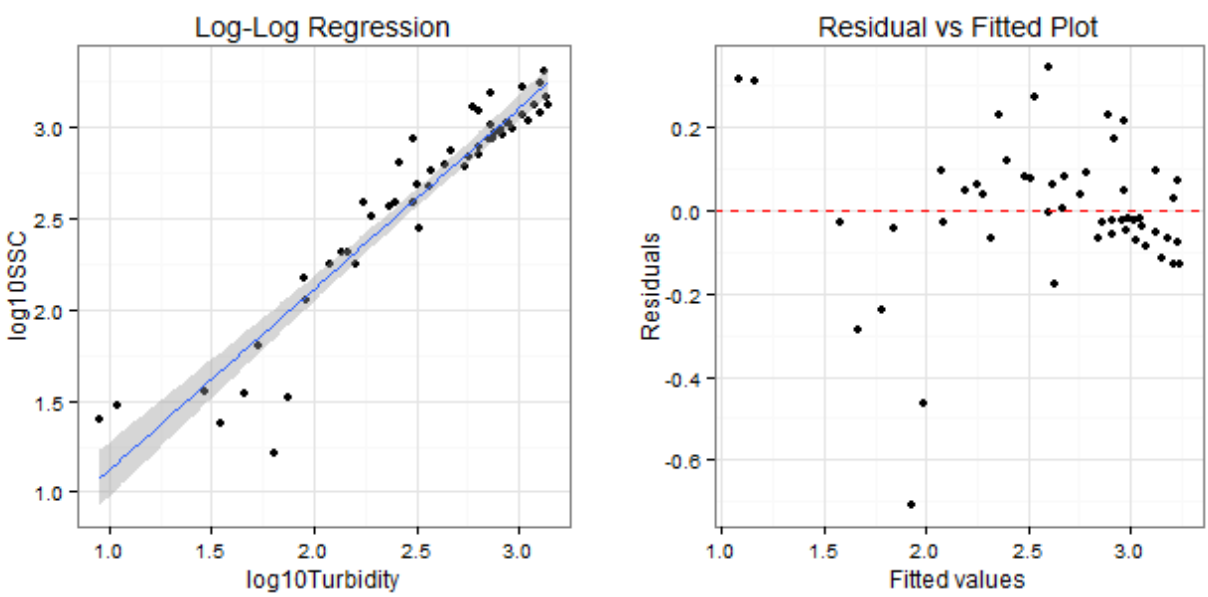


Figure A3b. Regression and residual plots of suspended sediment concentration as a function of turbidity during the study period on Arroyo Mocho at Pleasanton (AMP) during WY 2011.

AMP - WY 2012

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that both correlated to SSC but the p-value for discharge was larger than 0.025 and so only turbidity was used. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A $\log_{10}$-transformed data model for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The regression and residual plot of the selected model is provided in Figure A3c.

The final model for AMP WY 2012 is:

$$\log_{10}(SSC) = 1.04973 \log_{10}(Turb) + 0.40833$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 37
Root-mean-squared error (RMSE) = 0.2093
Model standard percentage error (MSPE) = -38.2 to +61.9%
Adjusted coefficient of determination (R^2_a) = 0.86
p-value = < 2.2e-16
Duan bias correction factor = 1.5373

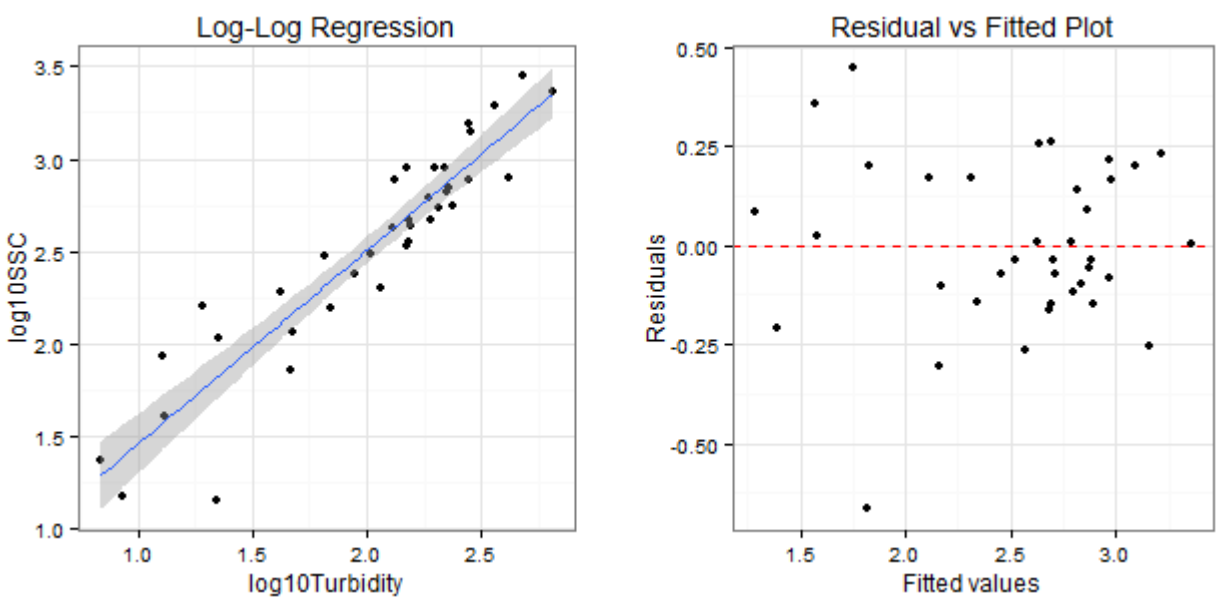


Figure A3c. Regression and residual plots of suspended sediment concentration as a function of turbidity during the study period on Arroyo Mocho at Pleasanton (AMP) during WY 2012.

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that both potential explanatory variables correlated to SSC. Regression analysis was performed in R. Simple and multi-linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A multi-linear regression model on $\log_{10}$-transformed data was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The predicted/fitted versus observed and standardized residual plot of the selected model is provided in Figure A3d.

The final model for AMP – WY 2013 is:

$$\log_{10}(SSC) = 0.6062 \log_{10}(Turb) + 0.7013 \log_{10}(Q) - 0.4477$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU
Q = discharge in cubic feet per second

Model information:

Number of Measurements = 16
Root-mean-squared error (RMSE) = 0.113
Model standard percentage error (MSPE) = -22.9 to +29.6
Adjusted coefficient of determination (R^2_a) = 0.67
p-value = 0.00027
Duan bias correction factor = 1.22393

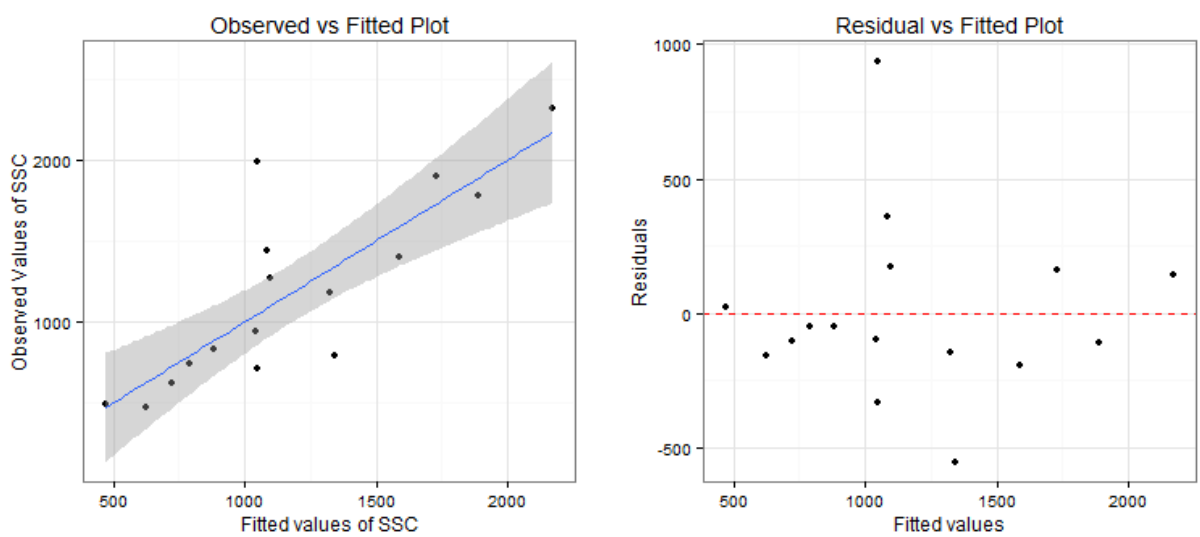


Figure A3d. Observed versus fitted values and standardized residual plots of suspended sediment concentration as a function of turbidity and discharge during the study period on Arroyo Mocho at Pleasanton (AMP) for WY 2013.

AMP – All WYs combined (used to estimate WY 2014)

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that both potential explanatory variables correlated to SSC. Regression analysis was performed in R. Simple and multi-linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A multi-linear regression model on $\log_{10}$-transformed data was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The predicted/fitted versus observed and standardized residual plot of the selected model is provided in Figure A3e.

The final model for AMP – All WYs combined is:

$$\log_{10}(SSC) = 0.58056 \log_{10}(Turb) + 0.28678 \log_{10}(Q) + 0.60635$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU
Q = discharge in cubic feet per second

Model information:

Number of Measurements = 147
Root-mean-squared error (RMSE) = 0.23
Model standard percentage error (MSPE) = -41.1 to +69.7%
Adjusted coefficient of determination (R^2_a) = 0.77
p-value = <2.2e-16
Duan bias correction factor = 1.609262

Figure A3e. Observed versus fitted values and standardized residual plots of suspended sediment concentration as a function of turbidity and discharge during the study period on Arroyo Mocho at Pleasanton (AMP) for all WYs combined.

AMP - WY 2015

Plots of SSC (response variable) versus turbidity (potential explanatory variable) and discharge (potential explanatory variable) indicated that only turbidity correlated to SSC. Regression analysis was performed in R. Simple linear regressions on untransformed and $\log_{10}$-transformed data were evaluated. A $\log_{10}$-transformed data model for SSC and turbidity was selected on the basis of the residual plots, a higher adjusted R^2 and narrower model standard percentage error (MSPE). The Duan bias correction factor (Duan, 1983) was applied during retransformation. The regression and residual plot of the selected model is provided in Figure A3f.

The final model for AMP WY 2015 is:

$$\log_{10}(SSC) = 0.90234 \log_{10}(Turb) + 0.35547$$

where

SSC = suspended sediment concentraton in mg/L
Turb= turbidity in NTU

Model information:

Number of Measurements = 42
Root-mean-squared error (RMSE) = 0.1336
Model standard percentage error (MSPE) = -26.5 to +36.02%
Adjusted coefficient of determination (R^2_a) = 0.69
p-value = 5.293e-12
Duan bias correction factor = 1.29749

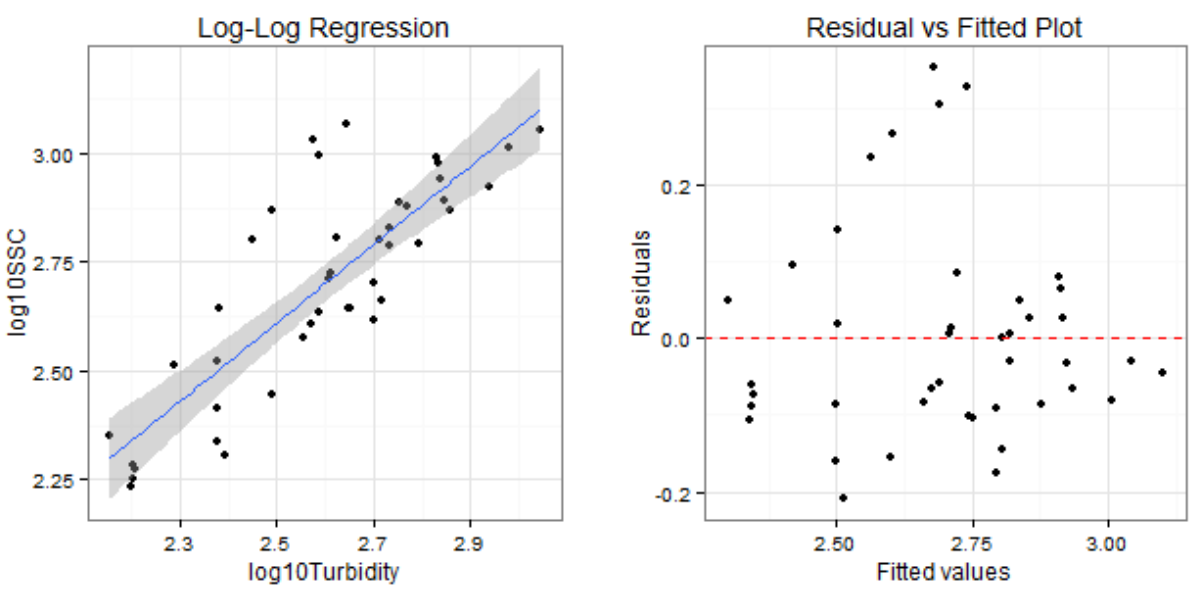


Figure A3f. Regression and residual plots of suspended sediment concentration as a function of turbidity during the study period on Arroyo Mocho at Pleasanton (AMP) during WY 2015.

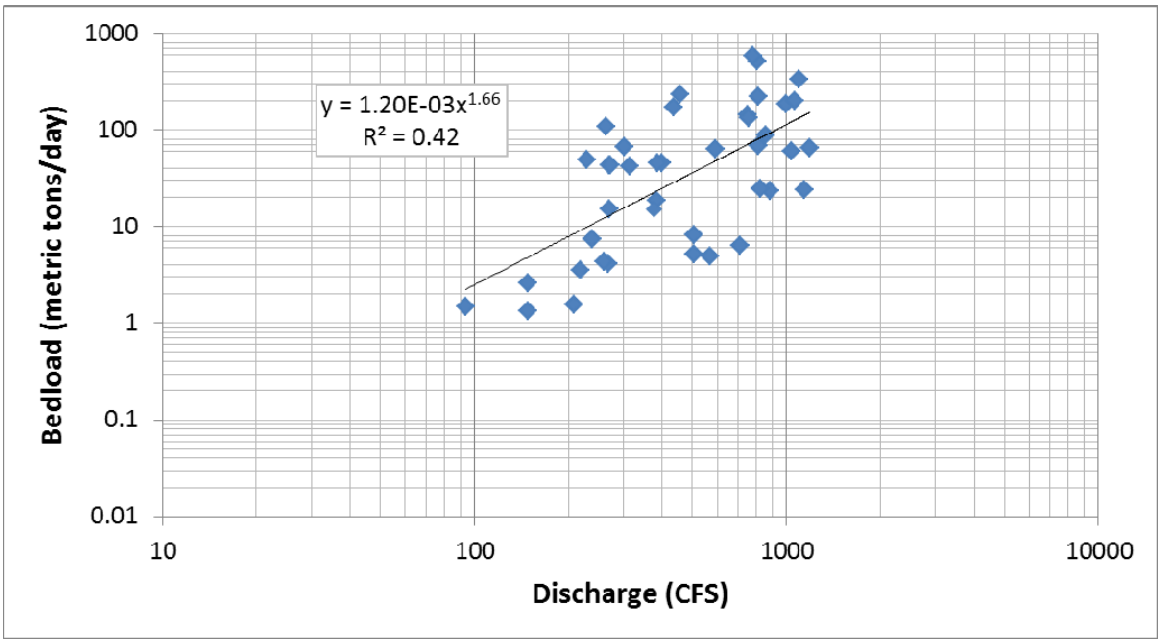


Figure A3g. Relationship between discharge and bedload transport rates at the Arroyo Mocho at Pleasanton (AMP) gage location.

Tables A3. Daily results from monitoring at Arroyo Mocho at Pleasanton (AMP) for each WY.

WY 2011 Daily Results

	DECEMBER				JANUARY				FEBRUARY				MARCH			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	25.06	71.37	5.27	0.00	4.19	31.01	0.95	0.00	10.55	35.75	0.95	0.00
2	NA	NA	NA	NA	19.21	62.01	3.03	0.00	3.61	23.09	1.18	0.00	11.46	41.96	1.18	0.00
3	NA	NA	NA	NA	13.09	36.19	1.15	0.00	2.43	21.86	1.31	0.00	11.31	47.57	1.31	0.00
4	NA	NA	NA	NA	16.19	35.79	1.42	0.00	1.78	21.22	1.88	0.00	11.65	67.23	1.88	0.00
5	NA	NA	NA	NA	16.40	34.18	1.37	0.00	1.63	16.70	1.44	0.00	12.71	46.32	1.44	0.00
6	NA	NA	NA	NA	17.97	33.13	1.45	0.00	1.54	13.76	10.06	0.00	34.99	107.61	10.06	0.00
7	NA	NA	NA	NA	17.07	33.66	1.41	0.00	1.57	14.92	4.66	0.00	30.83	57.70	4.66	0.00
8	57.75 *P*	130.16 *P*	9.37 *P*	0.08 *P*	15.39	35.52	1.33	0.00	1.97	15.57	0.92	0.00	8.71	42.30	0.92	0.00
9	39.33	79.65	3.03	0.16	16.74	33.32	1.37	0.00	1.61	15.15	0.41	0.00	5.20	32.38	0.41	0.00
10	10.03	35.52	1.15	0.00	16.06	33.76	1.33	0.00	2.00	20.63	0.28	0.00	4.26	26.48	0.28	0.00
11	7.88	30.56	1.42	0.00	16.46	36.13	1.46	0.00	2.54	21.55	0.23	0.00	3.87	23.85	0.23	0.00
12	7.54	27.74	1.37	0.00	13.25	28.66	1.01	0.00	2.15	39.65	0.12	0.00	2.98	17.00	0.12	0.00
13	8.04	27.15	1.45	0.00	13.77	32.43	1.20	0.00	1.40	21.37	0.27	0.00	3.55	26.21	0.27	0.00
14	17.26	66.67	1.41	0.00	21.39	40.66	2.13	0.00	3.15	27.17	0.93	0.00	11.54	32.49	0.93	0.00
15	42.11	106.95	1.33	0.00	13.62	29.90	1.07	0.00	5.38	35.12	0.43	0.00	6.02	29.16	0.43	0.00
16	19.09	37.68	1.37	0.00	4.52	25.87	0.28	0.00	43.94	147.15	6.62	0.00	32.16	83.06	6.62	0.00
17	23.36	46.03	1.33	0.00	4.72	21.71	0.24	0.00	59.06	151.39	3.16	0.70	22.90	55.70	3.16	0.00
18	45.58	70.56	1.46	0.00	7.58	21.16	0.40	0.00	77.56	113.47	79.96	0.63	61.65	249.99	79.96	1.66
19	204.84	359.46	1.01	68.10	6.63	23.17	0.39	0.00	142.34	201.31	111.21	4.60	126.66	356.28	111.21	3.73
20	72.72	108.04	1.20	0.75	5.38	21.00	0.27	0.00	87.45	96.61	1049.17	1.28	307.92	1156.40	1049.17	17.68
21	26.36	40.89	2.13	0.00	6.62	29.43	0.48	0.00	43.06	52.32	124.65	0.00	148.71	313.65	124.65	5.00
22	25.06	42.55	1.07	0.00	8.63	27.16	0.57	0.00	22.05	36.19	22.04	0.00	81.07	105.61	22.04	0.82
23	21.32	39.11	0.28	0.00	8.27	27.82	0.56	0.00	11.28	31.15	61.27	0.00	101.16	214.15	61.27	2.36
24	18.57	37.85	0.24	0.00	7.88	24.11	0.46	0.00	7.38	42.70	1981.69	0.00	449.51	940.39	1981.69	45.13
25	25.24	65.88	0.40	0.00	7.85	21.87	0.42	0.00	111.56	436.53	1223.52	3.61	395.79	879.69	1223.52	31.06
26	52.20	92.74	0.39	0.00	7.97	23.04	0.45	0.00	102.33	187.18	68.86	2.11	145.85	192.11	68.86	4.69
27	20.86	39.94	0.27	0.00	10.56	29.50	0.79	0.00	41.31	60.72	38.56	0.00	118.34	129.77	38.56	3.33
28	15.81	45.35	0.48	0.00	14.16	38.28	1.33	0.00	17.65	39.56	13.24	0.00	83.53	63.59	13.24	0.64
29	120.56	191.40	0.57	3.04	14.76	39.69	1.43	0.00	-	-	-	-	57.81	41.22	5.87	0.00
30	38.84	69.06	0.56	0.00	31.36	124.75	12.76	0.00	-	-	-	-	42.62	35.46	3.70	0.00
31	13.33	39.61	0.46	0.00	21.17	51.87	3.10	0.00	-	-	-	-	35.79 *P*	37.18 *P*	1.49 *P*	0.00 *P*
Total			24.40	72.13			49.95	0.00			4809.02	12.93			4820.09	116.11

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2012 Daily Results

	NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	14.84	41.57	1.51	0.00	13.23	83.45	2.72	0.00	13.71	107.97	3.61	0.00	3.05	52.34	0.39	0.00	20.75	92.59	4.70	0.00	18.05	121.01	5.82	0.00
2	14.85	49.30	1.78	0.00	18.01	85.33	3.79	0.00	13.24	112.47	3.64	0.00	3.58	49.21	0.44	0.00	10.41	70.83	1.92	0.00	7.68	85.02	1.67	0.00
3	15.90	44.96	1.75	0.00	18.41	82.16	3.70	0.00	7.48	93.04	1.78	0.00	16.00	103.99	4.25	0.00	11.44	96.77	2.94	0.00	13.10	72.28	2.33	0.00
4	32.77	164.17	17.39	0.00	18.84	90.77	4.19	0.00	3.20	65.63	0.52	0.00	18.27	97.44	4.35	0.00	18.17	114.25	5.08	0.00	20.01	83.78	4.12	0.00
5	11.65	98.66	3.17	0.00	7.87	80.60	1.60	0.00	3.22	69.07	0.55	0.00	17.49	91.34	3.91	0.00	15.02	110.15	4.06	0.00	19.70	80.31	3.88	0.00
6	24.71	162.61	11.40	0.00	3.07	98.38	0.75	0.00	8.71	108.91	3.00	0.00	17.15	88.93	3.74	0.00	8.14	138.56	2.62	0.00	18.75	72.87	3.34	0.00
7	10.49	81.64	1.96	0.00	2.95	88.16	0.63	0.00	18.14	138.16	6.13	0.00	22.79	96.78	5.42	0.00	2.69	80.65	0.54	0.00	12.38	70.95	2.18	0.00
8	14.32	74.67	2.62	0.00	9.75	109.01	2.61	0.00	18.15	125.40	5.57	0.00	16.25	91.42	3.66	0.00	3.68	91.73	0.83	0.00	20.04	63.39	3.11	0.00
9	14.07	72.24	2.49	0.00	18.99	93.67	4.34	0.00	13.61	115.84	4.01	0.00	10.40	89.54	2.32	0.00	3.34	96.78	0.80	0.00	19.87	60.02	2.92	0.00
10	22.26	104.25	5.68	0.00	18.36	96.00	4.31	0.00	18.50	125.96	5.70	0.00	12.31	94.65	3.34	0.00	2.93	83.32	0.60	0.00	28.31	89.30	8.14	0.00
11	25.08	98.98	6.07	0.00	18.53	94.75	4.31	0.00	9.79	112.60	2.83	0.00	3.05	42.49	0.32	0.00	2.49	72.57	0.44	0.00	48.71	131.95	18.14	0.00
12	23.18	94.88	5.43	0.00	9.49	91.56	2.12	0.00	6.09	96.64	1.44	0.00	2.66	38.95	0.26	0.00	2.54	59.04	0.36	0.00	71.70	204.13	47.61	0.83
13	22.04	91.86	4.95	0.00	6.57	98.05	1.58	0.00	11.97	111.79	3.60	0.00	4.74	46.59	0.58	0.00	11.58	95.73	3.39	0.00	189.82	433.80	219.88	8.60
14	12.31	70.40	2.37	0.00	6.65	96.88	1.59	0.00	11.82	113.73	3.48	0.00	5.50	41.45	0.57	0.00	13.30	140.45	4.75	0.00	56.29	141.54	20.87	0.01
15	11.87	82.79	2.45	0.00	10.32	95.66	2.50	0.00	2.39	79.01	0.46	0.00	7.14	62.12	1.10	0.00	14.22	155.23	5.54	0.00	32.33	89.87	7.19	0.00
16	12.05	92.60	2.72	0.00	18.69	90.19	4.13	0.00	2.83	80.45	0.55	0.00	3.13	48.76	0.38	0.00	44.16	308.44	108.06	1.20	21.76	75.92	4.05	0.00
17	9.18	83.50	1.96	0.00	18.15	84.12	3.73	0.00	3.12	70.86	0.54	0.00	2.55	29.41	0.18	0.00	87.77	411.27	146.07	2.69	19.65	70.94	3.41	0.00
18	9.17	87.44	2.61	0.00	18.16	72.83	3.24	0.00	14.73	121.58	4.68	0.00	2.65	29.69	0.19	0.00	6.79	162.33	2.84	0.00	6.71	65.38	1.10	0.00
19	22.70	103.85	5.87	0.00	14.18	68.85	2.35	0.00	18.50	126.32	5.72	0.00	2.46	36.38	0.22	0.00	8.21	99.61	2.13	0.00	3.23	51.88	0.41	0.00
20	44.63	168.59	20.01	0.05	7.24	70.19	1.24	0.00	30.96	169.11	26.97	0.39	2.37	29.22	0.17	0.00	6.81	105.88	1.76	0.00	8.85	59.01	1.63	0.00
21	8.71	100.48	2.06	0.00	6.85	74.94	1.25	0.00	169.91	490.00	327.98	7.51	2.38	31.96	0.19	0.00	6.59	94.98	1.54	0.00	19.60	71.41	3.43	0.00
22	3.44	90.33	0.76	0.00	4.47	94.30	1.00	0.00	31.11	129.64	9.94	0.00	2.70	23.97	0.16	0.00	10.06	110.37	3.26	0.00	18.51	60.05	2.74	0.00
23	13.84	94.17	3.32	0.00	3.93	87.92	0.85	0.00	68.45	151.22	27.64	0.66	9.63	39.38	1.21	0.00	13.90	122.60	4.20	0.00	10.61	60.12	1.60	0.00
24	19.90	87.07	4.24	0.00	2.56	89.87	0.59	0.00	13.27	111.30	3.83	0.00	9.30	53.94	1.35	0.00	20.33	125.85	10.85	0.19	5.67	54.60	0.78	0.00
25	19.14	82.41	3.87	0.00	2.39	71.66	0.42	0.00	5.83	84.34	1.22	0.00	2.21	32.32	0.18	0.00	136.96	404.47	183.16	4.85	6.18	49.85	1.21	0.00
26	19.06	73.84	3.45	0.00	2.40	76.14	0.44	0.00	5.33	68.18	0.90	0.00	2.24	29.76	0.17	0.00	17.98	112.89	5.05	0.00	30.65	134.47	13.39	0.00
27	19.03	72.26	3.36	0.00	3.78	84.04	0.79	0.00	15.74	114.84	4.81	0.00	2.40	22.65	0.13	0.00	31.48	135.14	17.82	0.34	5.49	55.21	0.76	0.00
28	7.90	69.07	1.36	0.00	5.52	77.62	1.05	0.00	9.67	95.14	2.59	0.00	4.72	42.65	0.58	0.00	41.00	142.53	17.30	0.22	3.76	38.31	0.36	0.00
29	2.82	74.56	0.52	0.00	2.89	69.92	0.48	0.00	3.09	55.76	0.43	0.00	26.88	87.62	6.00	0.00	14.65	99.51	3.57	0.00	3.12	31.22	0.24	0.00
30	6.13	81.90	1.20	0.00	3.67	68.23	0.63	0.00	2.99	50.56	0.38	0.00	-	-	-	-	7.73	79.31	1.57	0.00	6.84	32.09	0.60	0.00
31	-	-	-	-	7.50	97.87	1.91	0.00	2.94	51.68	0.38	0.00	-	-	-	-	27.83	132.17	11.87	0.00	-	-	-	-
Total			128.35	0.05			64.84	0.00			464.88	8.56			45.74	0.00			559.62	9.48			386.92	9.44

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2013 Daily Results

	October				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	30.60	59.37	6.32	0.00	52.05	64.06	9.19	0.00	18.19	22.38	1.00	0.00	6.23	7.98	0.12	0.00	17.25	21.51	0.91	0.00	14.44	25.81	1.05	0.00	2.13	1.14	0.01	0.00
2	NA	NA	NA	NA	12.30	16.86	0.54	0.00	367.74	517.32	934.04	29.63	15.86	20.04	0.84	0.00	15.00	15.92	0.67	0.00	17.57	21.64	0.94	0.00	8.66	14.06	0.36	0.00	7.22	3.03	0.10	0.00
3	NA	NA	NA	NA	14.68	16.25	0.59	0.00	48.06	69.48	9.82	0.00	7.40	9.71	0.25	0.00	19.27	19.60	0.93	0.00	17.39	24.56	1.05	0.00	14.33	20.51	0.72	0.00	16.61	6.26	0.26	0.00
4	NA	NA	NA	NA	14.27	17.08	0.60	0.00	17.67	20.95	0.92	0.00	19.03	23.35	1.09	0.00	14.38	15.88	0.63	0.00	7.81	13.06	0.37	0.00	25.95	33.60	2.29	0.00	15.19	5.58	0.22	0.00
5	NA	NA	NA	NA	14.39	18.35	0.65	0.00	136.74	174.98	105.24	5.75	20.10	25.06	1.25	0.00	9.49	11.29	0.34	0.00	3.32	6.50	0.06	0.00	16.06	20.54	0.81	0.00	16.86	6.16	0.25	0.00
6	NA	NA	NA	NA	11.08	16.34	0.50	0.00	41.58	52.79	5.74	0.00	41.77	47.15	4.96	0.00	11.16	13.23	0.36	0.00	7.56	11.33	0.22	0.00	12.03	16.28	0.54	0.00	7.24	3.70	0.09	0.00
7	NA	NA	NA	NA	13.44	17.28	0.66	0.00	20.49	23.13	1.20	0.00	22.34	24.94	1.39	0.00	11.35	13.61	0.38	0.00	15.34	18.80	0.77	0.00	16.23	18.78	0.82	0.00	6.15	2.90	0.05	0.00
8	NA	NA	NA	NA	6.78	9.91	0.27	0.00	19.82	21.74	1.06	0.00	12.03	14.74	0.54	0.00	14.74	17.11	0.65	0.00	21.50	24.00	1.27	0.00	26.45	38.44	3.49	0.00	8.56	2.78	0.06	0.00
9	NA	NA	NA	NA	14.92	24.44	1.20	0.00	17.77	18.01	0.78	0.00	18.45	21.26	0.96	0.00	17.58	21.02	0.91	0.00	18.39	22.18	1.00	0.00	4.12	6.43	0.07	0.00	11.93	4.46	0.14	0.00
10	NA	NA	NA	NA	14.00	20.92	0.79	0.00	13.91	15.03	0.58	0.00	8.70	11.02	0.31	0.00	16.34	19.50	0.78	0.00	17.76	21.65	0.94	0.00	3.16	4.30	0.03	0.00	17.22 *P*	6.24 *P*	0.16 *P*	0.00 *P*
11	NA	NA	NA	NA	17.11	23.38	0.98	0.00	3.81	4.73	0.04	0.00	5.21	7.26	0.12	0.00	7.40	10.18	0.25	0.00	7.91	11.53	0.33	0.00	2.99	3.58	0.03	0.00	NA	NA	NA	NA
12	NA	NA	NA	NA	16.76	23.72	0.97	0.00	10.15	10.02	0.35	0.00	14.92	19.73	0.77	0.00	5.80	8.14	0.14	0.00	3.89	5.86	0.06	0.00	3.11	4.25	0.03	0.00	NA	NA	NA	NA
13	NA	NA	NA	NA	8.80	14.38	0.37	0.00	11.78	10.43	0.41	0.00	18.00	22.53	0.99	0.00	11.36	14.78	0.41	0.00	9.45	14.43	0.37	0.00	3.06	4.73	0.04	0.00	NA	NA	NA	NA
14	NA	NA	NA	NA	6.20	11.83	0.26	0.00	18.20	15.23	0.68	0.00	13.45	17.71	0.67	0.00	11.16	13.30	0.36	0.00	11.25	19.10	0.53	0.00	3.11	5.01	0.04	0.00	NA	NA	NA	NA
15	NA	NA	NA	NA	4.06	7.87	0.09	0.00	20.80	17.91	1.29	0.00	3.39	6.25	0.05	0.00	13.40	14.63	0.50	0.00	16.58	27.93	1.16	0.00	2.73	3.88	0.03	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	5.30	10.41	0.21	0.00	25.96	19.76	1.32	0.00	3.48	5.93	0.05	0.00	7.83	10.48	0.27	0.00	18.32	19.72	0.88	0.00	2.88	3.65	0.03	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	20.98	30.61	2.05	0.02	18.69	14.37	0.75	0.00	3.34	5.55	0.05	0.00	10.21	14.71	0.58	0.00	18.46	18.22	0.82	0.00	2.51	2.98	0.02	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	63.28	93.25	17.06	0.58	5.66	4.96	0.07	0.00	3.68	6.20	0.06	0.00	19.41	20.56	0.98	0.00	7.98	8.13	0.24	0.00	2.55	3.18	0.02	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	10.64	16.35	0.56	0.00	4.52	4.47	0.05	0.00	3.41	6.34	0.05	0.00	50.38	91.32	22.83	0.75	4.47	4.10	0.05	0.00	2.48	2.70	0.02	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	4.80	8.91	0.11	0.00	4.05	4.14	0.04	0.00	6.11	7.96	0.18	0.00	16.20	28.77	1.59	0.00	15.08	12.75	0.49	0.00	2.61	2.84	0.02	0.00	NA	NA	NA	NA
21	NA	NA	NA	NA	33.32	41.87	4.15	0.00	19.80	17.25	1.12	0.00	9.50	12.44	0.35	0.00	5.82	9.39	0.14	0.00	13.86	10.33	0.35	0.00	2.37	1.86	0.01	0.00	NA	NA	NA	NA
22	NA	NA	NA	NA	20.59	26.69	1.38	0.00	173.70	184.87	138.18	8.47	5.64	7.98	0.15	0.00	15.46	19.73	0.86	0.00	15.67	12.90	0.51	0.00	2.44	1.85	0.01	0.00	NA	NA	NA	NA
23	NA	NA	NA	NA	17.23	23.48	0.99	0.00	238.81	276.59	333.39	15.81	7.28	9.77	0.22	0.00	19.32	22.03	1.04	0.00	18.25	16.19	0.72	0.00	2.22	1.77	0.01	0.00	NA	NA	NA	NA
24	NA	NA	NA	NA	16.91	22.46	0.93	0.00	306.65	686.14	986.63	21.63	46.22	79.63	30.87	1.39	18.32	20.41	0.92	0.00	19.28	17.07	0.81	0.00	2.38	1.77	0.01	0.00	NA	NA	NA	NA
25	NA	NA	NA	NA	16.90	22.17	0.92	0.00	81.29	78.09	18.26	0.99	50.56	85.13	13.34	0.33	9.52	12.67	0.41	0.00	6.39	8.44	0.21	0.00	2.27	1.62	0.01	0.00	NA	NA	NA	NA
26	NA	NA	NA	NA	16.39	21.48	0.86	0.00	90.09	86.03	19.65	1.03	19.51	23.33	1.17	0.00	9.32	11.51	0.39	0.00	8.67	12.71	0.38	0.00	2.49	1.36	0.01	0.00	NA	NA	NA	NA
27	NA	NA	NA	NA	14.71	18.92	0.76	0.00	38.45	37.98	3.83	0.00	15.92	18.12	0.71	0.00	18.29	23.39	1.05	0.00	14.88	20.00	0.73	0.00	7.52	2.77	0.09	0.00	NA	NA	NA	NA
28	NA	NA	NA	NA	44.07	68.37	19.22	0.91	15.53	17.03	0.69	0.00	7.67	10.32	0.25	0.00	11.99	17.94	0.66	0.00	14.24	20.55	0.72	0.00	16.95	5.65	0.23	0.00	NA	NA	NA	NA
29	NA	NA	NA	NA	16.31	22.77	0.99	0.00	17.43	18.57	0.88	0.00	7.35	8.62	0.20	0.00	-	-	-	-	14.36	21.15	0.75	0.00	6.31	2.53	0.08	0.00	NA	NA	NA	NA
30	2.60 *P*	2.88 *P*	0.01 *P*	0.00 *P*	423.08	552.63	957.52	32.43	19.69	21.92	1.06	0.00	10.25	11.89	0.38	0.00	-	-	-	-	14.23	19.80	0.69	0.00	2.12	1.13	0.01	0.00	NA	NA	NA	NA
31	1.44	2.16	0.01	0.00	-	-	-	-	19.00	22.57	1.05	0.00	13.36	14.53	0.52	0.00	-	-	-	-	22.74	34.21	2.05	0.00	-	-	-	-	NA	NA	NA	NA
Total			0.01	0.00			1022.47	33.95			2578.31	83.30			63.77	1.73			39.12	0.75			20.37	0.00			10.92	0.00			1.17	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2014 Daily Results

	NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May				June			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	16.61	77.14	3.14	0.00	2.17	35.84	0.19	0.00	2.27	31.41	0.17	0.00	18.99	132.94	6.51	0.00	49.52	169.79	25.06	0.40	2.18	21.81	0.12	0.00	1.64	14.93	0.06	0.00
2	NA	NA	NA	NA	6.58	58.58	1.05	0.00	2.20	33.78	0.18	0.00	13.14	121.13	7.69	0.00	6.76	64.49	1.15	0.00	31.50	126.53	13.29	0.14	1.67	22.08	0.09	0.00	1.45	13.73	0.05	0.00
3	NA	NA	NA	NA	5.65	58.20	0.83	0.00	2.38	36.61	0.21	0.00	10.90	110.82	3.71	0.00	4.11	43.55	0.44	0.00	5.10	52.35	0.68	0.00	1.54	24.07	0.09	0.00	1.25	13.55	0.04	0.00
4	NA	NA	NA	NA	3.79	59.81	0.56	0.00	2.23	38.51	0.22	0.00	2.83	53.83	0.38	0.00	7.53	56.75	1.07	0.00	9.82	58.13	1.51	0.00	1.60	24.72	0.10	0.00	3.05	18.14	0.14	0.00
5	NA	NA	NA	NA	4.47	67.35	0.82	0.00	2.40	36.05	0.21	0.00	2.42	41.19	0.24	0.00	3.78	47.75	0.44	0.00	5.37	44.23	0.60	0.00	1.48	22.08	0.08	0.00	1.51	13.76	0.05	0.00
6	NA	NA	NA	NA	10.46	83.33	2.39	0.00	2.26	39.11	0.22	0.00	30.96	203.44	21.87	0.00	11.56	87.40	2.69	0.00	3.17	35.80	0.28	0.00	1.50	21.81	0.08	0.00	1.14	12.79	0.04	0.00
7	NA	NA	NA	NA	51.19	240.59	40.44	0.54	2.16	33.63	0.18	0.00	11.05	125.08	3.53	0.00	3.85	51.04	0.49	0.00	3.11	34.55	0.27	0.00	1.43	20.24	0.07	0.00	1.03	12.72	0.03	0.00
8	NA	NA	NA	NA	5.13	74.83	0.97	0.00	2.45	41.09	0.25	0.00	18.87	149.36	7.70	0.00	2.95	50.70	0.37	0.00	2.96	32.44	0.24	0.00	1.36	19.10	0.06	0.00	0.93	11.38	0.03	0.00
9	NA	NA	NA	NA	3.28	58.41	0.47	0.00	3.04	43.82	0.33	0.00	30.09	167.37	12.84	0.00	2.72	38.20	0.25	0.00	2.34	29.17	0.17	0.00	1.36	18.84	0.06	0.00	0.90	9.63	0.02	0.00
10	NA	NA	NA	NA	3.05	50.19	0.38	0.00	2.30	35.35	0.20	0.00	10.97	116.45	3.29	0.00	2.82	34.92	0.24	0.00	2.55	28.68	0.18	0.00	1.37	19.92	0.07	0.00	1.08	10.05	0.03	0.00
11	NA	NA	NA	NA	2.82	50.05	0.34	0.00	2.49	39.09	0.24	0.00	4.26	85.18	0.91	0.00	2.77	34.35	0.23	0.00	2.53	30.13	0.19	0.00	1.30	19.15	0.06	0.00	1.05 *P*	10.04 *P*	0.01 *P*	0.00 *P*
12	NA	NA	NA	NA	2.64	47.38	0.31	0.00	2.33	32.51	0.19	0.00	3.25	51.72	0.42	0.00	2.48	31.78	0.19	0.00	2.36	25.78	0.15	0.00	1.56	25.58	0.10	0.00	NA	NA	NA	NA
13	NA	NA	NA	NA	4.49	51.66	0.60	0.00	2.33	33.84	0.19	0.00	2.84	42.54	0.30	0.00	2.45	28.76	0.17	0.00	2.25	24.65	0.14	0.00	1.43	21.86	0.08	0.00	NA	NA	NA	NA
14	NA	NA	NA	NA	2.90	44.82	0.32	0.00	2.42	39.10	0.23	0.00	2.85	44.60	0.32	0.00	2.54	26.84	0.17	0.00	2.26	25.16	0.14	0.00	1.29	19.11	0.06	0.00	NA	NA	NA	NA
15	NA	NA	NA	NA	2.45	42.73	0.26	0.00	2.34	31.60	0.18	0.00	2.80	44.78	0.32	0.00	2.62	27.99	0.18	0.00	2.27	26.56	0.15	0.00	1.18	17.08	0.05	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	2.28	45.66	0.26	0.00	2.49	36.02	0.22	0.00	2.99	43.85	0.33	0.00	2.49	24.13	0.15	0.00	2.25	26.34	0.15	0.00	1.18	16.09	0.05	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	2.44	42.58	0.26	0.00	2.33	34.48	0.20	0.00	2.23	40.46	0.22	0.00	2.51	23.25	0.14	0.00	2.23	27.44	0.15	0.00	1.23	17.81	0.05	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	2.49	41.94	0.26	0.00	2.44	32.05	0.20	0.00	2.10	38.45	0.20	0.00	2.39	24.24	0.14	0.00	2.33	28.04	0.16	0.00	1.33	20.55	0.07	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	2.28	38.44	0.22	0.00	2.37	31.03	0.18	0.00	2.87	40.84	0.29	0.00	2.56	26.73	0.17	0.00	2.23	29.17	0.16	0.00	1.40	17.93	0.06	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	2.29	41.91	0.23	0.00	2.38	32.18	0.19	0.00	2.20	37.34	0.20	0.00	2.74	26.93	0.18	0.00	1.74	26.98	0.12	0.00	1.31	21.45	0.07	0.00	NA	NA	NA	NA
21	NA	NA	NA	NA	2.07	36.67	0.19	0.00	2.43	35.32	0.21	0.00	2.08	36.30	0.19	0.00	2.47	27.46	0.17	0.00	1.68	26.82	0.11	0.00	1.31	20.40	0.07	0.00	NA	NA	NA	NA
22	NA	NA	NA	NA	2.22	41.29	0.23	0.00	2.52	30.39	0.19	0.00	2.18	36.04	0.19	0.00	2.41	27.33	0.16	0.00	1.54	27.79	0.10	0.00	1.40	19.50	0.07	0.00	NA	NA	NA	NA
23	NA	NA	NA	NA	2.13	40.16	0.21	0.00	2.63	32.80	0.21	0.00	2.30	38.69	0.22	0.00	2.36	24.34	0.14	0.00	1.64	26.92	0.11	0.00	1.27	20.16	0.06	0.00	NA	NA	NA	NA
24	NA	NA	NA	NA	2.46	35.50	0.22	0.00	2.66	36.21	0.24	0.00	2.35	37.53	0.22	0.00	2.32	27.26	0.15	0.00	1.76	27.17	0.12	0.00	1.88	27.21	0.13	0.00	NA	NA	NA	NA
25	NA	NA	NA	NA	2.10	36.48	0.19	0.00	2.42	31.98	0.20	0.00	1.93	31.30	0.15	0.00	3.40	35.43	0.36	0.00	13.50	49.78	2.43	0.00	2.46	23.49	0.14	0.00	NA	NA	NA	NA
26	NA	NA	NA	NA	2.16	34.85	0.19	0.00	2.54	35.23	0.22	0.00	22.35	128.87	14.98	0.05	18.01	97.67	6.11	0.00	11.32	46.56	1.46	0.00	1.61	23.81	0.09	0.00	NA	NA	NA	NA
27	17.83 *P*	81.57 *P*	1.04 *P*	0.00 *P*	2.26	40.08	0.22	0.00	2.45	34.42	0.21	0.00	24.59	134.63	9.80	0.00	9.82	79.82	2.50	0.00	3.40	29.60	0.25	0.00	1.40	23.07	0.08	0.00	NA	NA	NA	NA
28	17.94	80.07	3.52	0.00	2.13	34.07	0.18	0.00	2.43	30.47	0.18	0.00	135.32	473.22	262.70	5.88	3.19	41.19	0.32	0.00	2.43	25.59	0.15	0.00	1.29	17.91	0.06	0.00	NA	NA	NA	NA
29	17.26	73.52	3.11	0.00	2.37	34.54	0.20	0.00	2.17	32.28	0.17	0.00	-	-	-	-	15.52	76.73	4.42	0.00	2.15	23.11	0.12	0.00	2.01	16.08	0.08	0.00	NA	NA	NA	NA
30	17.17	74.60	3.14	0.00	2.10	33.59	0.18	0.00	3.15	39.55	0.31	0.00	-	-	-	-	14.31	69.25	2.78	0.00	2.75	23.23	0.16	0.00	1.54	15.81	0.06	0.00	NA	NA	NA	NA
31	-	-	-	-	2.23	38.55	0.21	0.00	3.03	36.78	0.27	0.00	-	-	-	-	32.86	133.73	21.93	0.33	-	-	-	-	1.38	14.82	0.05	0.00	-	-	-	-
Total			10.81	0.00			56.36	0.54			6.66	0.00			353.39	5.93			54.42	0.33			48.81	0.54			2.35	0.00			0.50	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

WY 2015 Daily Results

	October				NOVEMBER				DECEMBER				JANUARY				FEBRUARY				MARCH				APRIL				May			
DAY	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)	Q(cfs) avg	Mean SS Conc	SS Load (tons)	Bedload (tons)
1	NA	NA	NA	NA	5.29	14.63	0.19	0.00	19.51	59.79	3.42	0.00	3.23	29.66	0.23	0.00	2.22	17.33	0.09	0.00	2.22	19.96	0.11	0.00	1.45	22.83	0.08	0.00	1.20	14.56	0.04	0.00
2	NA	NA	NA	NA	3.01	14.60	0.11	0.00	252.28	264.87	246.28	16.59	3.01	26.79	0.20	0.00	2.28	20.25	0.11	0.00	2.07	18.41	0.09	0.00	1.36	22.38	0.07	0.00	1.15	14.99	0.04	0.00
3	NA	NA	NA	NA	1.56	10.57	0.04	0.00	268.04	201.37	172.27	16.82	3.15	27.10	0.21	0.00	2.35	20.21	0.12	0.00	2.81	16.35	0.12	0.00	1.30	21.39	0.07	0.00	1.16	18.78	0.05	0.00
4	NA	NA	NA	NA	1.37	10.86	0.04	0.00	31.47	83.51	6.91	0.00	3.01	25.98	0.19	0.00	2.27	20.41	0.11	0.00	2.33	16.29	0.09	0.00	1.32	21.61	0.07	0.00	1.20	16.70	0.05	0.00
5	NA	NA	NA	NA	1.31	12.26	0.04	0.00	14.17	44.24	1.55	0.00	2.79	25.21	0.17	0.00	2.31	18.95	0.11	0.00	2.08	18.96	0.10	0.00	2.65	33.46	0.25	0.00	1.19	15.69	0.05	0.00
6	NA	NA	NA	NA	1.11	12.04	0.03	0.00	9.40	30.54	0.71	0.00	2.75	24.33	0.16	0.00	54.61	124.90	37.43	1.77	2.10	17.55	0.09	0.00	3.14	20.35	0.16	0.00	1.23	14.05	0.04	0.00
7	NA	NA	NA	NA	1.19	8.48	0.02	0.00	6.92	24.07	0.41	0.00	2.69	22.55	0.15	0.00	123.47	193.96	67.53	3.39	2.01	17.58	0.09	0.00	33.38	70.37	6.81	0.00	1.23 *P*	18.26 *P*	0.03 *P*	0.00 *P*
8	NA	NA	NA	NA	1.27	8.21	0.03	0.00	3.63	18.84	0.17	0.00	2.66	18.59	0.12	0.00	113.41	318.71	107.99	3.49	1.97	23.12	0.11	0.00	9.03	47.97	1.25	0.00	NA	NA	NA	NA
9	NA	NA	NA	NA	1.29	11.20	0.04	0.00	2.88	17.54	0.12	0.00	2.53	18.36	0.11	0.00	90.58	434.57	106.35	2.20	1.95	17.06	0.08	0.00	2.52	37.07	0.23	0.00	NA	NA	NA	NA
10	NA	NA	NA	NA	1.25	10.62	0.03	0.00	2.70	16.64	0.11	0.00	2.50	20.47	0.12	0.00	19.20	122.08	6.03	0.00	1.86	15.11	0.07	0.00	1.91	39.07	0.18	0.00	NA	NA	NA	NA
11	NA	NA	NA	NA	1.19	8.01	0.02	0.00	456.01	232.36	454.25	48.02	2.44	22.04	0.13	0.00	9.04	69.72	1.55	0.00	5.24	20.40	0.28	0.00	1.84	26.30	0.12	0.00	NA	NA	NA	NA
12	NA	NA	NA	NA	1.07	9.93	0.03	0.00	562.73	705.33	1211.50	60.69	2.42	18.20	0.11	0.00	4.91	49.26	0.59	0.00	4.29	18.85	0.20	0.00	1.47	19.98	0.07	0.00	NA	NA	NA	NA
13	NA	NA	NA	NA	22.22	58.69	3.43	0.00	38.50	254.24	27.17	0.00	2.30	18.80	0.11	0.00	4.23	33.30	0.35	0.00	2.28	15.10	0.08	0.00	1.25	23.59	0.07	0.00	NA	NA	NA	NA
14	NA	NA	NA	NA	7.15	30.07	0.64	0.00	14.18	83.87	3.07	0.00	2.38	17.01	0.10	0.00	3.58	25.07	0.22	0.00	2.23	15.86	0.09	0.00	1.20	20.19	0.06	0.00	NA	NA	NA	NA
15	NA	NA	NA	NA	2.04	15.45	0.08	0.00	279.95	605.44	487.42	18.25	2.73	31.84	0.25	0.00	3.06	19.65	0.15	0.00	1.83	16.74	0.08	0.00	1.35	18.19	0.06	0.00	NA	NA	NA	NA
16	NA	NA	NA	NA	1.64	13.57	0.06	0.00	101.91	382.63	98.02	2.44	3.13	57.71	0.48	0.00	3.35	18.57	0.15	0.00	1.61	16.30	0.06	0.00	1.31	16.90	0.05	0.00	NA	NA	NA	NA
17	NA	NA	NA	NA	1.18	14.14	0.04	0.00	133.96	652.16	256.06	4.02	2.66	33.18	0.22	0.00	2.97	16.16	0.12	0.00	1.96	13.86	0.07	0.00	1.35	18.41	0.06	0.00	NA	NA	NA	NA
18	NA	NA	NA	NA	1.26	13.79	0.04	0.00	72.53	290.84	54.26	0.95	2.46	21.19	0.13	0.00	2.77	13.41	0.09	0.00	1.57	15.61	0.06	0.00	1.28	17.90	0.06	0.00	NA	NA	NA	NA
19	NA	NA	NA	NA	1.28	12.82	0.04	0.00	32.05	163.34	12.55	0.00	2.55	20.14	0.13	0.00	2.99	15.86	0.12	0.00	1.68	14.47	0.06	0.00	1.28	15.07	0.05	0.00	NA	NA	NA	NA
20	NA	NA	NA	NA	13.40	61.19	5.07	0.00	60.22	130.51	19.68	0.06	2.33	21.59	0.12	0.00	3.18	16.64	0.13	0.00	1.73	17.11	0.07	0.00	1.24	19.25	0.06	0.00	NA	NA	NA	NA
21	0.93 *P*	13.42 *P*	0.01 *P*	0.00 *P*	20.80	62.28	3.58	0.00	17.80	107.74	4.74	0.00	2.70	16.86	0.10	0.00	2.79	17.08	0.12	0.00	1.65	15.70	0.06	0.00	1.25	15.54	0.05	0.00	NA	NA	NA	NA
22	1.08	10.56	0.03	0.00	6.80	29.97	0.52	0.00	8.69	60.43	1.30	0.00	2.32	14.53	0.08	0.00	2.71	19.04	0.13	0.00	1.67	15.60	0.06	0.00	1.35	12.37	0.04	0.00	NA	NA	NA	NA
23	1.06	11.31	0.03	0.00	3.54	19.86	0.17	0.00	6.64	39.65	0.65	0.00	2.24	14.06	0.08	0.00	2.50	20.94	0.13	0.00	5.95	27.38	0.42	0.00	1.32	14.93	0.05	0.00	NA	NA	NA	NA
24	1.05	11.48	0.03	0.00	2.23	13.73	0.07	0.00	6.03	33.14	0.49	0.00	2.24	16.40	0.09	0.00	2.32	19.67	0.11	0.00	3.25	20.85	0.17	0.00	1.27	14.86	0.05	0.00	NA	NA	NA	NA
25	2.90	17.34	0.14	0.00	1.58	12.49	0.05	0.00	6.14	31.79	0.48	0.00	2.27	15.53	0.09	0.00	2.31	17.03	0.10	0.00	1.86	18.27	0.08	0.00	29.13	45.89	3.47	0.00	NA	NA	NA	NA
26	1.69	10.06	0.04	0.00	1.44	14.30	0.05	0.00	4.36	27.11	0.29	0.00	2.31	15.03	0.09	0.00	2.36	15.66	0.09	0.00	1.73	17.11	0.07	0.00	5.77	32.17	0.50	0.00	NA	NA	NA	NA
27	1.32	7.27	0.02	0.00	1.48	12.40	0.05	0.00	4.16	27.62	0.28	0.00	2.26	14.90	0.08	0.00	2.40	19.11	0.11	0.00	1.60	22.04	0.09	0.00	1.83	19.53	0.09	0.00	NA	NA	NA	NA
28	1.10	8.70	0.02	0.00	1.44	11.50	0.04	0.00	4.02	26.86	0.26	0.00	2.28	17.77	0.10	0.00	2.28	20.78	0.12	0.00	1.54	22.63	0.09	0.00	1.44	20.00	0.07	0.00	NA	NA	NA	NA
29	1.03	8.27	0.02	0.00	1.59	11.64	0.05	0.00	3.78	30.35	0.29	0.00	2.35	19.52	0.11	0.00	-	-	-	-	1.53	21.14	0.08	0.00	1.57	22.08	0.08	0.00	NA	NA	NA	NA
30	0.98	9.58	0.02	0.00	30.46	87.35	10.30	0.00	3.47	28.60	0.24	0.00	2.11	13.59	0.07	0.00	-	-	-	-	1.50	22.36	0.08	0.00	1.27	16.87	0.05	0.00	NA	NA	NA	NA
31	2.84	17.07	0.18	0.00	-	-	-	-	3.25	27.66	0.22	0.00	2.28	16.21	0.09	0.00	-	-	-	-	1.54	21.61	0.08	0.00	-	-	-	-	NA	NA	NA	NA
Total			0.56	0.00			24.89	0.00			3065.17	167.84			4.42	0.00			330.25	10.84			3.29	0.00			14.29	0.00			0.31	0.00

P = Partial indicates data missing within the day

NA indicates no data collected

Appendix B: Suspended Sediment Sample Data

Table B1. Suspended sediment sample data analyzed for the ALPL gage.

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
2/17/2011 5:15	ALP-01-01	10.0	29.7	20.7	
2/17/2011 12:45	ALP-01-02	12.1	28.2	25.2	
2/17/2011 14:30	ALP-01-03	104.9	154.5	390.0	
2/17/2011 15:00	ALP-01-04	101.6	397.9	796.0	
2/17/2011 15:30	ALP-01-05	71.3	298.0	517.0	
2/17/2011 16:15	ALP-01-06	45.7	190.2	279.0	
3/6/2011 4:00	ALP-02-01	9.5	23.4	39.7	
3/6/2011 8:00	ALP-02-02	34.0	92.8	182.0	
3/6/2011 9:00	ALP-02-03	40.0	84.0	152.0	
3/6/2011 10:30	ALP-02-04	63.7	166.6	316.0	
3/6/2011 10:45	ALP-02-05	61.1	135.7	249.0	9%
3/13/2011 20:30	ALP-03-01	13.8	36.9	98.0	
3/13/2011 21:00	ALP-03-02	13.2	28.6	58.4	13%
3/16/2011 0:45	ALP-03-03	22.3	53.1	128.0	
3/16/2011 5:30	ALP-03-07	25.9	46.7	67.0	0%
3/16/2011 9:15	ALP-03-08	25.9	28.9	36.6	
3/18/2011 14:30	ALP-03-12	101.6	207.5	387.0	
3/20/2011 0:00	ALP-04-12	129.2	399.4	738.0	9%
3/20/2011 4:15	ALP-04-14	91.0	1122.0	1038.0	2%
3/20/2011 4:45	ALP-04-15	87.5	1418.0	1125.0	2%
3/20/2011 6:30	ALP-04-16	68.3	1320.0	980.0	1%
3/20/2011 7:15	ALP-04-17	62.5	1178.0	871.0	1%
3/20/2011 8:00	ALP-04-18	57.0	893.0	693.0	
3/20/2011 8:45	ALP-04-19	53.1	651.3	521.0	
3/20/2011 9:15	ALP-04-20	50.6	542.0	438.0	
3/20/2011 9:45	ALP-04-21	48.1	447.0	380.0	
3/20/2011 10:30	ALP-04-22	45.7	379.9	323.0	
3/20/2011 11:45	ALP-04-23	40.0	307.5	260.0	
3/20/2011 13:15	ALP-04-24	36.8	239.0	213.0	
3/24/2011 12:45	ALP-05-06	63.9	154.0	193.0	3%
3/24/2011 13:30	ALP-05-07	203.7	362.6	631.0	10%
3/24/2011 14:00	ALP-05-08	168.4	540.7	990.0	7%
3/24/2011 15:30	ALP-05-10	208.3	395.0	674.0	8%
3/24/2011 16:45	ALP-05-11	192.3	303.9	463.0	
3/24/2011 18:30	ALP-05-12	284.5	785.0	1070.0	9%
3/24/2011 20:30	ALP-05-13	181.2	809.0	947.0	
3/24/2011 21:45	ALP-05-14	144.2	632.7	670.0	4%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
3/24/2011 22:15	ALP-05-15	136.6	560.6	571.0	
3/24/2011 23:15	ALP-05-16	115.0	463.6	461.0	3%
3/25/2011 0:30	ALP-05-17	91.0	392.4	398.0	
3/25/2011 3:45	ALP-05-18	48.1	464.9	402.0	2%
3/25/2011 10:30	ALP-05-20	15.6	311.1	285.0	
3/25/2011 13:00	ALP-05-21	10.0	246.7	211.0	4%
3/25/2011 16:30	ALP-05-22	5.3	185.7	195.0	
3/25/2011 21:45	ALP-05-23	1.3	134.0	123.0	4%
3/26/2011 5:45	ALP-05-24	1.0	89.0	97.5	
11/4/2011 1:20	ALP-01-01	19.3	89.3	278.0	10%
11/4/2011 1:40	ALP-01-02	24.0	222.5	454.0	5%
11/4/2011 2:20	ALP-01-03	20.0	135.6	273.0	
11/4/2011 2:40	ALP-01-04	21.3	108.9	217.0	
11/4/2011 6:30	ALP-01-06	19.0	73.9	124.0	
11/5/2011 21:00	ALP-01-08	27.0	41.5	360.0	8%
11/5/2011 21:50	ALP-01-09	37.0	173.6	325.0	
11/5/2011 22:50	ALP-01-10	38.0	117.4	189.0	6%
11/6/2011 6:00	ALP-01-12	20.0	44.2	57.2	9%
11/19/2011 2:00	ALP-02-01	9.0	40.0	74.4	17%
11/19/2011 4:00	ALP-02-02	8.1	41.0	56.8	
11/20/2011 1:20	ALP-02-03	24.0	106.6	387.0	4%
11/20/2011 2:20	ALP-02-04	14.7	69.4	318.0	
1/20/2012 21:50	ALP-03-10	26.0	455.0	1208.0	7%
1/20/2012 23:20	ALP-03-14	45.7	222.1	319.0	6%
1/23/2012 7:30	ALP-04-02	49.0	131.6	269.0	
1/23/2012 8:10	ALP-04-03	47.3	107.3	185.0	5%
2/7/2012 13:50	ALP-04-07	11.0	38.7	64.7	
2/15/2012 5:10	ALP-05-01	9.7	38.5	58.2	
2/29/2012 8:40	ALP-05-02	23.3	145.7	377.0	
2/29/2012 9:00	ALP-05-03	22.0	121.7	292.0	7%
2/29/2012 12:40	ALP-05-05	12.7	42.5	63.4	
3/16/2012 20:20	ALP-06-03	20.3	203.1	388.0	5%
3/16/2012 21:00	ALP-06-04	142.0	890.0	1974.0	6%
3/16/2012 21:20	ALP-06-05	182.0	640.5	953.0	8%
3/16/2012 21:40	ALP-06-06	200.0	485.5	940.0	5%
3/16/2012 22:00	ALP-06-07	173.0	355.0	625.0	6%
3/16/2012 22:20	ALP-06-08	137.0	303.3	506.0	
3/16/2012 23:00	ALP-06-09	118.0	233.5	394.0	7%
3/17/2012 0:20	ALP-06-10	124.7	182.7	294.0	
3/17/2012 2:40	ALP-06-11	65.7	124.8	182.0	
3/17/2012 5:30	ALP-06-12	36.0	78.5	102.0	8%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
3/17/2012 10:20	ALP-06-13	15.7	42.8	47.9	
4/13/2012 0:10	ALP-07-01	141.0	284.6	584.0	8%
4/13/2012 0:30	ALP-07-02	152.0	248.1	492.0	7%
11/30/2012 7:15	ALP-02-02	217.0	730.0	1716.0	
11/30/2012 8:00	ALP-02-03	355.0	574.7	1145.0	
11/30/2012 8:30	ALP-02-04	361.0	435.3	829.0	
11/30/2012 9:30	ALP-02-05	238.0	357.2	653.0	
12/2/2012 9:30	ALP-02-09	316.0	383.9	766.0	9%
12/2/2012 10:30	ALP-02-10	633.0	533.5	1005.0	8%
12/2/2012 10:45	ALP-02-11	595.0	471.8	901.0	9%
12/2/2012 11:45	ALP-02-12	595.0	335.0	614.0	
12/2/2012 12:15	ALP-02-13	507.0	277.0	493.0	
12/2/2012 13:30	ALP-02-14	270.0	223.8	380.0	
12/22/2012 7:30	ALP-03-01	217.0	486.3	929.0	
12/22/2012 7:45	ALP-03-02	256.0	433.8	850.0	
12/22/2012 8:15	ALP-03-03	280.0	317.1	524.0	
12/23/2012 18:15	ALP-03-05	480.0	452.4	807.0	
12/23/2012 18:45	ALP-03-06	441.0	377.2	616.0	
12/23/2012 21:45	ALP-03-09	212.0	1137.0	933.0	
12/23/2012 22:30	ALP-03-10	153.0	947.0	762.0	
12/23/2012 23:00	ALP-03-11	135.0	716.1	582.0	
12/23/2012 23:30	ALP-03-12	126.0	516.9	429.0	
12/24/2012 0:00	ALP-03-13	115.0	417.1	332.0	
11/13/2014 3:05	ALPL 1-04	40.3	782.7	1681.0	
11/13/2014 3:25	ALPL 1-05	55.2	751.9	1377.0	
11/13/2014 3:35	ALPL 1-06	55.4	623.3	1146.0	
11/13/2014 3:50	ALPL 1-07	51.3	491.9	808.0	
11/13/2014 4:10	ALPL 1-09	40.9	350.1	469.0	
11/13/2014 4:45	ALPL 1-11	25.5	237.8	311.0	
11/30/2014 11:45	ALPL 1-17	59.4	605.3	1135.0	
11/30/2014 11:55	ALPL 1-18	73.7	622.1	1203.0	
11/30/2014 12:10	ALPL 1-19	92.6	512.0	945.0	
11/30/2014 13:05	ALPL 1-21	87.0	340.1	537.0	
11/30/2014 13:35	ALPL 1-23	54.0	234.3	315.0	
12/11/2014 11:00	ALPL 2-01	276.3	482.1	860.0	
12/11/2014 11:40	ALPL 2-03	385.8	308.5	481.0	
12/11/2014 15:25	ALPL 2-04	365.1	192.1	373.0	
12/12/2014 0:30	ALPL 2-05	836.2	394.6	680.0	
12/12/2014 1:35	ALPL 2-06	811.7	375.1	676.0	
12/12/2014 5:45	ALPL 2-09	368.3	543.0	554.0	
12/12/2014 6:35	ALPL 2-10	293.9	648.5	576.0	

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
12/12/2014 8:00	ALPL 2-11	195.4	598.2	527.0	
12/12/2014 11:15	ALPL 2-14	107.4	385.2	326.0	
12/15/2014 4:10	ALPL 3-02	120.2	277.8	394.0	
12/15/2014 7:30	ALPL 3-03	338.0	263.4	430.0	
12/15/2014 13:15	ALPL 3-05	151.3	528.1	408.0	
12/15/2014 14:05	ALPL 3-06	131.9	655.6	479.0	
12/15/2014 16:10	ALPL 3-07	106.6	621.9	444.0	
2/6/2015 19:20	ALPL 5-01	78.1	488.2	1050.0	
2/6/2015 19:50	ALPL 5-02	84.7	403.0	804.0	
2/7/2015 11:50	ALPL 5-04	226.4	604.5	1259.0	
2/7/2015 12:10	ALPL 5-05	204.4	484.7	919.0	

Table B2. Suspended sediment sample data analyzed for the AMH gage.

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
12/26/2010 4:45	AMH-03-05	rejected	3.0	9.5	
12/29/2010 11:45	AMH-04-04	rejected	27.0	15.0	
12/29/2010 14:30	AMH-04-05	rejected	37.0	38.6	
1/1/2011 4:30	AMH-04-07	rejected	1.0	0.8	
1/4/2011 15:45	AMH-04-14	rejected	1.0	0.5	
1/5/2011 16:00	AMH-04-16	rejected	3.0	2.3	
1/5/2011 16:45	AMH-04-17	rejected	5.0	1.9	
1/30/2011 17:00	AMH-05-02	rejected	53.0	50.6	
2/8/2011 11:15	AMH-05-14	rejected	3.0	3.1	
2/8/2011 20:15	AMH-05-16	rejected	4.0	2.7	
2/17/2011 14:30	AMH-06-10	rejected	108.0	163.0	
2/19/2011 0:30	AMH-06-21	rejected	270.0	377.0	
2/19/2011 1:00	AMH-06-22	rejected	318.0	442.0	
2/19/2011 2:30	AMH-06-23	rejected	248.0	301.0	
2/19/2011 7:15	AMH-06-24	rejected	194.0	178.0	
2/25/2011 14:00	AMH-07-03	rejected	320.0	444.0	
2/25/2011 14:30	AMH-07-04	rejected	708.0	811.0	
2/25/2011 15:00	AMH-07-05	rejected	1379.0	1093.0	7.8%
2/25/2011 16:15	AMH-07-06	rejected	1226.0	949.0	4.8%
2/25/2011 17:30	AMH-07-07	rejected	935.0	692.0	
2/25/2011 18:30	AMH-07-08	rejected	733.0	544.0	
2/25/2011 19:15	AMH-07-09	rejected	571.0	453.0	
2/25/2011 20:15	AMH-07-10	rejected	486.0	364.0	
2/25/2011 21:15	AMH-07-11	rejected	402.0	303.0	

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
2/25/2011 22:30	AMH-07-12	rejected	326.0	240.0	
2/26/2011 0:00	AMH-07-13	rejected	225.0	194.0	
2/26/2011 1:45	AMH-07-14	rejected	197.0	151.0	
2/26/2011 4:00	AMH-07-15	rejected	150.0	111.0	
2/26/2011 7:00	AMH-07-16	rejected	106.0	84.7	
2/26/2011 11:30	AMH-07-17	rejected	66.0	55.8	
3/20/2011 4:15	AMH-10-03	rejected	393.0	310.0	
3/20/2011 5:30	AMH-10-05	rejected	> sensor max	2691.0	6.6%
3/20/2011 6:15	AMH-10-06	rejected	> sensor max	3233.0	9.0%
3/20/2011 7:00	AMH-10-07	rejected	> sensor max	2762.0	10.2%
3/20/2011 7:45	AMH-10-08	rejected	> sensor max	2437.0	8.6%
3/20/2011 8:30	AMH-10-09	rejected	> sensor max	2132.0	7.1%
3/20/2011 9:15	AMH-10-10	rejected	> sensor max	2030.0	6.7%
3/20/2011 10:00	AMH-10-11	rejected	> sensor max	1871.0	5.9%
3/20/2011 11:30	AMH-10-12	rejected	1490.0	1550.0	5.4%
3/20/2011 12:15	AMH-10-13	rejected	1375.0	1362.0	
3/20/2011 13:00	AMH-10-14	rejected	1273.0	1224.0	5.9%
3/20/2011 14:00	AMH-10-15	rejected	1092.0	1063.0	
3/20/2011 14:30	AMH-10-16	rejected	1008.0	976.0	4.7%
3/20/2011 15:15	AMH-10-17	rejected	945.0	915.0	
3/20/2011 16:30	AMH-10-18	rejected	800.0	844.0	5.9%
3/20/2011 17:00	AMH-10-19	rejected	710.0	735.0	
3/20/2011 18:15	AMH-10-20	rejected	649.0	656.0	4.7%
3/20/2011 20:00	AMH-10-21	rejected	563.0	584.0	
3/20/2011 21:45	AMH-10-22	rejected	493.0	498.0	3.7%
3/20/2011 23:15	AMH-10-23	rejected	418.0	426.0	
3/24/2011 13:00	AMH-11-01	rejected	259.0	527.0	
3/24/2011 13:45	AMH-11-02	rejected	218.0	444.0	
3/24/2011 14:30	AMH-11-03	rejected	178.0	243.0	12.0%
3/24/2011 15:30	AMH-11-04	rejected	147.0	173.0	
3/24/2011 16:15	AMH-11-05	rejected	237.0	270.0	
3/24/2011 17:00	AMH-11-07	rejected	535.0	581.0	
3/24/2011 17:30	AMH-11-08	rejected	879.0	927.0	5.7%
3/24/2011 18:00	AMH-11-09	rejected	1107.0	1239.0	
3/24/2011 18:30	AMH-11-10	rejected	1347.0	1557.0	
3/24/2011 19:00	AMH-11-11	rejected	> sensor max	2447.0	7.6%
3/24/2011 19:45	AMH-11-12	rejected	> sensor max	3257.0	8.8%
3/24/2011 20:30	AMH-11-13	rejected	> sensor max	3378.0	10.4%
3/24/2011 21:15	AMH-11-14	rejected	> sensor max	3127.0	10.0%
3/24/2011 22:00	AMH-11-15	rejected	> sensor max	2714.0	8.1%
3/24/2011 22:45	AMH-11-16	rejected	> sensor max	2268.0	7.3%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
3/24/2011 23:30	AMH-11-17	rejected	> sensor max	1899.0	7.5%
3/25/2011 0:15	AMH-11-18	rejected	1622.0	1972.0	10.3%
3/25/2011 1:00	AMH-11-19	rejected	1500.0	1714.0	7.2%
3/25/2011 1:30	AMH-11-20	rejected	1385.0	1531.0	6.6%
3/25/2011 2:15	AMH-11-21	rejected	1280.0	1388.0	0.0%
3/25/2011 3:15	AMH-11-22	rejected	1134.0	1232.0	6.7%
3/25/2011 4:15	AMH-11-23	rejected	1007.0	1098.0	
3/25/2011 4:45	AMH-11-24	rejected	925.0	975.0	5.4%
11/1/2011 12:30	AMH-01-02	1.1	0.6	21.0	34.5%
11/2/2011 0:50	AMH-01-04	0.7	0.4	2.0	0.0%
11/2/2011 1:10	AMH-01-05	0.7	0.4	13.5	11.4%
11/3/2011 23:50	AMH-01-08	0.6	2.8	3.2	
11/4/2011 15:50	AMH-01-10	0.9	8.2	8.6	
11/5/2011 21:20	AMH-01-12	21.3	73.6	83.2	
11/5/2011 23:00	AMH-01-14	26.0	39.4	43.2	
11/6/2011 16:10	AMH-01-16	0.8	5.0	5.1	0.0%
1/23/2012 8:30	AMH-03-02	16.0	44.5	65.0	
1/23/2012 9:30	AMH-03-03	25.0	43.4	36.6	
3/2/2012 10:40	AMH-04-03	2.1	2.1	4.7	25.0%
3/2/2012 12:00	AMH-04-04	1.9	2.1	3.2	
3/2/2012 12:40	AMH-04-05	2.1	2.1	5.0	
3/2/2012 22:30	AMH-04-06	1.2	1.9	4.4	
3/2/2012 23:50	AMH-04-07	1.1	1.9	4.3	0.0%
3/3/2012 6:00	AMH-04-08	1.1	1.8	1.6	
3/3/2012 6:30	AMH-04-09	1.1	1.8	2.8	0.0%
3/3/2012 7:00	AMH-04-10	1.2	1.8	0.8	
3/4/2012 0:20	AMH-04-13	1.1	1.6	4.0	0.0%
3/4/2012 1:10	AMH-04-14	1.1	1.6	4.5	27.2%
3/4/2012 1:30	AMH-04-15	0.9	1.6	2.4	
3/4/2012 4:00	AMH-04-16	0.9	1.6	2.8	0.0%
3/4/2012 4:50	AMH-04-17	1.0	1.6	2.0	0.0%
3/4/2012 10:50	AMH-04-18	1.4	1.5	2.4	0.0%
3/4/2012 23:50	AMH-04-20	1.1	1.3	4.0	
3/5/2012 3:50	AMH-04-22	1.1	1.3	1.6	0.0%
3/5/2012 4:50	AMH-04-23	1.1	1.2	2.8	0.0%
3/7/2012 0:10	AMH-05-03	1.3	0.7	5.1	
3/10/2012 16:30	AMH-05-11	0.9	1.2	2.4	0.0%
3/12/2012 16:30	AMH-06-01	0.9	1.8	3.5	
3/12/2012 17:00	AMH-06-03	0.8	1.8	6.4	0.0%
3/12/2012 21:50	AMH-06-05	0.2	1.8	9.1	
3/16/2012 20:40	AMH-06-06	133.4	285.9	401.0	6.1%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
3/16/2012 21:10	AMH-06-07	360.7	200.3	397.0	
3/16/2012 21:40	AMH-06-08	250.3	136.7	246.0	24.4%
3/16/2012 22:10	AMH-06-09	155.7	96.9	129.0	
3/16/2012 22:50	AMH-06-10	122.0	66.8	78.9	
3/17/2012 1:10	AMH-06-11	26.3	40.3	34.6	
3/19/2012 15:00	AMH-06-12	0.6	3.5	6.4	
4/1/2012 12:30	AMH-07-01	0.5	0.1	26.3	26.9%
4/1/2012 14:20	AMH-07-02	0.1	0.1	4.5	
4/10/2012 8:40	AMH-07-03	0.8	0.8	11.1	
4/10/2012 16:30	AMH-07-04	0.8	2.8	21.1	
12/2/2012 10:00	AMH 2-7	975.0	225.5	422.0	17.6%
12/2/2012 10:30	AMH 2-8	815.0	199.1	352.0	21.2%
12/2/2012 11:30	AMH 2-9	290.0	140.2	158.0	8.9%
12/22/2012 9:00	AMH 3-4	133.0	167.6	125.0	
12/23/2012 15:00	AMH 3-5	130.0	96.6	76.1	2.9%
12/23/2012 20:00	AMH 3-7	105.0	187.9	128.0	
12/23/2012 20:30	AMH 3-8	150.0	425.6	349.0	
12/23/2012 21:00	AMH 3-9	172.0	1305.0	836.0	1.4%
12/23/2012 21:45	AMH 3-10	186.0	1123.0	833.0	
12/23/2012 22:15	AMH 3-11	183.0	859.0	700.0	
12/23/2012 23:00	AMH 3-12	715.0	> sensor max	2511.0	4.3%
12/23/2012 23:45	AMH 3-13	1400.0	> sensor max	2879.0	
12/24/2012 0:30	AMH 3-14	1640.0	> sensor max	2660.0	7.0%
12/24/2012 1:15	AMH 3-15	1210.0	> sensor max	2158.0	
12/24/2012 2:00	AMH 3-16	842.0	> sensor max	1728.0	4.2%
12/24/2012 2:45	AMH 3-17	645.0	> sensor max	1454.0	
12/24/2012 3:30	AMH 3-18	499.0	1484.0	1162.0	1.8%
12/24/2012 4:00	AMH 3-19	422.0	1332.0	1019.0	
12/24/2012 4:30	AMH 3-20	354.0	1176.0	896.0	1.3%
12/24/2012 5:45	AMH 3-21	235.0	794.3	659.0	
12/24/2012 6:30	AMH 3-22	207.0	637.6	554.0	1.0%
12/24/2012 7:15	AMH 3-23	186.0	547.5	466.0	
12/24/2012 8:00	AMH 3-24	169.0	464.4	375.0	1.6%
11/20/2014 20:25	AMH 1-01	23.0	406.7	3324.0	
11/20/2014 20:35	AMH 1-02	37.1	227.6	290.0	
12/12/2014 7:55	AMH 4-01	155.1	411.0	376.0	
12/12/2014 8:15	AMH 4-02	161.2	460.2	459.0	
12/12/2014 9:15	AMH 4-03	152.5	414.0	406.0	
12/12/2014 10:15	AMH 4-04	132.7	318.2	310.0	
12/12/2014 11:05	AMH 4-05	114.7	257.0	231.0	

Table B3. Suspended sediment sample data analyzed for the AMP gage.

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
12/8/10 13:15	AMP-03-01			33.8	
12/9/10 0:00	AMP-03-04	95.0	90.0	147.0	
12/15/10 8:15	AMP-03-17	45.0	53.0	63.1	
12/19/10 16:30	AMP-04-02	245.0	191.0	326.0	
12/19/10 21:15	AMP-04-03	133.3	136.0	205.0	
12/20/10 4:15	AMP-04-04	106.7	92.0	113.0	
12/21/10 0:15	AMP-04-06	39.7	29.0	35.9	
12/25/10 23:15	AMP-04-22	67.3	175.0	387.0	
1/17/11 6:15	AMP-06-18	4.0	9.0	24.8	
1/17/11 7:45	AMP-06-20	4.0	74.0	33.2	
1/17/11 9:00	AMP-06-21	4.1	35.0	23.8	
1/17/11 13:30	AMP-06-22	4.0	11.0	30.0	
1/29/11 11:30	AMP-07-06	14.0	64.0	16.4	29%
1/30/11 14:30	AMP-07-11	34.2	120.0	175.0	
1/30/11 18:00	AMP-07-14	48.2	249.0	386.0	
1/30/11 19:30	AMP-07-15	55.1	160.0	179.0	
1/31/11 4:15	AMP-07-20	37.6	46.0	34.7	
2/16/11 6:30	AMP-08-09	25.0	304.0	865.0	13%
2/17/11 16:15	AMP-09-04	66.3	261.0	634.0	
2/19/11 8:45	AMP-09-14	166.8	146.0	208.0	
2/25/11 14:15	AMP-10-01	147.2	233.0	364.0	
2/25/11 16:15	AMP-10-02	165.1	470.0	747.0	
2/25/11 16:45	AMP-10-03	180.6	719.0	1032.0	
2/25/11 17:15	AMP-10-04	198.9	861.0	1060.0	
2/25/11 18:15	AMP-10-05	216.2	749.0	865.0	
2/25/11 19:00	AMP-10-06	220.2	629.0	706.0	
2/25/11 19:45	AMP-10-07	212.3	543.0	598.0	
3/18/11 19:15	AMP-11-01	189.6	320.0	478.0	
3/18/11 19:45	AMP-11-02	189.6	372.0	580.0	
3/18/11 21:00	AMP-11-03	184.2	327.0	281.0	
3/18/11 21:45	AMP-11-04	175.4	437.0	614.0	
3/19/11 0:00	AMP-11-06	147.2	363.0	475.0	
3/19/11 1:00	AMP-11-07	133.3	304.0	387.0	
3/20/11 6:45	AMP-11-12	228.3	1261.0	1717.0	5%
3/20/11 7:15	AMP-11-13	299.5		2567.0	6%
3/20/11 8:00	AMP-11-14	402.6		2312.0	4%
3/20/11 8:45	AMP-11-15	469.0		2035.0	4%
3/20/11 9:30	AMP-11-16	504.6		1901.0	4%
3/20/11 10:15	AMP-11-17	514.6		1767.0	6%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
3/20/11 11:00	AMP-11-18	508.0		1671.0	4%
3/20/11 11:45	AMP-11-19	491.5		1519.0	4%
3/20/11 13:00	AMP-11-20	444.2	1378.0	1308.0	2%
3/20/11 13:30	AMP-11-21	429.0	1262.0	1193.0	
3/20/11 14:00	AMP-11-22	414.2	1107.0	1091.0	3%
3/20/11 14:45	AMP-11-23	402.6	921.0	968.0	
3/20/11 15:15	AMP-11-24	382.7	829.0	904.0	2%
3/24/11 14:15	AMP-12-01	334.4	598.0	1297.0	
3/24/11 14:45	AMP-12-02	414.2	729.0	1527.0	14%
3/24/11 15:15	AMP-12-03	498.0	640.0	1228.0	
3/24/11 16:30	AMP-12-04	624.8	1044.0	1657.0	8%
3/24/11 17:30	AMP-12-05	760.4	1323.0	2002.0	
3/24/11 18:00	AMP-12-06	821.0		2339.0	5%
3/24/11 18:45	AMP-12-07	907.6		2410.0	6%
3/24/11 19:30	AMP-12-08	970.0		2150.0	8%
3/24/11 20:15	AMP-12-09	1028.0		2129.0	7%
3/24/11 21:00	AMP-12-10	1129.0		2492.0	7%
3/24/11 21:45	AMP-12-11	1263.0		2467.0	7%
3/24/11 22:30	AMP-12-12	1358.0		2341.0	7%
3/24/11 23:15	AMP-12-13	1346.0		2127.0	7%
3/25/11 0:00	AMP-12-14	1263.0		1939.0	10%
3/25/11 0:45	AMP-12-15	1139.0		1742.0	8%
3/25/11 1:45	AMP-12-16	974.8	1347.0	1444.0	
3/25/11 2:15	AMP-12-17	893.6	1199.0	1315.0	4%
3/25/11 3:00	AMP-12-18	781.7	1037.0	1174.0	
3/25/11 3:45	AMP-12-19	678.7	885.0	1042.0	4%
3/25/11 4:15	AMP-12-20	617.4	809.0	977.0	
3/25/11 4:45	AMP-12-21	566.4	753.0	928.0	4%
3/25/11 5:30	AMP-12-22	504.6	710.0	866.0	
3/25/11 6:30	AMP-12-23	435.0	631.0	768.0	3%
3/25/11 7:30	AMP-12-24	382.7	570.0	684.0	
11/1/11 21:10	AMP-01-01	14.0	6.9	23.6	22%
11/1/11 22:00	AMP-01-02	14.0	8.6	15.1	
11/4/11 4:10	AMP-01-03	42.0	42.1	191.0	1%
11/4/11 6:30	AMP-01-04	75.0	88.7	240.0	6%
11/4/11 8:00	AMP-01-05	65.0	69.0	157.0	
11/20/11 14:10	AMP-02-07	105.0	64.8	301.0	8%
11/29/11 16:00	AMP-02-15	2.9	12.9	85.6	
1/12/12 3:10	AMP-03-02	7.7	22.0	14.2	45%
1/20/12 22:40	AMP-03-09	133.0	133.2	780.0	10%
1/20/12 23:10	AMP-03-10	176.7	148.4	890.0	10%

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
1/21/12 1:30	AMP-03-11	309.0	276.9	1540.0	12%
1/21/12 1:50	AMP-03-12	394.7	473.0	2808.0	15%
1/21/12 2:10	AMP-03-13	445.3	358.6	1950.0	12%
1/21/12 2:30	AMP-03-14	477.0	282.4	1401.0	
1/21/12 3:10	AMP-03-15	458.0	196.7	898.0	
1/21/12 5:50	AMP-03-16	291.7	153.4	463.0	3%
1/21/12 14:50	AMP-03-19	75.3	47.3	115.0	
1/26/12 19:30	AMP-04-03	6.2	13.1	40.1	0%
2/9/12 8:40	AMP-04-07	2.7	19.2	159.0	
3/15/12 16:10	AMP-06-04	18.7	46.3	71.2	7%
3/16/12 20:00	AMP-06-09	137.0	128.4	424.0	8%
3/16/12 20:30	AMP-06-10	120.0	103.6	308.0	
3/16/12 22:20	AMP-06-11	177.7	220.3	900.0	
3/16/12 22:40	AMP-06-12	267.7	641.7	2286.0	14%
3/16/12 23:00	AMP-06-13	302.0	414.4	796.0	22%
3/16/12 23:20	AMP-06-14	299.7	275.5	770.0	13%
3/16/12 23:40	AMP-06-15	293.0	205.3	549.0	11%
3/16/12 23:50	AMP-06-16	293.7	188.0	473.0	12%
3/17/12 1:00	AMP-06-17	304.0	234.5	559.0	
3/17/12 4:50	AMP-06-19	153.3	114.1	202.0	
3/25/12 3:10	AMP-07-01	277.7	150.5	352.0	11%
3/25/12 4:50	AMP-07-02	319.0	148.1	335.0	7%
4/1/12 23:10	AMP-07-03	5.5	22.6	107.0	6%
4/12/12 8:00	AMP-07-05	180.0	184.2	621.0	12%
4/13/12 1:10	AMP-07-07	241.3	226.3	698.0	
4/13/12 1:40	AMP-07-08	295.3	223.1	656.0	14%
4/13/12 2:00	AMP-07-09	288.0	155.2	434.0	
11/30/12 8:30	AMP-02-02	690.0	264.8	1984.0	
11/30/12 9:00	AMP-02-03	840.0	209.2	1440.0	
11/30/12 9:30	AMP-02-04	923.0	176.6	1272.0	
12/2/12 13:00	AMP-02-07	1050.0	227.8	788.0	8%
12/2/12 14:30	AMP-02-08	737.0	242.2	715.0	5%
12/2/12 15:45	AMP-02-09	466.0	176.3	467.0	2%
12/23/12 21:45	AMP-03-01	609.0	154.3	620.0	
12/23/12 23:00	AMP-03-02	558.0	252.4	831.0	
12/24/12 0:45	AMP-03-03	774.0	541.3	1895.0	
12/24/12 1:45	AMP-03-04	931.0	670.4	2315.0	
12/24/12 2:45	AMP-03-05	836.0	585.2	1779.0	
12/24/12 3:30	AMP-03-06	704.0	508.6	1398.0	
12/24/12 4:15	AMP-03-07	588.0	442.3	1180.0	
12/24/12 5:15	AMP-03-08	481.0	363.7	944.0	

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
12/24/12 6:15	AMP-03-09	398.0	287.7	741.0	
12/24/12 8:15	AMP-03-11	288.0	190.9	493.0	
12/2/14 9:15	AMP 1-07	255.4	376.2	1074.0	
12/2/14 9:30	AMP 1-08	346.1	438.7	1166.0	
12/2/14 9:40	AMP 1-09	401.0	387.0	986.0	
12/2/14 10:00	AMP 1-10	478.5	280.5	630.0	
12/2/14 14:50	AMP 1-12	547.7	194.4	327.0	
12/2/14 16:20	AMP 1-13	500.0	164.0	188.0	
12/2/14 16:30	AMP 1-14	468.2	167.0	192.0	
12/2/14 16:40	AMP 1-15	444.9	170.0	179.0	
12/2/14 17:00	AMP 1-17	409.6	171.0	171.0	
12/3/14 3:10	AMP 1-20	594.6	310.5	739.0	
12/3/14 3:35	AMP 1-22	643.3	240.3	440.0	
12/3/14 6:50	AMP 1-24	723.0	142.4	223.0	
12/12/14 0:20	AMP 2-04	1334.0	420.0	642.0	
12/12/14 2:35	AMP 2-06	1371.5	678.0	979.0	
12/12/14 4:55	AMP 2-07	1150.0	684.0	950.0	
12/12/14 7:05	AMP 2-09	846.0	540.0	672.0	
12/12/14 12:35	AMP 2-10	309.8	450.0	441.0	
12/12/14 15:50	AMP 2-12	203.9	308.0	279.0	
12/15/14 9:00	AMP 2-14	720.2	404.0	515.0	
12/15/14 9:35	AMP 2-15	692.5	589.0	759.0	
12/15/14 10:15	AMP 2-16	651.2	689.0	876.0	
12/15/14 13:40	AMP 2-18	351.7	539.0	616.0	
12/15/14 18:15	AMP 3-02	187.1	520.2	458.0	
12/15/14 22:10	AMP 3-03	121.3	503.5	414.0	
12/16/14 7:30	AMP 3-07	66.1	247.0	202.0	
12/16/14 22:10	AMP 3-08	379.0	239.1	332.0	
12/16/14 23:55	AMP 3-09	340.0	704.1	781.0	
12/17/14 0:15	AMP 3-10	325.9	1107.0	1138.0	
12/17/14 0:30	AMP 3-11	308.5	950.0	1031.0	
12/17/14 2:10	AMP 3-13	226.8	718.7	738.0	
12/17/14 3:35	AMP 3-14	191.1	867.0	842.0	
12/17/14 5:10	AMP 3-15	152.2	620.7	617.0	
12/17/14 7:50	AMP 3-17	121.3	444.7	441.0	
12/17/14 10:20	AMP 3-20	125.9	237.2	218.0	
2/8/15 16:55	AMP 4-02	245.0	408.3	529.0	
2/8/15 17:35	AMP 4-03	241.3	565.4	774.0	
2/8/15 18:05	AMP 4-04	215.9	517.1	636.0	
2/8/15 22:25	AMP 4-08	123.7	237.2	259.0	
2/9/15 2:05	AMP 4-09	204.8	357.7	376.0	

Date/Time	Sample ID	Discharge (cfs)	Turbidity (NTU)	SSC (mg/L)	% Sand
2/9/15 5:15	AMP 4-12	169.2	387.3	429.0	
2/9/15 5:35	AMP 4-13	155.3	503.9	504.0	
2/9/15 7:10	AMP 4-15	115.3	371.4	406.0	

Appendix C: Bedload Sample Data

Table C1. Bedload sample data analyzed for the ALPL gage.

Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
ALP-100	12/19/2010 0:10	11	0	NA
ALP-101A	12/19/2010 7:45	345	20.85	10.94
ALP-102A	12/19/2010 9:30	271	127.49	0.31
ALP-102B	12/19/2010 9:56	243	51.97	0.29
ALP-103A	12/19/2010 10:19	219	82.11	0.13
ALP-103B	12/19/2010 10:29	209	36.05	0.50
ALP-104A	12/19/2010 11:02	199	39.21	0.72
ALP-104B	12/19/2010 11:12	199	64.71	0.49
ALP-105	2/17/2011 15:52	55	0	NA
ALP-106A	2/25/2011 10:15	74	1.84	12.16
ALP-106B	2/25/2011 10:33	68	1.50	8.70
ALP-107A	3/20/2011 1:34	66	4.15	3.16
ALP-107B	3/20/2011 1:52	69	1.49	4.13
ALP-108	3/24/2011 13:29	201	0	NA
ALP-109	3/24/2011 13:47	199	0	NA
ALP-110A	3/24/2011 14:31	134	6.43	3.00
ALP-110B	3/24/2011 14:44	151	29.14	0.88
ALP-111A	3/24/2011 15:10	206	14.28	0.55
ALP-111B	3/24/2011 15:23	212	25.58	1.45
ALP-112A	3/24/2011 15:47	205	12.46	1.72
ALP-112B	3/24/2011 16:00	199	15.12	2.74
ALP-200	3/14/2012 12:20	3	0	NA
ALP-300A	11/30/2012 9:58	255	58.18	0.21
ALP-300B	11/30/2012 10:10	275	30.15	0.49
ALP-301A	11/30/2012 10:47	380	137.70	0.21
ALP-301B	11/30/2012 11:01	427	167.84	0.25
ALP-302A	11/30/2012 11:23	447	275.60	0.27
ALP-302B	11/30/2012 11:33	451	466.03	0.25
ALP-303A	11/30/2012 12:38	474	299.37	0.24
ALP-303B	11/30/2012 12:48	464	189.00	0.35
ALP-304A	11/30/2012 13:24	451	70.32	0.30
ALP-304B	11/30/2012 13:42	421	164.45	0.11
ALP-305A	11/30/2012 14:17	350	141.91	0.07
ALP-305B	11/30/2012 14:25	329	68.96	0.16
ALP-306	12/2/2012 8:54	98	0	NA
ALP-307	12/2/2012 9:15	225	0	NA

Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
ALP-308A	12/2/2012 9:28	304	21.91	0.82
ALP-308B	12/2/2012 9:41	428	73.09	0.72
ALP-309A	12/2/2012 9:57	567	182.44	0.17
ALP-309B	12/2/2012 10:12	647	112.67	0.44
ALP-310A	12/2/2012 10:32	628	202.68	0.36
ALP-310B	12/2/2012 10:45	595	382.81	0.24
ALP-311A	12/2/2012 11:10	599	379.87	0.20
ALP-311B	12/2/2012 11:21	610	192.67	0.37
ALP-500A	12/11/2014 13:50	493	214.60	0.23
ALP-500B	12/11/2014 14:08	473	299.18	0.44
ALP-501A	12/11/2014 14:40	433	217.29	0.16
ALP-501B	12/11/2014 14:52	409	158.40	0.21
ALP-502A	12/11/2014 16:18	294	54.06	0.40
ALP-502B	12/11/2014 16:35	281	12.75	0.91
ALP-503A	12/11/2014 17:48	249	4.00	1.59
ALP-503B	12/11/2014 18:13	264	2.50	7.37

Table C2. Bedload sample data analyzed for the AMH gage.

Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
AMH-100	12/17/2010 23:01	23	0	NA
AMH-101A	12/19/2010 10:00	68	0.38	2.68
AMH-102	12/29/2010 2:16	72	0	NA
AMH-103	12/29/2010 2:36	65	0	NA
AMH-104	3/20/2011 1:01	55	0	NA
AMH-105	3/20/2011 1:17	48	0	NA
AMH-106A	3/24/2011 15:00	279	152.15	0.18
AMH-106B	3/24/2011 15:11	276	37.47	0.07
AMH-107A	3/24/2011 15:39	284	18.81	0.28
AMH-107B	3/24/2011 15:50	296	48.06	0.24
AMH-108A	3/24/2011 16:30	307	22.55	0.09
AMH-108B	3/24/2011 16:43	319	32.31	0.23
AMH-300A	11/30/2012 12:42	160	1.52	0.17
AMH-300B	11/30/2012 13:01	156	1.13	0.16
AMH-301A	11/30/2012 13:24	151	0.41	0.20
AMH-301B	11/30/2012 13:48	142	0.03	5.00
AMH-302A	12/2/2012 10:08	965	77.63	0.43
AMH-302B	12/2/2012 10:31	805	64.34	0.23

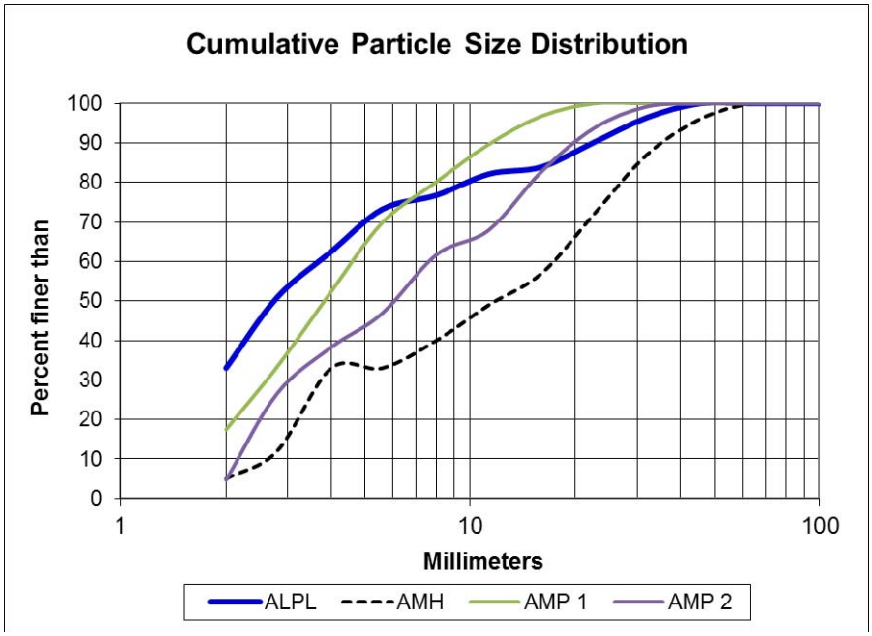
Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
AMH-303A	12/2/2012 10:50	625	44.51	0.16
AMH-303B	12/2/2012 11:14	424	36.50	0.29
AMH-304A	12/2/2012 11:34	270	26.69	0.33
AMH-304B	12/2/2012 11:53	192	0.69	NA
AMH-305A	12/2/2012 12:28	114	0	0.15
AMH-305B	12/2/2012 12:50	80	0	NA

Table C3. Bedload sample data analyzed for the AMP gage.

Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
AMP-100A	12/18/2010 1:01	55	0	NA
AMP-100B	12/18/2010 1:06	55	0	NA
AMP-101A	12/19/2010 7:01	94	1.49	4.50
AMP-102A	12/19/2010 12:04	456	233.78	0.45
AMP-102B	12/19/2010 12:17	435	171.21	0.23
AMP-103A	12/19/2010 13:48	314	42.36	0.18
AMP-103B	12/19/2010 14:00	302	67.76	0.13
AMP-104	12/28/2010 21:46	28	0	NA
AMP-105	12/28/2010 22:56	41	0	NA
AMP-106	12/28/2010 23:54	56	0	NA
AMP-107	2/17/2011 14:21	43	0	NA
AMP-108A	2/25/2011 13:39	149	2.58	0.97
AMP-108B	2/25/2011 13:52	148	1.33	0.58
AMP-109A	3/20/2011 14:50	400	45.43	2.50
AMP-109B	3/20/2011 15:08	388	45.69	0.69
AMP-110A	3/20/2011 15:32	382	18.68	1.01
AMP-110B	3/20/2011 15:49	376	15.17	0.94
AMP-111	3/24/2011 9:36	112	0	NA
AMP-112	3/24/2011 11:06	116	0	NA
AMP-113A	3/24/2011 13:23	229	49.37	1.21
AMP-113B	3/24/2011 13:49	264	107.71	0.70
AMP-114A	3/24/2011 17:56	814	68.45	0.45
AMP-114B	3/24/2011 18:24	860	89.20	0.54
AMP-115A	3/24/2011 19:48	1002	185.48	0.42
AMP-115B	3/24/2011 20:21	1040	60.97	5.95
AMP-116A	3/24/2011 21:04	1140	23.97	16.00
AMP-116B	3/24/2011 21:20	1189	65.32	15.76
AMP-200	3/14/2012 15:09	8	0	NA

Sample ID	Date & Time	Instantaneous Discharge (cfs)	Instantaneous Bedload (metric tons/day)	Ratio Sand/Gravel
AMP-201	3/16/2012 23:58	297	0	NA
AMP-202A	4/13/2012 8:58	272	43.19	0.29
AMP-202B	4/13/2012 9:06	273	42.94	0.20
AMP-203A	4/13/2012 9:22	272	15.09	0.64
AMP-203B	4/13/2012 9:31	268	4.14	0.25
AMP-204A	4/13/2012 9:46	260	4.37	0.40
AMP-204B	4/13/2012 10:14	240	7.40	0.27
AMP-205A	4/13/2012 10:42	219	3.55	0.47
AMP-205B	4/13/2012 11:06	209	1.54	0.49
AMP-300A	11/30/2012 15:38	750	143.19	0.34
AMP-300B	11/30/2012 16:00	712	6.37	1.06
AMP-301A	11/30/2012 16:40	568	4.98	6.53
AMP-301B	11/30/2012 17:00	508	5.15	8.98
AMP-302A	12/2/2012 12:38	1095	336.65	0.21
AMP-302B	12/2/2012 12:56	1061	200.68	0.34
AMP-303A	12/2/2012 13:40	890	23.66	4.86
AMP-303B	12/2/2012 13:59	829	24.69	3.82
AMP-304A	12/2/2012 15:06	594	63.08	0.34
AMP-304B	12/2/2012 15:30	508	8.25	3.98
AMP-500A	12/11/2014 17:03	811	222.33	0.19
AMP-500B	12/11/2014 17:19	805	519.18	0.26
AMP-501A	12/11/2014 18:21	755	134.70	0.97
AMP-501B	12/11/2014 18:57	779	592.70	0.28

Appendix D: Pebble Count Sample Data



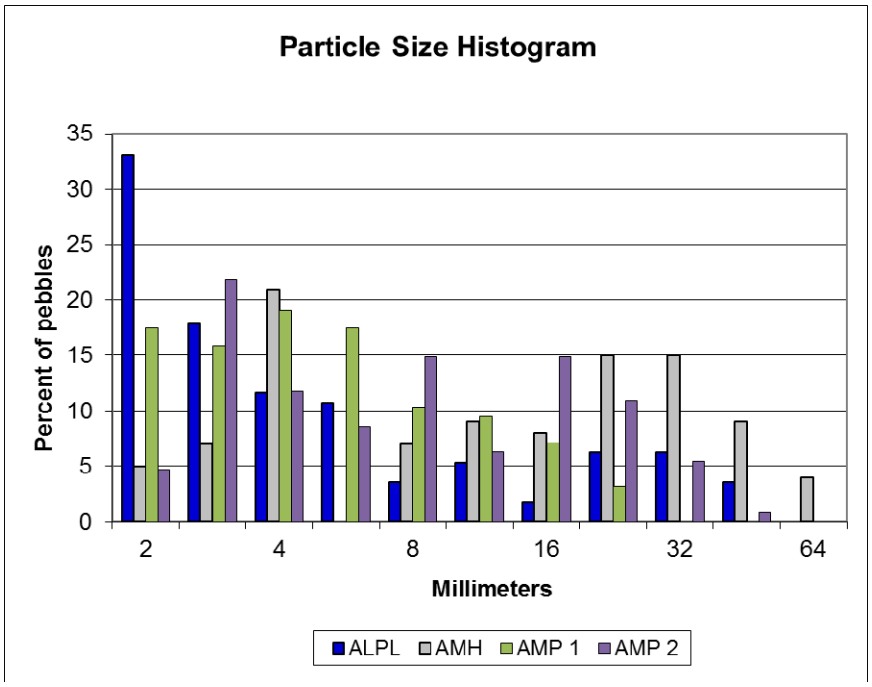


Figure D1. Cumulative particle size distribution and histogram of bed sediment pebble counts conducted at each of the gaging locations during the Fall 2010. Site AMP 1 is located between the weir and the bridge, and site AMP 2 is located 5 channel widths downstream of the weir.

Table D1. Particle characteristics of bed sediment pebble counts conducted at each of the gaging locations during the Fall 2010.

Particle Characteristics				
	ALPL	**AMH**	**AMP 1**	**AMP 2**
D_{16}	< 2mm	3.1 mm	< 2mm	2.6 mm
D_{50}	2.8 mm	11.9 mm	3.9 mm	6.2 mm
D_{84}	16.1 mm	30.3 mm	9.4 mm	16.8 mm

Appendix 7.4

Geospatial Terrain Mapping of Sediment Sources within the Arroyo Mocho Watershed

Paul Bigelow
Sarah Pearce
Lee Benda
Lester McKee
Kevin Andras
Jamie Kass

May 2012

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

REGIONAL WATERSHEDS PROGRAM

Geospatial Terrain Mapping of Sediment Sources within the Arroyo Mocho Watershed

CONTRIBUTION NO. 665
MAY 2012

Revised August 2013

Produced by:

Paul Bigelow, Bigelow Watershed Geomorphology
Sarah Pearce, SFEI
Lee Benda, Earth Systems Institute
Lester McKee, SFEI
Kevin Andras, Earth Systems Institute
Jamie Kass, SFEI

SAN FRANCISCO ESTUARY INSTITUTE
4911 Central Avenue, Richmond, CA 94804 www.sfei.org

PROFESSIONAL GEOLOGIST
LEE ELLIOTT BENDA
No.8296
STATE OF CALIFORNIA

This report should be cited as:
Bigelow, P., Pearce, S., Benda, L., McKee, L., Andras, K. and Kass, J. 2012. Geospatial Terrain Mapping of Sediment Sources within the Arroyo Mocho Watershed. (Revised August 2013). Regional Watersheds Program. Contribution number 665. Bigelow Watershed Geomorphology, Earth Systems Institute and San Francisco Estuary Institute, Richmond, CA.

Introduction and Objective

Zone 7 has contracted with SFEI to study channel depositional processes in aggraded areas within Zone 7's service area. This study will provide improved understanding of erosion and sediment sources, and therefore, may identify opportunities to reduce channel sedimentation, potentially avoiding the costs and regulatory burden typically associated with de-silting projects.

Opportunities to help defray costs and regulatory burden for de-silting aggraded areas may include adjustments to channel geometry or vegetation, characterizing upstream erosion with the goal of identifying controllable sediment sources, and analyzing historic conditions to identify areas that are prone to sedimentation. Improved understanding may lead to innovative management strategies that can include upstream mitigation of erosion sources.

Sediment that is generated within the Arroyo Mocho watershed that influences sediment loading within Zone 7's service area consists of chronic sediment sources (including shallow landslides, gullies, bank slumps and erosion, and surface erosion) and more episodic sources of sediment (including earthflows and large deep-seated landslides). The purpose of this report is to document the results of using the *terrain mapping technique to estimate the spatial distribution of chronic sediment supplied within Zone 7's service area, upstream of the confluence of the Arroyo de la Laguna and Arroyo Mocho*. This report also provides a cursory overview of potential source control measures that could be further investigated.

Background

The Arroyo Mocho watershed drains an area of 573 km^2 (221 mi^2) and, for this study, was defined as containing the tributary basins of: Alamo Creek (containing Alamo Creek (Canal)), Tassajara Creek (containing Chabot Canal, Tassajara Creek, and Line G-3), Cayetano Creek/Las Positas (containing Cottonwood Creek, Collier Canyon Creek, Cayetano Creek, and Arroyo Las Positas), Altamont Creek (containing Altamont Creek), Arroyo Seco (containing Arroyo Seco) and Arroyo Mocho (containing the upper watershed portion of Arroyo Mocho, and the mainstem downstream of the Las Positas confluence) (Figure 1). The estimated stream network length within the Arroyo Mocho watershed is 193 km (120 mi) (SFEI 2011). Elevation ranges between 60 and 1230 m (197 to 4,035 ft) (Figure 1) and mean annual precipitation averages 428 mm (17 in) in Pleasanton (Figure 2, Prism 2012). Land use includes urban and commercial areas in the valley, agricultural areas (primarily grazing and viticulture), and forested and non-forested lands in the upper watershed (Figure 3).

The larger Arroyo Mocho watershed is underlain by a sequence of folded and faulted rocks mapped as the Cretaceous Franciscan Formation, Cretaceous Great Valley Sequence, Miocene sedimentary units, Plio/Pleistocene Livermore Gravels, and Quaternary valley fill alluvium (Graymer et al. 1996, Helley and Graymer 1997). From these bedrock units and the soils they produce, many different processes of sediment sourcing are observed, each with different amounts, rates, and size classes of sediment generated. These processes include hillslope mass movement, soil creep, gullying, channel bank erosion and bed incision, and land-use related

erosion (e.g. roads, grazing, construction). However, the location and relative magnitude of these processes are known to vary in relation to underlying geology, soils, aspect, slope and convergence, vegetation, and landuse/land management. Therefore we anticipate that the dominant processes and resulting sediment supply will vary considerably from one sub-watershed to another in the area of Zone 7 interest.

The southern portion of the Arroyo Mocho sub-watershed is underlain by Franciscan Formation, characterized by steep topography and rugged hillslopes that have experienced large mass movements (landslides) in the geologic past, as illustrated by the number of large, deep-seated landslides depicted on existing landslide maps (Davenport 1985, Wentworth et al. 1997, Roberts et al. 1999, Majmundar 1991 and 1996). The hillslopes in the upper portion of the sub-watershed are steep, however the stream gradient is fairly low, creating a gentler, slightly wider valley, with more opportunity for sediment storage to occur. In the lower portion of the sub-watershed, the channel flows through a steep, narrow canyon with virtually all sediment sourced from these canyon walls delivered directly to the channel. And at the outlet of the canyon, Livermore Gravels outcrop; this unit is described as unconsolidated to semi-consolidated gravel, sand, silt and clay, with an abundance of fines between the coarser grains (DWR, 1966). Erosion into these outcropping terraces provides a plentiful source of coarse gravel.

The eastern portion of the watershed, primarily the Arroyo Seco and Altamont Creek basins, are underlain by the Cretaceous Great Valley Sequence, Miocene sedimentary units, and Quaternary alluvium. The portions underlain by the Miocene units (in particular the Cierbo and Neroly Formations) tend to have steep slopes that are prone to landsliding (Majmundar, 1991). These basins are of lower elevation (compared to the southern Arroyo Mocho sub-watershed), with rolling grassy hills that grade into the eastern portions of the valley floor. Besides landsliding, channel gullying, bank slumping, and bank erosion contribute to the sediment production.

The northern basins (Alamo Creek, Tassajara Creek, Cayetano Creek) have lower portions underlain by Plio/Pleistocene Livermore Gravels that are gentle rolling grassy hills that grade into wide valley floor surfaces. These hillslopes primarily produce sediment via shallow landslides and creep related to expansive soils (Davenport 1985, Wentworth et al. 1997, Roberts et al. 1999, Majmundar 1991 and 1996), while the channels produce sediment from bank slumping and bank erosion. The upper portions of these basins contain steeper topography reflecting the underlying Miocene sedimentary bedrock geology, with certain units (Green Valley/Tassajara Group) prone to earthflows (Majmundar, 1991). In addition, expansive clays in the soil can cause creep even on slopes as gentle as 13% (Davenport, 1985).

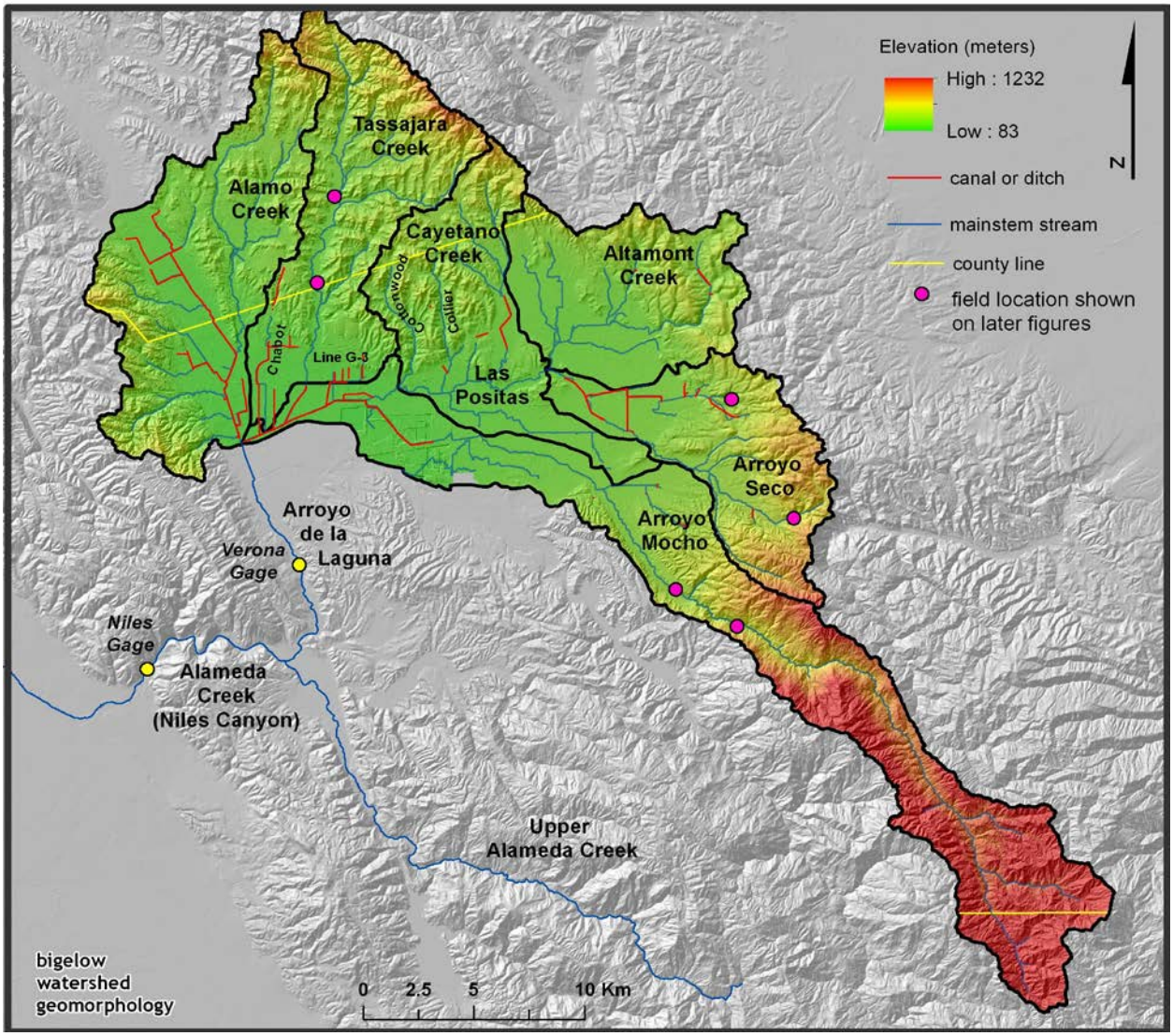


Figure 1. Arroyo Mocho watershed showing the six major basins, mainstem channels, and flood control channels.

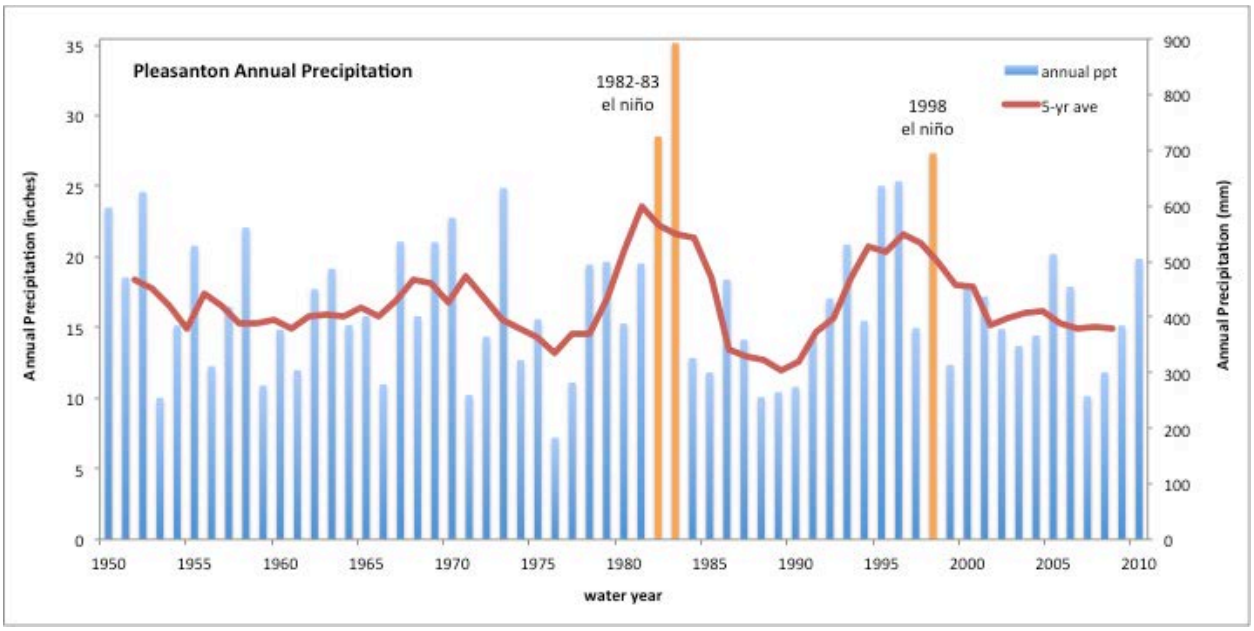


Figure 2. Mean annual precipitation over the past 60 years for Pleasanton, California (Prism 2012).

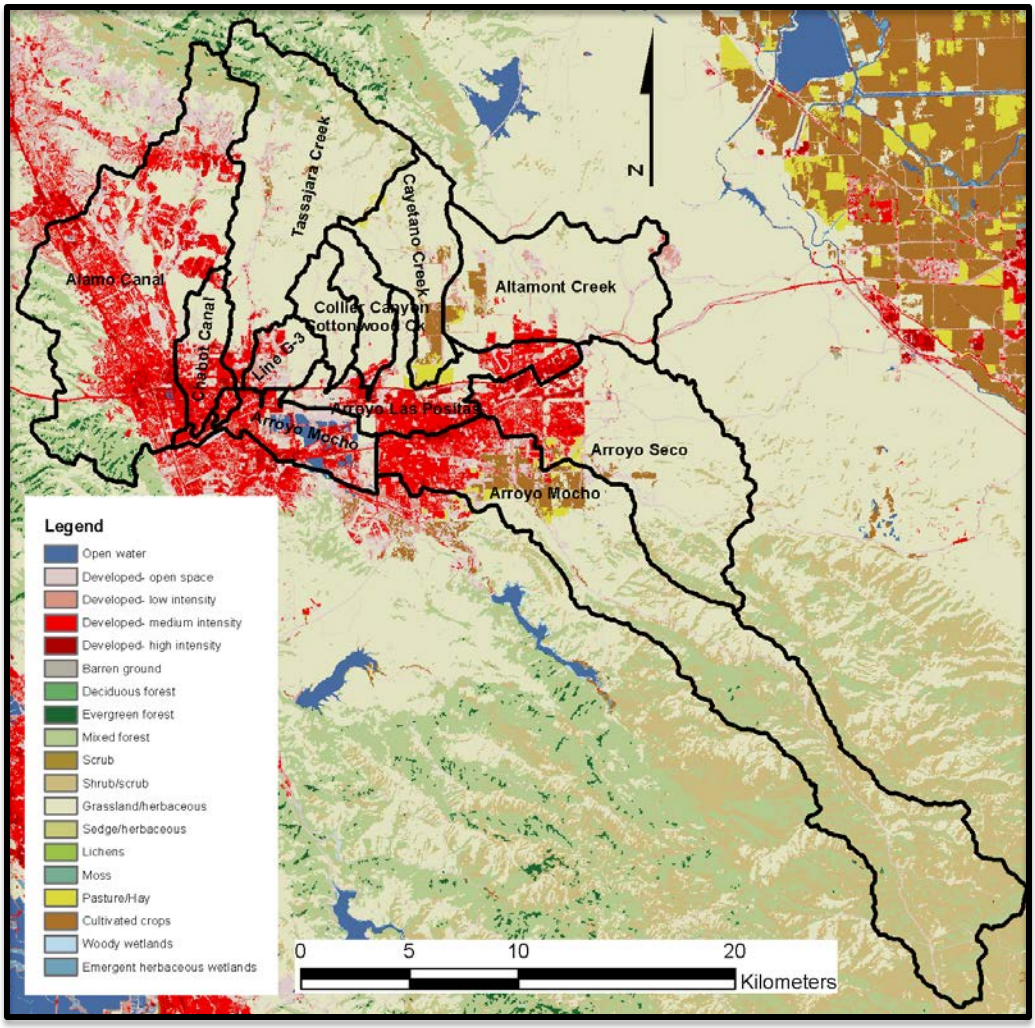


Figure 3. Current land use in the Arroyo Mocho watershed (data from NLCD, 2006).

Historically the watershed contained many creeks that flowed from the canyons and spread across the valley floor, depositing their sediment and recharging groundwater. These distributary channels built broad alluvial fans that graded into the wide valley floor surface. At the western edge of the valley was the 2,600 acre Pleasanton Marsh Complex (Tulare Lake), a freshwater wetland that acted as a sediment sink, trapping all of the coarse and most of the fine sediment from upstream, while recharging ground water (Beagle et al., 2013) (Figure 4). As early as the 1880s, the marsh was ditched, drained and developed, and along with the extensive groundwater withdrawal in the valley, these anthropogenic actions removed the marsh, along with the surface and groundwater storage functions that it provided (Beagle et al., 2013). Now the channels have direct connections from the upper watersheds, across the valley floor, to the outlet of Arroyo de la Laguna (via artificial channels in most locales). These changes have fundamentally altered the Livermore Valley floor from a sediment sink to a sediment conduit with increased sedimentation potential downstream.

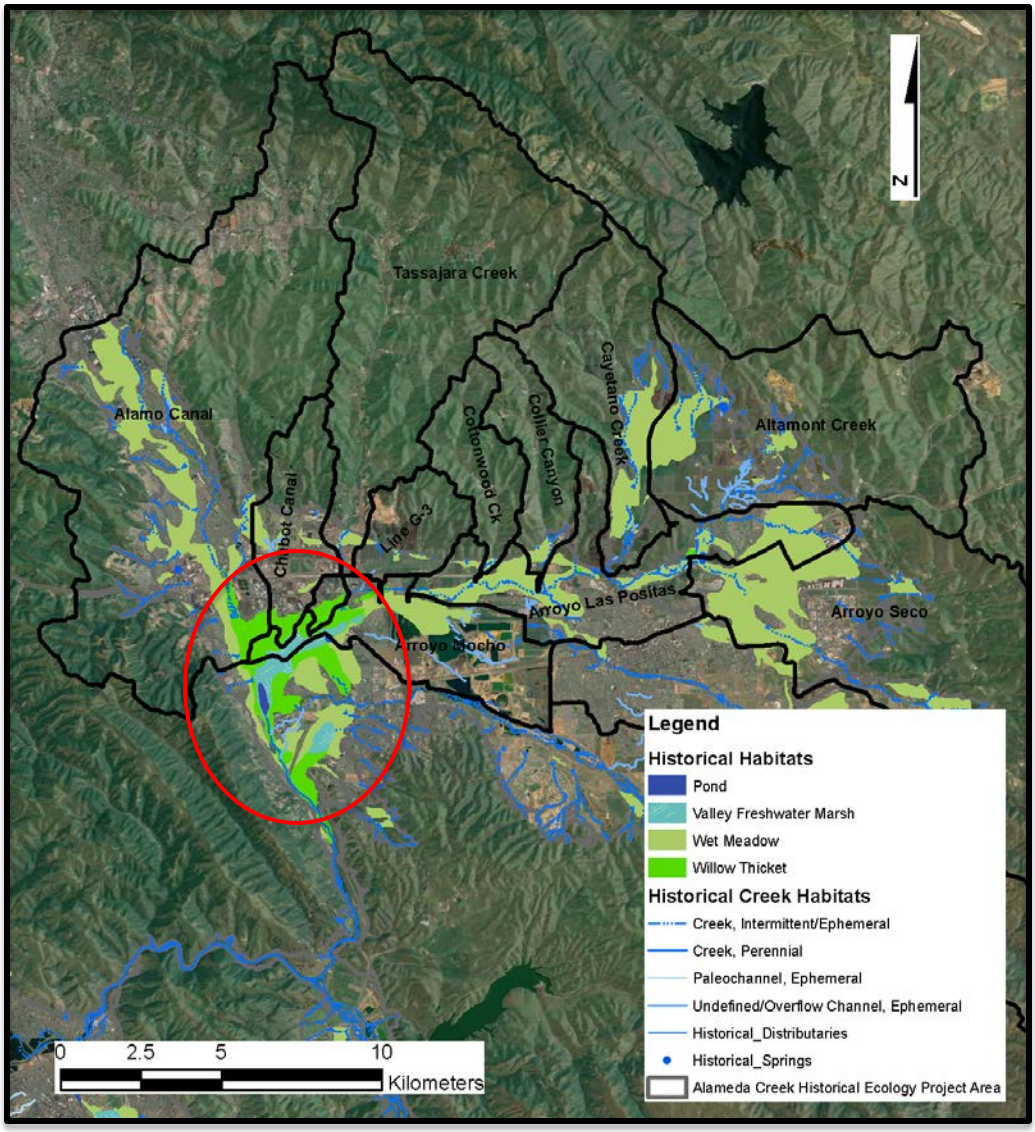


Figure 4. Map of a portion the Livermore Valley illustrating some of the historical wetland habitat types (from Beagle et al., 2013). The Pleasanton Marsh Complex (within the red circle) is located at the southeast corner of the Arroyo Mocho watershed, and includes the pond, valley freshwater marsh, wet meadow, and willow thicket historical wetland habitat types.

Methods

We generated a digital terrain model using NetMap, a watershed analysis tool that provides spatially registered and largely automated mapping of watershed features that govern erosion, network, valley and channel morphologic types, and sources of riverine habitat heterogeneity. NetMap is tailored for a variety watershed and geomorphic analyses across the Pacific Northwest, Pacific Rim, and parts of Europe (see netmaptools.org Benda et al. 2007, 2009, 2011). The primary steps in the terrain mapping included:

1. Development of an attributed stream layer and erosion potential grid[1] using NetMap in conjunction with a high resolution DEM.

2. Generation of a vegetation height grid to modify erosion predictions.

3. Prediction of relative erosion potential throughout the study basin (focused along stream channels) using the vegetation and erosion grids.

4. Conversion of the erosion potential to sediment yield based on gage data.

5. Aggregation of the erosion predictions at various scales: reach, subwatershed, basin.

6. Field validation of erosion predictions in the field.

DEM and Stream Network

An attributed stream channel network was delineated using a 2m DEM based on algorithms for flow direction and channel delineation described by Clarke et al. (2008). The DEM was compiled and resampled from a 0.3 m DEM for Alameda County and a 3 m DEM for Contra Costa and Santa Clara Counties, all derived from Light Detection and Ranging (LiDAR)[2] data collected by the USGS. The channel network was divided into a linked set of channel segments (ranging from 2 – 80 m length, averaging 30 m). Contributing area and channel length were calculated from the DEM for each segment. Bankfull channel width and depth and mean annual flow were estimated using available regional regressions:

$$\text{bankfull channel width (m)} = 3.3494\ (\text{drainage area } [km^2])^{0.3737} \qquad (1)$$

$$\text{bankfull depth (m)} = 0.3593\ (\text{drainage area } [km^2])^{0.3593} \qquad (2)$$

Bankfull channel width and depth regressions were derived for the "San Francisco Bay Area" with no data points or correlation coefficient provided (Dunne and Leopold 1978), but the streams used to derive the curves "were from near Leopold's residence in Berkeley (a listing of sites was not separately maintained)" (Emmet 2004). Each segment of the channel network was attributed with suite of parameters calculated from the DEM including elevation, drainage area, stream gradient, stream order (Strahler 1957), valley width, debris flow probabilities (scour, passage, deposition, tributary confluence effects probabilities, and intrinsic potential for salmonid habitat by species, and many more attributes (see Miller 2003 and Benda et al. 2007 for details). From these attributes, others can be calculated for example, stream power

[1] A GIS grid defines geographic space as an array of equally sized square grid points arranged in rows and columns. Each grid point stores a numeric value that represents a geographic attribute (such as elevation or surface slope) for that unit of space. Each grid cell is referenced by its x,y coordinate location (http://en.wikipedia.org/wiki/Esri_grid)

[2] LiDAR is an optical remote sensing technology that measures the distance to a target (surfaces) with light, often using laser pulses from an aircraft. Because LiDAR penetrates through vegetation canopy to the land surface and can be collected at high spatial densities, it can be used to develop high resolution DEMs to detect subtle topographic features such as landslide terrain, river terraces, and river channel banks.

(drainage area * gradient), valley width index (valley width/channel width), etc. All of the NetMap data layers generated for Zone 7 are available at: http://www.netmaptools.org/coverage and the analyses tools at http://www.netmaptools.org/analysis_tools.

Generic Erosion Potential (GEP)

Erosion in the form of shallow landslides, gullies and surface erosion is often driven by slope steepness and slope curvature (Dietrich and Dunne 1978, Sidle 1987). To estimate a measure of erosion potential in the watersheds, a dimensionless index in NetMap that employs slope gradient and local topographic convergence was used (Miller and Burnett 2007a, Benda et al. 2011):

$$GEP = (AL \cdot S)/b \qquad (3)$$

where GEP is the generic erosion potential, b is a measure of local topographic convergence (the length of an elevation contour crossed by flow out of a pixel, values less than one pixel indicate convergent topography), AL is a measure of local contributing area (within one pixel length) and S is slope gradient (Miller and Burnett 2007a). GEP is a dimensionless index of erosion potential with values from 0 – 1, where larger values correspond to steeper, more convergent topography. Steeper, more convergent topography (e.g., higher values of GEP) should correspond to higher landslide densities and, in areas prone to surface erosion, to higher gully-initiation-point densities. Thus, GEP is a relative measure of erosion potential that encompasses processes of shallow landsliding, gullying, and surface erosion that is applicable to both humid and semiarid landscapes.

Limiting Estimates to Near Stream Sources

During field work and based on satellite imagery (Google Earth) we observed that many of the channels had an arroyo form: an incised topography within a broad valley floor, with steep and occasionally bare eroding banks. These raw banks appear to dominate the chronic (annual) supply of sediment to channels in the study basin (and thus the main source of sediment to the aggrading channels downstream in flood control areas). Often at the top of the arroyo bank, a flat valley floor exists, with essentially no sediment production or delivery to the channel. In addition, in the steeper channel reaches most of the sediment production occurred on the channel banks and hillslope areas adjacent to the channel; hillslopes farther removed from the channel did not appear to be delivering sediment on an annual basis. Based on these observations, we confined the analysis of erosion sources to areas adjacent to channels (e.g., the arroyo landform). We chose a zone or buffer of 6x the bankfull width (equation 1) around the channel that generally captures the steep eroding banks of the arroyo channel form. The value of 6x was chosen based upon field observation and evaluation of test field locations, where values of 2x, 4x, and 6x were considered. The 6x buffer maximizes the inclusion of hillslope areas that appear to be contributing sediment annually, yet limits the area that is not contributing, for the majority of the channel network length. This approach excludes more

episodic supply from mass wasting sources that are located further from the channel that require a long-term sediment budget approach to estimate (see later).

Effects of Vegetation on Erosion

During our initial field reconnaissance we observed that arroyo bank erosion was reduced by vegetation, where larger and denser vegetation created stable channel bottoms and banks. Reaches that had little to no vegetation tended to be more erosive compared to reaches that had shrubs or trees established on the banks. We hypothesize that the existing vegetation is reducing erosion by lessening raindrop impact, providing increased soil strength through the root network, reducing surface erosion, rill erosion, and shallow bank slumps and slips (e.g. Thorne 1990, Simon and Darby 1999, Abernethy and Rutherford 2001). This is true in particular in these arroyo channel systems because there is little organic groundcover in the absence of vegetation.

While bank erosion and landsliding can occur under vegetation, the fundamental role of vegetation in reducing erosion is well established (e.g. Thorne 1990, Simon and Darby 1999, Abernethy and Rutherford 2001). For example, the amount (percentage) of bare soil is related to surface erosion (Benavides-Solorio and MacDonald 2005) and bare soil should be inversely proportional to vegetation cover. In addition increasing tree age (and thus rooting extent and depth) is related to increasing stability of the soil (Sidle 1987). Consequently we developed a method that relates vegetation cover to our erosion potential index. We created an erosion reduction parameter based on vegetation height and density (2 m GIS grid) using the first (representing the tallest vegetation) and last (representing the ground surface) return LiDAR points. The GIS grid was truncated to heights between 0 – 42 m to remove artifacts common in raw LiDAR data and the resulting grid was processed with fill and inverse fill operations to remove local sinks and peaks. A tree height of 42 m was estimated to be maximum height for old growth deciduous or conifer trees in the watershed based on the known species of trees and their typical maximum heights. The last return raster was then subtracted from the first returns to produce vegetation height. The vegetation height grid was converted (normalized) to the same 0 – 1 scale as GEP based on our estimate of the relationship between tree height and bank stabilization (erosion reduction) (Figure 5):

$$\text{Erosion reduction} = 0.1906 \ln(\text{tree height in m}) + 0.136 \qquad (4)$$

Because the tree canopy height of each 2 m grid cell is represented, this grid also represents the density of vegetation, another factor that can reduce erosion (e.g. Beeson and Doyle 1995, Wang et al. 2004). Using equation 4, a grid cell with a tree canopy height of 1 , 21 , or 42 m would be normalized to 0-1 scale values of 0.14, 0.72, and 0.85, respectively (i.e. 14, 72, and 85% erosion reduction). Equation 4 was derived from (1) the general relationship between vegetation (tree) height and canopy width, rooting width and depth, and associated bank stabilization (e.g. Smith 1964, Tubbs 1977, Gilman 1988), and (2) our field observations of tree height and bank stabilization. Here, we generally observed that stability of the banks increases with vegetation height up to a maximum of 11 meters and then levels off. We generally

observed that grasses were less effective than shrubs, and shrubs were less effective than larger trees in reducing arroyo bank erosion. The resulting erosion reduction grid was subtracted from the initial GEP grid to estimate erosion sources. For example, where a grid cell has a GEP value of 1 and a corresponding erosion reduction value of 0.5, the resulting modified GEP would be 0.5; where there was no vegetation, GEP values were unchanged. Maximum GEP reduction due to the greatest vegetation height was 0.85 (85%). We were unable to obtain raw LiDAR for Santa Clara County, so it was not possible to create a vegetation reduction grid for this small southeastern portion of the watershed at the headwaters of Arroyo Mocho canyon (Figure 1).

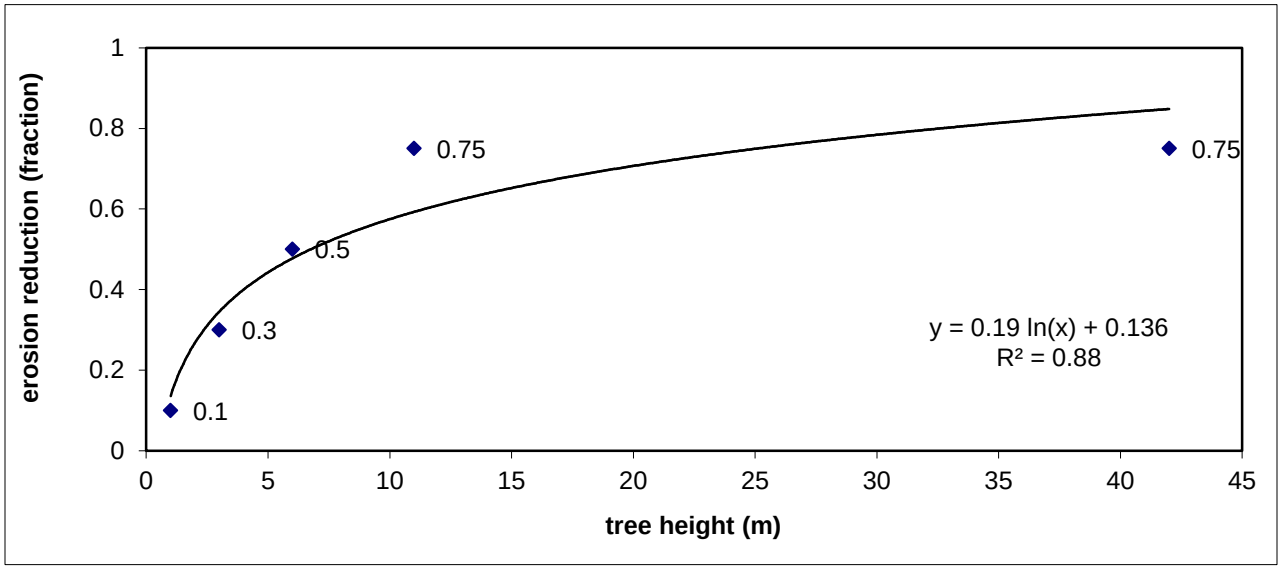


Figure 5. Estimated relationship between tree height and reduction in erosion (bank stabilization) used to reduce generic erosion potential (GEP) estimates (see text for details). Relationship based on field observations and the general relationship between vegetation and bank stability (see text for details).

Conversion to Sediment Yield, Statistics, and Field Checking

Because GEP is a dimensionless index of erosion from 0 - 1, we converted GEP to sediment yield for a more useful and intuitive visual display of erosion across the watershed. To accomplish this in NetMap we linearly scaled the independently estimated sediment yield rate to GEP values. High values of GEP present higher erosion rates and lower values of GEP represents lower erosion rates. To obtain the conversion factor relating GEP to sediment yield in the study basin we used Equation 5:

$$conversion\ factor = GEP\ cell\ x\ \frac{mean\ sediment\ yield\ rate\ at\ Verona\ Gage}{mean\ GEP\ basin} \qquad (5)$$

where GEP cell is the value for each individual grid cell, and mean GEP basin is the mean of all grid cells in the watershed. An average sediment yield rate of 155 tonnes km^{-2} yr^{-1} was used

based on estimates from the Verona Gage on Arroyo de la Laguna (Figure 1) from 1994 – 2006 for the drainage area below reservoirs that includes both suspended and bed load (Bigelow et al. 2008). The conversion of GEP to sediment yield value is an approximation but likely corresponds to the correct order of magnitude in the context of sediment budgeting technology (Reid and Dunne 1996). Summary statistics were calculated for GEP and sediment yield at four scales: pixel ($2m^2$), reach (mean 586 m^2), subwatershed (mean 2.7 km^2), and tributary basin (mean 51 km^2). The erosion predictions were checked during two days of field observations and by draping erosion predictions over satellite imagery from Google Earth (i.e. converting erosion grids to .kml files).

Sediment Aggregation Downstream and Sediment Storage Potential

We also aggregated (summed and area weighted) the predicted sediment yield through the stream network to illustrate how sediment yield varies downstream through the channel network. The aggregated sediment yield value at the bottom of the watershed equals the basin average sediment yield. To identify areas prone to sediment storage that could be targeted for restoration (reconnection of channels to floodplains) we calculated the sediment storage index for larger streams draining areas > 2 km^2:

$$storage\ potential = \frac{valley\ width\ index}{stream\ power\ index} \qquad (6)$$

where the stream power index is drainage area * gradient, and valley width index (e.g. Grant and Swanson 1995) is valley width (at 2x bankfull depth) /channel width (all of these parameters are available in NetMap). Stream power reflects the ability of a channel to transport or store sediment: streams with higher stream power have less opportunity to create large in-channel storage reservoirs in contrast with streams of lower power that can store sediment. The valley width index reflects the potential width of the flood plain for sediment storage.

Results

Erosion Predictions and Field Observations

GEP characterizes erosion in the form of shallow landslides, gullies and surface erosion that is driven by slope steepness and slope convergence. During a two-day field reconnaissance we observed steep eroding banks (bare of vegetation) in areas of high predicted GEP values, a result verified using Google Earth imagery (Figures 6 - 11). In addition, we observed much more stable banks in areas with lower GEP values. These observations indicate that the erosion predictions appear reasonable for delineating relative erosion potential within and between the watersheds in the Zone 7 study area.

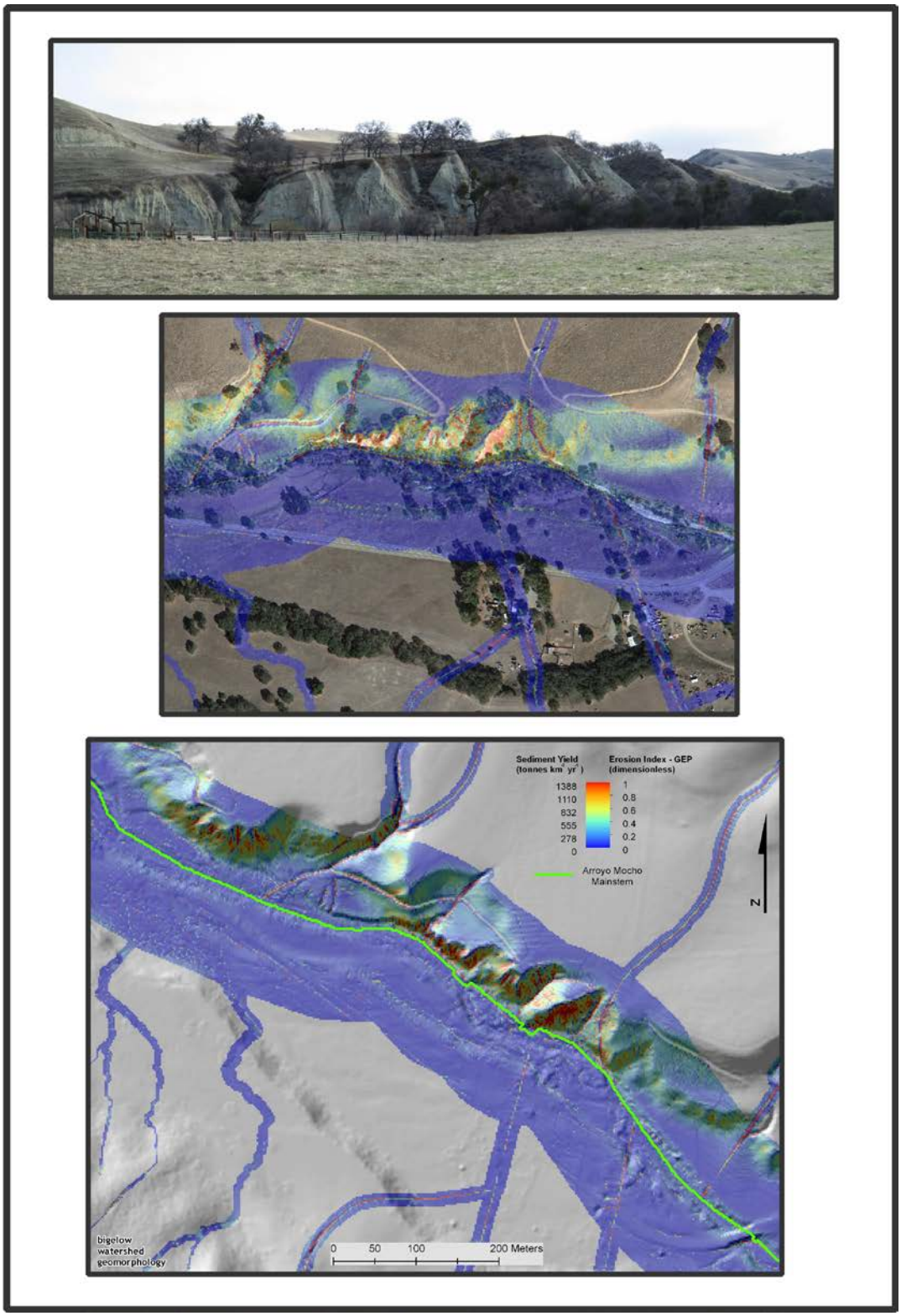


Figure 6. Eroding terrace in middle Arroyo Mocho basin, showing field photo (upper), and pixel scale modified GEP and predicted sediment yield values draped over Google Earth image (middle) and the 2m DEM (lower). Site location is shown on Figure 1. Initial GEP grid was derived from DEM using NetMap (Benda et al. 2007, 2011).

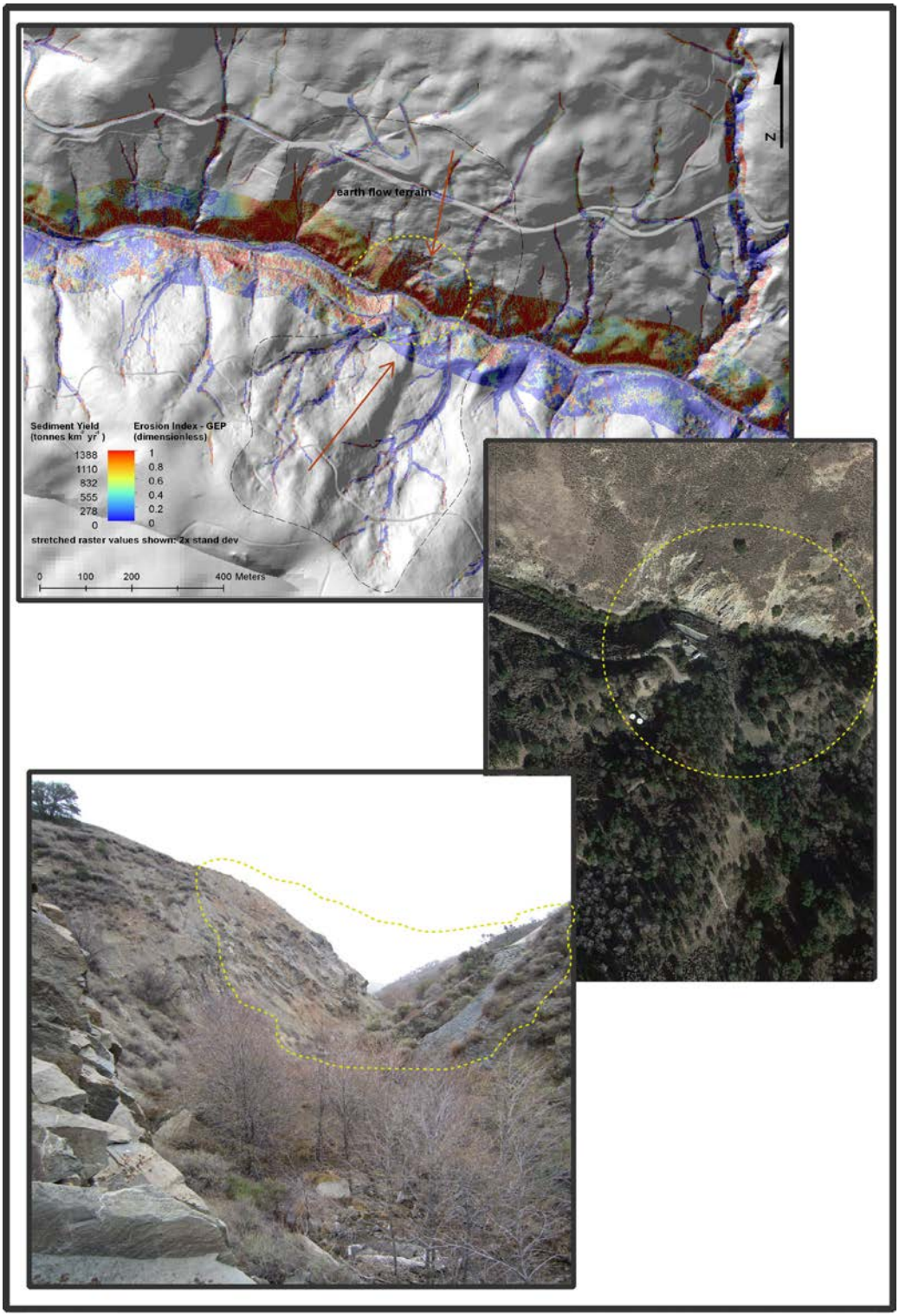


Figure 7. Deep-seated landslide/earthflow terrain in upper Arroyo Mocho basin, showing pixel scale modified GEP and predicted sediment yield values draped over the 2m DEM (upper), and Google Earth image (middle) and field photo (lower) showing the eroding earthflow toes. Site location is shown on Figure 1. Initial GEP grid derived from DEM using NetMap.

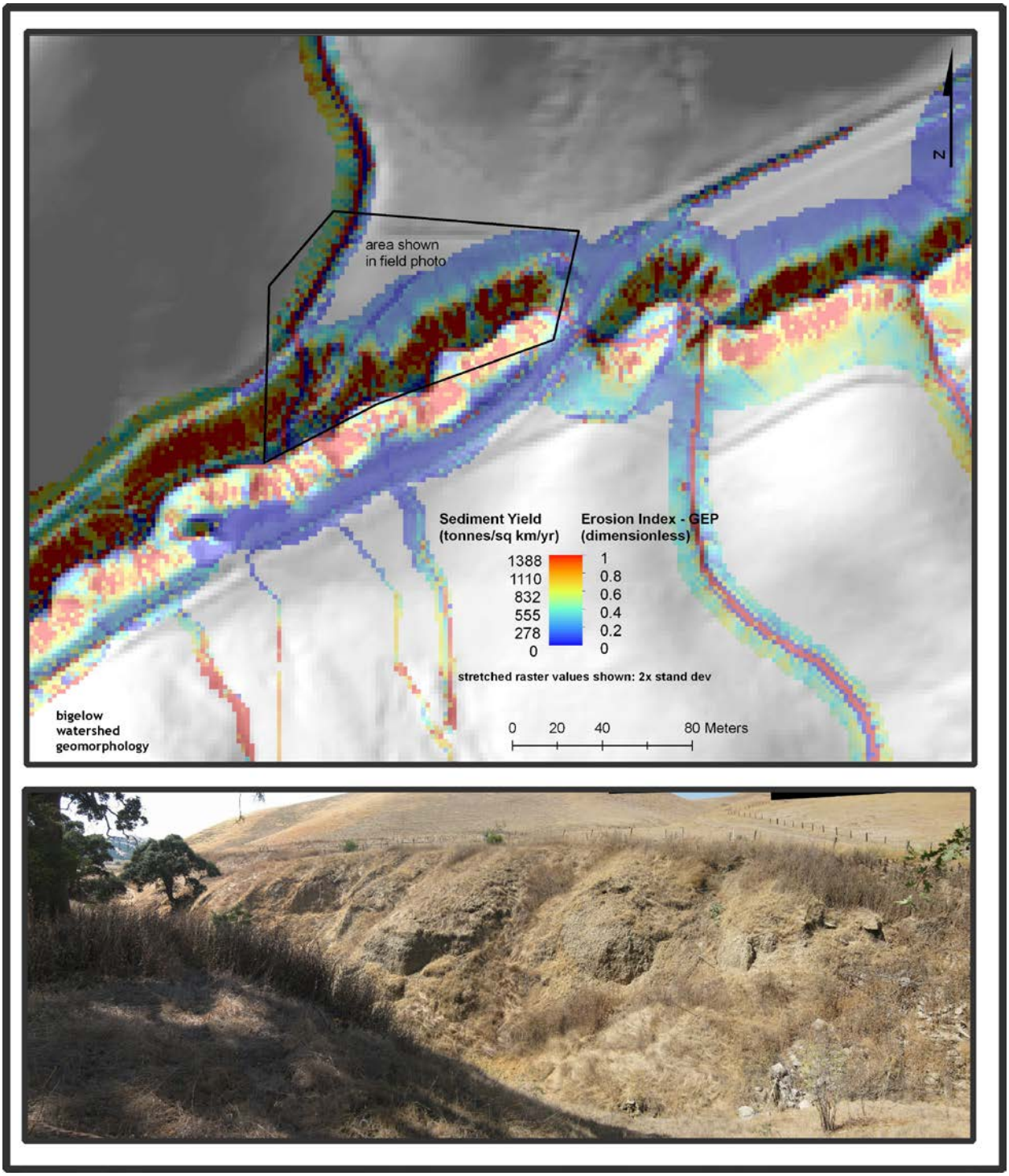


Figure 8. Incised channel and eroding bank in Arroyo Seco basin showing pixel scale adjusted GEP and predicted sediment yield draped over 2 m DEM (upper) and field photo (lower). Site location is shown on Figure 1. Initial GEP grid derived from DEM using NetMap.

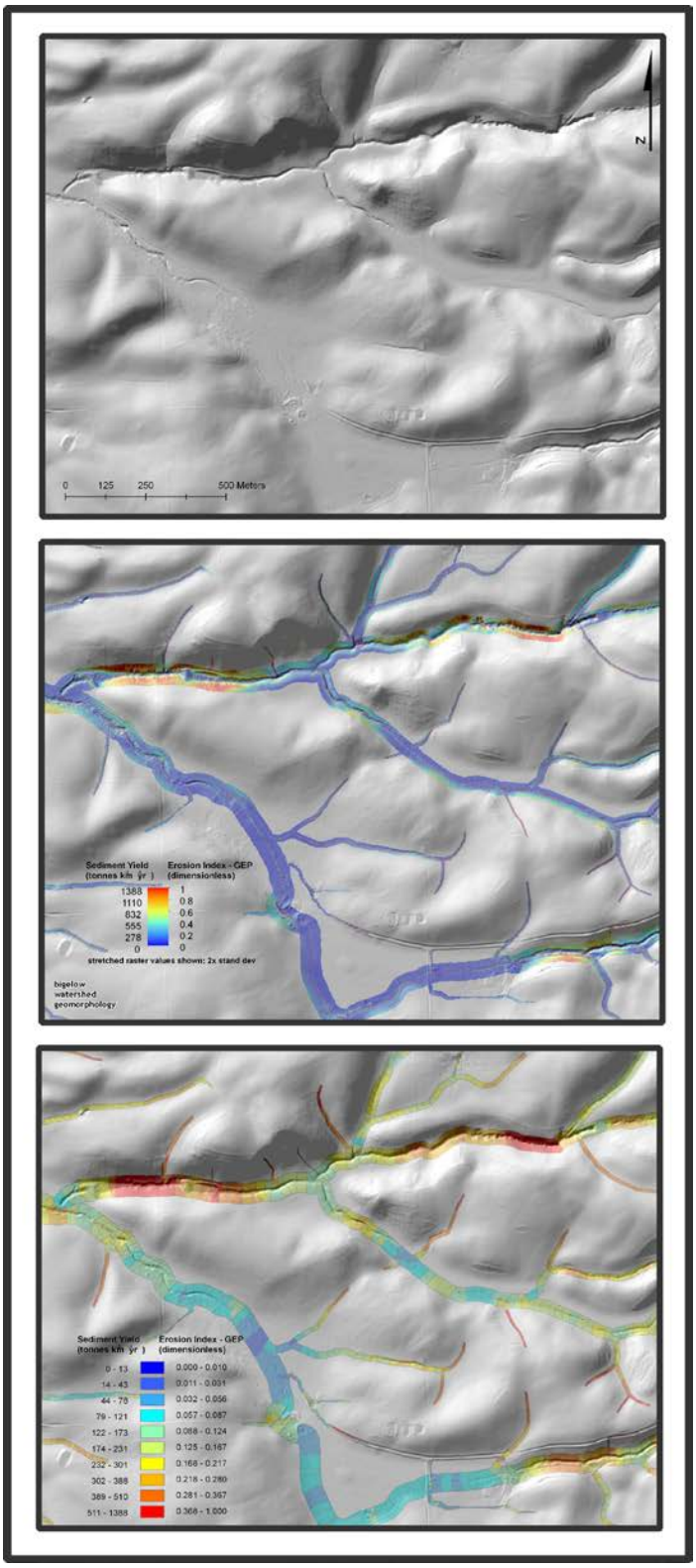


Figure 9. Patchy channel incision in Altamont Creek basin, showing channel incision on the 2 m DEM (upper) and pixel (middle) and reach (lower) scale vegetation modified GEP and predicted sediment yield. Site location is shown on Figure 1. Initial GEP grid derived from DEM using NetMap.

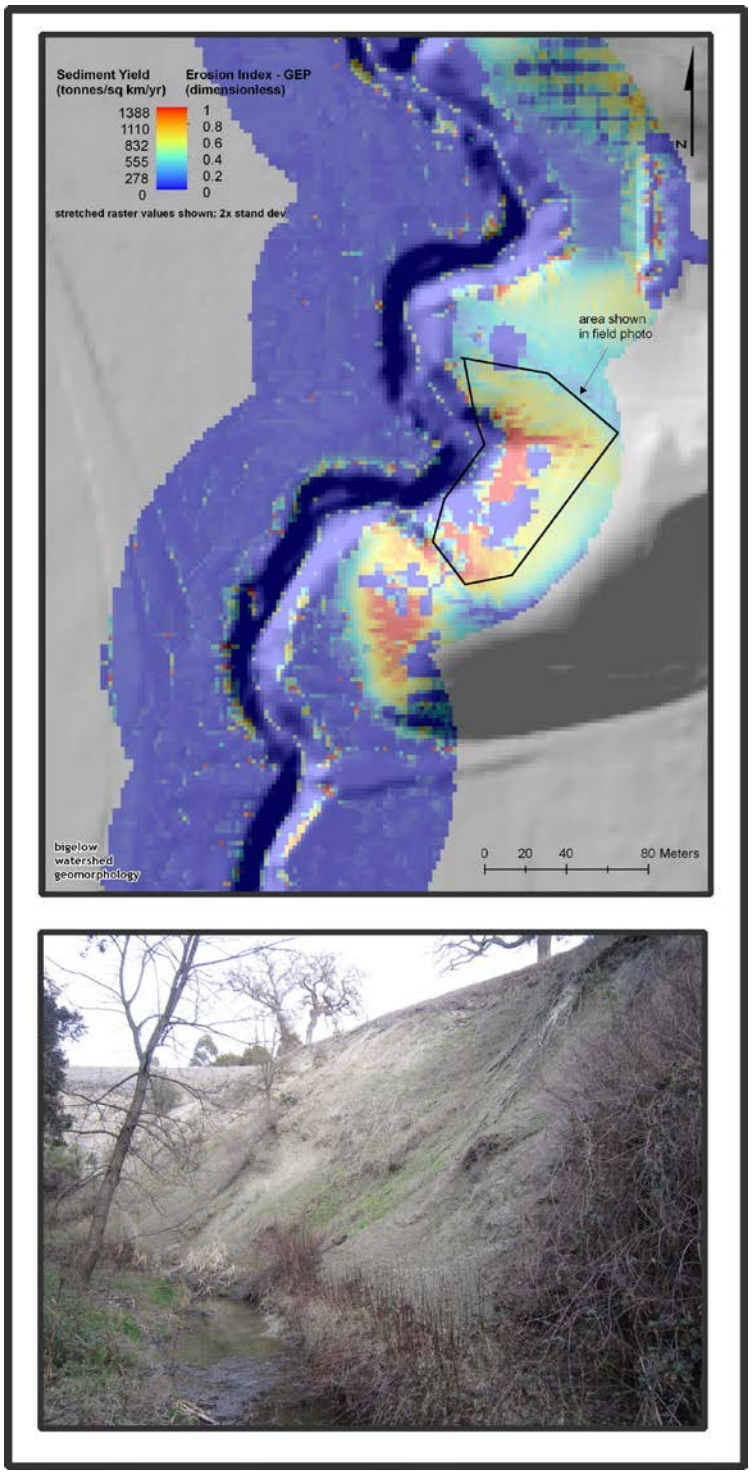


Figure 10. Incised channel eroding into hillslope on Upper Tassajara Creek basin, showing pixel scale vegetation modified GEP and predicted sediment yield draped over 2 m DEM (upper) and field photo of eroding bank. Site location is shown on Figure 1. Initial GEP grid derived from DEM using NetMap.

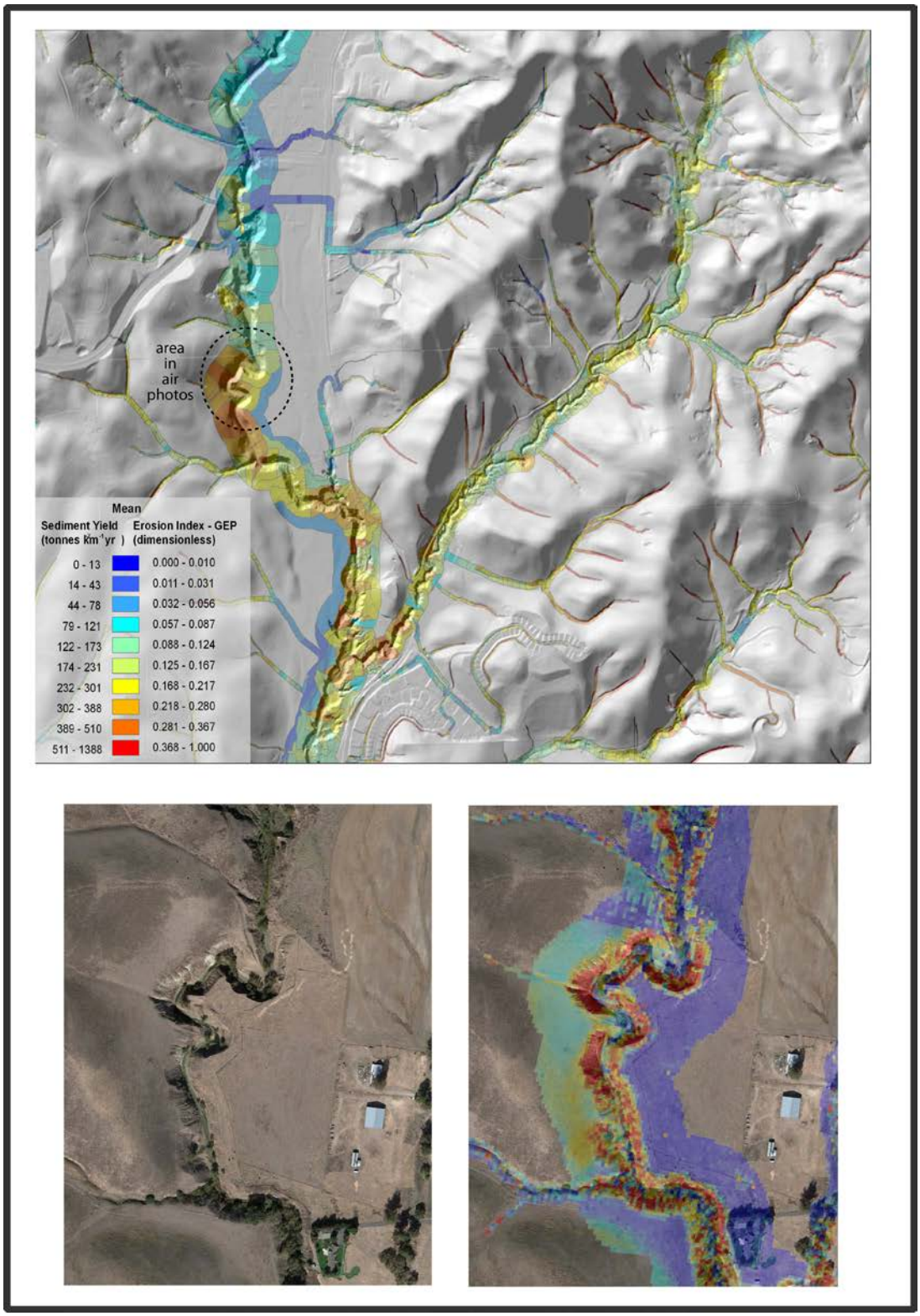


Figure 11. Incised channel on lower Tassajara Creek basin showing vegetation modified GEP and predicted sediment yield at the reach scale (upper) and Google Earth image (lower left) with pixel scale modified GEP draped over image. Site location is shown on Figure 1. Initial GEP grid derived from DEM using NetMap.

Spatial Distribution of Sediment Sources
The spatial distribution of GEP and predicted sediment yield at the tributary basin scale (HUC 12 basins) varies considerably (Figure 12). At this largest scale, the more erosive areas are concentrated in the steeper dissected basins of the southeastern watershed, primarily the upper three Arroyo Mocho basins, Arroyo Seco, and Altamont Creek, where GEP values (and predicted sediment yield) are up three hundred percent higher than western areas at the basin scale (Figure 12). When the basins are grouped into entire tributaries, the Arroyo Mocho tributary dominates predicted sediment yield, supplying nearly half the total load (Figure 13). When viewed at the subwatershed scale (Figure 14), the more erosive subwatersheds (in red) are not isolated to a single larger basin, but generally are grouped in several steep or heavily incised areas across the entire Arroyo Mocho watershed, including steeper uplands or in canyon areas where eroding terraces (Figure 6) or where deep-seated landslides or earthflows impinge on the channel (Figure 7). In addition to these steep erosive subwatersheds, other subwatersheds in the lower Tassajara and Cayetano basins also display higher predicted sediment yields. Similarly to the upper Arroyo Mocho, Arroyo Seco, and Altamont Creek basins, these areas are experiencing the shallow landslides, earthflows and expansive soils related to the underlying Plio/Pleistocene Livermore Gravels and Miocene sedimentary units. At the subwatershed scale, yellow to red areas have predicted erosion rates roughly 300 – 800% greater than blue areas (Figure 14). The information displayed in Figure 14 may be useful for prioritizing potential source control activities.

At the subwatershed scale spatial variability in predicted erosion and sediment supply potential can be evaluated at the stream reach scale that often highlights incised areas with banks eroding into steep hillslopes (Figures 9 and 11). At the reach scale, the spatial distribution of erosion can be viewed at the level of individual pixels to identify eroding banks (bare of vegetation) (Figures 6 - 11). The spatial distribution of GEP and predicted sediment yield at these four scales provides a physical basis for evaluating and prioritizing sediment sources within the large 573 km^2 Arroyo Mocho watershed.

Sediment Aggregation Downstream and Sediment Storage. NetMap was used to aggregate (summed and area weighted) the predicted sediment yields through the stream network at the scale of stream segments to illustrate how sediment yield varies downstream through the channel network (Figure 15). The information displayed in Figure 15 is also useful for prioritizing potential source control activities at a finer scale, showing which channels to focus on, rather than entire subwatersheds (Figure 14). Similar to the previous terrain mapping summaries (Figures 12 - 14), this channel reach scale analysis illustrates higher sediment supply from the more dissected steep terrain of Arroyo Mocho canyon. We also aggregated the total sediment yield downstream by segment and divided it by the total load to show the percentage of the load by tributary (Figure 16). The estimation of sediment supply to channels represents a preliminary partial sediment budget (e.g. Reid and Dunne 1996), based on predictions as described above and on limited field observations that steeper and more convergent terrain have a higher erosion (primarily bank erosion and gullying, but also shallow landsliding and surface erosion) and thus a higher sediment supply to channels.

Using equation (6), sediment storage potential is predicted to vary considerably across the stream network. Certain portions of the mainstems are predicted to have a higher potential sediment storage compared to other segments (Figure 17). The higher sediment storage potential reflects a combination of terrain attributes that would encourage sediment deposition (wide valleys and low channel gradients, see methods). These predictions do not capture areas prone to sediment storage from channel constrictions (e.g. bridges, Lung 2010) or confluence effects that may exert primary control on aggradation in Zone 7 flood control channels.

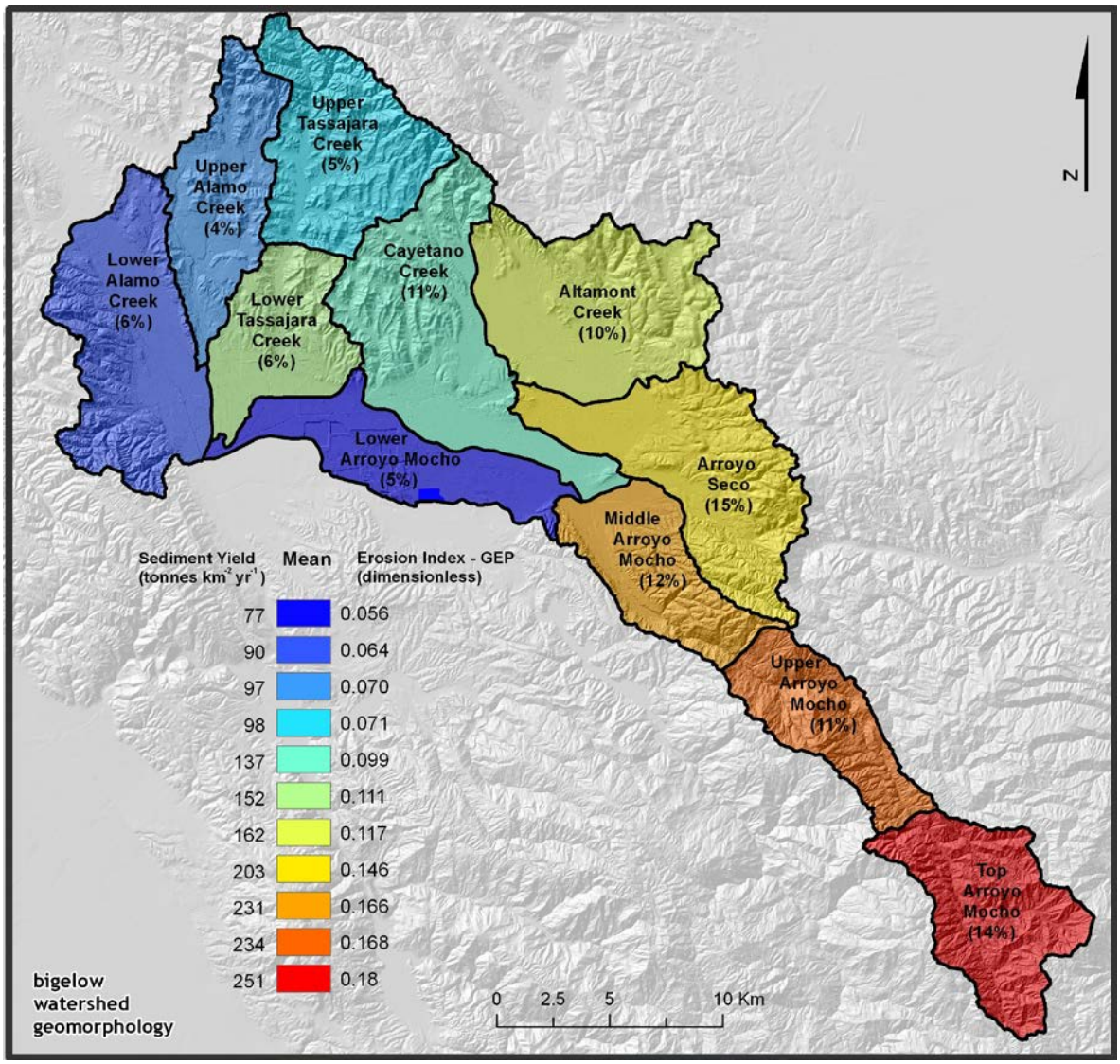


Figure 12. *Average (per unit area)* vegetation modified GEP and predicted sediment yields for the 11 major basins (HUC 12) in the Arroyo Mocho watershed. Yellow to red areas have estimated erosion rates roughly 200 – 300% greater than blue areas. Values in parentheses are the percentage of the *total* (i.e. basin as a whole, not per unit area) Arroyo Mocho watershed modified GEP or sediment yield for each basin. Initial GEP grid derived from DEM using NetMap.

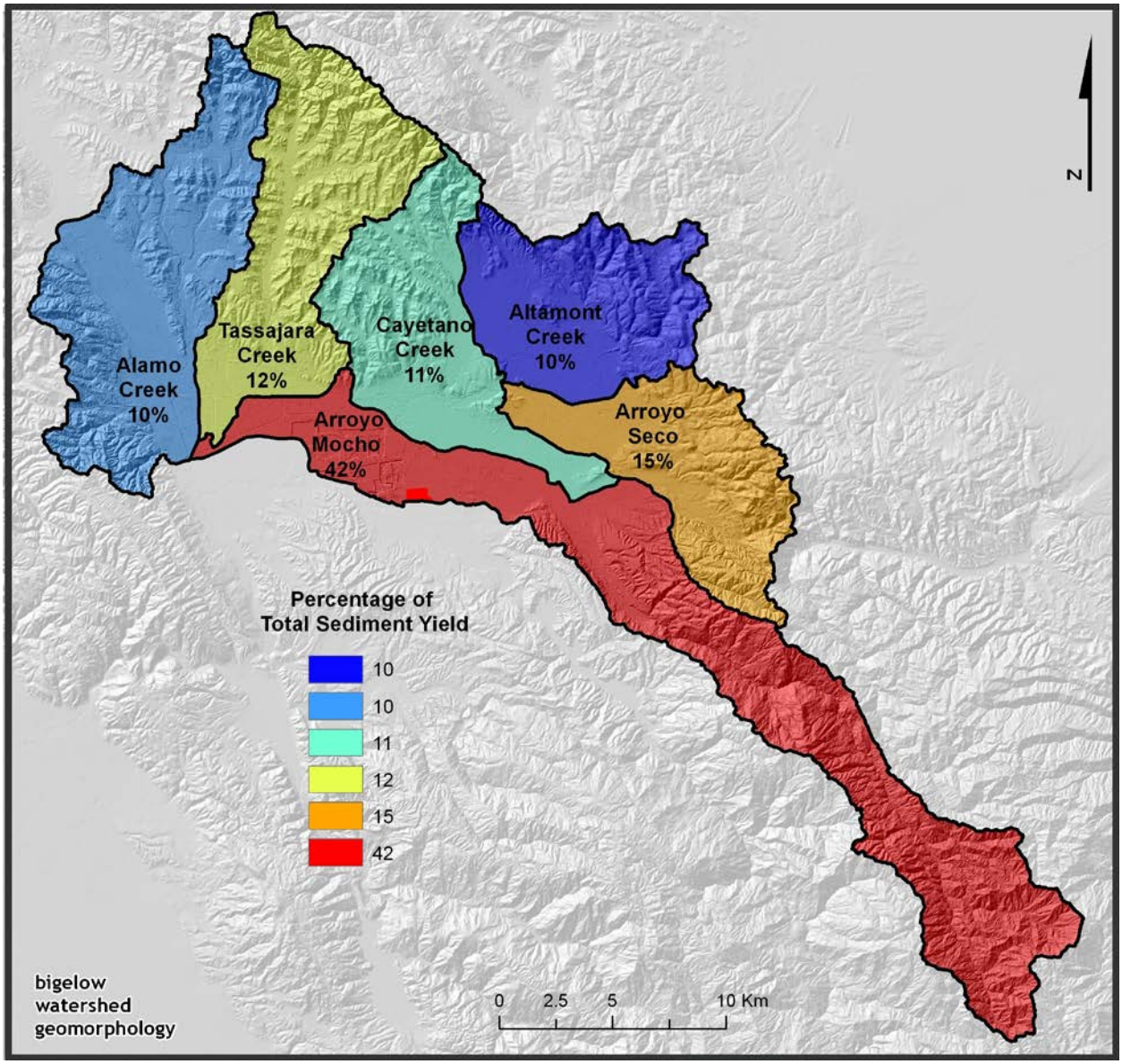


Figure 13. Percentage of the *total* predicted sediment yield for each of the six major tributary basins (i.e total yield for that tributary basin as a whole, *not* per unit area).

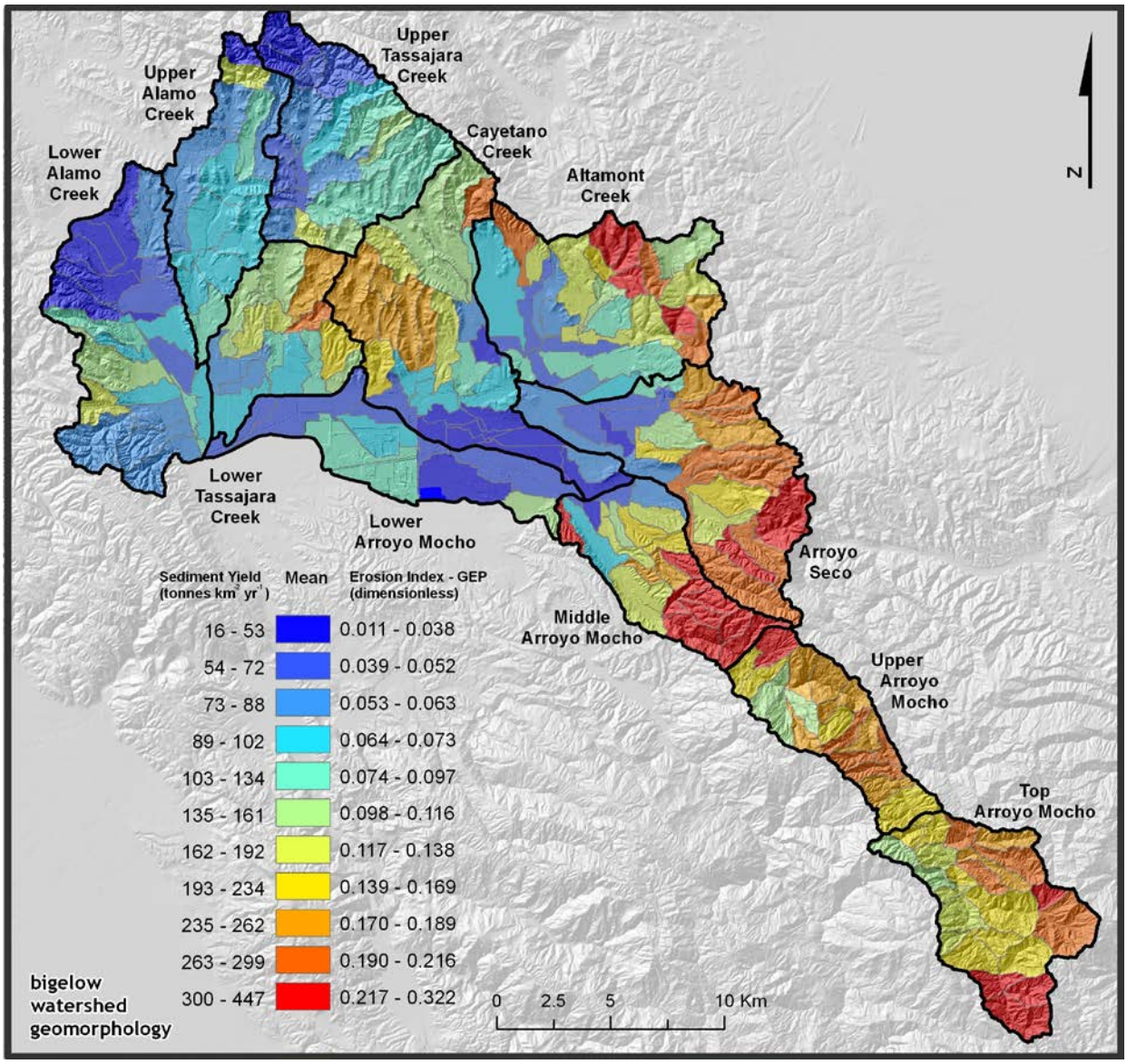


Figure 14. *Average* vegetation modified GEP and predicted sediment yields (*per unit area*) summarized at the subwatershed scale. At this subwatershed scale, yellow to red areas have estimated erosion rates roughly 300 – 800% greater than blue areas. Initial GEP grid derived from DEM using NetMap (Benda et al. 2007, 2011).

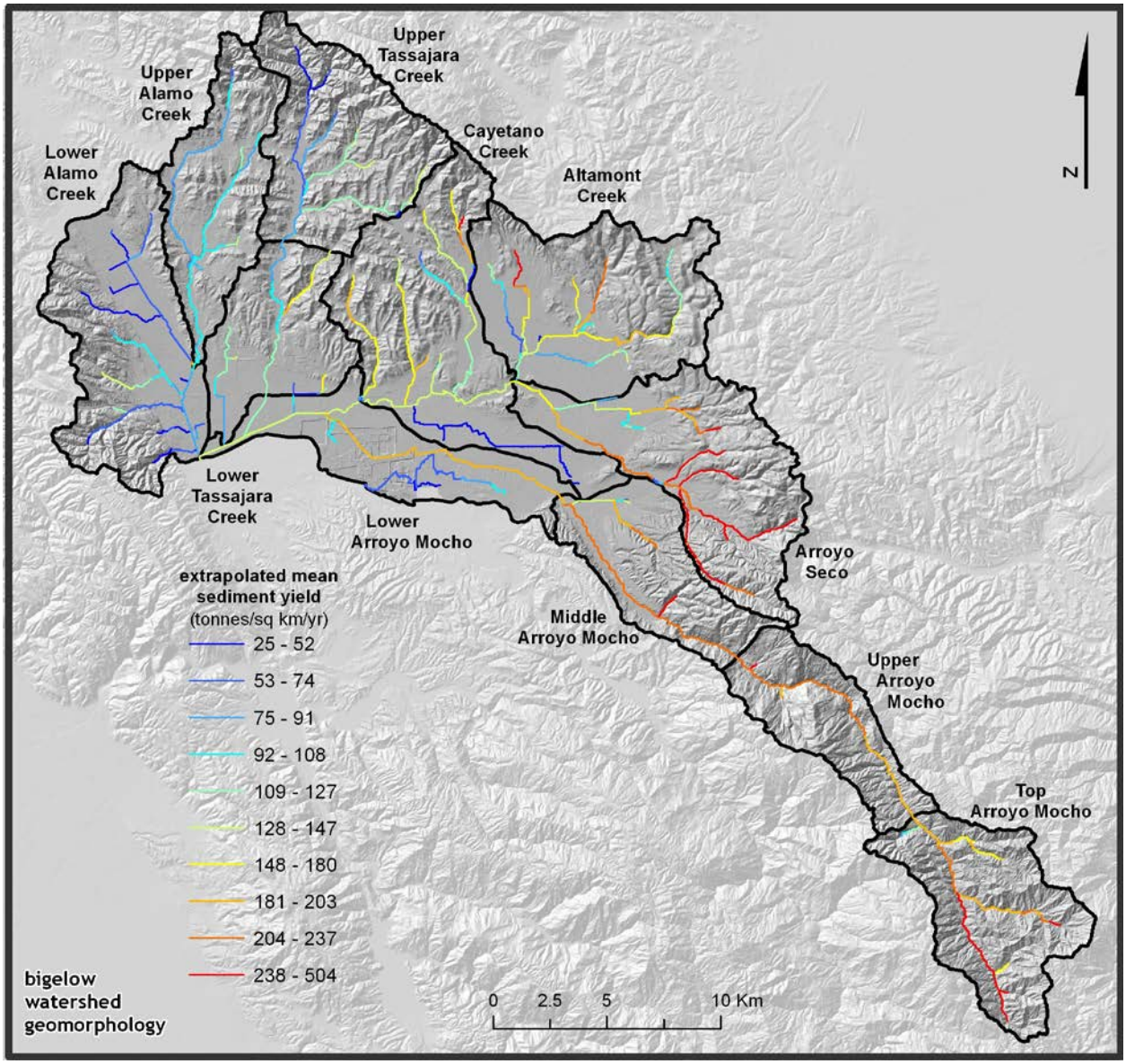


Figure 15. Predicted sediment yield (per unit area) aggregated downstream (summed and area weighted) through the stream network for mainstem streams (draining areas > 2 km^2).

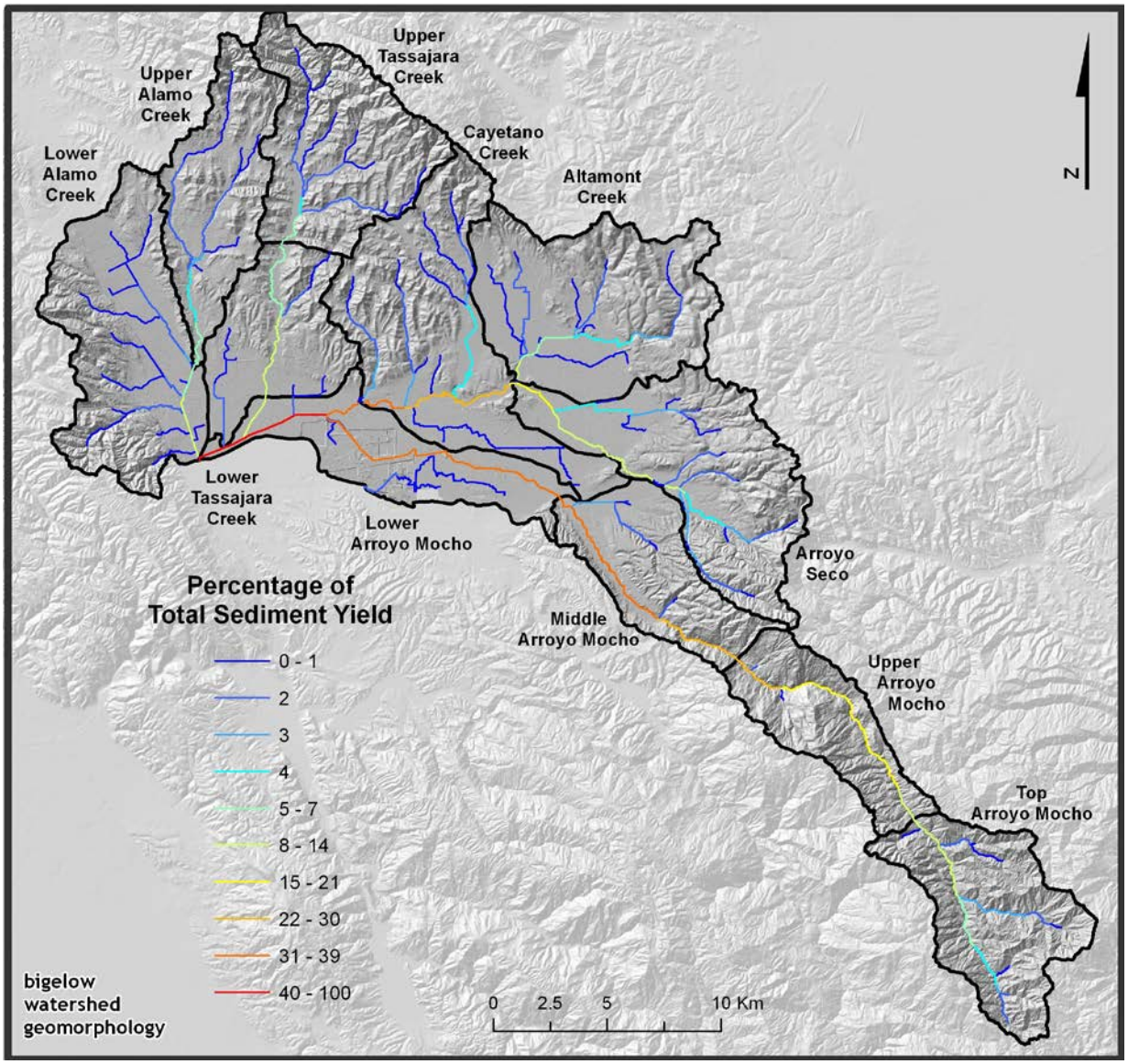


Figure 16. Percentage of *total* predicted sediment yield aggregated downstream through the stream network for mainstem streams (draining areas > 2 km^2).

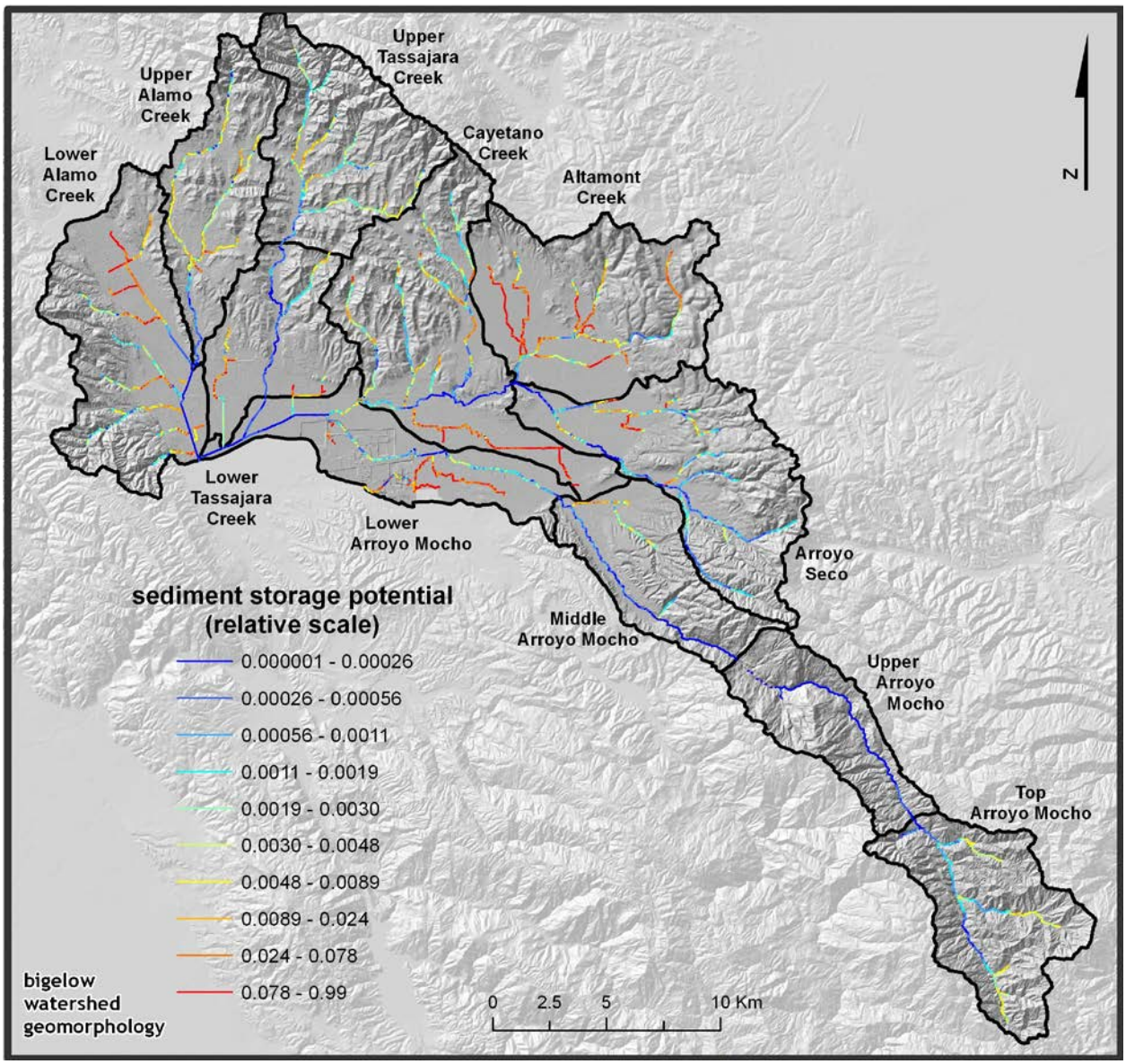


Figure 17. Predicted sediment storage potential for mainstem channels (draining areas > 2 km^2) based on valley width index (valley width/channel width) and stream power (drainage area * gradient). Areas with a high valley width index and low stream power are shown in red. These predictions do not capture areas prone to sediment storage from channel constrictions (e.g. bridges) or confluence effects. Valley width, stream gradient, and drainage area parameters derived from DEM using NetMap (Benda et al. 2007, 2011), channel widths predicted from drainage area based on regional regression relationship (Dunne and Leopold 1978).

Limitations and Recommendations

Here we provide some initial recommendations for characterizing and mitigating sediment sources based on this study. The recommendations for additional characterization describe some of the limitations of our terrain mapping study and potential improvements. The recommendations are listed in order of decreasing importance and priority.

1) Causes of Incision. The channels of the Arroyo Mocho watershed often have an incised arroyo form with steep and eroding banks. The channels appear to have undergone several phases of incision, and may have historically had an incised arroyo channel form. Clarifying the causes and episodes of incision would help inform mitigation efforts by focusing on the causal mechanism (e.g. valley floor channelization, altered riparian vegetation, increased suburban runoff, etc., also see Rogers 1988). This would require a combination of literature and air photo review and some field work.

2) Sediment Source Control. Based on our brief field observations, we describe two potential strategies that might be considered in sediment management plans for Zone 7 flood control channels:

a) **Promote Riparian Vegetation Growth**. The link between channel stability and riparian vegetation is well established (e.g. Thorne 1990, Simon and Darby 1999, Abernethy and Rutherford 2001). Using comparative cross sections from 1957 and 1988, Rogers (1987) indicates substantial incision and loss of riparian trees in several Contra Costa County channels, including Alamo Creek in Zone 7. To encourage riparian growth in bare and eroding areas, strategies could be employed including tree and shrub planting and exclusion of cattle from riparian areas. Bare but not actively eroding areas and incised areas that are trending towards stabilization (i.e. starting to form an inner floodplain) are probably best candidates for riparian restoration (Fischenich and Morrow 2000). Such areas could be prioritized based on the characterization of sediment supply in this report and further study described in this section. While riparian restoration could potentially reduce erosion in any subwatershed, it is likely more applicable and effective in low gradient reaches with perennial flow, for example in the Cayetano Creek, Altamont Creek, Tassajara, and Arroyo Seco basins. Initial small pilot projects would also help determine areas best suited for riparian restoration. This approach requires the cooperation of land owners and could be eligible for funding from Federal and State grants.

b) **Promote Sediment Sinks and Floodplain Deposition on Valley Floors**. Historically the Livermore Valley floor was a sediment sink, where tributaries deposited sediment as broad coalescing fans across the valley floor and a constriction of the valley at the outlet to Arroyo de la Laguna created a depositional lagoon (the Pleasanton Marsh Complex) (Figure 4). While opportunities to reconnect channels to Livermore Valley floor floodplains may be limited by suburban development near channels, there may be more opportunities to promote sediment storage on tributary valley floors. This

approach would be appropriate in specifically targeted locations within any of the basins. Indeed this appears to be a strategy downstream of suburban development in some basins, such as Upper Alamo Creek, and smaller scale cattle ponds that trap sediment from highly disturbed areas (Figure 18A). We also observed some basins where the channel disappears into flat valley bottoms that store sediment. There may be some locations on the Livermore Valley floor that could be targeted for sediment storage, where there is sufficient space to allow channels to reoccupy floodplains or become multithread channels (Figure 18B). Ideal locations for promoting sediment storage could be identified based on valley width, stream gradient, and other attributes contained in the NetMap stream layer and prioritized based on the characterization of sediment supply (e.g. Figures 14 and 15) in this report, the historical ecology analysis for Zone 7 (Beagle et al., 2013), and further characterization described in this section.

3) Sediment Supply from Earthflow Terrain. GEP generally captures erosion sources driven by steep and convergent slopes, but does not adequately capture lower gradient sediment sources such as earthflows. GEP may be an adequate indictor of the erosion potential at earthflow toes, however, it does not address the rate of erosion. Earthflows tend to move after cumulative weeks and months of heavy precipitation (Keefer and Johnson 1983, Rogers 1987). Short term rates of earthflow movement in the Eastbay hills range from centimeters per year in the Berkeley hills over 9 years (Hilley et al. 2004) to meters per year in the Castro Valley hills over one year (Keefer and Johnson 1983). Earthflows can dominate sediment supply to channels in the Coast Range (e.g. Kelsey 1977, Bedrossian and Custis 2002, Mackey and Roering 2011) and also in the East Bay Hills (Bigelow et al., 2013). Hummocky terrain characteristic of earthflows is apparent on high resolution hillshade maps, particularly in the northern tributary basins with clay rich formations (e.g. Figure 20 upper, also see Davenport 1985, Wentworth et al. 1997, Roberts et al. 1999, Majmundar 1991 and 1996). Characterizing sediment supply from earthflows would entail compiling past mapping of earthflows, improved mapping from high resolution LiDAR hillshade maps, and some characterization of earthflow activity and rates from the field and literature. Earthflows could be a significant portion of the sediment contribution from the northern and eastern basins over the decadal time scale. However the sediment caliber from earthflow terrain in the northern tributaries is finer compared to southern basins, and may imply a lower bedload component that is aggrading in valley floor flood control channels (see recommendation on bedload yield later).

These hillslope mass wasting sources are generally natural (Figure 20), and earthflow mitigation opportunities may be limited to opportunistic and untested vegetation restoration of native bunch grasses. Kelsey (1977, 1978) suggested the conversion of deep-rooted native bunch grasses to shallow-rooted annual grasses for cattle grazing by early settlers may have caused a substantial increase in the sediment flux to channels from earthflows on the Van Duzen River in Northern California, and other historical grazing impacts on sediment supply have been hypothesized for the East Bay hills (Reid 1987). Controlling and reducing erosion from earthflow terrain is typically difficult or cost prohibitive due to the deeper failure planes and larger area of the mass movement (e.g. entire hillsides). Riparian restoration downstream of earthflow-dominated areas would likely increase sediment storage in locations that are ideal sediment

sinks (low gradient, wide valleys, e.g. Figure 17). Initial small scale pilot projects would indicate the effectiveness of such strategies. A more detailed analysis and literature review of mitigation opportunities from mass wasting could also be conducted.

4) Episodic Sediment Supply. The predicted sediment supply in the terrain analysis represents an average condition using only topographic attributes that characterize *chronic or annual (persistent)* sediment supply (primarily bare steep channels banks). However, erosion and sediment supply from most landscapes are highly variable in space and time resulting from highly stochastic processes driven by interactions among storms, vegetation and topography (Benda and Dunne 1997). The terrain mapping approach generally characterizes sediment supply from bank erosion and small streamside slides that appear to dominate. However, episodic mass wasting from hillslope areas further from the steams may be triggered during more extreme events such as El Niño storms (e.g. Ellen and Wieczorek 1982). Such events can dominate the long term sediment supply on the Alameda Creek system, for example, El Niño events in 1983 and 1998 (Figure 2) accounted for 37% of the total load at Niles gage (1970-2010) (Beagle et al. 2012) and a 1958 flood event comprised 48% of the total load at Niles (1957-1970) (Brown and Jackson 1973). Patchy remnant fill terraces created by the 1950s extreme floods are occasionally visible in the higher order channels of the Alameda Creek watershed today (Bigelow et al. 2008, Pearce et al. 2009, Beagle et al. 2012) and we observed such fill terraces in the Arroyo Mocho canyon (Figure 19).

Some characterization and comparison of the episodic and chronic (persistent) sediment supply could be used to determine: (1) what proportion of the long-term sediment supply is dominated by episodic events and (2) the spatial distribution of sediment sources from episodic supply. Characterizing the episodic supply of sediment from past hillslope mass wasting would entail generating a landslide inventory from historic air photos spanning large storm events and some field work to estimate the input from shallow streamside slides not easily visible on air photos and sampling of large landslide scarp depths that cannot be estimated from air photos.

5) Improved Mapping of Incised Channels. Channel incision and gullying in the Arroyo Mocho watershed is discontinuous or patchy. In this study we used digital terrain modeling (NetMap using GEP) to characterize erosion from steep banks of incised channels. However, it may be possible to improve the identification and mapping of incised channels. This would entail developing a new analysis tool in NetMap that would define the width and depth of channel incision throughout the channel network by locating the break in slope between the natural hillslope or valley floor and the steep incised channel bank.

6) Bedload Yield. This terrain mapping approach characterizes total sediment supply to the stream network without regard to the proportion of bedload to the overall sediment load. The proportion of bedload to the total sediment load generally decreases downstream due to particle attrition (abrasion and breakage) (e.g. Madej 1995, Benda and Dunne 1998). Attrition rates will also vary based on lithology (e.g. Madej 1995). Some characterization of the bedload yield variation throughout the stream network would help prioritize potential mitigation efforts to areas that have a higher bedload yield filling the valley floor flood control channels. For

example, harder Franciscan rocks underlying the upper Arroyo Mocho watershed may result in a larger bedload component relative to the northern tributaries underlain by weaker lithologies. This type of characterization could involve tumbling mill analysis of colluvium throughout the watershed to estimate attrition rates by lithology. The bedload yield throughout the stream network could be simply estimated by a proportion of the overall sediment yield that decreases exponentially with increasing drainage area (e.g. Dietrich and Dunne 1978). This decay function would be further adjusted based directly on lithology attrition rates within the watershed relative to each other (e.g. a lithology with twice the attrition rate of another would decay twice as fast). More involved estimates of the variation in bedload yield are also possible (e.g. Madej 1995, Collins and Dunne 1989, Benda and Dunne 1997).

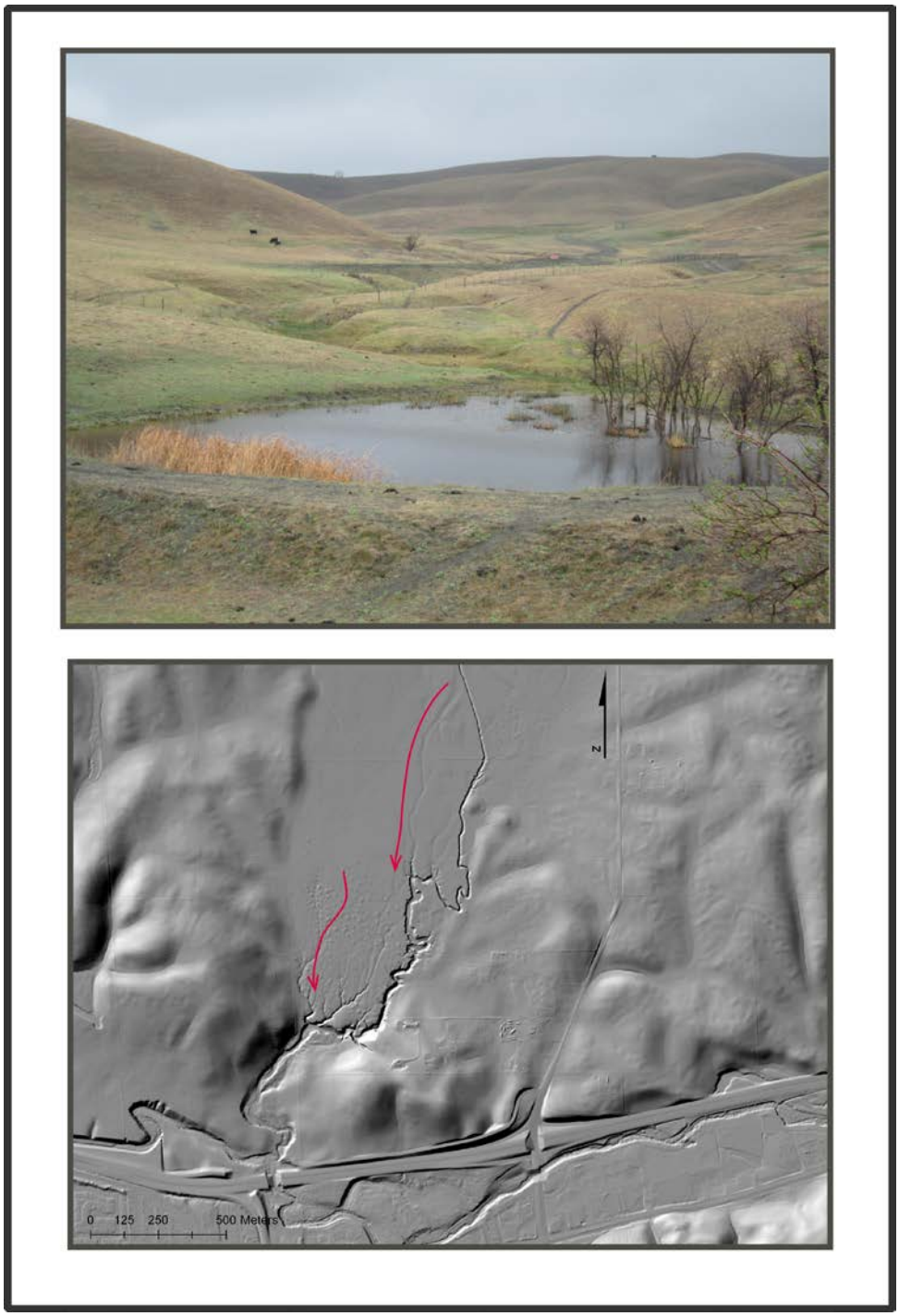


Figure 18. (18A upper) Example of a stock pond in upper Tassajara Creek that traps sediment below a highly disturbed valley floor. (18B lower) Example of an area that could promote sediment storage in lower Cayetano Creek, where a "plug and pond" style restoration project could recreate a multithread channel connected to its floodplain. The US Forest Service commonly restores incised meadow areas using such an approach where the incised channel is plugged with check dams or filled and new channels are reconnected to the floodplain.

Figure 19. Cut and fill terraces (~2m high) observed in Arroyo Mocho canyon just downstream of massive earthflow sources. Sycamores on the floodplain/terrace tread in the lower photo appear to be greater than 50 years old, possibly dating to the historic 1950s floods.

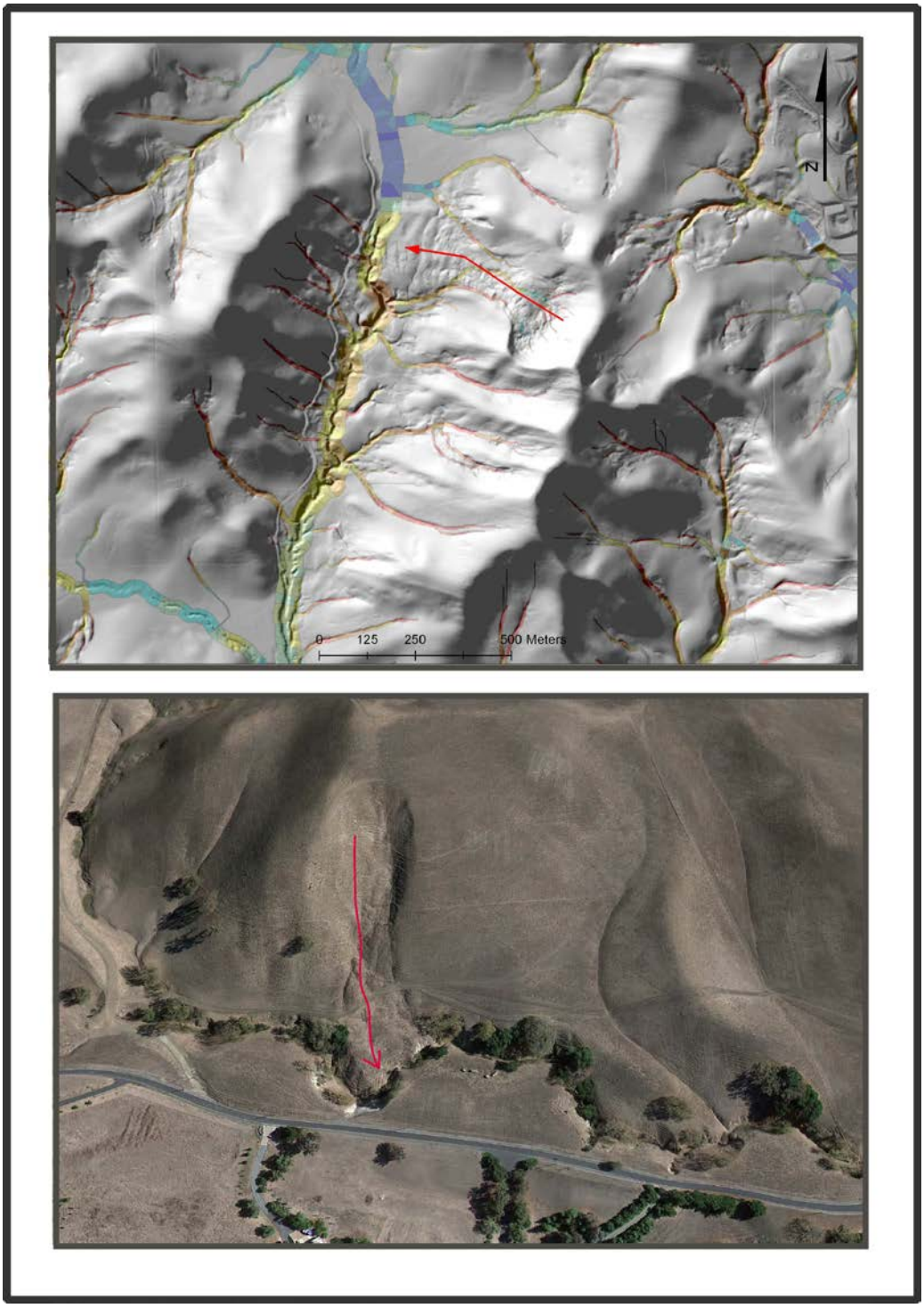


Figure 20. Examples of mass wasting in Cayetano Creek basin that are likely triggered and move episodically during large storms or months of heavy precipitation. Sediment supply from such episodic supply is not fully captured by the terrain mapping estimates of chronic sediment supply characterized in this study. The GEP index captures the steep and convergent landform of the earthflow toe, however, it does not address erosion rates which might be accelerated compared to other, non earthflow related, arroyo landforms.

References

Abernethy B, Rutherford ID. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological Processes 15: 63–79.

Beagle, J.R., Bigelow, P., McKee, L. J., Pearce, S. 2012. Sediment Source Reconnaissance of Stonybrook and Sinbad Creek Watersheds: A rapid evaluation of two small tributaries near the Alameda Creek Flood Control Channel. Prepared for the Alameda County Flood Control and Water Conservation District.

Beagle, J., Baumgarten, S., Grossinger, R., Stanford, B., Askevold, R., 2013. Historical Channel Change Analysis for Arroyo Mocho and Arroyo Las Positas: process-based perspective on landscape-scale management strategies. Prepared for: Zone 7 Water Agency. San Francisco Estuary Institute, Richmond, CA. 67 pp.

Bedrossian, T.L. and K. Custis. 2002. Review of July 2002 EPA Analysis of Impacts of Timberland Management on Water Quality. California Geological Survey Memorandum. ftp://ftp.consrv.ca.gov/pub/dmg/thp/documents/memorandas/EPA.pdf

Beeson, C.E, and Doyle. P .E, 1995, Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin, vol. 31, no. 6, p. 983-990.

Benavides-Solorio, J. and L. H. MacDonald, 2005. Measurement and prediction of post-fire erosion at the hillslope scale, Colorado Front Range. International Journal of Wildland Fire 14:1-18.

Benda, L. and Dunne, T. 1997. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research, v.33: 2865-2880.

Benda, L., Miller, D. J., Andras, K., Bigelow, P., Reeves, G., and Michael, D. 2007. NetMap: A new tool in support of watershed science and resource management, Forest Sci., 52, 206–219.

Benda, L., Miller, D., Lanigan, S., and Reeves, G. 2009. Future of applied watershed science at regional scales, EOS, T. Am. Geophys. Un., 90, 156–157.

Benda, L., Miller, D., and Barquín, J. 2011. Creating a catchment perspective for river restoration, Hydrol. Earth Syst. Sci. Discuss., 8, 2929-2973, doi:10.5194/hessd-8-2929-2011.

Bigelow, P., Pearce, S., and McKee, L., 2013. Evaluation of Sediment Sources to Don Castro Reservoir: On the magnitude, spatial distribution, and potential reduction of sediment supply in the Upper San Lorenzo Creek watershed. Prepared for the Alameda County Flood Control and Water Conservation District, Hayward, CA. Prepared by the San

Francisco Estuary Institute and Bigelow Watershed Geomorphology. SFEI Contribution number 669. 49 pp.

Bigelow, P., S. Pearce, L. McKee, and A. Gilbreath. 2008. A sediment budget for two reaches of Alameda Creek. Prepared for Alameda Flood Control and Water Conservation District.

Brown, W.M. and L.E. Jackson. 1973. Erosional and depositional provinces and sediment-transport in the south central San Francisco Bay region, California: San Francisco Bay Environment and Resources Planning Study, Interpretative Report 3, U.S. Department of the Interior, Geological Survey Miscellaneous Field Studies Map 515, U.S. Department of Housing and Urban Development, 3 sheets.

Clarke, S., Burnett, K. M., and Miller, D. J. 2008. Modeling streams and hydrogeomorphic attributes in Oregon from digital and field data, J. Am. Water Resour. Assoc., 44, 459–477.

Collins, B., and T. Dunne. 1989. Gravel transport, gravel harvesting and channel-bed degradation in rivers draining the southern Olympic Mountains, Washington, U.S.A., Environ. Geol. 13:213-224.

Davenport, C.W. 1985. Landslide Hazards in Parts of the Diablo and Dublin 7.5' Quadrangles, Contra Costa County, California. California Division of Mines and Geology Open-File Report 86- 7 SF, Landslide Hazard Identification Map No. 3.

Department of Water Resources, 1996. Livermore and Sunol Valleys: evaluation of ground water resources. Appendix A: Geology. Bulletin No. 118-2. State of California, Resources Agency. August, 1996. 79 pp.

Dietrich, W.E. and T. Dunne, 1978. Sediment Budget for a Small Catchment in Mountainous Terrain: Zietschrift fur Geomorphologie, Suppl. 29:191-206.

Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. W. H. Freeman & Company. San Francisco. 818 p.

Emmett, W.H. 2004. A historical perspective on regional channel geometry curves. Stream Notes - January. U.S. Forest Service Streams Systems Technology Center.

Ellen, S. and Wieczorek, G.F., editors. 1988. Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U. S. Geological Survey Professional Paper 1434

Fischenich, J.C., and Morrow, J.V. 2000. Reconnection of floodplains with incised channels. US Army Engineer Research and Development Center Technical Notes Collection (ERDC-TN-EMRRP-SR-09).

Gilman, E. 1988. Predicting root spread from trunk diameter and branch spread. Journal of Arboriculture 14(4): 85–89.

Grant, G.E., Swanson, F.J. 1995. Morphology and processes of valley floors in mountain streams, western Cascades, Oregon. Natural and Anthropogenic Influences in Fluvial Geomorphology. Geophysical Monograph, vol. 89, pp. 83–101.

Graymer, R.W., Jones, D.L., and E.E. Brabb. 1996. Preliminary geologic map emphasizing bedrock formations in Alameda County, California: A digital database. USGS Open-File Report: 96-252.

Helley, E.J., and Graymer, R.W. 1997. Quaternary geology of Alameda County, and parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, California: A digital database. USGS Open-File Report: 97-97.

Hilley GE, Burgmann R, Ferretti A, Novali F, Rocca F. 2004. Dynamics of slow-moving landslides from permanent scatterer analysis. Science 304(5679): 1952–1955.

Keefer, D.K., and Johnson, A.M., 1983. Earth flows – Morphology, mobilization and movement. U.S. Geological Survey Professional Paper 1264.

Kelsey, H. M. 1977. Landsliding, Channel Changes, Sediment Yield and Land Use in the Van Duzen River Basin, North Coastal, California: Ph.D. Dissertation, Published in Earth Resources Monograph 3, U. S. Forest Service Region 5, 370 p.

Kelsey, H. M. 1978. Earthflows in Franciscan Melange, Van Duzen River Basin, California: Geology, v. 6, p. 361-364

Lung, P., 2010. Sediment and hydraulic challenges in the city of Livermore. Alameda Creek Watershed Council Annual Conference. October 28. Castro Valley, CA.

Mackey, B.H. and J.J. Roering. 2011. Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne LiDAR and historical aerial photographs, Eel River, California. Geol Soc Am Bull 123:1560–1576.

Madej, M.A. 1995. Changes in channel-stored sediment, Redwood Creek, Northwestern California, 1947-1980. Chapter O in U.S. Geological Survey Professional Paper 1454. Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. K.M. Nolan, H.M. Kelsey, and D.C. Marron, eds.

Majmundar, H.H., 1991. Landslide Hazards in the Livermore Valley and Vicinity, Alameda and Contra Costa Counties, California, Calif. Div. Mines and Geology Open-file Report 91-02, Landslide Hazard Identification Map 21. Map scale 1:24,000.

Majmundar, H.H., 1996. Landslides and related features, in Landslide hazards in the Hayward quadrangle and parts of the Dublin quadrangle, Alameda and Contra Costa Counties, California: Calif. Div. Mines and Geology, Open-file Report 95-14, plate B, map scale 1:24,000.

Miller, D. J. 2003. Programs for DEM Analysis. Seattle, WA, Earth Systems Institute: 38.

Miller, D. J. and Burnett, K. M. 2007a. Effects of forest cover, topography, and sampling extent on the measured density of shallow, translational landslides, Water Resour. Res., 43, 1–23.

NLCD, 2006. National Land Cover Database, United States Geological Survey, Sioux Falls, South Dakota. http://www.mrlc.gov/

Reid, L.M. and Dunne, T. 1996. Rapid evaluation of Sediment Budgets. Germany: GeoEcology paperbacks, Catena Verlag.

Reid, L.M. 1987. Erosion and deposition in a discontinuous gully system. Ph.D. dissertation, University of Washington, Geological Sciences. 270 pp.

Pearce, S., Bigelow, P., and McKee, L. 2009. Dry Creek Watershed Sediment Source Reconnaissance Technical Memorandum. Prepared for the Alameda County Flood Control and Water Conservation District, Hayward, CA. Regional Watershed Program, San Francisco Estuary Institute, Oakland, CA. 27 pp.

Prism 2012. Oregon State University parameter-elevation regressions on independent slopes model (Prism) climate mapping system and climate data archive: http://www.prism.oregonstate.edu

Rogers, J.D. 1987. Pleistocene to Holocene transition in central Contra Costa County. In n Field Trip Guide to the Geology of the San Ramon Valley and Environs, pp. 29-51. Northern California Geological Society, San Ramon, California.

Roberts, S., M.A. Roberts, and E.M. Brennan. 1999. Landslides in Alameda County, California, A Digital Database Extracted from Preliminary Photointerpretation Maps of Surficial Deposits by T.H. Nilsen in USGS Open-File Report 75-277.

Sidle, R.C. 1987. A dynamic model of slope stability in zero-order basins. International Association of Hydrological Sciences, Publication 165:101-110.

Simon A, Darby SE. 1999. The nature and significance of incised river channels. In Incised River Channels: Processes, Forms, Engineering and Management, Darby SE, Simon A (eds). John Wiley and Sons: London; 3–18.

SFEI. 2011. Bay Area Aquatic Resource Inventory Basemap. San Francisco Estuary Institute, Richmond, CA. http://www.sfei.org/BAARI

Smith, J.G. 1964. Root spread can be estimated from crown width of Douglas Fir, Lodgepole Pine, and other British Columbia tree species. The Forestry Chronicle 40(4): 456-473.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Tran. Am. Geophys. Union 38:913–920.

Thorne CR. 1990. Effects of vegetation on riverbank erosion and stability, In Vegetation and Erosion: Processes and Environments, Thornes JB (ed.). John Wiley & Sons: 125–144.

Tubbs, C.H. 1977. Root-crown relations of young sugar maple and yellow birch. Research Note NC-225. USDA Forest Service, North Central Forest Experiment Station.

Wang, Z.Y., G.H. Huang, G.Q. Wang, and J. Gao. ”Modeling of Vegetation-Erosion Dynamics in Watershed Systems.” Journal of Environmental Engineering. Vol 130, No. 7, July 1, 2004.

Wentworth Carl M., Scott E. Graham, Richard J. Pike, Gregg S. Beukelman, David W Ramsey, Andrew D. Barron. 1997. Summary Distribution of Slides and Earth Flows in Alameda County, CA. USGS OF 97-745.

Appendix 7.5

Landscape Scale Management Strategies for Arroyo Mocho and Arroyo Las Positas

Julie Beagle
Sean Baumgarten
Robin Grossinger
Ruth Askevold
Bronwen Stanford

2014

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

LANDSCAPE SCALE MANAGEMENT STRATEGIES

for Arroyo Mocho and Arroyo Las Positas

PROCESS-BASED APPROACHES FOR DYNAMIC, MULTI-BENEFIT URBAN CHANNELS

SAN FRANCISCO ESTUARY INSTITUTE

Prepared for

ZONE 7 WATER AGENCY

SFEI PUBLICATION #714

ACKNOWLEDGEMENTS

SFEI would like to acknowledge Zone 7 Water Agency for funding this exploratory document, particularly Carol Mahoney, Joe Seto and Brad Ledesma. Thanks also to Phil Stevens and the staff at the Urban Creeks Council for their input, as well as Heath Bartosh of Nomad Ecology. This project was made possible by the Alameda Creek Watershed Historical Ecology Study, completed in 2013, which was funded by the San Francisco Public Utilities Commission and Alameda County Flood Control and Water Conservation District, with additional support from Zone 7 Water Agency, Alameda County Water District, and the Alameda County Resource Conservation District.

SUGGESTED CITATION

Beagle J, S Baumgarten, RM Grossinger, RA Askevold, Stanford B. 2014. Landscape Scale Management Strategies for Arroyo Mocho and Arroyo Las Positas: Process-Based Approaches for Dynamic, Multi-Benefit Urban Channels. SFEI Publication #714, San Francisco Estuary Institute, Richmond, CA.

COVER AND REPORT IMAGES

Cover, left to right and top to bottom: USDA 2005; USDA 1939; photo by Sean Baumgarten; Thompson and West 1878, courtesy of David Rumsey Map Collection.

Further use or reproduction of images in the report is prohibited without express written permission from the responsible source institution. For permissions and reproductions inquiries, please contact the responsible source institution directly.

LANDSCAPE SCALE MANAGEMENT STRATEGIES

for Arroyo Mocho and Arroyo Las Positas

PROCESS-BASED APPROACHES FOR DYNAMIC, MULTI-BENEFIT URBAN CHANNELS

Prepared by

SAN FRANCISCO ESTUARY INSTITUTE

Julie Beagle

Sean Baumgarten

Robin Grossinger

Bronwen Stanford

Ruth Askevold

Prepared for

ZONE 7 WATER AGENCY

SFEI PUBLICATION #714

CONTENTS

1. OVERVIEW 1

Report structure 2

Methods summary 2

Summary of change and current challenges 4

2. LANDSCAPE EVOLUTION: NATURAL PROCESSES AND HUMAN EFFECTS IN THE LIVERMORE-AMADOR VALLEY 9

Geology 9

Riparian vegetation 14

Groundwater 16

Wetlands 17

3. ARROYO MOCHO AND ARROYO LAS POSITAS CASE STUDIES: CONNECTING PAST, PRESENT, AND FUTURE 23

Arroyo Mocho historical ecology background 23

Case Studies 26

Conceptual Models of Arroyo Mocho Evolution 42

Arroyo Las Positas historical ecology background 44

Conceptual Models of Arroyo Las Positas Evolution 56

4. CONCLUSIONS 59

Summary of recommendations and next steps 59

Long term planning considerations 60

Recommended actions for next steps 61

REFERENCES CITED 63

APPENDIX A: METHODS A1

APPENDIX B. RIPARIAN MAPPING ON ARROYO MOCHO B3

1. OVERVIEW

At the request of a number of partners, the San Francisco Estuary Institute (SFEI) recently completed the Alameda Creek Watershed Historical Ecology Study (Stanford et al. 2013). This report builds on findings from the historical ecology study, developing focused technical information to support environmental management of the Arroyo Mocho and Arroyo Las Positas channel reaches managed by the Zone 7 Water Agency (Zone 7) in the Livermore-Amador Valley. This effort is part of an update of the Stream Management Master Plan (SMMP), which defines management goals, objectives, and implementation strategies for the streams, channels and arroyos under its jurisdiction (Zone 7 2006).

This report is intended to help Zone 7 staff address contemporary management challenges by developing a better understanding of their underlying causes, which often include historical land use impacts and underlying physical processes. The aim of this work is to improve the ability of the SMMP to accurately identify both opportunities and constraints associated with strategies for stream management improvement, regarding riparian vegetation and floodplains, and sediment management. Improved understanding may lead to innovative and potentially cost-saving management strategies that can include upstream mitigation of erosion sources (where feasible), restoration of in-channel complexity, and re-connection of streams to floodplains for sediment storage and ecological benefit, among others.

Many of the management challenges on Arroyo Mocho and Arroyo Las Positas involve sediment processes. Watersheds naturally produce, store, and transport sediment. There are a variety of different types of natural inputs of sediment to a watershed, including episodic sources such as landslides, debris flows, and earth flows, as well as chronic sources such as soil creep and bank erosion. Storage of sediment naturally occurs as the inputs from watershed surfaces and channel erosion are transported downstream through the channel network. This occurs on in-channel bars or in wide braided stream reaches, and on off-channel floodplains as high flows deposit sediment adjacent to channels. Some of the sediment produced in the watershed is transported all the way downstream to a receiving water body, such as the Bay. This balance of the production of sediment (the input), minus the storage of sediment, equals the output to a point downstream. Each watershed has a different sediment balance (Input – Storage = Output), based on factors such as bedrock geology, tectonics, climate and the resulting differences in slope, hillslope formations, discharge and channel networks. The sediment balance can change decadally with changes in land and water management and climate.

Human development has altered this sediment balance in Bay Area watersheds in many ways. Increases in impervious surfaces, and

impoundments have created an imbalance of water and sediment produced from the watershed, often leading to channel downcutting, or incision. Some sources of sediment production have become more predominant, such as bank erosion from incising reaches of streams, and erosion due to land management such as intensive cattle grazing. The straightening, simplification and leveeing of streams has reduced the ability of channels to sort and store sediment on in-channel bars or to occupy a wide enough corridor to maintain in-channel complexity such as braiding. Instead, sediment is often stored at bridge pilings and other man-made depositional environments. Additionally, channel incision and levee construction have disconnected channels from their adjacent riparian zones, reducing floodplain deposition on the valley floors and limiting access to off-channel habitat for fish and wildlife. These modifications have led to excessive erosion in some reaches of streams, and sediment-starved reaches in others. This imbalance, along with the impoundment of sediment in reservoirs, has reduced overall sediment delivery to the Bay. Thus, management of these systems is complex and difficult.

Flood control managers will continue to face challenges associated with sediment imbalances, but will also be under increasing pressure to develop management regimes that integrate multiple benefits, such as ecological functions (e.g., floodplain and riparian forest habitat), improved water quality, and cost effective flood control. As such, it behooves today's flood control managers to consider multiple benefit approaches when envisioning large-scale redesign plans that are intended to function for many decades.

This report focuses mainly on the storage component of the sediment balance, in the upper part of the Alameda Creek watershed within the Livermore-Amador Valley (the Valley). The study focuses on two creeks in the Valley, Arroyo Mocho and Arroyo Las Positas, with particular attention paid to in-channel erosion and aggradation problem areas as identified by earlier efforts by Zone 7 and others. The report mentions several other creeks draining the upper part of Alameda Creek watershed (Alamo Canal, Tassajara Creek, Collier Creek, etc.), yet remains focused on the valley-bottom reaches of the Arroyo Mocho and Arroyo Las Positas. Through our analyses, and building on research synthesized in the Alameda Creek Watershed Historical Ecology Study (Stanford et al. 2013), we identify long-term geomorphic trends and develop restoration concepts aimed at improving watershed functioning from both a geomorphic and ecological perspective. These concepts provide a starting point for more detailed analysis and modeling, which could lead to more resilient channel re-designs that:

- Integrate multiple benefits (e.g., flood protection, sediment management, groundwater recharge, ecosystem functions, etc.)

- Provide robust ecological functions that sustain native plant and wildlife species
- Increase flexibility to adapt to future climatic regimes
- Reduce maintenance costs

Designing resilient systems within a highly modified setting, such as the Livermore-Amador Valley, requires an understanding of how the systems used to function under more natural conditions, and how they have changed through time (Collins and Montgomery 2001; Grossinger 2012). This perspective provides a framework for developing conceptual approaches that integrate dynamic natural processes within developed landscapes to maximize target functions. To be effective, this thinking must take place at a large scale and consider long term processes and responses (Simenstad et al. 2006, Greiner 2010, Wiens et al. 2012, Parrott and Meyer 2012).

The resilient landscapes approach uses a strong understanding of historical and contemporary physical and ecological drivers to design hybrid landscapes. In the past, watershed modification often involved constraining highly dynamic channels and hillslopes: for example, channelizing alluvial fans, diking wetlands, and leveeing streams. Many contemporary watershed management challenges, such as sedimentation, stream channel incision, bank failures, and flooding, derive directly from these alterations, which often exacerbated "problems" upstream and downstream. Understanding historical landscape patterns and processes helps us to predict how these dynamic systems might respond to future modifications or a changing climate. Historical analysis does not enable us to recreate exact historical configurations, but rather enhances our understanding of underlying physical and ecological processes. While in many cases landscape processes and ecological features have been profoundly altered, in other cases natural processes are still quite active and impactful. To facilitate the recovery of degraded or damaged ecosystems, as well as cost effective flood management, knowledge of the state and evolution of the pre-modified ecosystem and how it has changed is invaluable (Jackson and Hobbs 2009).

Management must be effective over both short- and long-term time frames. Some interventions will necessarily take place at a site scale and over the shorter term, because of time, budget, and land availability limitations. However, to be maximally effective and achieve multiple benefits, short-term management actions should be implemented with a longer term vision in mind (Beagle et al. 2013). The landscape scale approach is also important for identifying opportunities to improve ecological connectivity and long-term adaptability to climate change and other environmental shifts. Some of these opportunities may be critical to the ecological function and resilience of the area, but may not be able to be addressed in the immediate

site scale project design. Thus, a central component of translating a resilient landscape perspective to site-scale design is envisioning an adaptable restoration or management process that includes actions that are possible in the short-term but also incorporates a longer-term vision of what is needed at the landscape scale.

This report highlights potential short-term, site scale opportunities along the Arroyo Mocho and Arroyo Las Positas corridors in the Valley. It is also intended as a starting point for developing a vision for a longer-term, landscape scale management approach. The ultimate goals of the approach are to provide multiple benefits, reduce maintenance costs, increase flexibility to adapt to changing climates, and enhance ecosystem functions and resilience.

Report structure

The report is organized around two main questions: 1) How do the physical, ecological, and anthropogenic changes of the Livermore-Amador Valley over the past 200 years, with a focus on Arroyo Mocho and Arroyo Las Positas, contribute to contemporary management challenges? 2) How can we combine our understanding of these historical changes with an understanding of contemporary watershed dynamics to improve watershed and channel functions in the future?

The first section of this report provides an overview of the physical and ecological processes and characteristics that defined the Valley historically. The second section applies this information to two high priority streams within the Zone 7 service area - Arroyo Mocho and Arroyo Las Positas - and discusses a range of potential management strategies.

Methods summary

The historical ecology study of the Alameda Creek Watershed (Stanford et al. 2013) served as a baseline of information for this report, providing a broad array of information about the ecological and physical processes that shaped this watershed. Other key data sources included San Francisco Estuary Institute (SFEI) studies examining sediment dynamics in the watershed, SFEI riparian vegetation surveys (as part of this project), Zone 7 reports and the currently-in-revision SMMP, local expertise from Zone 7 staff, USGS topographic quadrangles, aerial photographs, and a variety of other historical and contemporary reports, data inputs, and field observations. We synthesized historical and contemporary information to 1) examine physical gradients and drivers; 2) analyze hydrogeomorphic, ecological, and land use changes over time; 3) devise landscape-level management strategies; and 4) develop conceptual models illustrating potential landscape trajectories. The conceptual models are designed

to enhance the conversation about priority restoration planning, flood protection, and watershed management for the future over both short and longer term time scales. We also surveyed contemporary riparian vegetation in selected areas to improve understanding of the current condition and future potential of riparian vegetation communities.

We examined physical and ecological patterns, processes, and problems throughout the Valley, but we focused our analysis on a 102 km^2 (39 mi^2) rectangular area encompassing the valley-bottom portions of Arroyo Mocho and Arroyo Las Positas surrounding the City of Livermore (Figure 1.1). This area extends from Springtown in the northeast corner to the confluence with the Arroyo Mocho, near the Chain of Lakes (gravel pits). Within this area we focused our analyses on five "case studies" that highlight particular management challenges, physical changes, or restoration/preservation opportunities on varying time scales (see figure 1.1). For a full description of the methods used in the study, see Appendices A and B.

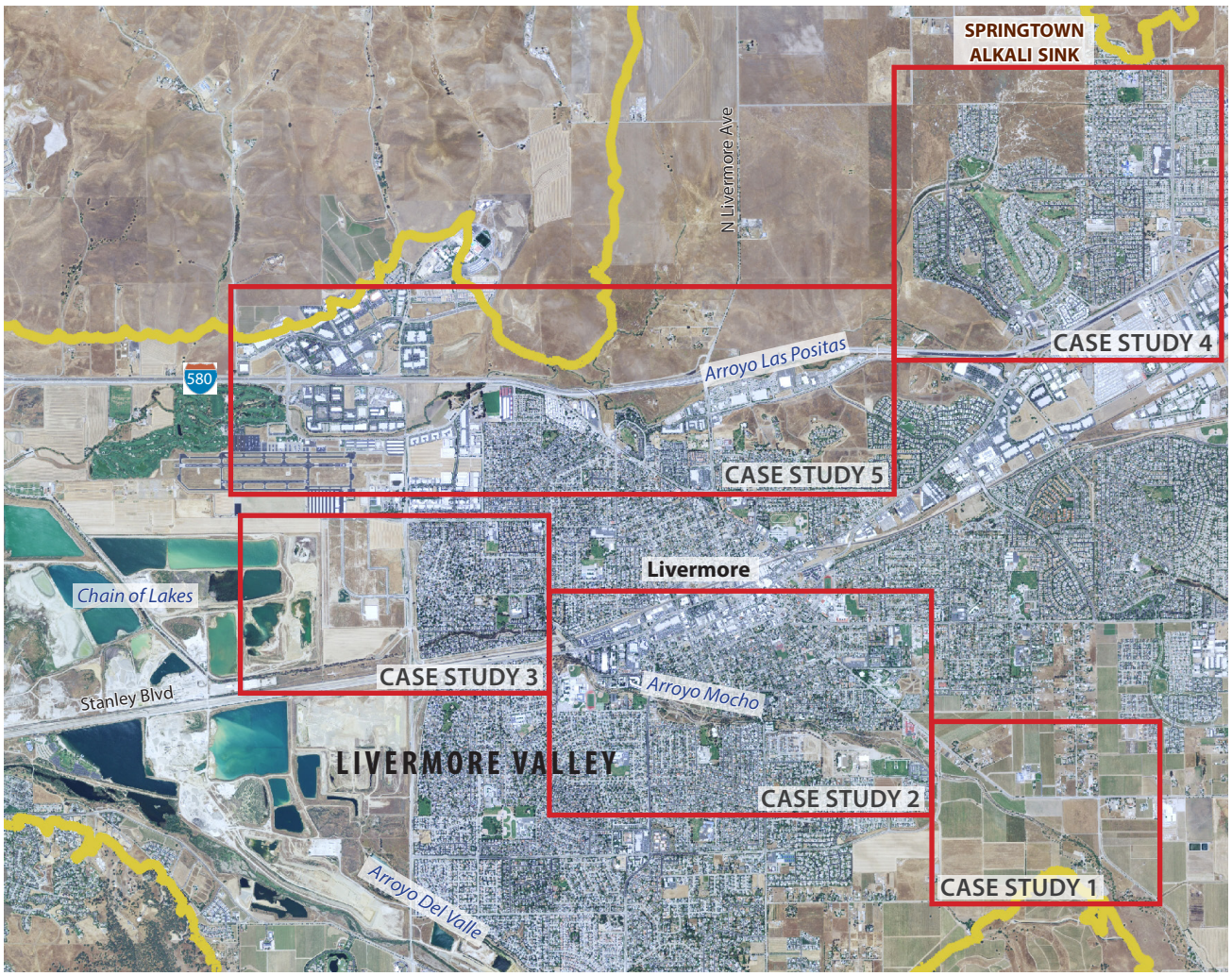


Figure 1.1. The study area focused on a 102 km^2 (39 mi^2) area encompassing much of the valley-bottom portions of Arroyo Mocho and Arroyo Las Positas surrounding the City of Livermore. The thick yellow line at the edge of the Valley indicates the extent of the Alameda Creek Watershed Historical Ecology Study boundary (Stanford et al. 2013). Case studies are outlined in red.

Summary of change and current challenges

The Livermore-Amador Valley has developed rapidly in recent decades, and today contains a complex mix of urban and suburban development, agriculture, and rangelands. For thousands of years before European settlement, the Chochenyo Ohlone managed the Valley landscape (Treutlein and Fages 1972, Crespí and Bolton 1927). As Europeans arrived in the late 18th century, residents of Mission San José began using the Valley to pasture cattle, and grazing persisted as the dominant land use for decades. In the mid-19th century, waves of early immigrants returning from the Gold Rush settled in the Valley, and began dryland farming of grains. Limited acreage of orchards and row crops was introduced in the late 1800s, but grain production continued to dominate across most of the Valley as late as the 1940s (Grossinger et al. 2008, Stanford et al. 2013).

As the population increased in Dublin, Livermore, and Pleasanton in the early- to mid-1900s, dryland grain farming was largely replaced by residential subdivisions and office parks. Demand for reliable drinking water and flood protection increased over a fairly short time span in the mid-20th century (Figure 1.2). Zone 7 Water Agency was founded in 1957 in order to place under local control, through a locally elected board of directors, the vital matters of flood protection and water resource management in eastern Alameda County. With a service area of 1100 km^2 (425 mi^2), Zone 7 is charged with supplying potable water to residents of the cities of Dublin, Pleasanton, and Livermore, as well as roughly 1.21 hectares (3,500 acres) of farmland. In addition, Zone 7 is responsible for providing flood protection for Livermore-Amador Valley residents, and it has largely succeeded in abating the flooding which was common place prior to the 1960s. Today Zone 7 maintains 37 miles (60 km) of channels that receive and convey urban drainage, runoff, and eroded sediment from the tri-cities and the surrounding watersheds.

As shown in Figure 1.2, urbanization has resulted in a substantial increase in the area covered by impervious surfaces (roads, buildings, parking lots, etc.) within the Valley. Within our study area (shown in Figure 1.2, within the historical ecology study boundary, and focusing on the Valley floor portions of Arroyo Mocho and Arroyo Las Positas), the areal extent of impervious surfaces (as determined by aerial photo interpretation and USGS mapping) increased from 848 acres in 1940 (3.3% total land cover) to 10,496 acres in 2009 (41.46% total land cover) (Table 1.1). Urbanization, and the corresponding increase in impervious surfaces, has well-documented impacts on the hydrology, geomorphology and ecology of stream systems, including increased erosion, increased sediment

transport, decreased fish habitat, increased risk of flooding, and decreased groundwater recharge (see Dunne and Leopold 1978, Booth 1990, Kondolf and Larson 1995, Everard 2012).

Agricultural and urban development has also resulted in the loss of riparian habitat within Livermore Valley. Along the valley-bottom reaches of Arroyo Mocho, for example, most of the riparian corridor historically was between 60-200 meters (197 to 656 feet) wide, and in some areas extended as wide as 400 meters (over 1,300 feet). Today, 77% of the riparian corridor is less than 60 meters (197 feet) wide (Figure 1.3). In many places the riparian vegetation that exists today is also much denser, though narrower than what existed historically, and is composed of a different suite of species, including non-native species such as eucalyptus.

In recent decades, the populations of Dublin, Livermore and Pleasanton have more than doubled from a total of 99,000 in 1980 to 197,000 in 2010 (US Census Bureau 2010), and remaining agriculture in the Valley has shifting from non-irrigated rangeland to irrigated and controlled drainage viticulture. As a result, water quantity and sediment flux have been altered considerably. Erosion and sedimentation are major problems in different parts of the Arroyo Mocho and Arroyo Las Positas watersheds. In order to maintain channel flood capacity, the City of Livermore has conducted periodic channel de-silting of aggraded areas near several bridges. Periodic desilting is conducted on an as-needed basis by Zone 7 and the City of Livermore and studies are underway to better define the sediment transport and depositional processes. This report highlights some of the causes of these management challenges and suggests potential approaches to both sediment management and habitat enhancement.

Table 1.1. Acres of impervious surface within study area.

Year	Acres of impervious surface	Percentage of study area
1800	0	0%
1940s	848	3%
1980s	6,335	25%
2009	10,496	41%

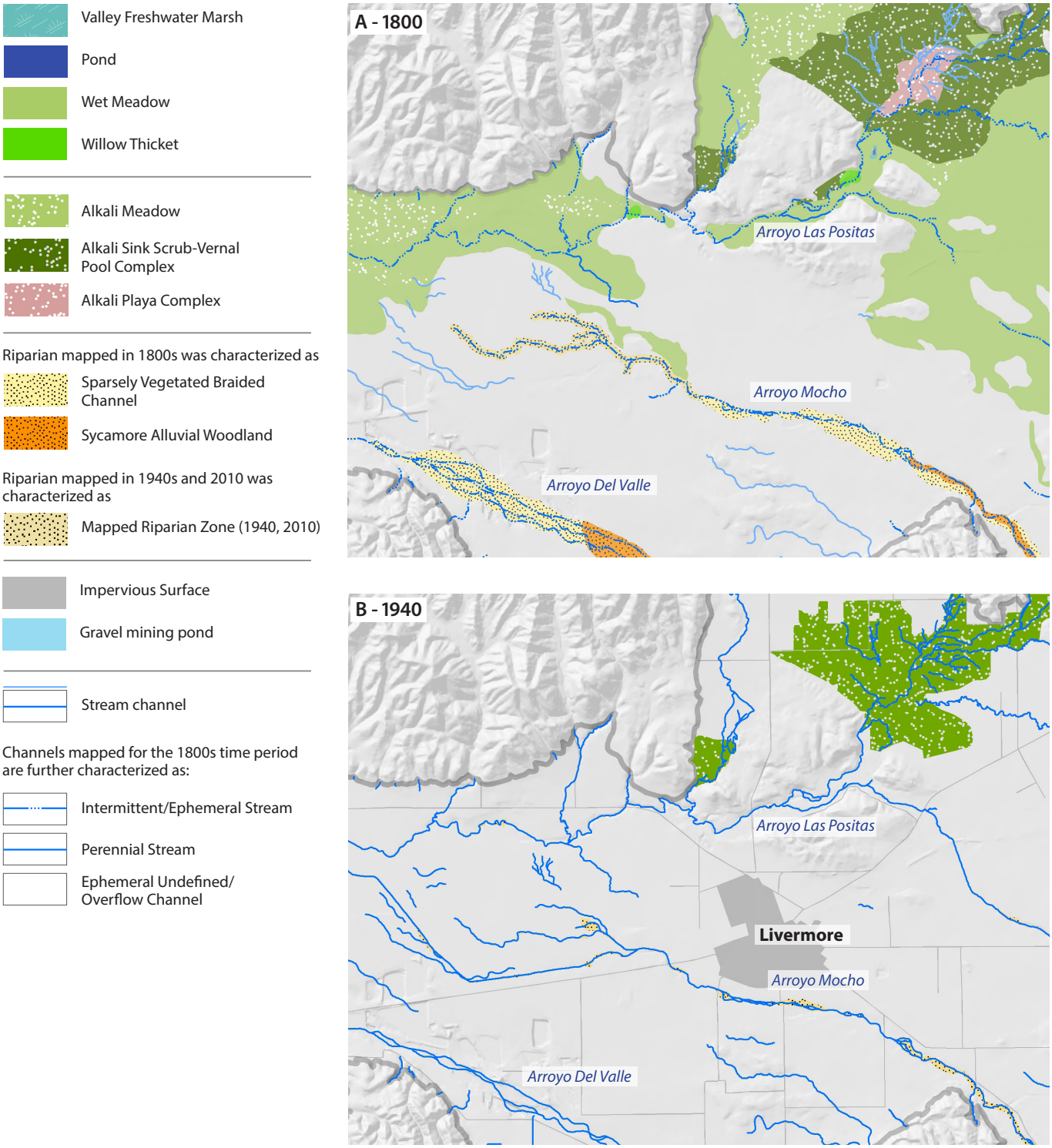
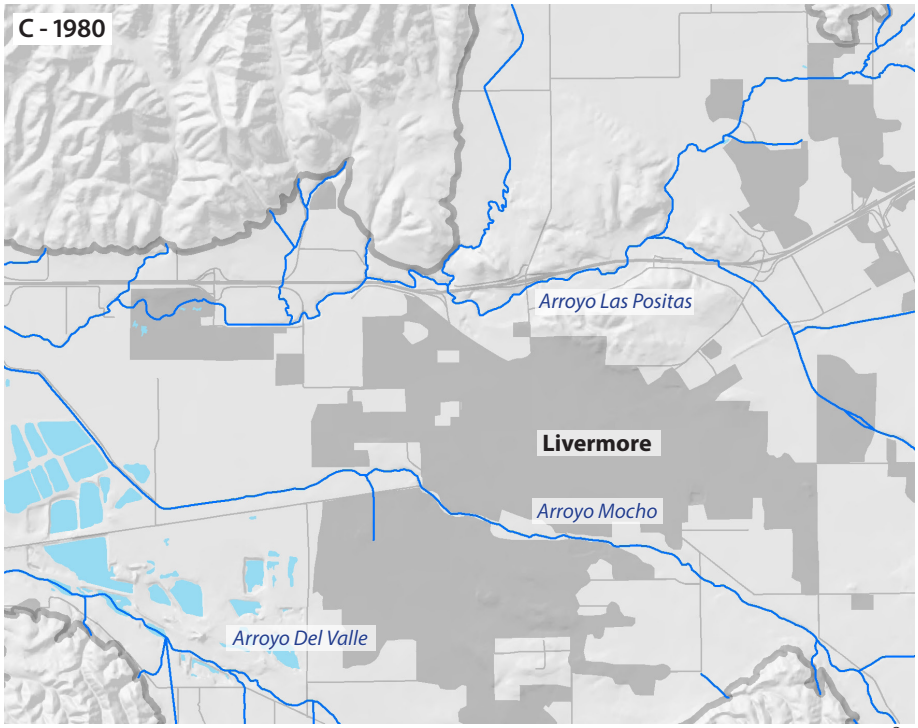
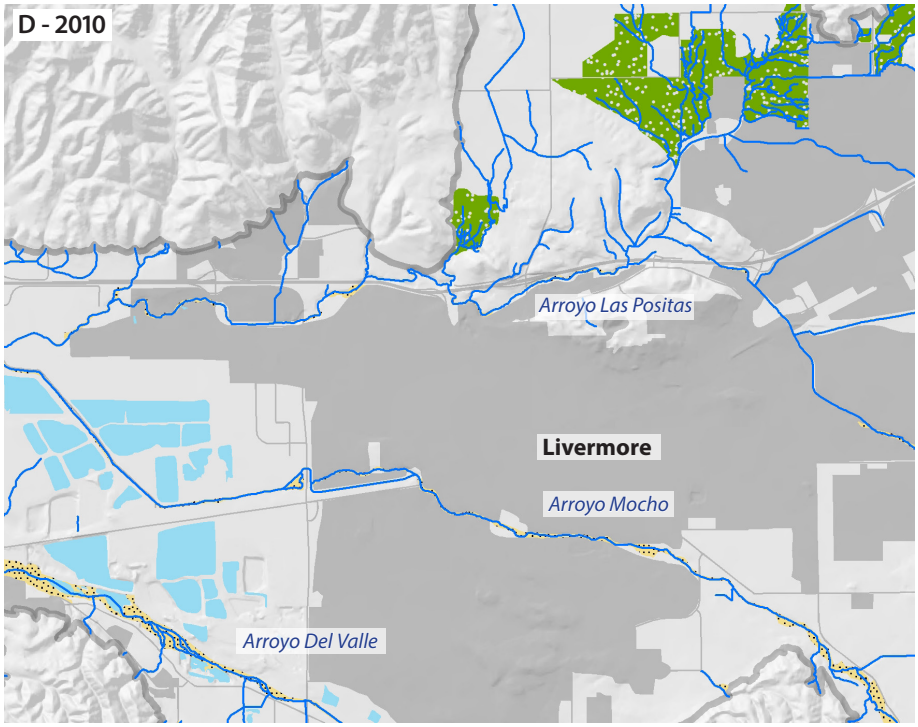


Figure 1.2. Change over time of wetland and riparian habitat, stream configurations, gravel mining locations and general extent of urban development (impervious surfaces) between 1800, 1940, 1980 and ca. 2010. A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1940, 1942). C. Conditions in 1980 (USGS 1980, 1981, USGS 2005). D. Conditions in 2010 (USDA 2009, ICF International 2010, SFEI 2011).



NOTE: CHANNELS ARE MAPPED IN LESS DETAIL FOR 1980



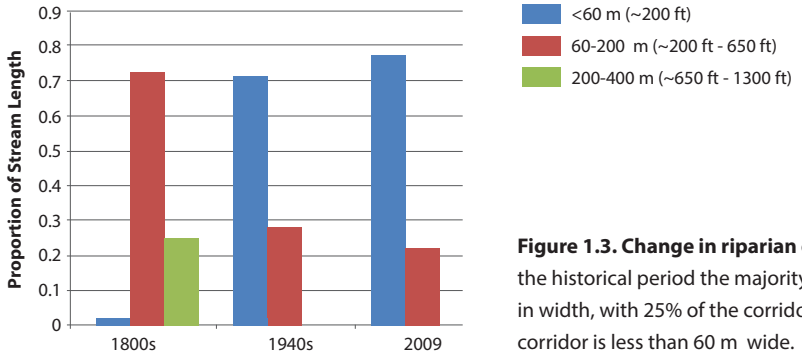


Figure 1.3. Change in riparian corridor width along Arroyo Mocho over time. In the historical period the majority of riparian areas measured between 60 and 200 m in width, with 25% of the corridor over 200 m wide. In 2009, over 75% of the riparian corridor is less than 60 m wide.

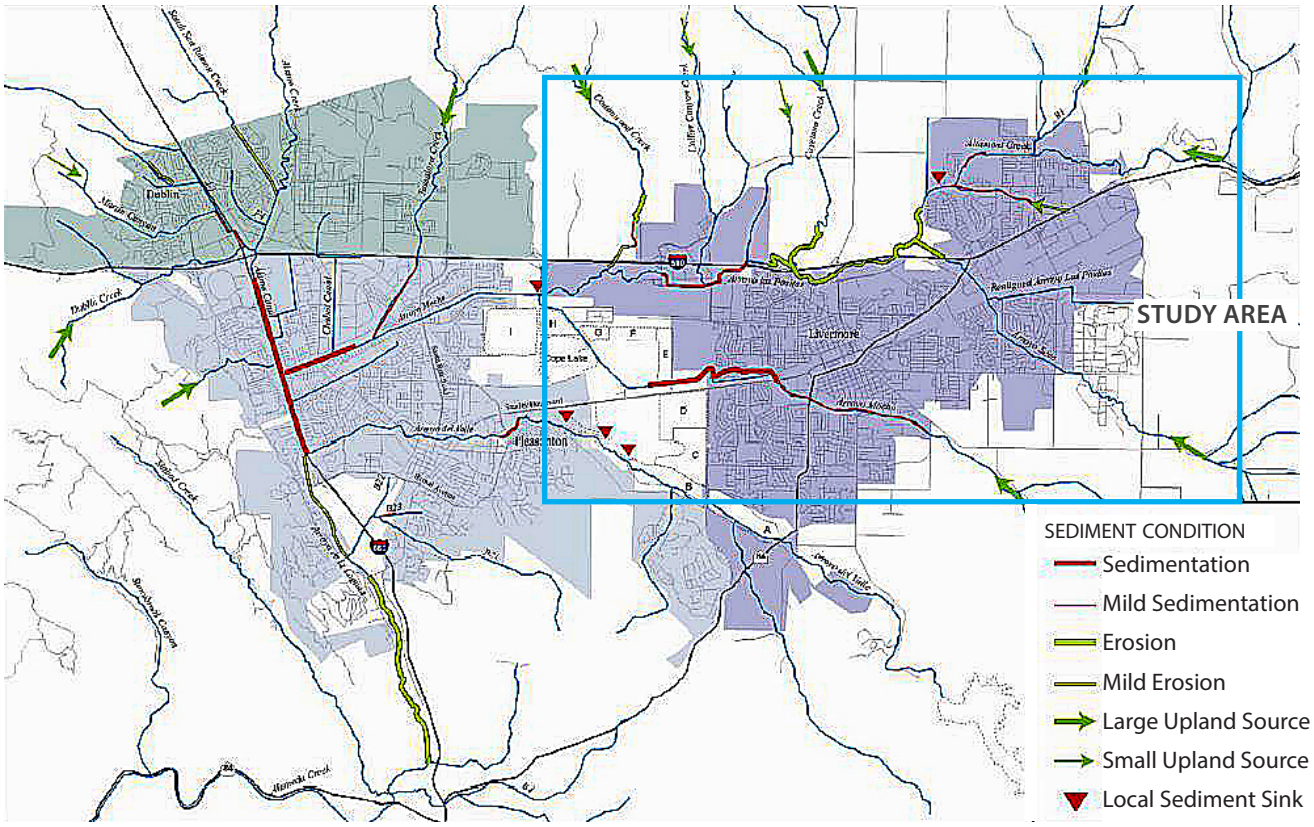


Figure 1.4. Sediment Conditions in Zone 7 jurisdiction as identified by the SMMP. Both erosion and sedimentation occur frequently in the study area (outlined in blue). Our case studies (Chapters 3 and 4) focus in part on these key problem areas.

2. LANDSCAPE EVOLUTION: NATURAL PROCESSES AND HUMAN EFFECTS IN THE LIVERMORE-AMADOR VALLEY

Identifying both the causes of and potential solutions to watershed management challenges first requires the development of a historical landscape perspective incorporating ecological, hydrologic and geologic processes. Many of the problems we face may be longer term geologic and geomorphic responses to climate, tectonics and landscape evolution, which have been both exacerbated or potentially masked by anthropogenic influences. In this section we detail the geologic and geomorphic history of Livermore-Amador Valley and of Arroyo Las Positas and Arroyo Mocho. We then discuss the evolving riparian vegetation, groundwater, and wetland features and patterns in that context (Figure 2.1).

Geology

The Livermore-Amador Valley is an east-west down-dropped depression between the Diablo Range and the East Bay hills (Howard 1979, Carpenter et al. 1984, Sloan 2006). The shape of the alluvial Livermore-Amador Valley floor has changed over time in response to tectonic activity and paleo-fluvial processes, which altered the depositional patterns across the valley floor. Researchers suggest that Pliocene-age uplift of the Diablo Range created alluvial fan deposits along the edges of the Livermore-Amador Valley (Carpenter et al. 1984). Concurrently Arroyo Mocho, the largest stream in the Valley during the Pliocene, deposited Livermore Gravels in a north-west trending direction and finer sediment along the northern edge of the Valley (Figuers and Ehman 2004). To the west, the Valley is bounded by the East Bay hills and flanked by the Hayward and Calaveras faults; to the east, the Valley is bounded by the Altamont Hills and the Greenville Fault; and to the north and south, the Valley is bounded by the Diablo Range. A number of smaller faults cross the Valley, interrupting the flow of groundwater and creating springs. (For more complete discussion see Stanford et al. 2013.)

Because it was created by geological processes rather than carved by streams, the Valley is oversized for its fluvial inputs, allowing streams space to spread and sink. Underlying the Valley are Sierran deposits carried from the volcanically active mountain ranges in the late Pliocene (Ferriz 2001, Sloan 2006). These deposits consists of layers of silt and clay alternating with gravels (Williams 1912, Fisher et al. 1966, Sowers 2003, Sloan 2006). The Valley formed when the surrounding hills began to lift between 6 and 2.5 million years ago (Ferriz 2001, Sloan 2006). The drainages created by this continued uplift contributed sediment, known as the Livermore Gravels, which resulted in deposits up to 4,000 feet thick in places (Howard

HISTORICAL LAND COVER, EARLY-1800s

- Valley Freshwater Marsh
- Pond
- Wet Meadow
- Willow Thicket

- Alkali Meadow
- Alkali Sink Scrub-Vernal Pool Complex
- Alkali Playa Complex

- Sparsely Vegetated Braided Channel
- Confined Riparian Woodland/Savanna
- Sycamore Alluvial Woodland

- Oak Savanna
- Grassland

- Perennial Stream
- Intermittent Stream
- Slough/ Overflow Channel
- Distributary
- Spring

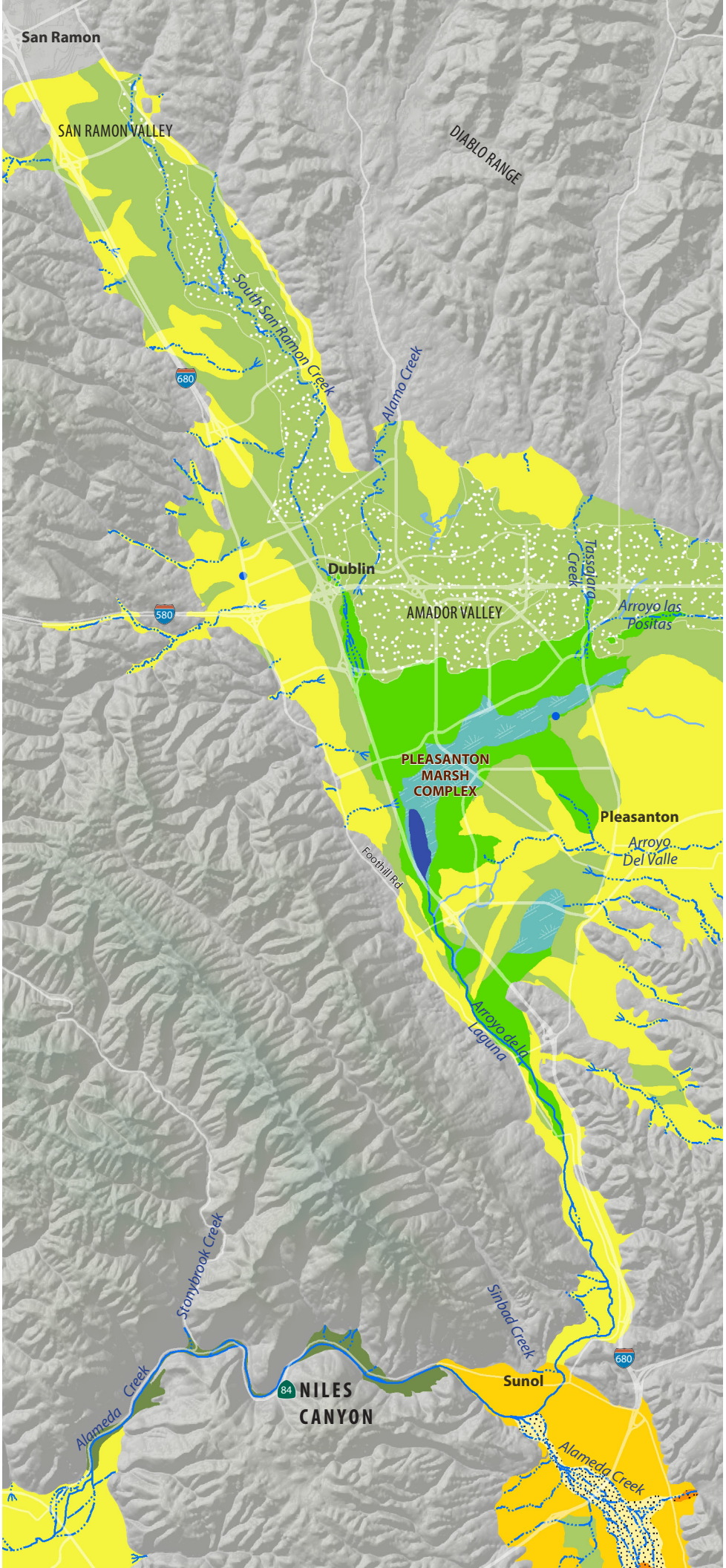
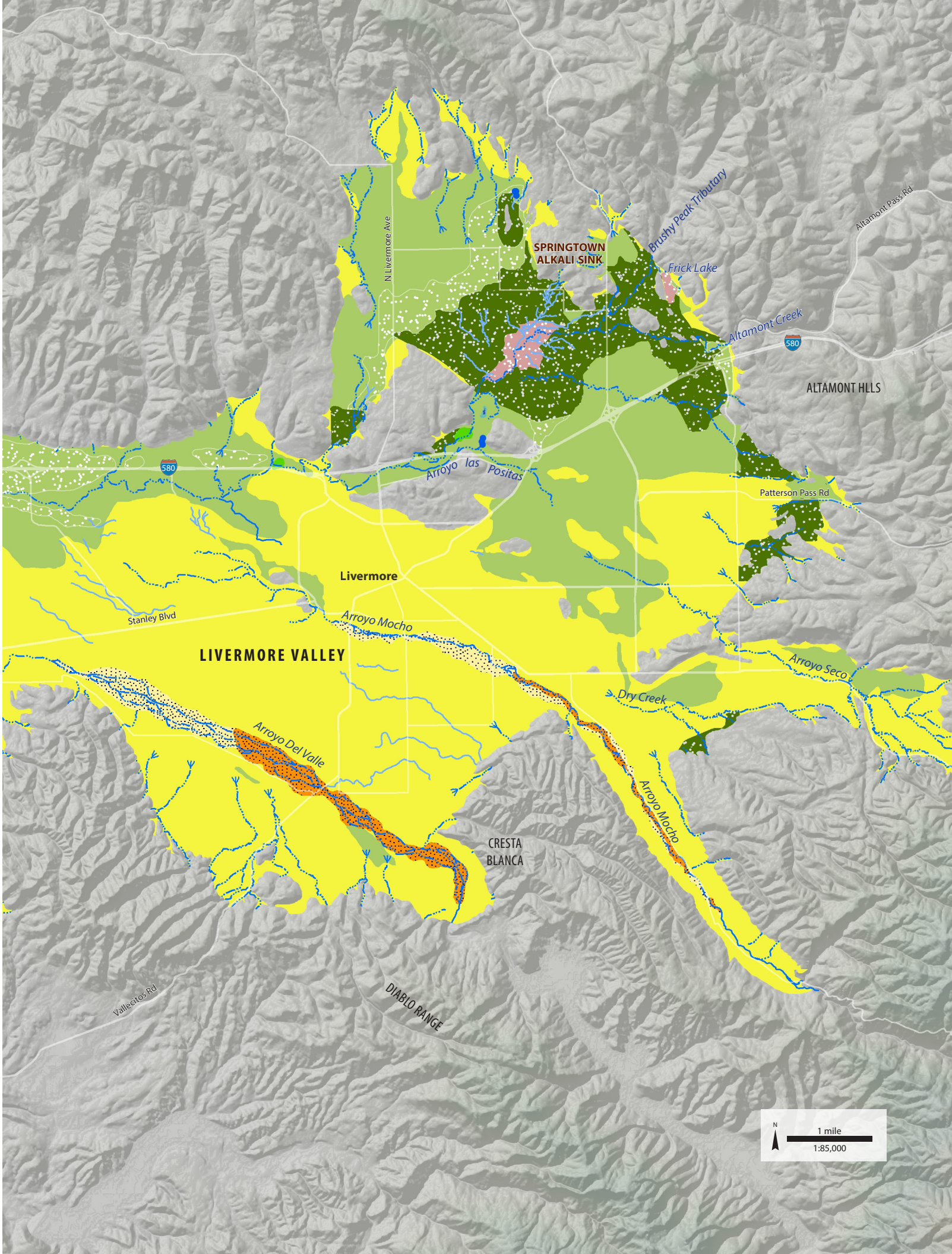


Figure 2.1. Livermore-Amador Valley ca. 1800. Patterns across Livermore-Amador Valley varied from north to south and from east to west. The two wetland complexes—Pleasanton marsh complex in the west and Springtown alkali sink in the east—were prominent historical features. (Stanford et al. 2013)


SPRINGTOWN
ALKALI SINK
Brushy Peak Tributary
Frick Lake
Altamont Pass Rd
N Livermore Ave
Altamont Creek
580
ALTAMONT HLLS
Arroyo las Positas
Patterson Pass Rd
Livermore
Stanley Blvd
Arroyo Mocho
LIVERMORE VALLEY
Arroyo Seco
Dry Creek
Arroyo Del Valle
Arroyo Mocho
CRESTA
BLANCA
Vallecitos Rd
DIABLO RANGE
N
1 mile
1:85,000

1979, Sloan 2006). Over the millennia watercourses shifted, alternately flowing north through San Ramon Valley and south through Sunol (Williams 1912, Ferriz 2001). At times the San Ramon Valley route was blocked, allowing sediment to settle in the low points of the Valley and resulting in the deposition of layers of silt and clay (Williams 1912, Ferriz 2001, Sloan 2006).

In the 1800s, two broad braided creeks, Arroyo Del Valle and Arroyo Mocho, drained from the Diablo range into the southern portion of the Valley. A series of smaller creeks with narrower channels – most notably Arroyo Las Positas – also drained into the Valley, particularly from the north and east. Most sediment was produced in the upper watersheds of Arroyo Mocho and Arroyo Del Valle. The geology of the surrounding hills influenced sediment types and patterns of deposition and storage through the watershed. The headwaters of Arroyo Mocho, Arroyo Del Valle, and Alameda Creek flowed from the high sediment-producing steep hillslopes of the Franciscan formation, resulting in a comparatively coarse bedload in these streams, and a comparatively high sediment yield. Coarse sediment entered the Valley primarily in pulses during flood events, and from large mass wasting events. Smaller drainages in northern Livermore-Amador Valley, such as Arroyo Las Positas, derive from the less erosive Great Valley Sequence, resulting in a finer sediment load and less stream power overall (Figure 2.2). Two major wetland complexes existed in the historical period (ca. 1800s): the Pleasanton marsh in the western part of the Valley, where perennial water was available, and the Springtown sink in the eastern part of the Valley, where intermittent flow created high alkali concentrations and vernal pool complexes. These wetlands naturally acted as fine sediment sinks, off channel habitat, and detention basins under high flow conditions (Figure 2.3).

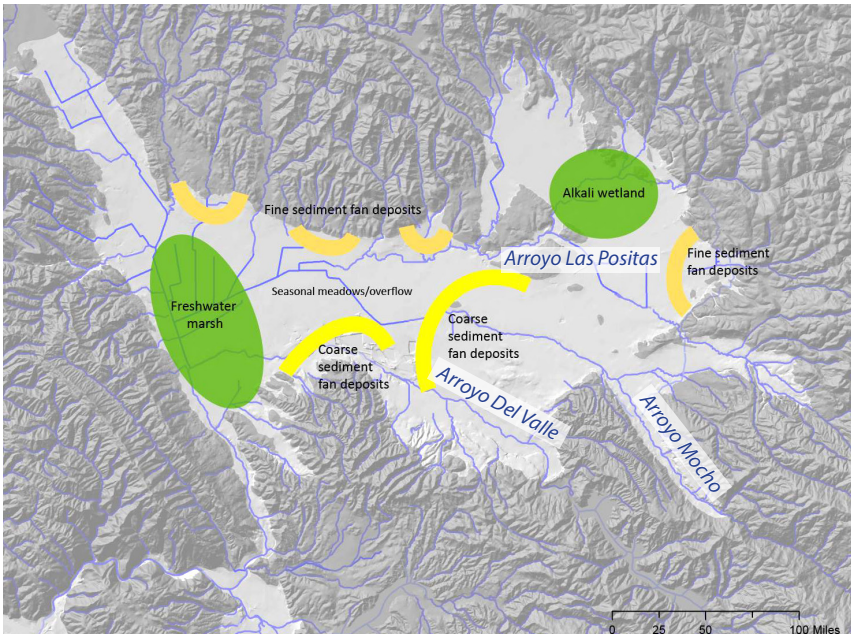


Figure 2.2. Conceptual depiction of the arrangement of alluvial fan deposits and wetlands in Livermore-Amador Valley. These fan deposits would have changed in size and dominance over time, but the imprints of their most recent forms are still visible in the topography of the Valley.

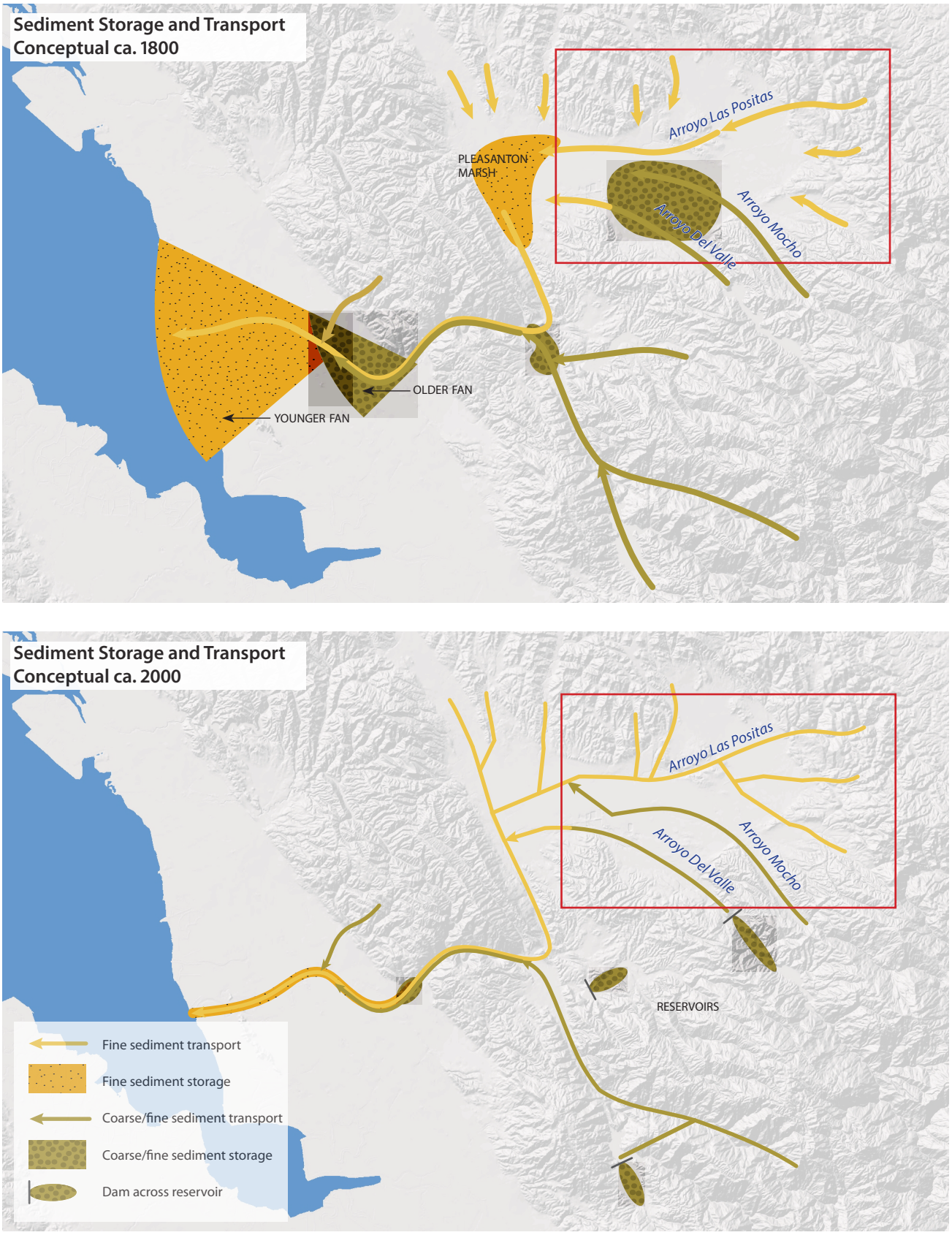


Figure 2.3. Conceptual depiction of sediment storage and transport. These diagrams show changes in dominant sediment deposition patterns that the watershed has accommodated (study area outlined in red). Rather than spreading sediment broadly across their floodplains, streams now often store sediment within their lower channels, resulting in aggradation and the need for active management. Much of the coarse sediment supply to the valley floor that occurred historically is now being trapped behind reservoirs. Almost all reaches transport both fine and coarse sediment—this diagram attempts to show which is dominant. Coarse sediment is defined as >2mm.

Currently, both the natural and constructed channels within the Zone 7 service area experience erosional and depositional changes annually. Upstream erosional processes (both episodic and chronic), channel incision, and bank failures have increased downstream aggradation, exacerbating management challenges related to flow and sediment. The watershed has also experienced changes in sediment supply, largely related to changes in land use. Historically, the dominant supply of coarse sediment came from the upper watersheds, which created the alluvial fans of Arroyo Mocho and Arroyo Del Valle (Figure 2.2). Today, the Arroyo Mocho sub-basin contributes over 40% of the sediment yield to Livermore-Amador Valley. Arroyo Seco, Altamont creek and Cayetano creek, all tributaries of Arroyo Las Positas, each contribute between 10-15% of the total load to the Valley (Bigelow et al. 2012). Periodic landslides and debris flows, channel incision and widening, and stream bank failures, likely account for the major sources of sediment flux (Bigelow et al. 2008, Pearce et al. 2009, Beagle et al. 2011, Beagle et al. 2012, Bigelow et al. 2012).

Riparian vegetation

Variations in channel morphology and dry season flow patterns historically resulted in a wide diversity of riparian vegetation types in the Livermore-Amador Valley. Different stream reaches exhibited distinct patterns in both riparian width and species composition. Stanford et al. (2013) mapped willow-cottonwood forest and willow thickets along reaches with high groundwater such as Arroyo de la Laguna and the Pleasanton marsh complex; sycamore alluvial woodland in the broad, braided, intermittent reaches of Arroyo Mocho, and Arroyo Del Valle; herbaceous cover with sparse oaks and sycamores along small drainages with low flow (lower Mocho and Del Valle, Arroyo Las Positas, and small tributaries); and alkali sink scrub through the alkali reaches of Springtown. Within the study area historically, stream corridor width (from one edge of the riparian vegetation across the stream to the other edge) varied from extremely narrow borders of herbaceous riparian vegetation with occasional oak trees, to over 800 feet (244 m) through the broad braided reaches of Arroyo Mocho (Figure 2.4).

Along most stream reaches riparian vegetation has been narrowed and floodplains have been eliminated to make more space for housing, agriculture, and roads. Long stretches of riparian habitat have been removed to make way for agricultural and urban development, and aggregate mining. Other changes are less obvious. Many of the riparian communities best adapted to xeric conditions—sycamore alluvial woodland and sparse oaks—have been converted to wetter types because of more managed perennial flows resulting in low flow, willow-lined channels. The wide reaches have largely been eliminated; in other cases, even if the riparian corridor width persists, streams have often been disconnected from their floodplains. There are also some notable remnants of historical riparian cover, such as the sycamore alluvial woodlands in southeastern Livermore Valley (Figure 2.4). The historical habitat patterns represent

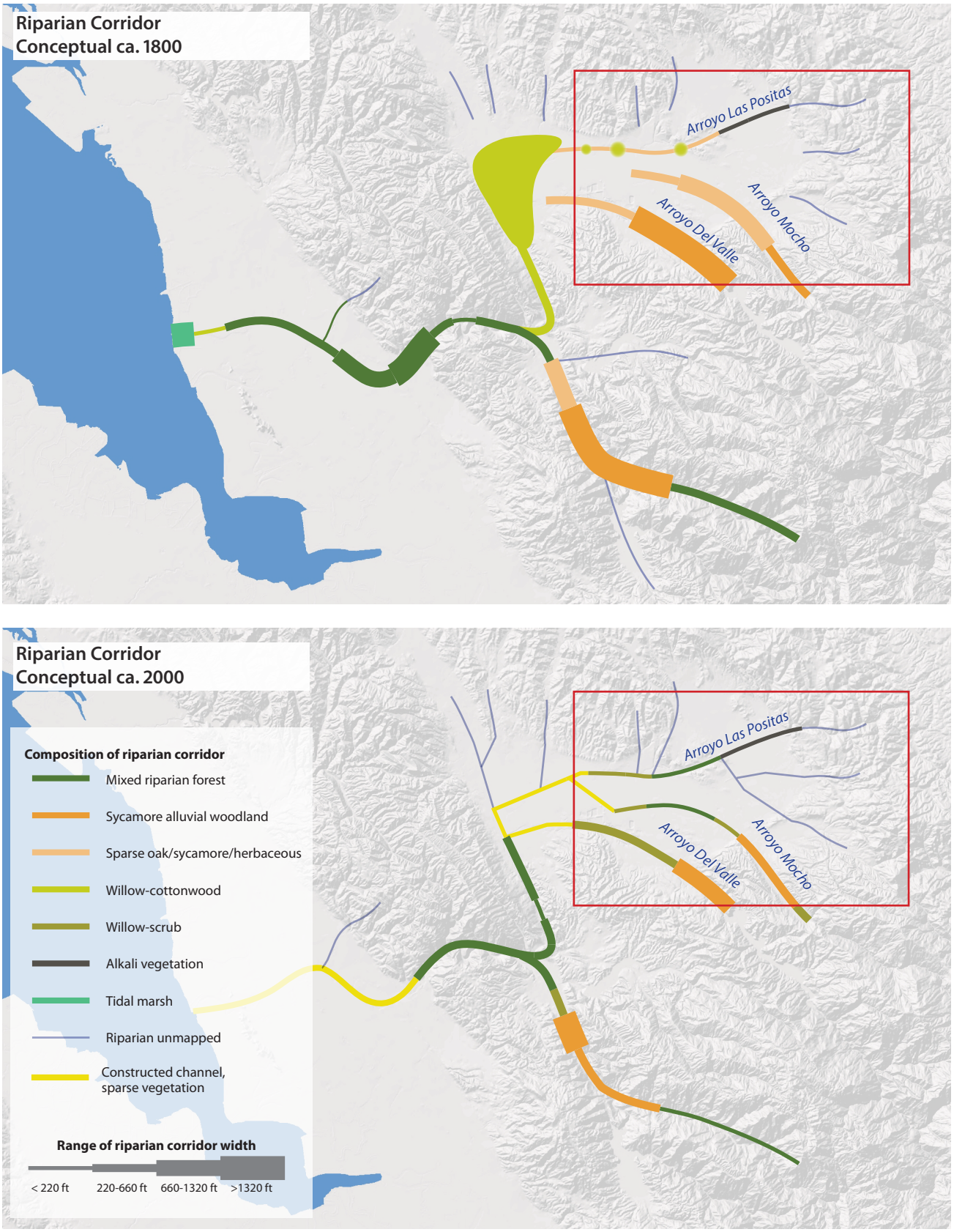


Figure 2.4. Conceptual depiction of riparian cover. The diversity of riparian widths and types has been greatly simplified, reducing the diversity of ecological functions in the Alameda Creek watershed. In particular, the broad willow forests and floodplains are no longer present. Widths have narrowed—if we consider the Pleasanton marsh complex a riparian habitat type, the riparian corridor extended 4,000 feet wide in places. Species composition has also shifted—today, mixed riparian forest may include exotic species such as eucalyptus. In the contemporary diagram we introduced two additional classes to represent willow scrub and the sparse vegetation along flood control channels, neither of which were present historically. The study area is outlined in red.

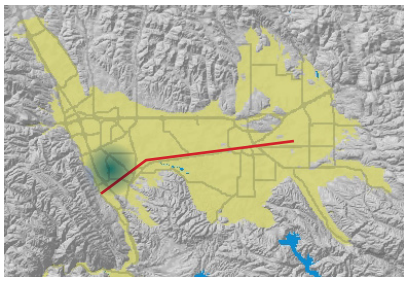
a diverse palette to draw upon as we attempt to re-establish riparian biodiversity in contemporary stream settings.

Groundwater

A large groundwater basin lies beneath the Livermore-Amador Valley, containing multiple distinct aquifers and aquitards (clay layers separating aquifers). Historically, groundwater recharge occurred where water flowed over permeable substrates such as the coarse gravels of the alluvial valleys and fans of southeastern Livermore Valley. The groundwater basin supported numerous surface water features, including artesian springs and wetlands. The large wetland systems in the Valley – the Springtown alkali sink and the Pleasanton marsh complex (see Wetlands on p. 17) – occurred where poorly drained clay soils precluded groundwater recharge and where faults, bedrock barriers, and topography forced groundwater to the surface (Lee 1916). Figure 2.5 shows a cross section of historical water levels over time (including the surface water in 1899 at Pleasanton marsh).

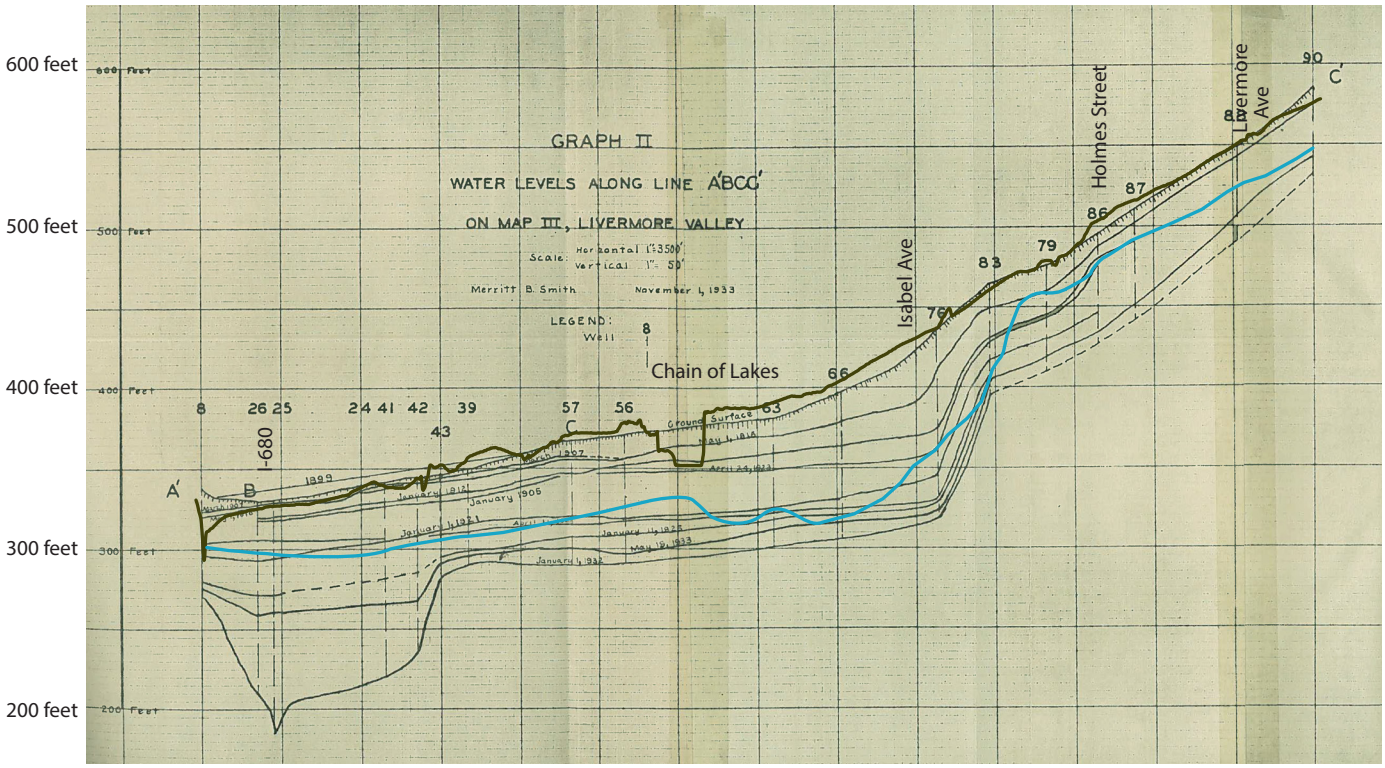
Extensive groundwater withdrawal in the early 1900s, combined with a decades-long drought, contributed to the drying of Pleasanton marsh and other wetlands. For instance, in 1907 groundwater levels just south of Pleasanton marsh were still several feet below the ground surface. By 1921, water levels had dropped to approximately 35 feet below the surface, and by 1932 groundwater levels had dropped to nearly 120 feet below the surface (Figure 2.5; Smith 1934). In some areas, groundwater levels fell by over 10 feet in a single year (Smith 1934). Groundwater from the Bernal sub-basin continued to be used as a water source for the San Francisco

Figure 2.5. Cross section comparing historical and contemporary groundwater levels. This cross section, extending from the city of Livermore, through the Chain of Lakes to the outlet of the Valley at Arroyo de la Laguna, documents the rise and fall of shallow groundwater elevation over time including levels from 2010 (Smith 1934, Zone 7 2010). The approximate location of the cross section and the Pleasanton Marsh complex are shown on the locator map.



Ground surface (Sanborn Mapping 2007)

Groundwater surface (shallow) – Fall 2010 (Zone 7 2010)



Public Utilities Commission (SFPUC) through the 1940s, when low water levels caused pumping to be reduced (Fisher et al. 1966, CA Department of Transportation 1998).

Today, recharge through abandoned quarry ponds and releases of State Water Project water through Arroyo Mocho and Arroyo Del Valle help to maintain groundwater levels (DWR 2006). Groundwater is pumped for water supply for the Valley, and water levels are closely monitored to ensure that they do not interfere with mining in the remaining quarries. Modern groundwater levels are still lower than pre-hydromodification levels, but they are substantially higher than they were in the early 1900s.

Wetlands

In the mid-1800s, the Valley contained an estimated 19,600 acres of seasonal wetlands, with an additional 650 acres of perennial wetlands and 2,000 acres of willow thicket or swamp. The two largest wetlands were the Pleasanton marsh complex on the western side of the Valley, and the Springtown alkali sink on the northeastern side of the Valley. Wetlands also dominated much of the northern and western sides of the Valley, stretching from east to west in a nearly continuous swath (see Figure 2.1). Variation in rainfall both seasonally and interannually created substantial spatial variation in the extent of wetlands: in the winter, much of the Valley would have been saturated, while in summer the seasonal wetlands dried to hard, grassy land. Today only 1,220 acres of wetlands remain – 800 acres of alkali seasonal wetland, mostly in Springtown, as well as 400 acres of freshwater seasonal wetland and 20 acres of perennial freshwater marsh (ICF International 2010).

Pleasanton marsh complex

The Pleasanton marsh complex, an important component to the functioning of the Valley historically (though not in the study area for this particular document), spread across about 2,600 acres at the western edge of Livermore-Amador Valley (or 10,000 acres including the surrounding seasonal wetlands). This wetland extended from Interstate 580 on the north to the intersection of Sunol Boulevard with Interstate 680 on the south, and from Foothill Boulevard east beyond Santa Rita Road, covering much of modern-day Pleasanton (Figure 2.6). The location and character of the Pleasanton marsh complex were controlled by the geology and hydrology of the Valley. The alluvial fans of Arroyo Mocho and Arroyo Del Valle confined the marsh on the eastern side, while the East Bay hills and Vallecitos Valley bounded the marsh to the west and south.

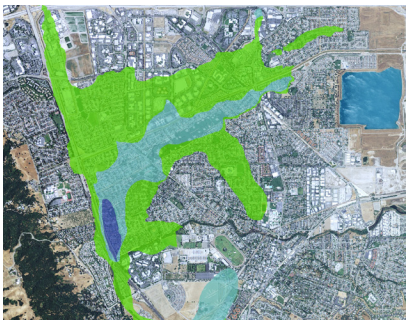


Figure. 2.6. Historical extent of the Pleasanton marsh overlaid on modern aerial imagery. This graphic shows the three main habitat types that made up the Pleasanton marsh: a perennial pond (dark blue), freshwater marsh (light blue), and willow thickets extending into seasonally inundated wetlands (green). At its most inundated, the marsh would have covered much of modern day Pleasanton.

In the center of the marsh complex, a perennial pond occupied the lowest portion of the Valley and was drained directly by Arroyo de la Laguna to the south (LaCroze 1860, Whitney 1873, Allardt 1874, Allardt [1880]1907, Edwards 1932, California Legislature Assembly 1854:54, Gutmann 1919:25). The pond grew and shrank based on rainfall and groundwater

Figure 2.7. Ditching and draining of channels in Livermore-Amador Valley. These images show A. A dredger in action on Arroyo de la Laguna in the early 20th century, and B. The impacts of dredging as seen on the channel banks (Von Geldern 1907). This type of dredging and consequent impacts were widespread in the Livermore-Amador Valley from the 1880s onward into the 20th century.

Figure 2.8. Photos of flooded Pleasanton valley in 1907. A. photograph from April 4, 1907, looking south from the bridge over the Chabot Canal. The caption on the original photograph reads, "Old Lake Pleasanton on the left, water two feet deep." B. Photograph from April 4, 1907 looking east along the levee of Chabot Canal from the same bridge (Von Geldern 1907). Flood waters frequently re-occupied the low lying areas of the "Old Lake Pleasanton" until the 1950s.

levels. Surrounding this pond was a swath of valley freshwater marsh, dominated by tules (*Schoenoplectus* spp.*),* yet the marsh would have included a suite of other freshwater emergent species, including rushes *(Juncus* spp.*)* and sedges *(Carex* spp.*).* Further removed, the willow thickets around the border of the perennial wetland occupied areas inundated for shorter periods (Howe 1851, Allardt [1880]1907, La Croze 1860, Duerr 1872, Cash 1875). While the center of the marsh was perennially saturated, the extent of open water within the rest of the marsh complex varied seasonally and interannually. In the wet season, open water likely extended across the marsh and into the wet and alkali meadows to the north, contracting in late summer.

From as early as the 1880s, the Pleasanton marsh began to be ditched, drained and developed (Figure 2.7). Yet, despite this rapid conversion, the wetland did not entirely disappear. Into the 20th century, the drainage canals initially "would easily silt up and overflow with tule and weeds and the property would be flooded nearly every year" (Gutmann 1919). Photos give an adequate idea of the expanse of water that would collect in the location of the marsh long after the initial ditching and draining efforts (Figure 2.8; von Geldern 1907:63).

Early engineers recognized the impact of draining the marsh on the watershed: "The sinks communicate with the creeks, and the creeks with the canals, and the result of this arrangement in the beginning of the wet season will be that the first rains are led more rapidly to the valley's main outlet," (von Geldern 1907:65). Diking of the marsh reduced surface storage and sediment deposition, and directed water more rapidly through Arroyo de la Laguna, through Niles canyons and into lower Alameda Creek. After this diking, severe incision was observed on Arroyo de la Laguna and downstream.

Springtown alkali sink

The Springtown alkali sink was a large alkali wetland east of Livermore. Significant portions of the alkali wetland still exist, though its extent has been greatly reduced. The Springtown alkali sink contained a variety of alkali wetland types, including alkali playa, alkali sink scrub, vernal pool complex, and alkali meadow. See page 48-49 for more in-depth discussion of the sink's habitats and ecological functions.

Influences of topography and climate

Topography as well as climate influenced wetland distribution in Livermore-Amador Valley. Bedrock exposures protrude above the valley floor at two significant points in the study area. These hills interrupt the flow of ground- and surface-water, creating poorly-drained areas, which facilitated the development of wetlands. East of Livermore, the

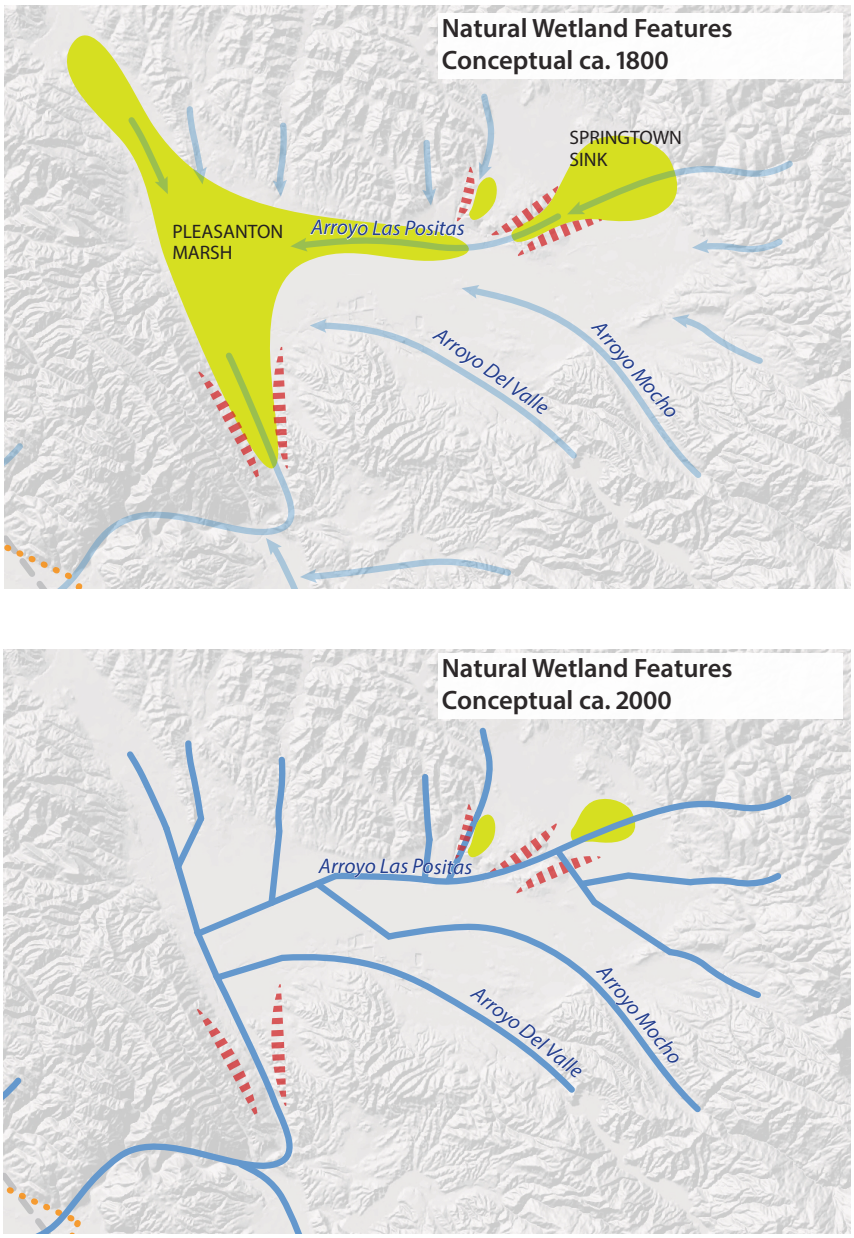


Figure 2.9. Conceptual depiction of wetland forcing features. This diagram shows how landscape-level patterns of topography and soils determine where wetlands occur—and where they do not. The well drained upper fans of Arroyo Mocho, Arroyo Del Valle, and Alameda Creek precluded the formation and maintenance of wetlands across much of the study area, instead facilitating groundwater recharge. Wetland mosaics formed in the poorly drained distal ends of fans. These processes combined with natural bedrock barriers to create the watershed's most important wetland complexes at Pleasanton and Springtown. Today most large natural wetlands are remnants of these former features, maintained by many of the same processes. Another small alkali area still exists in an undeveloped area near Cayetano Creek.

Springtown alkali sink was located behind the knolls of the Springtown anticlines, formed by late Quaternary uplift (Sawyer 1999) and supported seasonal alkali wetlands with low scrub and herbaceous vegetation (Figure 2.9). The basin west of Pleasanton, confined by the East Bay hills and by alluvial fans formed in the Pliocene, developed into the Pleasanton marsh complex containing many springs and supporting a large area of open water, seasonal wetlands, and extensive willow thickets and freshwater marshlands. The Pleasanton marsh complex occurred at the lowest point of the Valley, and as a result received more ground and surface water inputs and was more consistently saturated than the Springtown sink. The dry climate gradient of the Valley also shaped vegetation patterns in these wetland areas.

3. ARROYO MOCHO AND ARROYO LAS POSITAS CASE STUDIES: CONNECTING PAST, PRESENT, AND FUTURE

The landscape perspective outlined in the preceding sections sets the foundation for a focused analysis of the management challenges and restoration potential of two stream systems: Arroyo Mocho and Arroyo Las Positas. In the following sections, we explore the underlying physical and ecological processes acting on reaches of these two stream systems during the historical period (ca. 1800). We then explore change over time in certain problem locations identified by the SMMP (Zone 7 2006), using information about historical ecology and physical processes to further understand possibilities for designing with nature into the future. To facilitate analysis at a useful level of detail, this discussion is organized into discrete "case studies" corresponding to short stream reaches, but in reality these reaches are closely interconnected and should be managed holistically within the context of the watershed. Each case study includes a problem statement summarizing current management challenges, a review of underlying physical and ecological processes, an analysis of changes over time, and an assessment of future management and restoration potential. The first three case studies focus on Arroyo Mocho, while the last two focus on Arroyo Las Positas; each set of case studies is prefaced with a brief discussion of pertinent historical ecology background information.

Arroyo Mocho historical ecology background

Morphology and historical sediment supply

Arroyo Mocho drains a 60 square mile (155 km^2) watershed, smaller than its now impounded neighbor Arroyo Del Valle (146 mi^2 (378 km^2) upstream of the dam and 21.6 mi^2 (56 km^2) downstream of the dam). Historically the Arroyo Mocho transitioned from a narrow single-threaded channel through a semi-confined canyon along Mines Road to a broad stream corridor with occasional braiding reaches across its fan, ending in a series of distributaries near Isabel Road and Stanley Blvd. It was described as "narrower and more shifting" than Arroyo Del Valle (Fuller 1912:41). Over time, the active channel of Arroyo Mocho shifted back and forth between these low banks (Fuller 1912:41). One of several detailed General Land Office surveys was made by William Carlton, who crossed the creek twice (once going north and once going south) in April 1874. He described banks 200 feet wide and a "main channel" of Arroyo Mocho six hundred feet wide. He also described ascending a bench 25 feet (7.6 m) high (Carlton 1874). In the 1940 aerial photographs, this bench is still visible, and traces can still be followed in the 2007 LiDAR surveys (Figure 3.1).

As Arroyo Mocho approached the historical town of Livermore (near the current intersection of Holmes Street and Murietta Boulevard), it became more braided. Multiple channels can be seen in aerial photographs from 1940, and in times of flood the creek scoured beyond these channels to banks on either side, depicted in early maps as a substantially broader

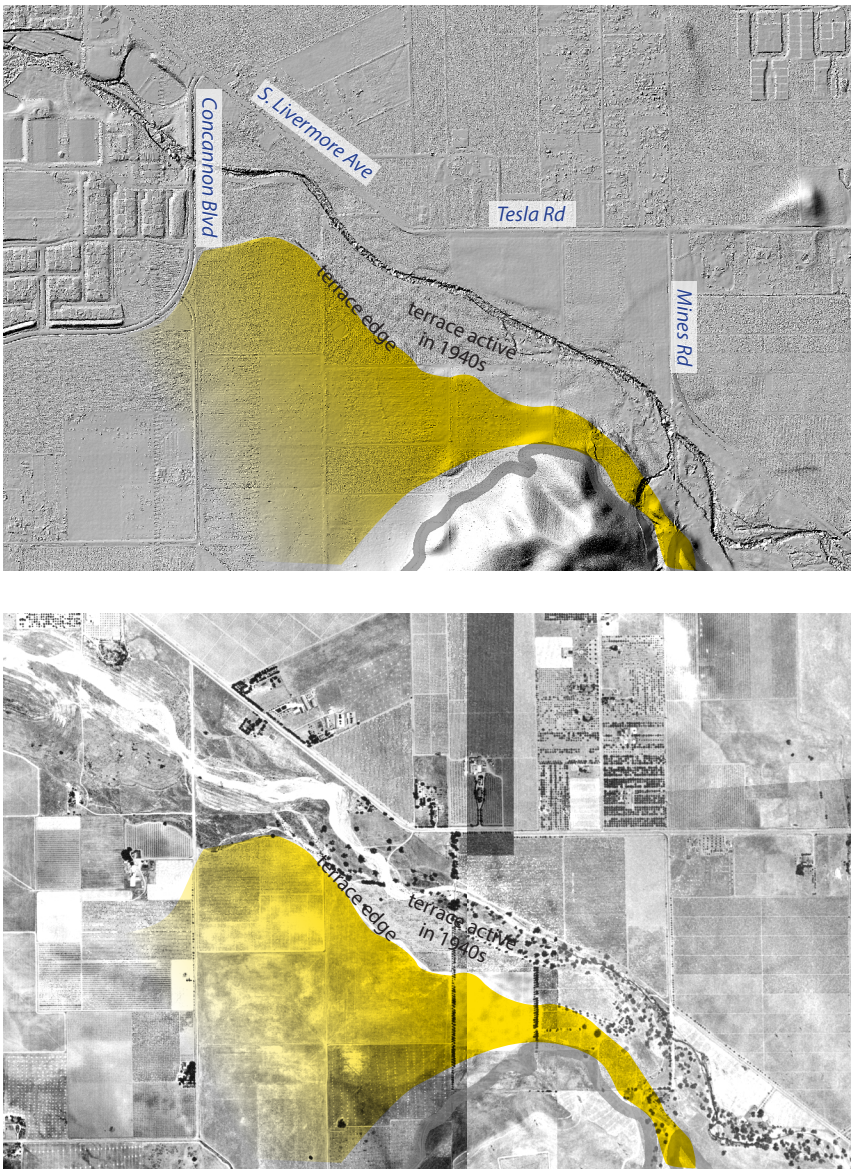


Figure 3.1. Terrace evident in 2007 LiDAR and 1940 imagery. A terrace surface on the south side of Arroyo Mocho is visible in the 2007 LiDAR digital elevation model (the edge of the terrace can be seen in yellow). The terrace is also evident in aerial photography from 1940, when the terrace boundary can be seen at the edge of the cultivated fields. Because Arroyo Mocho has been confined to a single-thread channel, the terrace is no longer active, but the signature of a formerly shifting channel still persists. (USDA 1940, Sanborn Mapping 2007)

reach (Allardt 1874, Thompson and West 1878, USDA 1940). The creek periodically overflowed even these broader banks into the town of Livermore (Williams 1912:305). Gravel mining could exacerbate erosion—"the consequent washing away of the banks and bed of the creek…made the crossing quite dangerous" according to the Echo (1894a). The dynamic and erosive nature of the stream and its proximity to Livermore may explain the more intensive ditching of Arroyo Mocho through this stretch compared with further upstream.

The creek historically occupied a much broader zone than it does today. In the climatic and geomorphic setting of the 19th and early 20th centuries, Arroyo Mocho was an actively aggrading stream due to its high coarse sediment supply and high stream power. The historical record indicates that at least by 1900, Arroyo Mocho was undersized for high flows and frequently flooded across the Valley. Cyril Williams described the undersized creek in 1912: "the channel of the creek is wide and shallow, and

in times of ordinary or heavy floods these banks overflow, upon occasion even through the town of Livermore" (Williams 1912:305).

The high discharge and slope, paired with a substantial coarse bedload supply, supported the active braiding and multi-stem form of Arroyo Mocho in this reach. It is possible that in the early Holocene, Arroyo Mocho created an alluvial fan as it spread over the Livermore Valley, and at a certain point, a shift in sediment supply and discharge caused the channel to incise into its fan, leaving behind the large benches and terraces still seen in the LiDAR data. Meanwhile, active braiding continued within the confines of the abandoned terraces or former fan surface. The shifting channels, bars, and bank erosion maintained the shallow and wide channel and the bed slope likely remained high enough to transport the gravels and support braiding (Knighton 1998). As the slope of the channel lessened towards the bottom of the fan, the median gravel size likely decreased as stream power diminished, and the braiding decreased in width and complexity (Knighton 1998).

Flows

Arroyo Mocho maintained perennial surface flow through its confined canyon. As it entered the Valley, flow became intermittent as water slowly sank through the alluvial gravels near the town of Livermore. Towards the top of the alluvial fan, surveyor Sherman Day described a "copious stream running here over a rocky and a gravelly bed" in August 1853 (Day 1853). Further downstream he described pools, adjacent to a reach of stream that was "entirely dry." West of Oak Knoll Cemetery, downstream of the Western Pacific Railroad crossing, Arroyo Mocho crossed a thrust fault (the Livermore Fault), and historically began to bifurcate into distributary channels and to lose its defined channel form (Day 1853, Halley 1876). Although different sources propose different reasons for the name Mocho (translated as "cut-off"), surveyor Sherman Day explained that it was so named "because it terminates about 2 miles W. of Livermore by spreading itself out on the plain" (Day 1853). In times of flood, surface flow continued as sheet flow or through poorly defined and discontinuous channels, but much of the flow sank into the coarse gravels of the Valley.

The stream responded to interannual variability in rainfall and runoff conditions. During wet years, the distributary channels supported a surface water connection to the Pleasanton marsh, providing corridors for migratory species, nutrient exchange, and other ecological functions. In dry years, no surface connection existed between Arroyo Mocho and the rest of the Alameda Creek watershed (Sowers 2003, Stanford et al. 2013). Subsurface flow from Arroyo Mocho seeped towards the Pleasanton marsh complex and Arroyo Las Positas, and was seen as an important groundwater source (Williams 1912). Even today, this creek is used to recharge groundwater. The lack of a defined channel in the lower part of Arroyo Mocho and the unpredictable and varying nature of sheet flow patterns likely motivated early efforts to ditch and redirect the creek, which may have occurred as early as 1878 (Thompson and West 1878).

Riparian vegetation

Arroyo Mocho supported a riparian corridor that varied in width and density, but most likely averaged around 800 feet (244 m) wide in the braided reaches. This zone of creek influence included sycamore alluvial woodland, oaks, and bars and islands, and the creek was flanked by active benches and abandoned terraces. Surveyor Day observed white (valley) oaks in 1853 "on a level clay, flat bench, being at the bottom of the 'Arroyo Mocho', coming out of the mountains" (Day 1853). Scalebroom scrub *(Lepidospartum squamatum)* was also recorded along Arroyo Mocho (Sharsmith 1945). Scalebroom occurs primarily in the Great Basin and deserts and is associated with intermittently flooded alluvial deposits and vegetation types, such as sycamore alluvial woodland and mulefat scrub *(Baccharis salicifolia;* Sharsmith 1945, Magney 1992, Sawyer et al. 2009).

Near Livermore, sycamore alluvial woodland disappeared and tree cover was likely sparser due to the intermittent water supply, but large riparian trees continued. A local historian stated that "the banks [of Arroyo Mocho]… abound with oak and sycamore trees of great size" (Wood 1883). General Land Office (GLO) surveyor Sherman Day crossed Arroyo Mocho just over half a mile west of Oak Knoll, and described a creek 60 feet wide, with "a wide gravel bottom…the creek is lined with sycamores along its margin" (Day 1853).

As the stream bifurcated in the distributary reach, vegetation would have been minimal, consisting mainly of hydrophytic grasses as the stream was integrated into the larger matrix of oak savanna and grassland before reaching the marsh.

Fish

Fish assemblages in intermittent streams in Livermore-Amador Valley were highly variable depending on local environmental conditions and life history needs. Fish populations used large intermittent creeks such as Arroyo Mocho seasonally, particularly as a migration corridor to other suitable intermittent or perennial habitats with year-round pools found within the upper watershed (Leidy in Stanford et al. 2013:272). The perennial open water of the Pleasanton marsh would have provided important off-channel rearing habitat, especially in dry years. When surface connections between Arroyo Mocho and other intermittent tributaries were made during high flow events, large intermittent tributary creeks functioned as critical migration corridors and potentially significant rearing habitat for steelhead depending on the amount and distribution of annual precipitation.

Case Studies

Arroyo Mocho was controlled by the slope and size of its canyon, which propelled the stream into the open Valley where it built an alluvial fan, braided through it, transitioned to a single-thread channel, and finally bifurcated into multiple distributaries (Figure 3.2). The following case studies delve deeper into the components of the landscape, following Arroyo Mocho downstream.

A summary of historical riparian characteristics along the alluvial reaches of Arroyo Mocho is shown in Table 3.1, highlighting the dominant morphology, substrate, flow characteristics and riparian vegetation patterns during the historical period. These zones correspond generally to two of the three case studies presented in this chapter.

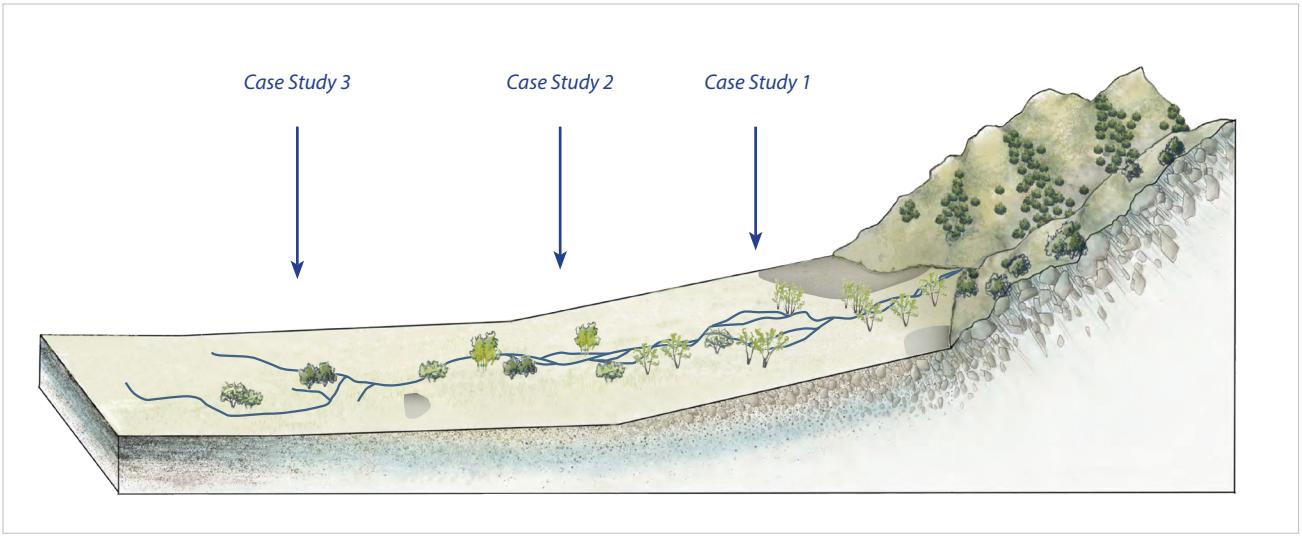


Figure 3.2. Conceptual model of historical Arroyo Mocho, ca. 1800. This diagram shows a simplified oblique view of Arroyo Mocho as it exits its canyon, braids across its fan, and spreads out, losing channel definition and forming distributaries. The graphic shows a gradual fining of bed material, change in relative depth to groundwater (shown in light blue), and corresponding changes in vegetation patterns as the stream flows downslope.

Table 3.1. Riparian characteristics of alluvial reaches of Arroyo Mocho, ca. 1800

Creek	Reach	Case Study	Watershed Area (sq. miles)[1]	Dominant Morphology[2]	Dominant Geomorphic Process [2]	Substrate[3]	Dry Season Flow	Riparian Corridor Width Classes[4]	Riparian Vegetation[5]
Arroyo Mocho	Upper Mocho (canyon mouth to Tesla Road)	--	45	Single-stem, meandering	Production, transport, depo-sitional	Boulders, gravels, sand	Perennial/ Intermit-tent with pools	200-660 ft (60-200 m)	Sycamore alluvial wood-land
	Middle Mocho (Tesla Road to Oak Knoll)	Case Studies 1 & 2	55	Braided	Transport, depositional	Boulders, gravels, sand	Intermit-tent	660-1320 ft (200-400 m)	Sycamore alluvial wood-land
	Lower Mocho (Oak Knoll to distributaries)	Case Study 3	59	Distributary channels	Depositional	Gravels, silt, clay	Intermit-tent	200-660 ft (60-200 m)	Sycamore, Sparse oak

[1]Watershed area was calculated at the downstream endpoint of each reach using contemporary USGS Streamstats, but is likely representative of the historical drainage area.

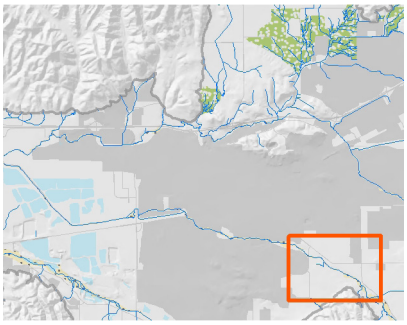
[2]Dominant morphology and process were determined from the mapped form of the creek, our understanding of fluvial geomorphic processes, and geology data.

[3]Substrate classes were developed from historical descriptions, soils and geology mapping, and historical photographs.

[4]Riparian corridor width measures from the outer edge of stream-associated vegetation on one side of the stream to the other, including the stream bed. These widths were based largely on the width of a representative reach in the historical aerial imagery and current geomorphic features in the 2007 LiDAR data (USDA 1940, Sanborn Mapping 2007).

[5]Broad historical riparian vegetation classes were developed from available species data, and describe the inner corridor of riparian vegetation. Further from the creek, riparian vegetation would have included valley oaks and/or sycamores.

CASE STUDY 1: ARROYO MOCHO SOUTHEAST: *ROOM FOR RE-BRAIDED CHANNELS*



PROBLEM STATEMENT

This first case study encompasses the most upstream reach of Arroyo Mocho within the Valley, from just downstream of where the stream diverges from Mines Road on the southeast to Robertson Park on the northwest (Figure 3.3). Management challenges in this reach stem from changes in channel planform and loss of riparian habitat. Arroyo Mocho has been converted from a braided to single-threaded channel along a large segment of this reach to make room for high value agriculture (Figure 3.3). This change in planform, and reduced room for the stream to migrate and braid, has likely reduced naturally-organized in-channel sediment storage throughout the reach and increased sediment transport to downstream reaches, contributing to documented sedimentation problems at Holmes Street Bridge and other locations (see Figure 1.4). The narrowing of the stream corridor has been accompanied by a substantial reduction in the extent of the riparian corridor, including a loss of sycamore alluvial woodland habitat.

UNDERLYING PHYSICAL AND ECOLOGICAL PROCESSES

Historically, this reach of Arroyo Mocho represented a transition zone between the confined, single-threaded channel of the bedrock canyon upstream, and the low-gradient, multi-threaded channel in the Valley downstream. In the canyon, transport of water and sediment (as opposed to storage) were the dominant processes. As the stream emerged from the confined canyon and entered the valley floor, however, the high sediment supply combined with the change in bed slope and the widening of the stream corridor across its alluvial fan supported the formation of a multi-threaded channel and braided bars (in-channel storage) in many places (see Figure 3.2). As the stream flowed over its fan and its slope decreased, it became a losing reach, with surface water gradually sinking into the gravelly substrate and recharging groundwater aquifers. Flooding was frequent, and during heavy floods the stream would overflow its banks, inundating the surrounding floodplain.

Suitable groundwater depths, the presence of alluvial substrates, and variable stream discharges supported sycamore alluvial woodland, a rare California ecosystem type, along much of this reach of Arroyo Mocho (Keeler-Wolf et al. 1996:14-18). Sycamore alluvial woodland is a sycamore-dominated (more than 50% of relative cover in tree layer of *Platanus racemosa)* riparian woodland type that grows along the alluvial benches of braided streams (Keeler-Wolf et al. 1996). The understory includes California buckeye (*Aesculus californica*), blue elderberry (*Sambucus* spp.), and mule fat (*Baccharis salicifolia*), but the habitat type may also include areas of unvegetated channel (Holland 1986). Seasonally dry sycamore alluvial woodland supported a distinct suite of wildlife including yellow-legged frog *(Rana boylii),* horned lizard *(Phrynosoma coronatum frontale),* and lesser nighthawk *(Chordeiles acutipennis)*.

Sycamores likely occurred on in-channel bars as well as banks and terraces within the active floodplain, which are discernible in LiDAR images (Figure 3.1). The sycamores themselves reinforced the braided channel form by stabilizing banks and in-channel bars. The width of the riparian corridor ranged from approximately 200 to 1300 ft (60 to 400 meters) (Table 3.1).

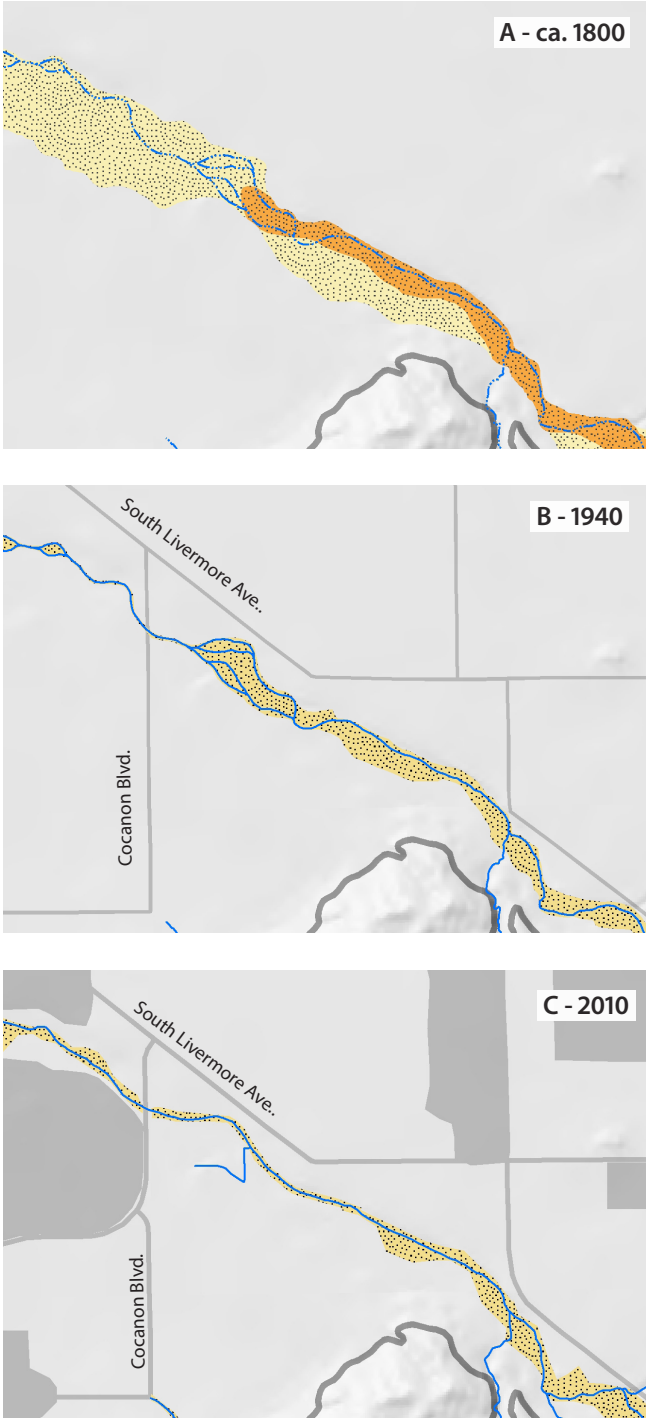


Figure 3.3. Change over time of riparian habitat extent, stream configuration, and extent of impervious surfaces between 1800, 1940, and 2010 on southeast Arroyo Mocho. A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1940, 1942). C. Conditions ca. 2010 (USDA 2009, ICF International 2010, SFEI 2011).

HISTORY OF CHANGES OVER TIME

Though extensive agricultural development had already occurred in this area by 1940, Arroyo Mocho still persisted as a broad, multi-threaded stream along this reach. During the late 20th century, however, farming expanded into much of the historical stream corridor. In the intervening years, large portions of the riparian corridor were cleared, and the stream was converted from braided to single-threaded (Figure 3.3). The stream is now confined to a narrow channel bordered by agricultural land (Figure 3.3c, Figure 3.4). Despite the changes associated with agricultural expansion, the areas surrounding this reach are still relatively undeveloped: farms and vineyards are the predominant land use.

The conversion from a braided to single-threaded channel likely had a significant impact on the sediment transport dynamics of this reach, decreasing sediment deposition and increasing sediment transport by concentrating flows through a single channel, and presumably increasing stage and flow velocities. This

Riparian mapped in 1800s was characterized as

- Sparsely Vegetated Braided Channel
- Sycamore Alluvial Woodland

Riparian mapped in 1940s and 2010 was characterized as

- Mapped Riparian Zone (1940, 2010)

- Stream channel

Channels mapped for the 1800s time period are further characterized as:

- Intermittent/Ephemeral Stream
- Perennial Stream
- Ephemeral Undefined/ Overflow Channel

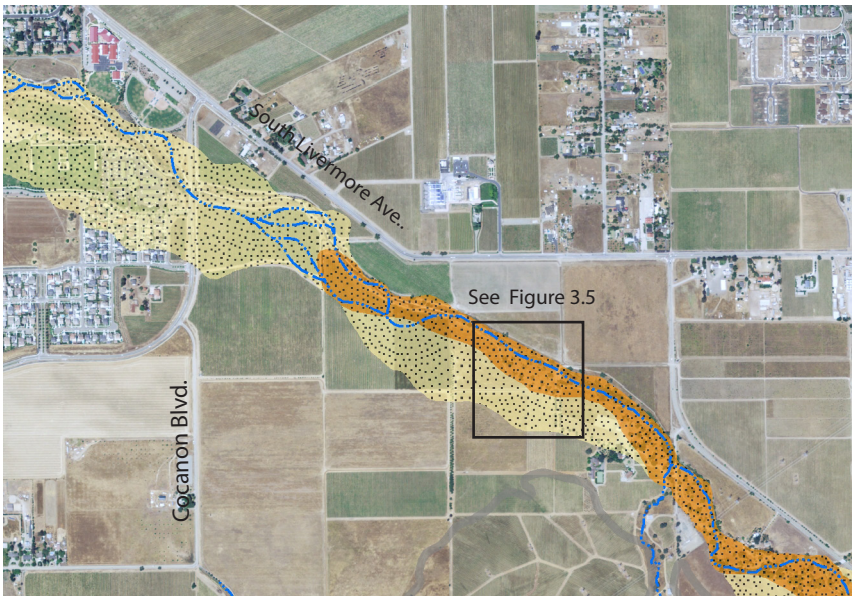
- Impervious Surface

Figure. 3.4. Transformation of upper Arroyo Mocho from a broad, braided channel with sycamore alluvial woodland in the historical period (top, showing historical habitat types over modern aerial) to a narrow single stem channel. This reach holds potential for re-introduction of a braided system in the long term future (bottom), if the land ownership pattern changes. (USDA 2009, Stanford et al. 2013)

Sparsely Vegetated Braided Channel

Sycamore Alluvial Woodland

Intermittent/Ephemeral Stream



change in planform has also likely impacted the hydrology of the stream and thus the channel geometry. With confined flows through this reach, and elevated stage and water surface slope, shear stress on the banks and bed may have increased, causing bed lowering and decreasing the time to peak discharge further downstream.

The South Bay Aqueduct (SBA), constructed in the early 1960s as part of the State Water Project (SWP), discharges water into Arroyo Mocho just upstream of the boundary of Case Study 1 (DWR 2001). Water inputs from the SBA, as well as runoff from surrounding urban areas, may have increased base flows and reduced stream flow variability. The altered hydrology has likely increased the density of species such as willows and reduced the extent of xeric-adapted habitats, such as sycamore alluvial woodland.

FUTURE POTENTIAL

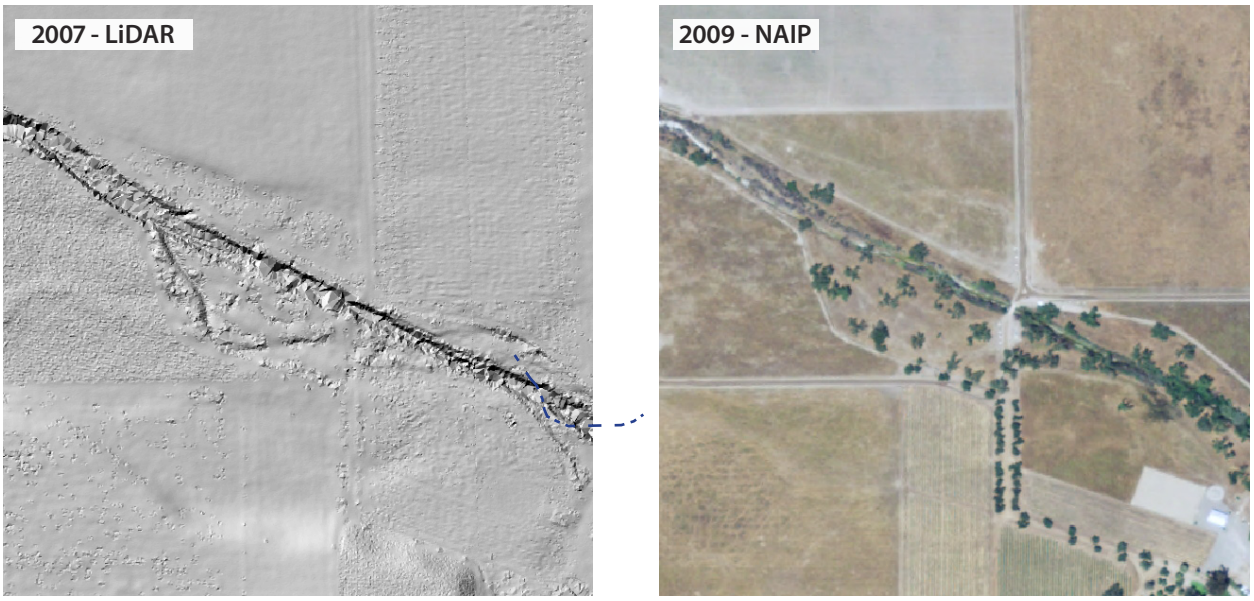
Although a large portion of this reach of Arroyo Mocho has been artificially confined to a single-thread channel, the underlying physical controls that historically maintained a braided channel – and associated watershed functions such as sediment storage and groundwater recharge – remain relatively unchanged. Arroyo Mocho's large, undammed watershed still produces a large supply of coarse sediment, while other fundamental physical drivers – the reduction in stream gradient and change in confinement occurring at the mouth of the canyon – still promote sediment deposition, though it is happening in different places than it did historically. The fact that these physical controls are relatively intact suggests a high potential for the reestablishment of natural sediment dynamics and a broad braided channel along portions of this reach. Allowing the channel to widen and braid could potentially help to restore riparian habitats and increase in-channel sorted sediment storage upstream. The increase in sediment storage on in-channel bars that would accompany such a management action might help to restore the balance of sediment in the upper Arroyo Mocho reach, thus potentially limiting sedimentation problems at downstream bridge footings. Restoration of a braided channel would also increase the travel time and decrease peak flows by broadening the hydrograph. Sediment transport modeling should be used to assess the volume, storage potential, and impact on flood capacity of such a restoration action.

Several locations within this reach appear to have high potential for re-introduction and self-maintenance of a multi-threaded channel. Near the center of the case study, a small unfarmed area that currently supports riparian tree cover may have supported a multi-threaded reach at varying times in the recent past, as can be seen in LiDAR images (Figure 3.5). Approximately ¼ mile further downstream is another, larger area that was mapped as braided in the early 19th century (see Figure 3.4). Although the modern single-threaded channel is closely surrounded by farmland (especially at the second location), these areas represent potentially promising sites for restoration of braided reaches in the future. Less important than the specific site for re-engaging channels is the concept of strategically establishing a wide channel corridor through this reach, which would potentially provide multiple benefits for downstream management, including in-channel storage of coarse sediment, decrease of slope, possible flood attenuation, and wildlife benefits.

Several constraints should be recognized with this type of management strategy. First, land ownership and land uses are the primary concerns and should be considered with care as Zone 7 is not a land use authority. Second, the degree to which the channel is incised will impact the potential to recreate a braided reach, and may necessitate an untenable volume of soil excavation. Third, the hydrology in this reach (and all of lower Mocho) has been altered by inputs from the South Bay Aqueduct. Given the managed perennial (and sometimes intermittent) flows release from the aqueduct, it may not be possible to recreate the intermittent and flashy flows which historically supported sycamore alluvial woodland in this reach (Gillies 1998), although there is evidence for persistence and regeneration of sycamore alluvial woodland in other nearby reaches.

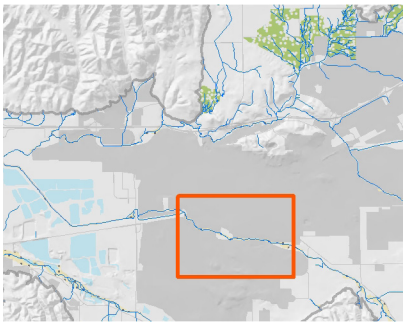
This case study explores management approaches that are necessarily part of a longer term strategy for watershed management. The land in question here is in private ownership and is used for high value agriculture, and thus may only become available after decades have passed. Nonetheless, Zone 7 might be able to plan for this type of land purchase in the longer term future, building it into a multi-step watershed plan for sediment management and riparian forest regeneration.

Figure. 3.5. Future potential for restoration of braided reach on Arroyo Mocho. This reach of the creek shows the topographic signatures of a multi-thread channel, and is not currently in cultivation (see inset box on Figure 3.4). There appears to be a high potential for increase in-channel storage and channel widening in this reach. (Sanborn Mapping 2007, USDA 2009)



CASE STUDY 2: ARROYO MOCHO (HOLMES STREET BRIDGE TO MADEIROS PARKWAY)

BRAIDING STRATEGIES FOR SEDIMENT STORAGE



PROBLEM STATEMENT

The second case study is located just downstream of Case Study 1, and includes the portion of Arroyo Mocho between Robertson Park and Stanley Boulevard, which together create a uniquely continuous wide riparian corridor within the urban fabric of Livermore (Figure 3.6). This segment of Arroyo Mocho supports a relatively mature riparian forest with an abundance of native tree species. It is neither channelized nor significantly incised, though it has a dominant low flow channel (it is not actively braided). The stream is separated from the urban development of Livermore by a narrow corridor of undeveloped public land. The primary management problem in this area is the significant sedimentation occurring upstream of Holmes Street Bridge and Stanley Boulevard Bridge (located at the downstream end of the case study), necessitating periodic excavation (Figure 3.6) . In addition, the stream segment between Stanley Boulevard and Holmes Street Bridge is cited as one of the "primary areas subject to flooding" (Zone 7 2006:3-6) because of lack of capacity due to in-channel sediment deposition.

UNDERLYING PHYSICAL AND ECOLOGICAL PROCESSES

As it progressed across its alluvial fan, Arroyo Mocho continued to deposit sediment and lose stream power. Surface flow declined as water percolated through the coarse gravels, recharging underground aquifers. Historical sources indicate that Arroyo Mocho maintained a wide, braided channel through much of this reach as well (Figure 3.6a). By the approximate location of the modern-day Holmes Street Bridge, however, Arroyo Mocho's stream power and ability to transport sediment naturally declined to the point that the stream was unable to maintain its braided form and it transitioned to a single-threaded channel, depositing more sediment in the process.

Corresponding to the decrease in surface water availability as Arroyo Mocho flowed across the Valley through this reach, sycamore alluvial woodland graded into an even more sparsely-vegetated riparian corridor with occasional oaks (*Quercus* spp.), sycamores (*Platanus racemosa*), willows (*Salix* spp.*),* and shrubs (i.e., mulefat *(Baccharis salicifolia))* (Figure 3.6a). In the northwestern portion of the case study, near present-day Stanley Boulevard, a fringe of seasonal wet meadow bordered the stream to the north. Vegetation likely included grasses and a significant component of obligate and facultative wetland species such as wire rush (*Juncus balticus),* irisleaf rush *(Juncus xiphiodes),* buttercup *(Ranunculus californicus),* and blue eyed grass *(Sisyrinchium bellum)* (Holstein 2001).

HISTORY OF CHANGES OVER TIME

This reach of Arroyo Mocho runs through the heart of Livermore, and has thus been heavily impacted by urban development. By the mid-1900s, agriculture dominated the area south of Arroyo Mocho and had begun to encroach into the riparian corridor, but much of this reach still supported a broad and sparsely vegetated riparian zone. By 1980, the farms had been replaced with residential development, and large portions of the riparian corridor had been paved over. Today, with a few exceptions such as Robertson Park and Madeiros Parkway where a wider corridor of open space remains, the stream flows through a confined corridor closely bounded by residential development (Figure 3.6).

Holmes Street Bridge was constructed at the point where Arroyo Mocho historically shifted from a braided to a single-threaded channel. This was likely not a coincidence, given that the thinnest part of the channel would have been the most convenient place

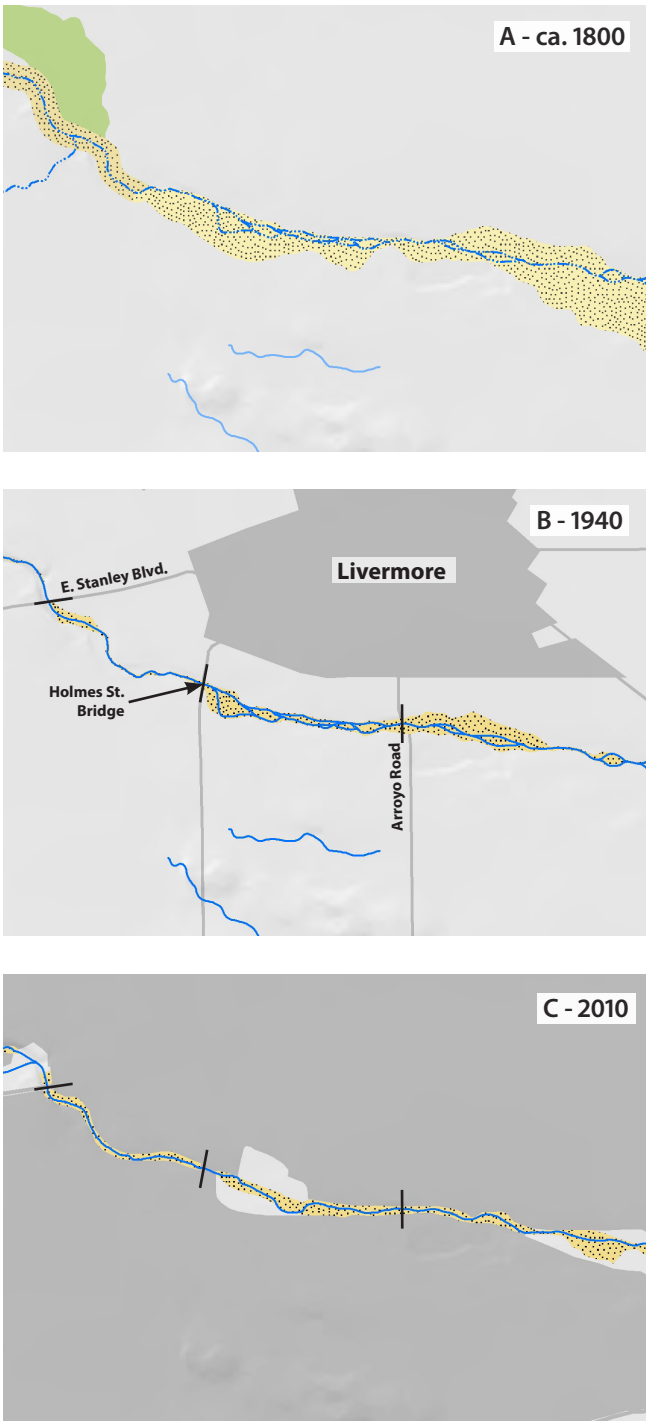
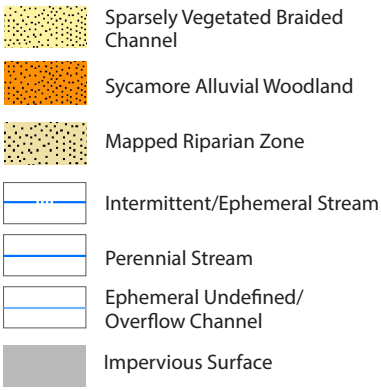


Figure 3.6. Change over time of riparian habitat extent, stream configuration, and extent of impervious surfaces between 1800, 1940, and 2010 on Arroyo Mocho (Robertson Park and Madeiros Parkway). A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1940). C. Conditions in 2010 (USDA 2009, ICF International 2010, SFEI 2011).

to build a bridge. However, the bridge likely further constricted the channel in this area, causing a bottleneck for water and sediment transport and resulting in the buildup of sediment behind the bridge (Figure 3.7).

The structure and composition of riparian vegetation in this reach have changed relative to historical conditions, though elements of the historical corridor still remain. Vegetation density has increased substantially, likely because of increased dry season flows resulting from urban runoff and inputs from the SBA. Through field observations (see Appendix B), we calculated average tree density between Concannon Blvd and Holmes Street to be approximately 65.7 trees/acre (this stretch of the river spans most of Case Study 2 and extends approximately 0.6 miles east into Case Study 1) (Figure 3.8). Average tree density was relatively high in the channel and on the inner bench (175.5 and 157.9 trees/acre, respectively), but much lower in the outer bench/floodplain (21.3 trees/acre). Sycamore alluvial woodland would generally have a lower tree density throughout alluvial distributions in central California (Gillies 1998, Keeler-Wolf et al. 1996).

The channel corridor currently supports a diversity of height, structure, and species, though species composition has changed dramatically. While the historical corridor



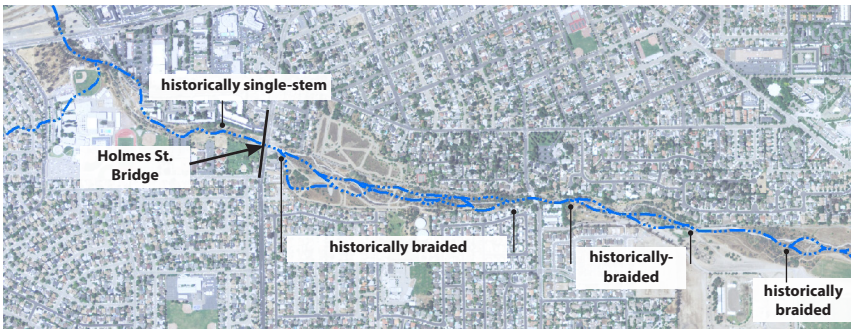


Figure. 3.7. Historical transition from braided to single stem channel at Holmes Street Bridge. This image overlays the historical channel network (Stanford et al. 2013) on the modern aerial imagery, highlighting the natural shifts in channel planform.

was a mix of sycamores, oaks, willows, and shrubs, today willows dominate the low flow channel, accounting for 81% of recorded trees. Seedlings or saplings account for 99% of these willows (see Appendix B). The benches contain a more even mix of (mostly native) tree species, including black walnut, California buckeye, Fremont cottonwood, valley oak, sycamore, eucalyptus, and ornamentals. Mature sycamores have persisted in a number of locations on the inner and outer benches of this reach, most notably in the southwestern portion of Robertson Park near the Del Valle Mobile Home Park and in the southwestern portion of Madeiros Parkway near Holmes Street (Figure 3.9). Mature sycamores were also observed in the backyards of private homes and in the parking lot of Roberston Park, often up to 100 m from the active channel; these trees most likely established during past floods when these areas were part of the active floodplain. Though these sycamores are no longer connected to the hydrologic regime of the channel, we might assume that they are being supported by adequate levels of groundwater. We also observed some sycamore regeneration, concentrated in the inner benches within Madeiros Parkway and several other locations, though regeneration rates appear to be fairly low (Appendix B, Figure B8).

FUTURE POTENTIAL

Although sedimentation at Holmes Street Bridge is a costly management problem, it is informative to recognize that this reach of Arroyo Mocho was in fact a depositional zone historically. Thus, rather than being an aberration due to human interference, the sedimentation at Holmes Street Bridge likely represents the continuation (and perhaps amplification) of a natural process. Nevertheless, the conversion of the channel from braided to single-threaded in this reach has likely

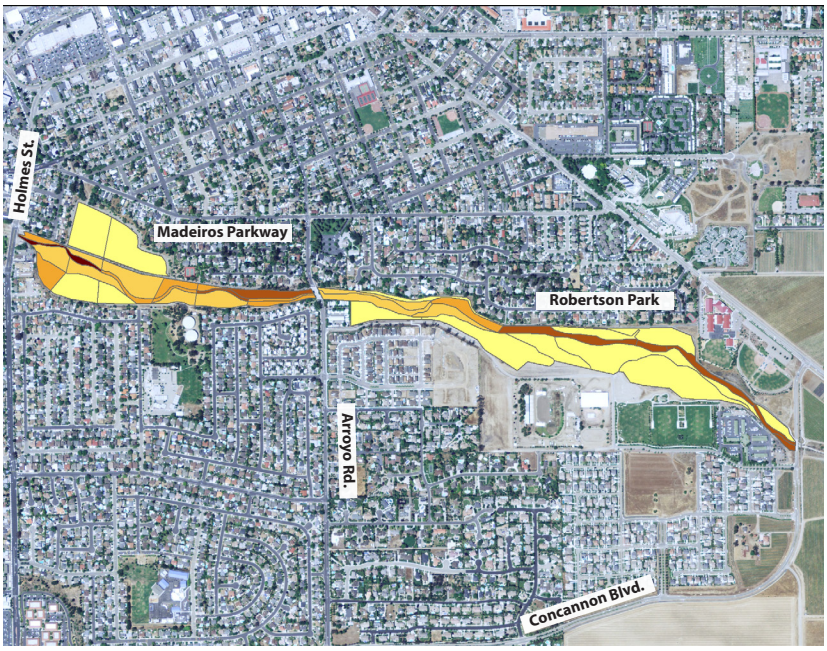


Figure. 3.8. Tree density by geomorphic zone on Arroyo Mocho. We mapped tree density by species type and age class along Arroyo Mocho, focusing on Robertson Park and Madeiros Parkway. Early results showed that while there is a wide corridor of potential riparian habitat, the density of trees is highest in the channels in Robertson Park, with a slightly more even distribution of densities in Madeiros Parkway. For more detail see Appendix B. (USDA 2009)

Trees per acre

- 4.5 - 51.2
- 51.3 - 98.5
- 98.6 - 152.7
- 152.8 - 260.2
- 260.3 - 485.8

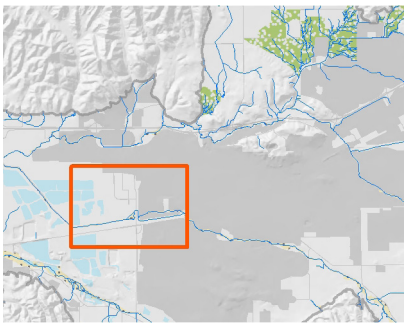
Figure. 3.9. Sycamores observed on mounds in parking lot of Robertson Park. Sycamores (*Platanus racemosa)* were observed growing up to 100 m away from the current low flow channel, but within the bounds of the historical extent of mapped riparian habitat (Stanford et al. 2013). Dendrochronology might be used as a tool to reconstruct disturbance regimes in this reach. (photo by Sean Baumgarten, November 1, 2012)

Figure 3.10. Field-observed inactive side channels. Light blue lines indicate the location of several swales or inactive side channels that were observed at low flow conditions in the field (November 1 and 13, 2012). Further observations should be made as to whether these are activated in high flows, or if they could be reconnected with the main stem without the context of future park design and management. (Sycamores shown in Figure 3.10 are circled in red)

exacerbated the sedimentation problem by increasing stream power and sediment transport capacity along some segments while concentrating sediment deposition in others.

One option to address sedimentation would be to redesign Holmes Street Bridge to reduce the constriction of the channel, thus making the site less susceptible to sedimentation. This approach would likely only provide a partial solution to this management problem, however, and would do little to advance other management goals such as riparian habitat restoration. A complementary solution could involve restoration of some components of the historical floodplain and braided stream morphology. As previously discussed, this reach of Arroyo Mocho is largely confined by intensive urban development, severely constraining options for floodplain restoration. However, there appear to be some opportunities for limited restoration of additional channels and sections of floodplain through the two parks. More specifically, inactive side channels or other locations for braided reach restoration were identified through our field and GIS analyses (Figure 3.10). However, sedimentation may continue to be a management challenge in this reach.

Cumulatively, increasing braiding and thus in-channel storage as explored in Case Studies 1 and 2 would potentially alleviate some of the sediment build up at the Holmes Street and Stanley Boulevard bridges as well as increase channel complexity and in-stream habitat. These first two case studies are presented as separate sites, but shoudl be considered in tandem to create beneficial impacts on the sediment dynamics of the system. One major constraint that could affect the success of this management strategy is the altered hydrology of the stream system relative to historical conditions. Increased base flows now encourage the growth of relatively dense riparian vegetation, which constricts the channel and inhibits lateral movement. Some vegetation control and ongoing maintenance may therefore be required along the low flow channel so that braiding could take place. Though braided channel morphology historically supported sycamore alluvial woodland, this habitat type may or may not be able to re-establish given the changed flow conditions. As evidenced by the sycamore saplings currently re-establishing along the main channel, however, there is a high likelihood that sycamores could persist in this reach as part of a mixed riparian forest.



CASE STUDY 3: ARROYO MOCHO DISTRIBUTARIES
RECONNECTING THE CHANNEL TO THE CHAIN OF LAKES

PROBLEM STATEMENT

The third Arroyo Mocho case study extends from Stanley Boulevard to the point where the stream turns north through the Chain of Lakes (Figure 3.11). The first portion of the reach to the east of Isabel Avenue consists of two separate channels: the flood control channel adjacent to Stanley Boulevard and an "alternate" channel running through a residential neighborhood approximately 0.1 miles to the north. The second portion of the reach to the west of Isabel Avenue consists of a single flood control channel.

Significant sedimentation is occurring within the flood control channel west of Isabel Avenue and in the alternate channel east of Isabel Avenue (see Figure 1.4). One outcome of this sedimentation is a reduction in channel capacity, leading to an increased risk of flooding.

This reach is also characterized by poor quality riparian habitat. East of Isabel Avenue, the riparian corridor is dominated by non-native grasses along a trapezoidal flood control channel with minimal native habitat value. The alternate channel to the north has a diverse mix of native and non-native riparian species and high vegetation density (Figure 3.12). West of Isabel Ave, the flood control channel is dominated by eucalyptus (Figure 3.13).

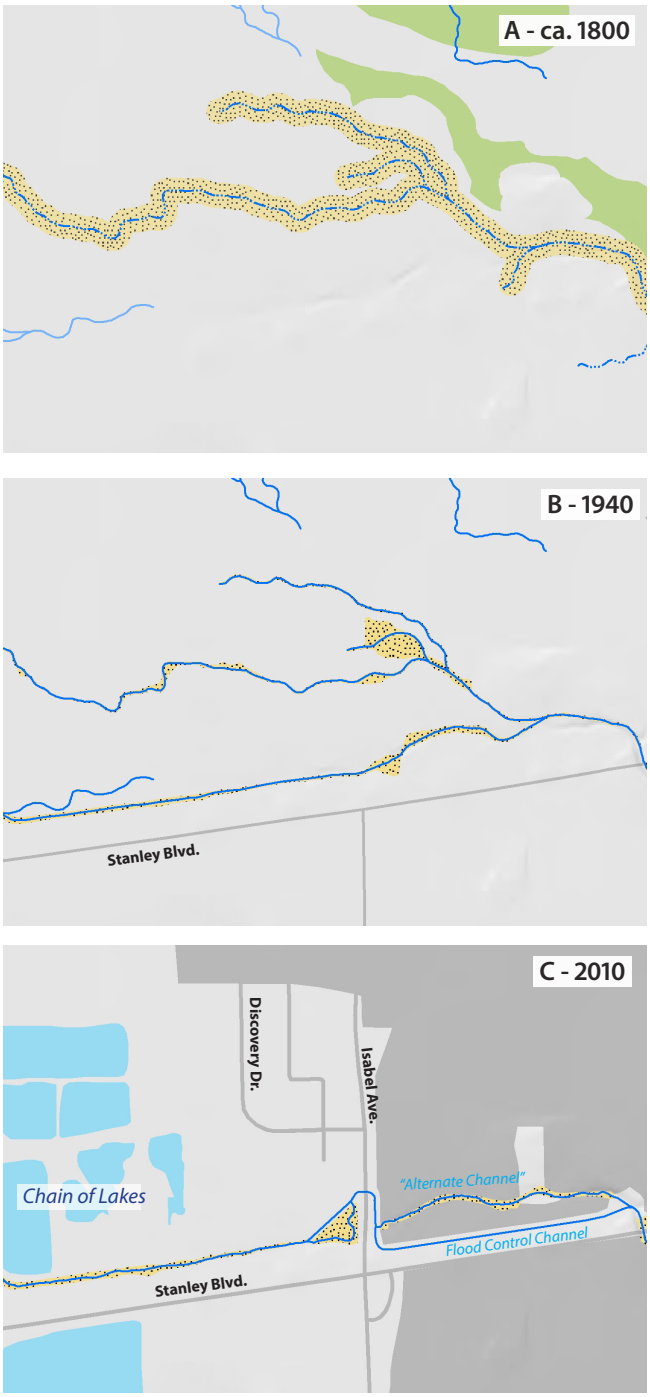


Figure 3.11. Change over time in riparian habitat extent, stream configuration, and extent of impervious surfaces between 1800, 1940, and 2010 on Arroyo Mocho distributaries. A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1940). C. Conditions in 2010 (USDA 2009, ICF International 2010, SFEI 2011).

- Sparsely Vegetated Channel
- Intermittent/Ephemeral Stream
- Perennial Stream
- Ephemeral Undefined/ Overflow Channel
- Impervious Surface

UNDERLYING PHYSICAL AND ECOLOGICAL PROCESSES

Historically, this reach was the terminus of Arroyo Mocho's alluvial fan and the site of its distributaries. Except during very high flow conditions, the remaining surface flow spread out and sank into the ground. As a result, this area functioned as an important groundwater recharge reach (Williams 1912), and did not support a riparian corridor of trees - rather, the distributaries flowed through an oak and grassland matrix.

To the west of Oak Knoll Cemetery, Arroyo Mocho crosses the Livermore Fault, which was one of the factors that may have caused the stream to sink subsurface. While the exact position at which Arroyo Mocho spread into distributary channels would have varied over time, historical maps and GLO survey notes converge on this as a general location of this transition (see Stanford et al. 2013). Subsurface flow continued east towards Pleasanton marsh (Williams 1912). Although the substrate in this part of lower Arroyo Mocho was dry and gravelly, the presence of the Livermore Fault created a series of springs (Tibbetts 1907, Unruh and Sawyer 1997). Travelling south along current Isabel Avenue, surveyor Sherman Day (1853) crossed an "open gravelly plain" and described "water in a swamp slough" in July 1853. This "swamp slough" was likely a small perennial wetland. By July, Arroyo Mocho would have completely dried up, so a wet slough must have been fed by a local spring. The presence of the perennial wetland and associated spring may have exacerbated the need for drainage, and preempted the early ditching of Arroyo Mocho to the south.

HISTORY OF CHANGES OVER TIME

Stream morphology and function in this reach have undergone dramatic changes from historical conditions. By 1889, and possibly as early as 1878, a ditch had been constructed to bypass the distributaries and rapidly convey streamflow westward and then northwards towards a confluence with Arroyo Las Positas. However, Arroyo Mocho did not maintain surface flow through the ditch throughout the year. Civil engineer Cyril Williams noted, "In ordinary or critical years the Arroyo Mocho Creek sinks into the Livermore Valley gravels, and seldom in such years reaches the Laguna Creek as surface flow" (Williams 1912:571; see also Gutmann 1919:6). Flows remain intermittent today, though they are augmented by the inputs of South Bay Aqueduct.

Figure 3.12 View of northern alternate channel (taken from Rockrose Street facing east). This small channel is densely wooded with mixed native riparian trees and eucalyptus (Photo by Sean Baumgarten, November 15, 2012).

Figure 3.13. Arroyo Mocho near Hagemann Bridge. Simplified channel lined with dense eucalyptus trees in creek along Stanley Blvd where historically the stream spread into distributaries (Photo by Sean Baumgarten, November 15, 2012).

Figure. 3.14. "Hauling gravel from Mocho Creek bed." Arroyo Mocho transported large volumes of sediment, including cobbles and gravels, which early residents of the Valley excavated for road surfaces long before commercial mining began in the area. (Photo #N252, courtesy Livermore Heritage Guild)

After the initial ditching, the basic channel planform apparently remained unchanged until 2000, when a flood control channel was constructed east of Isabel Ave (Zone 7 2006:3-31). Several years later, the Isabel Ave underpass was created.

Early residents of Livermore Valley began excavating gravel from the Arroyo Mocho creek bed for road surfaces (Figure 3.14). An 1894 newspaper editorial, for example, complained, "When will the powers that be give us needed bridges – instead of everlastingly hauling gravel?" (Echo 1894b). Commercial gravel mining was initiated in the early-mid 1900s and continues today within parts of the "Chain of Lakes", which line the channel from approximately ½ mile downstream of the Isabel Avenue crossing to the confluence with Arroyo Las Positas (Figure 3.15). Table 3.2 shows the acreage of gravel quarries in the Valley increasing over time.

As much as the planform of Arroyo Mocho has deviated from its historical position in this reach, there is some surprising evidence of geomorphic processes and subsurface hydrology operating even into the early 21st century. Google Earth Imagery from 1993 -2005 reveals that Arroyo Mocho's distributaries may still have been expressed at that time, varying in configuration from year to year, indicating that subsurface flow spreading from the fan of Arroyo Mocho may have continued to escape confinement and spread across the floodplain, even under the nearby housing development. It is possible that while the surface flow of Arroyo Mocho was moved several hundred feet to the south, the confinement of subsurface flow was less effective. In 2007, roads and a skeleton of development were created, and in subsequent aerial photographs, the distributaries are no longer observed as surface features (Figure 3.16).

The riparian vegetation cover in this reach has undergone dramatic changes over the past century. Historically, the distributaries discharged into grassland dotted with occasional oaks. Aerial photographs from 1940 show a sparsely vegetated channel closely bounded by farmland (Figure 3.16a). Today, the flood control channel east of Isabel Avenue is dominated by non-native grasses and has little habitat value. The alternate channel to the north supports a dense riparian forest of native and non-native species, which we calculated has an average tree density of 358.1 trees/acre. West of Isabel Avenue, the channel is lined by rows of mature eucalyptus, which account for more than 80% of the recorded trees along this portion of the riparian corridor (though we did observe occasional native riparian trees). Figure 3.17 shows the densities of

Table 3.2. Acreage of gravel quaries over time

Year	Acreage
1800	0
1940	Not mapped
1980	590*
2012	903*

* From Zone 7 estimates

Figure. 3.15. Contemporary aerial of the Chain of Lakes (USDA 2009).

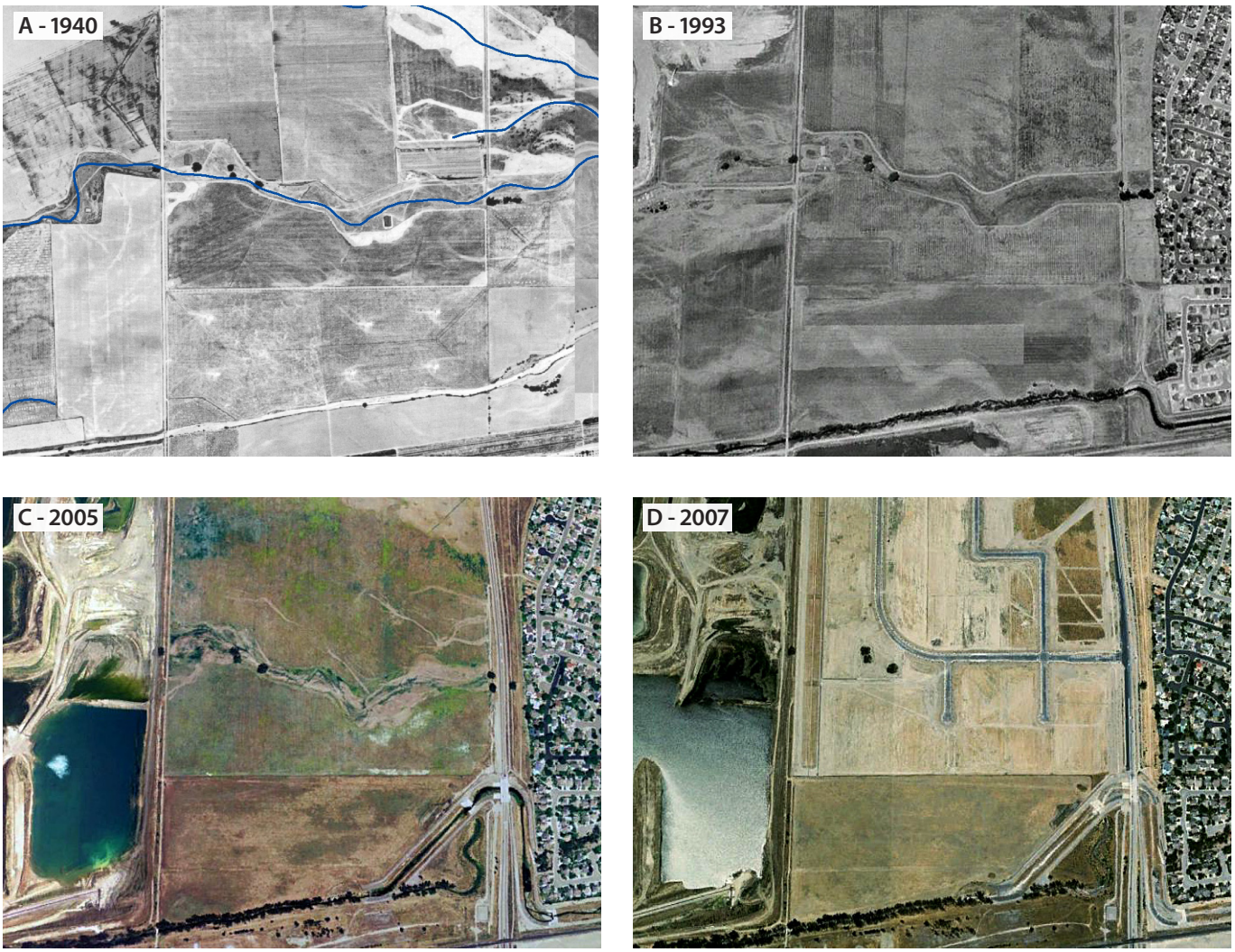


Figure 3.16. Arroyo Mocho distributaries. Aerial photos from1940, 1993, 2005, and 2007 show the persistence of Arroyo Mocho's distributaries decades after ditching and urbanization pressures. Until the new Discovery Drive was build in the late 2000s, evidence of surface flow into the Chain of Lakes matches with the historical location of the distributaries of Arroyo Mocho (USDA 1940, Google Earth 1993, 2005, 2007). Historical streams are overlaid on the 1940s aerial (A).

trees in this case study. The high densities are especially striking in comparison to the particularly low densities of oak that dotted this landscape in the historical period.

FUTURE POTENTIAL

Because the site through which Arroyo Mocho's distributaries historically flowed is still relatively undeveloped, and because Zone 7 is set to acquire several parcels of nearby land when the gravel mining operation halts in 2030, a unique opportunity for floodplain restoration exists that could help to address some of the persistent management problems in this reach. In the short term, Zone 7 might consider reconnecting one or several distributaries through the field just north of the flood control channel, west of Isabel Avenue. Allowing Arroyo Mocho to re-occupy the recently-used flow paths would allow the agricultural field to function as a recharge area during high flows, helping to decrease flood stage and providing important off-channel habitat.

Over the long term, establishing a seasonal connection between Arroyo Mocho and the gravel pits could provide multiple benefits for watershed management and habitat enhancement. The diking of the Pleasanton marsh resulted in the elimination of off-channel habitat in the Livermore-Amador Valley. Loss of this habitat is likely to limit the recovery potential for federally-listed salmonids. Further, the effects of floodplain pit excavation often include channel capture, bedload trapping and channel incision, and altered water tables. Research on the middle Russian River suggests that former gravel pits could to be modified to re-create ecologically productive off-channel habitats, including shallow emergent marsh and floodplain habitats (Cluer et al. 2009). "Reclaiming" some of the Chain of Lakes could potentially offer an opportunity for the re-creation of significant acreages of off-channel habitat, if extensively reshaped and seasonally connected to the main stem of Arroyo Mocho. Researchers note that salmonid predation risks are outweighed by the population-level benefits from growth provided by rearing habitat if sufficient cover and appropriate conditions are created (Cluer et al. 2009). However, hydraulic connections between the main channel and the ponds need to be carefully designed, with special attention paid to physical, biological, and chemical issues such as topography/elevation, water temperature and water quality, and timing of life history migration patterns of fish populations. Hydraulic modeling and sediment transport analysis is needed to estimate the effects of sedimentation expected from a seasonal connection to the Arroyo Mocho mainstem, or the distributaries, and over what time scale the ponds and the channel would evolve.

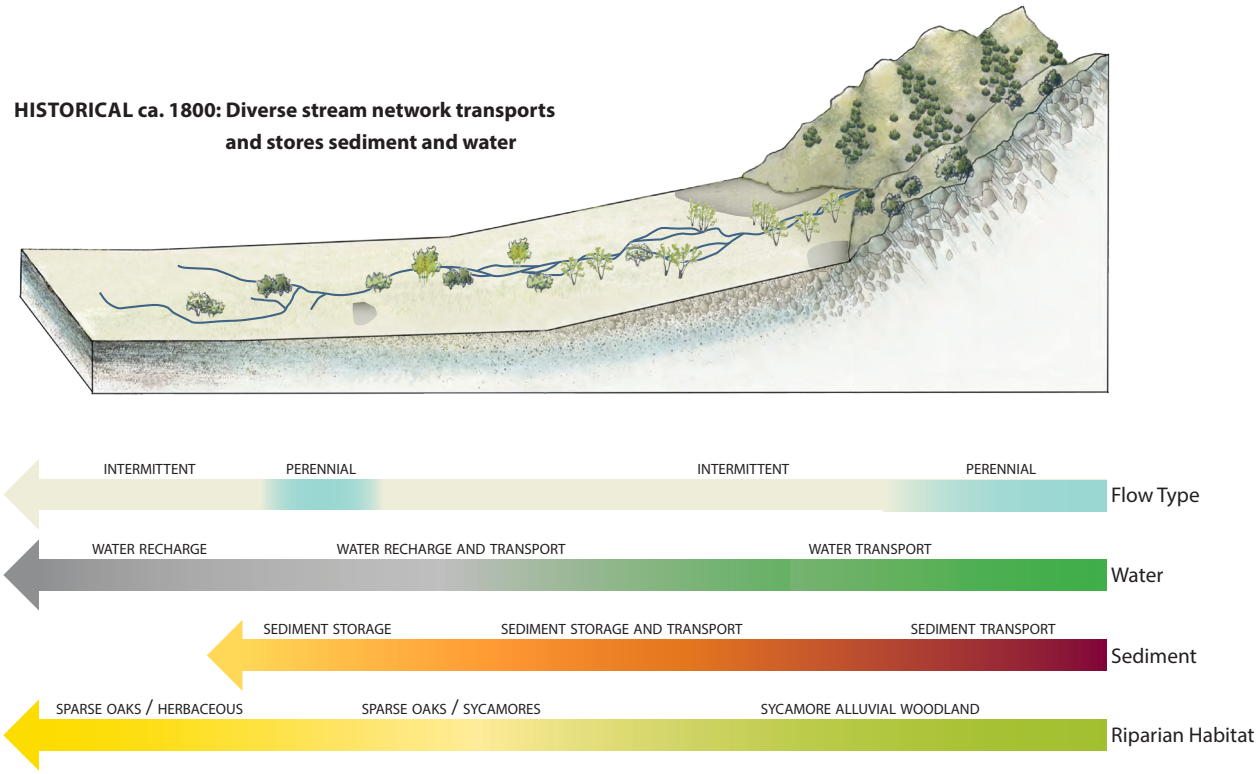
If pursued, the gravel pits would accommodate high flows and act as a potential sediment sink, as has occured on the Passalaqua Pit of the Russian River (Cluer et al. 2009). The pits could be re-engineered to provide a substantial amount of wetland habitat, by constructing gently-sloping banks to maximize the area of shallow water for fish at a range of water levels. Gently sloping banks also favor riparian vegetation establishment because there are larger areas with shallow water table. The Chain of Lakes may have the potential to support many of the functions historically provided by the Pleasanton marsh complex. As shown by the persistence of Arroyo Mocho's distributaries, many historical processes are still acting on this landscape, and these processes can be harnessed through a range of design and management approaches to address flooding, sedimentation, habitat loss, and other challenges (Figure 3.18).

Figure 3.17. Mapped tree density in Case Study 3. We mapped tree density by species type and age class along the Stanley reach of Arroyo Mocho. The side channel (north of the flood control channel) was particularly dense with a mix of native and non-native riparian trees. The downstream reach was still fairly dense by historical standards, but was composed of mostly non-native stands of eucalyptus. See Appendix B for more detail.

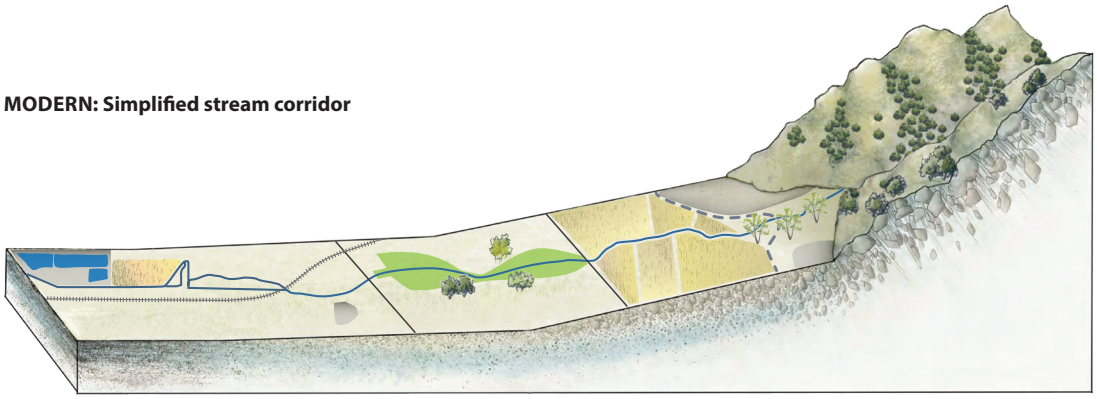
Conceptual Models of Arroyo Mocho Evolution

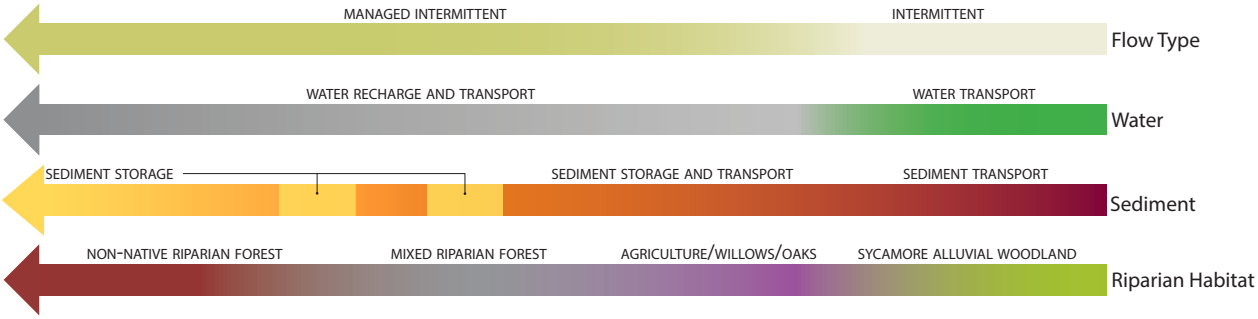
In this section, we present past, present and future conceptual models of Arroyo Mocho. These three oblique views represent conceptually the configuration of the stream: its substrate, slope, form, vegetation, and general surrouding land use. This is shown conceptually over three time periods: the historical period, present day conditions, and projecting into the future based on the case studies presented above (Figure 3.18). Below each graphic, we illustrate general gradients of different important physical and ecological controls on the system. These include seasonality of water flow, water recharge/transport, sediment dynamics, riparian character. While many of the underlying physical parameters have stayed the same, these surface expressions of water, sediment and vegetation have vastly changed, and thus provide a window into the potential for reestablishment of certain historical functions in certain places--or the use of these functions in different places, more appropriate for the modern landscape. For example, in a future scenario for Arroyo Mocho (opposite page), the distributaries are reconnected to the ditched channel and allowed to flow into the gravel ponds (in the long term). The vegetation, surface water, and sediment patterns designed for this reach may be more succesful when managed in concert with the patterns and processes illustrated in these conceptual models. Finally, the results of these case studies are meant to be taken as a group, or as a vision for this reach of Arroyo Mocho. Individually, these actions may incrementally increase habitat function and decrease management problems, but the goal of these conceptual models is to envision the stream as a unit, and plan cumulative restoration projects and management actions that together add up to a healthier, better functioning watershed.

Figure. 3.18. Past, present, and future conceptual models of Arroyo Mocho from the canyon to the Chain of Lakes.

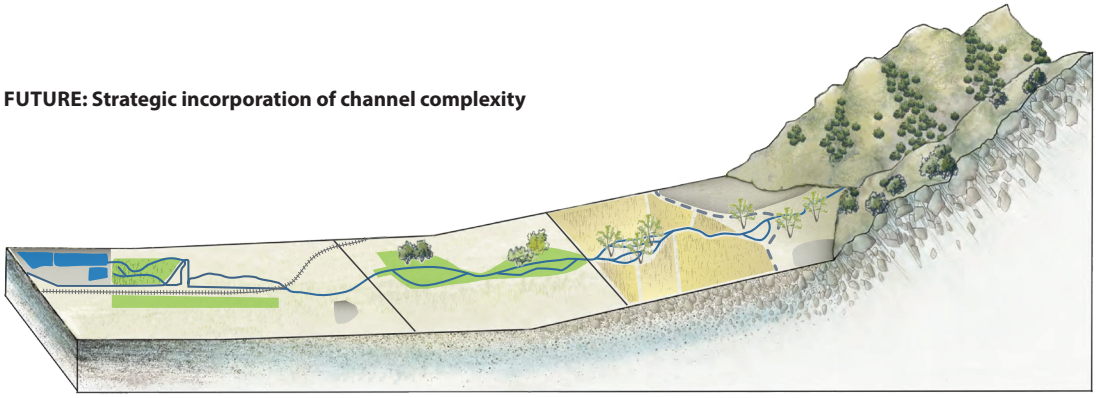


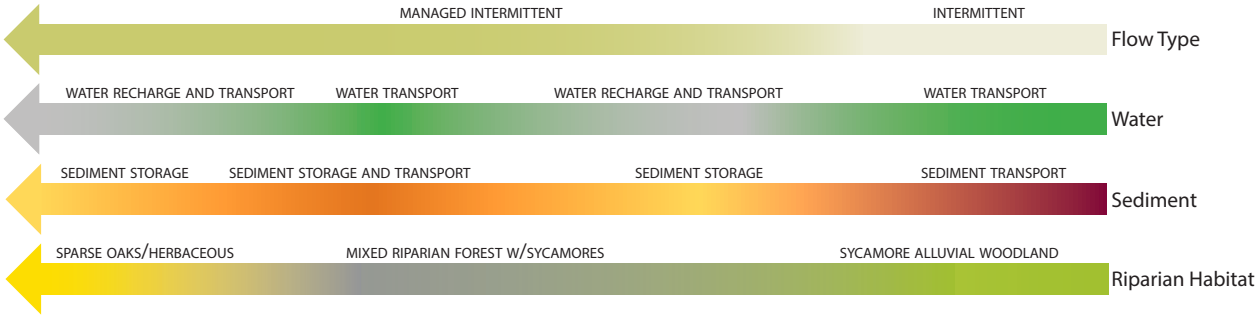
MODERN: Simplified stream corridor





FUTURE: Strategic incorporation of channel complexity





Arroyo Las Positas historical ecology background

Though they shared some attributes, such as intermittent surface flow, Arroyo Mocho and Arroyo Las Positas were historically very different systems that provided distinct ecological functions and supported a wide range of habitats. Many of the processes and drivers that defined these systems historically, especially differences in climate and geology, are still active and continue to influence the systems in different ways. Thus, while the valley floor portions of Arroyo Mocho and Arroyo Las Positas currently face some of the same management challenges, it is important to recognize that the underlying causes of these challenges are different for the two systems. The most effective strategies to address these challenges will most likely involve place-based solutions that factor in the historical and landscape contexts.

Morphology and historical sediment supply

Arroyo Las Positas currently drains 31 square miles (81 km^2) of eastern Livermore Valley, and flows west across the northern end of the down-dropped valley. It is intersected perpendicularly numerous times by a number of small creeks draining the northern hills. Together, Arroyo Las Positas and its tributaries fed the seasonal wetlands in the area by spreading across the Valley in discontinuous, often undefined channels (Higley 1857, Whitney 1873, Allardt 1874, Nusbaumer 1889, Westover and Van Duyne 1910).

Compared with Arroyo Mocho, which carried a high supply of coarse sediment, Arroyo Las Positas most likely transported a relatively low load of fine sediment per unit area. Three main factors were responsible for this difference: 1) Arroyo Las Positas drained a smaller area than Arroyo Mocho, 2) the hills drained by Arroyo Las Positas (the Altamont Hills) tended to have a lower slope, and were thus less prone to erosion than the hills drained by Arroyo Mocho, and 3) the upland areas in each drainage were composed of different types of sediment. Unlike the hills to the south of Livermore-Amador Valley, which are made up of the coarse and erosive Franciscan Complex, the hills to the north are composed of the fine-grained Great Valley Sequence (Graymer et al. 1996). These differences in source geology were reflected in the soils of the valley floor. While coarse gravels dominated the large alluvial fans of the southern drainages, clay and silty soils with some alkali influence were found across the northern half of the Valley (Westover and Van Duyne 1911). Likely due to its low sediment supply, its low transport capacity, and the clay-dominated composition of its bed and banks, Arroyo Las Positas was historically and continues to be a single-threaded, tightly meandering channel.

Flows

The small, discontinuous streams draining the Altamont Hills helped create the alkaline conditions of eastern Livermore. These creeks carried salts from originating in marine sedimentary rocks, which then percolated into the

groundwater and concentrated in the soils through high evaporation rates, creating the Springtown alkali sink (Trusk 1854 in Williams 1912, Westover and van Duyne 1911, Coats et al. 1988). Arroyo Las Positas historically re-formed downstream of the sink near Las Positas springs, and joined Altamont Creek near their present-day confluence. (The Las Positas springs were located just north of Interstate 580, east of Las Colinas Road.) Referred to as "Livermore's Creek" in early testimony, Arroyo Las Positas was named for the springs that fed it and maintained the creek as an important water supply in the otherwise dry eastern plain (Bryant [1848]1985). Early travelers and Gold Rush 49ers stopped at Las Positas and Livermore's rancho, as this was their last source of water before the San Joaquin River as they headed east (Moerenhout [1849]1935).

Immediately below Las Positas springs, the creek followed a confined path between two small knolls. A vegetated corridor, up to 130 feet (40 m) wide, likely consisted of a mix of willows and herbaceous vegetation (USDA 1940). Las Positas here was described in 1850 as "a shallow stream… supplying us with excellent water" (Ryan 1850). The creek appears to have followed several distinct courses over time, and was likely ditched to provide irrigation (see multiple channels in Thompson and West 1878, USGS 1907). Springs through this area along Las Positas were constricted between the hills and a thick clay cap (Williams 1912:49). As the City of Livermore developed, it initially relied on water from artesian springs in this area, although the water here was much more alkaline than that of the Pleasanton marsh complex (Williams 1912:227).

Some dry-season flow may have existed along Arroyo Las Positas near the Las Positas springs. Sherman Day described a "swampy water course" in July 1853 along Altamont Creek near Las Positas (1853). Surveyor Lewis recorded "running water" along a portion of the creek in summertime (1861:511).

Lower Arroyo Las Positas, below the springs and Altamont Creek, maintained a continuous single-threaded channel to the Pleasanton marsh complex. In contrast with the coarse gravels of Arroyo Mocho and Arroyo Del Valle, Las Positas flowed across a bed of comparatively fine sediment, skirting the edge of the wet and alkali meadows of central Livermore-Amador Valley. This contrast was of great importance to early engineers studying the Valley, because it meant that rather than providing groundwater recharge, Arroyo Las Positas functioned as a water transport system (Williams 1912, Fuller 1912). Cyril Williams described this contrast:

> The feeders of this artesian basin are the Arroyo Mocho and Valle Creeks; the other streams from the watershed, viz: the Positas, Tassajara, etc., traverse a territory where adobe and tight clay predominate, within and on the side of the channel, and on the surface of the surrounding country, with the result that the streams flowing over these, is continuous to the Laguna Creek, with no measurable loss into the gravels of the valley. (Williams 1912:31)

Flow data available from the USGS between 1912 and 1930 at Airway Boulevard illustrates the intermittent character of the stream, with an average of 92% of days per year without flow above 1 cfs in the 18 year period of record. Comparing that to data from the 1980s (which was a wetter time period, and gauged at a slightly different location on the stream), we see an average of only 17% of days per year with no flow above 1 cfs (Figure 3.19). We assume the difference in flow duration may not be due to the differing locations along the creek, but due to a combination of more rainfall, the increase in urban development, inputs from the South Bay Aqueduct, and perhaps tectonic shifts which activated springs (Stevens pers. comm.).

Riparian Vegetation

Riparian cover along Arroyo Las Positas (and the smaller tributaries) varied in width and composition as the stream flowed west. In the upper part of the watershed, the riparian vegetation was part of the larger alkali wetland. Alkali sink scrub and alkali meadow species bordered the creek, with iodine bush (*Allenrolfea occidentalis)* concentrated along the stream corridor (Burtt Davy 1898, Coats et al. 1988). As the creek flowed between the two bedrock knolls, groundwater came closer to the surface and artesian

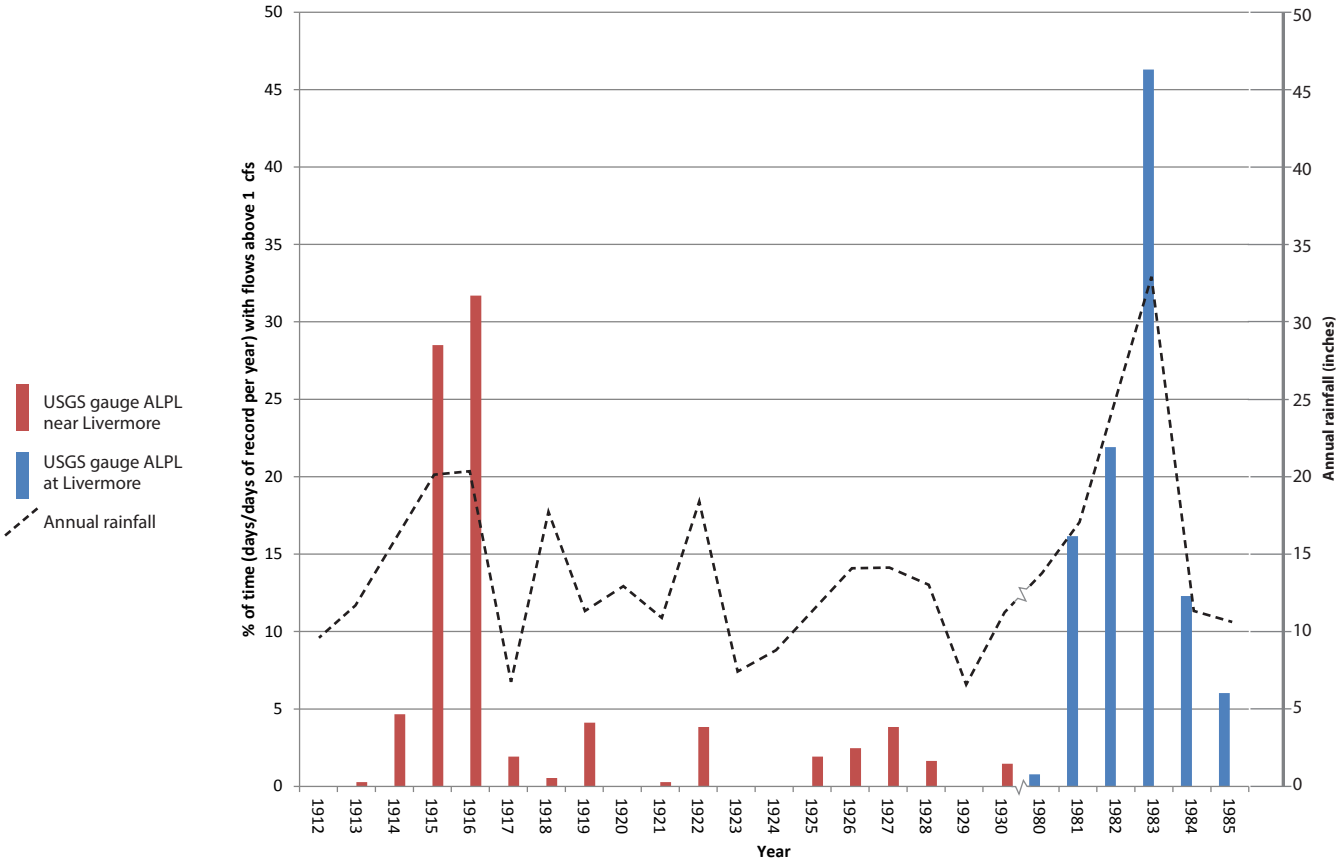


Figure. 3.19. USGS flow data from Arroyo Las Positas from 1912-1930, 1980-1985 displaying percent of time (days/year) with flows above 1 cfs in Arroyo Las Positas overlaid with annual rainfall data. In the first part of the 20th century flows were intermittent, and variable. Due to recent development, Delta inputs and perhaps tectonic shifting, the stream has become largely perennial. More data is necessary to fully confirm this hypothesis.

conditions developed (Williams 1912:49), supporting a vegetated corridor on the order of 100 feet wide (USDA 1940). This contrasts with the much wider, sycamore alluvial woodland-dominated braided channel of Arroyo Mocho at similar elevations.

Further downstream, historical sources suggest a relatively narrow riparian corridor, widening into patches of dense vegetation near springs or reaches with higher groundwater. Between these patches, riparian vegetation likely consisted of occasional oaks and herbaceous vegetation. However, even within this relatively unvegetated reach, there were patches of more dense riparian vegetation. Directly upstream of the confluence with Collier Creek, GLO surveyors noted crossing "a swampy water course" (Day 1853) in July, and oak trees lining the creek. Aerial photos from 1940 show several remnant swaths of willows 150-250 feet wide, indicating that even within this relatively sparsely vegetation reach, there was substantial variation (USDA 1940). These may have been anomalous reaches of rising or shallow groundwater, which enabled dense willows and other riparian vegetation to survive year round. The wetness of the soil may have made these areas unattractive to farmers, explaining why seasonal wetlands were still visible in the 1940s, at the height of agriculture in the Valley (Banke pers. comm.).

A conceptual framework for the historical patterns of topography, sediment, water, and vegetation on Arroyo Las Positas is shown in Figure 3.20. We present two case studies describing distinct reaches of this part of the stream, analyzing their historical function and change over time, and presenting conceptual scenarios for future management.

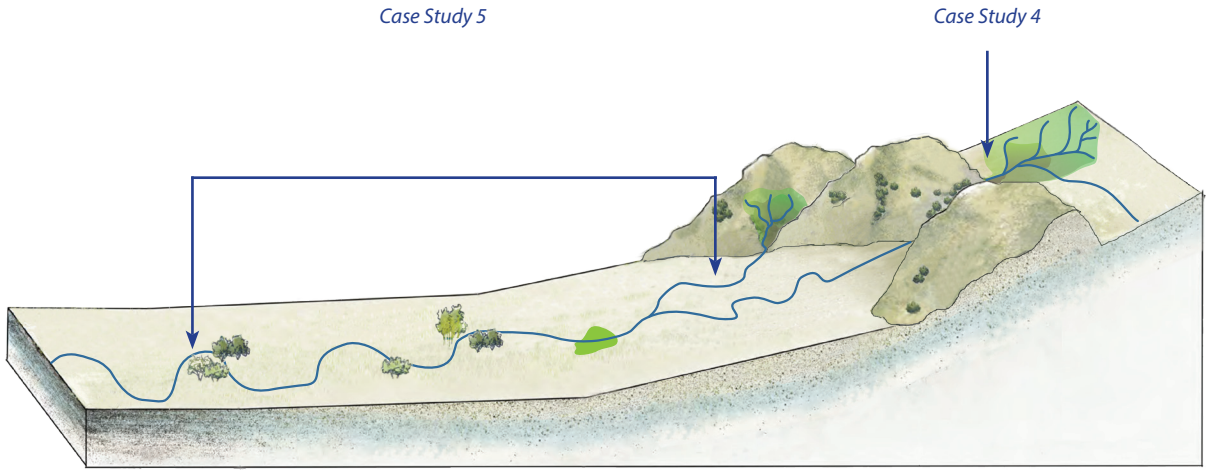
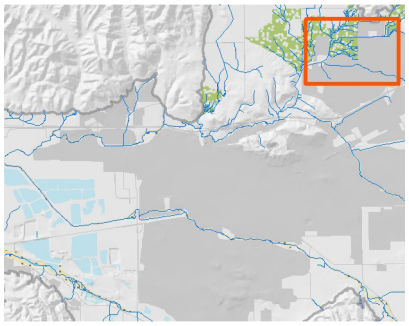


Figure 3.20. Conceptual model of historical Arroyo Las Positas, ca. 1800. This diagram shows a simplified oblique view of Arroyo Las Positas as it winds through the bedrock knolls (exaggerated) below Springtown, and across the northern part of the Valley. The green polygons indicate wetland areas of Springtown sink and an alkali area near Cayetano Creek. Some willow thickets were also present on the valley floor, supported by high groundwater.



CASE STUDY 4: SPRINGTOWN SINK
PRESERVATION OF REMAINING ALKALI WETLAND COMPLEX

PROBLEM STATEMENT

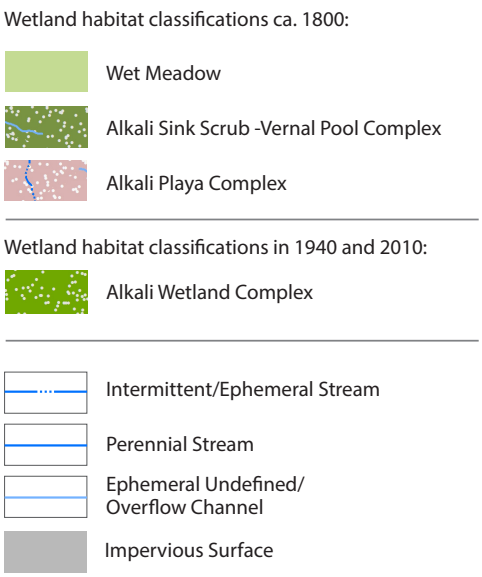
This case study encompasses the core of the historical Springtown alkali sink, extending approximately from present-day Dalton Avenue on the north to Wisteria Way on the south, and from Maralisa Court on the east to Monterey Drive on the west (Figure 3.21). The Springtown area once supported an extensive alkali sink wetland, extending up to 3,500 acres. Cattle grazing, off-road vehicle use, and the construction of residential subdivisions and the Springtown Golf Course in the 1960s and 70s have damaged or eliminated much of the original wetland (Coats et al. 1988:15). Channelization of Altamont Creek and other streams within the basin, combined with increases in urban runoff and other modifications to the flow regime, has resulted in channel incision and localized sedimentation problems (Zone 7 2006:3-19, Coats et al. 1993). These modifications are likely contributing to sedimentation and erosion problems downstream as well. Furthermore, the alkali-influenced complex habitat mosaic that made up the Springtown sink supported several types of rare and endangered plant and animal species that were historically common in parts of California but are becoming increasingly rare (Coats et al. 1993, Holland 2009, ICF International 2010).

UNDERLYING PHYSICAL AND ECOLOGICAL PROCESSES

Along with the Pleasanton marsh complex, the Springtown alkali sink was historically one of the main sites of surface water storage in the Livermore-Amador Valley. Composed of 3,500 acres of alkali wetlands east of Livermore, the sink formed in a small basin divided from the rest of the Valley by small bedrock protrusions and a fault (Springtown anticline and fault; Ferriz 2001, Sawyer and Unruh 2004, Unruh and Sundermann 2006). These barriers caused water to collect behind the hills and spread out, forming wetlands. Compact clay soils across much of the area also helped maintain the wetland by inhibiting drainage (Westover and Van Duyne 1911). A network of shallow, ephemeral streams flowed through the Springtown alkali sink.

The high alkalinity of the wetlands was derived from the marine sedimentary rocks in the surrounding watershed, which have a high salt content (Westover and Van Duyne 1911, Carpenter et al. 1984, Edwards and Thayer 2008, Mikesell et al. 2010). As these rocks eroded, water carried the salts downstream to the wetland, where they accumulated over time. This process resulted in extremely high concentrations of alkali salts (Coats et al. 1988, US DOE 2004). Alkali levels in this region were greater than 0.2% (in the first six feet), and ranged up to over 1% in some places (Westover and Van Duyne 1911). These salts percolated into the groundwater – one account described a well that was bored to 640 feet, only to produce water that "shot up through the well and rose to 40 feet above ground level…the water was strongly alkaline, and killed all vegetation in the vicinity" (Williams 1912:48).

While some accounts (such as the one above) note that the alkaline water "killed all vegetation," the alkali wetlands in fact supported several distinct habitat types and a unique assemblage of salt-adapted plant species. The center of the basin consisted of a mosaic of alkali playas – unvegetated areas with extremely high salt concentrations which formed seasonal ponds in the rainy season. Bordering this was an extensive complex of alkali meadow, alkali sink scrub, and vernal pools. Alkali meadow formed in seasonally flooded areas with poorly drained soils, and was dominated by species such as saltgrass



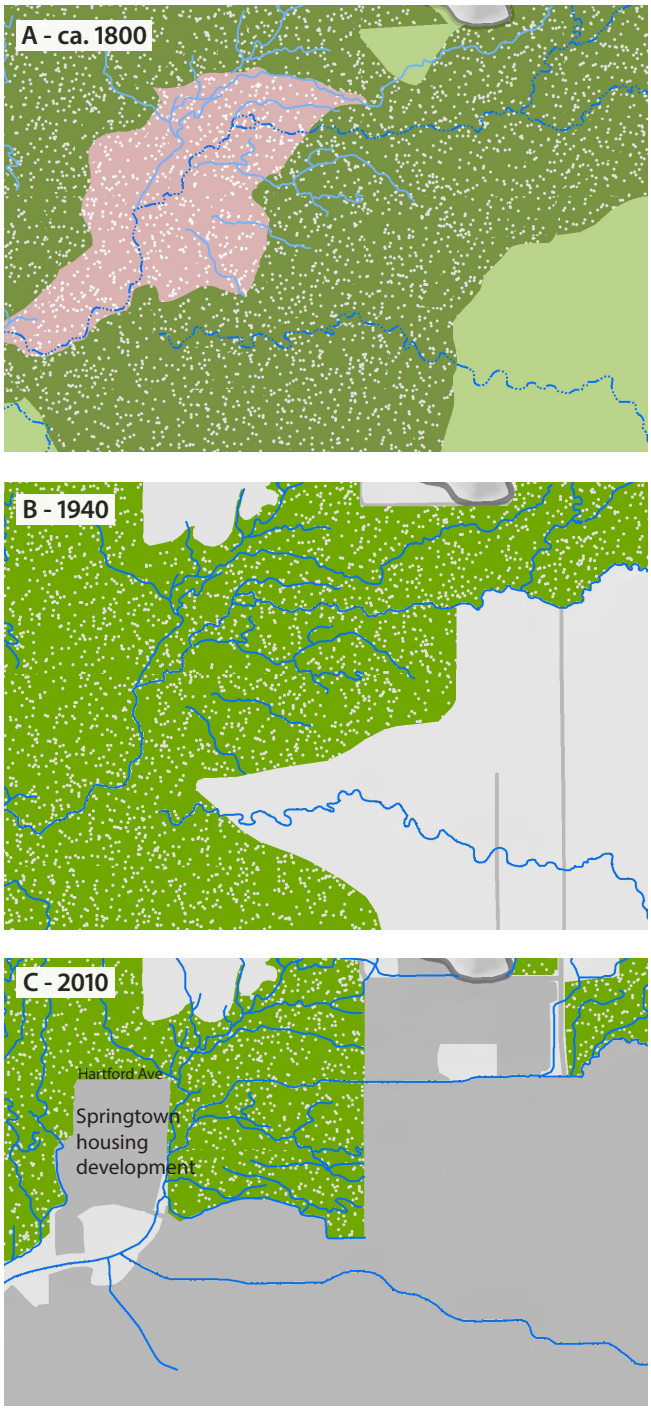


Figure 3.21. Changes in wetland habitat extent, stream configuration, and extent of impervious surfaces between 1800, 1940, and 2010 at the Springtown Sink. A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1942). C. Conditions in 2010 (USDA 2009, ICF International 2010, SFEI 2011).

(*Distichlis spicata*), alkali heath (*Frankenia salina*), and tidy tips (*Layia* spp.). Alkali sink scrub often occurred next to streams and alkali playas, and was dominated by shrub species such as iodine bush (*Allenrolfea occidentalis*) and seep weed (*Suaeda* spp.). Vernal pools were interspersed throughout the area, and supported specialized plants such as popcornflower (*Plagiobothrys* spp.) and downingia (*Downingia* spp.) (Goals Project 1999). Finally, at the eastern edge of the basin, Frick Lake (which shows up on maps as early as 1857) was a seasonal alkali lake or playa, drying in summer. The lake had no outlet historically, so alkali salts draining from the adjacent hills would have concentrated here over time. This lake exists in relatively unchanged form today (Kohlman et al. 2008). The range of habitat types – alkali lake/playas, sink scrub, vernal pools and alkali meadows – was organized along a gradient but also frequently intermixed, resulting in a diverse mosaic of species. Many small mounds, depressions, and swales formed the land surface, creating micro-scale variation in alkali concentrations and inundation frequency.

Case Study 4: Springtown, continued

HISTORY OF CHANGES OVER TIME

The vernal pools in the Springtown alkali sink represent the most intact remnants of a large alkali wetland complex extending from Byron Hot Springs to the Mount Hamilton Range (Keeler-Wolf et al. 1998). Holland (2009) reported a 27% decline in vernal pool area in the Springtown complex between 1986 and 2005. However, the full historical extent was much greater.

The Springtown alkali sink remained largely undeveloped from the historical period to 1968. Early USDA aerial photography shows scalds and mounding characteristic of a vernal pool alkali wetland complex (Figure 3.22). While agricultural land uses dominated the surrounding landscape, the alkali soils at Springtown may have discouraged efforts at farming. The area was grazed however, leading to soil compaction (Coats et al. 1993). Construction of subdivisions commenced in 1968, and in the past 45 years residential development has significantly reduced and fragmented wetland habitats at Springtown (Coats et al. 1988; Table 3.3). This development has apparently been designed with little consideration given to the ecological impacts to the wetland: rather than expanding incrementally along the edges of the wetland, early subdivisions were constructed at multiple locations within the interior of the wetland, resulting in a higher degree of habitat fragmentation (see Figure 3.21 a-c).

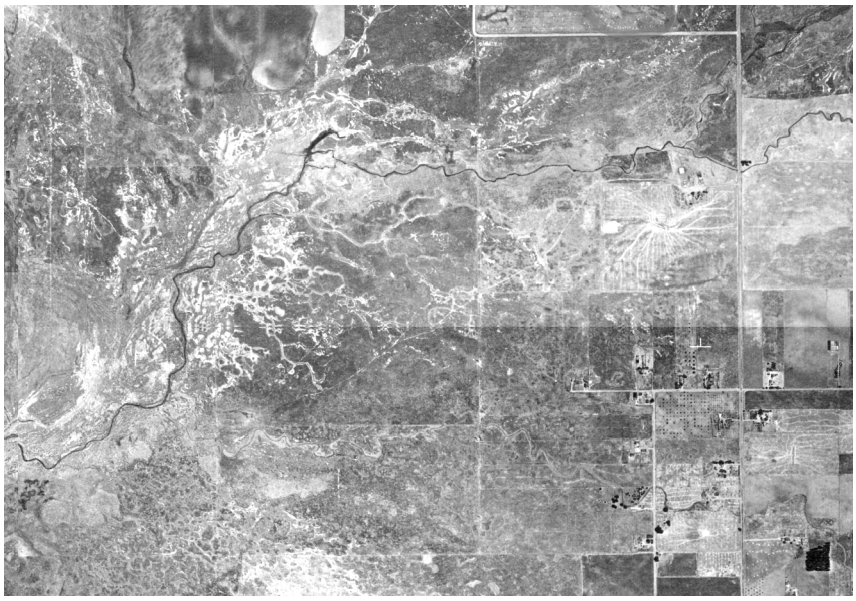


Figure. 3.22. Characteristic scalding patterns and mounds of vernal pool alkali wetland complex. The complex pattern of scalds (low, unvegetated areas of salt accumulation) and mounds (shown as small lighter areas) is characteristic of alkaline soils and vernal pool complexes (Coats et al. 1993).

Table 3.3. Undeveloped wetland acreage within Springtown sink over time.

	Springtown Alkali Wetland Acreage within Area of Interest	Percent remaining (%)
1800s	2,252.9	100
1940s	1,513.9	67
2009	875.75	39

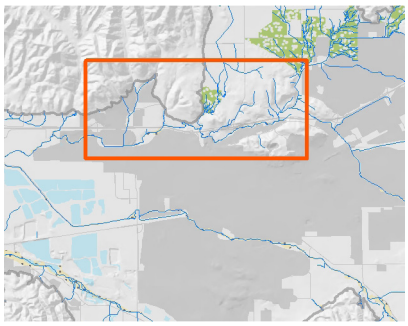
Urban development has been accompanied by a range of hydrologic modifications. In the 1970s, portions of Altamont Creek were channelized and numerous other drainages were diverted and extended to make way for subdivisions and to quickly convey water through the basin. Channelization and increased channel connectivity has resulted in increased erosion and decreased flooding within the basin. Channel density has increased through the remaining wetland complex from 4.49 miles/mile^2 in 1800 to 11.52 miles/mile^2 in 2009, reflecting the trend towards increased channelization. However, seasonal flooding still occurs within the Springtown wetland, as the physical drivers that formed the wetland (hills, faults, groundwater) are still relatively intact, but the frequency and extent of flooding is likely substantially less than what occurred historically (Coats et al. 1993:116,123).

FUTURE POTENTIAL

The Springtown alkali sink still supports significant remnants of several alkali-influenced habitat types, including alkali playas and scalds, alkali meadow, alkali sink-scrub, and vernal pool complex. Numerous rare and threatened plant and animal species occur within these remnant habitats, such as vernal pool fairy shrimp (*Branchinexta lynchi)*, California tiger salamander *(Ambystoma californiense),* Livermore tarplant *(Deinandra bacigalupii),* and the state and federally endangered palmate-bracted bird's beak *(Cordylanthus palmatus)* (Friends of Springtown Preserve n.d.). The ecological importance of the wetland has been recognized for some time, and approximately 51 acres are now protected within the Springtown Preserve operated by the California Department of Fish and Wildlife. Much of the wetland is still unprotected, however, and is threatened by development or degradation. Development would not only result in further habitat loss, but the additional hydrologic modifications that would likely accompany further development could also exacerbate watershed management problems. In the short term, we recommend that steps be taken to preserve and restore the remaining unprotected areas of alkali sink habitat in the Springtown area, as well as the hillslopes of the contributing watershed.

In the long term, Low Impact Development (LID) strategies in the Springtown area, and throughout the Valley, may be important to protect the remaining areas of the alkali sink and to address watershed management problems. LID refers to a suite of approaches and technologies designed to manage stormwater and reduce the environmental "footprint" of developed spaces. Examples of LID approaches include biofiltration devices or structures such as rain gardens, bioswales, and filter strips, as well as urban planning strategies that take into account natural hydrologic processes and endeavor to "design with nature" (Dietz 2007; Elliott and Trowsdale 2007). LID strategies could help to reduce channel incision and sedimentation in the Springtown area, transport of pollutants, and channel erosion in downstream reaches of Arroyo Las Positas. These strategies must be modeled to assess their effectiveness in poor drainage areas.

The Springtown sink has in some ways been irrevocably modified, but it also retains significant function. As evidenced by the persistence of alkali-influenced habitat types, the mounds and scalds, and the seasonal flooding patterns, the underlying hydrogeomorphology remains sufficiently intact to support the wetland. Preservation and enhancement of this complex is a significant opportunity for the long term ecological and hydrological functions of the Valley.



CASE STUDY 5: ARROYO LAS POSITAS *OFF-CHANNEL HABITAT OPPORTUNITIES*

PROBLEM STATEMENT

The final case study encompasses a large area of Arroyo Las Positas downstream from Springtown, below the bedrock knolls. The boundaries extend approximately from Springtown on the east to the Las Positas Golf Course on the west (Figure 3.23).

Channel incision is currently occurring along Arroyo Las Positas from the edge of Springtown to the I-580 crossing approximately 0.5 miles east of Livermore Municipal Airport (Zone 7 2006:3-18). The incision is likely caused in large part by expansion of impermeable surfaces upstream (discussed in Case Study 4), artificial increases in streamflows from the State Water Project (SWP) water, and golf course irrigation causing an imbalance of water and sediment. The degree of channel incision is especially great between North Livermore Avenue and Portola Avenue, where the channel is as much as several meters below the valley bottom.

Further downstream, sedimentation is occurring along Arroyo Las Positas at the I-580 and Airway Boulevard bridges (Zone 7 2006:3-21 to 3-22). One consequence of this sedimentation is increased flooding risk due to decreased channel capacity.

Finally, a privately-owned remnant patch of vernal pool habitat exists along Cayetano Creek, approximately 1/3 mile upstream of the confluence with Arroyo Las Positas (Figure 3.24). Despite its high conservation value, this area is unprotected and at risk from development.

UNDERLYING PHYSICAL AND ECOLOGICAL PROCESSES

Unlike the valley reaches of Arroyo Mocho, which provided significant groundwater recharge, most of the water flowing through Arroyo Las Positas historically was conveyed as surface flow further downstream. The relative importance of groundwater recharge and surface transport in these different systems was largely determined by soil type: the coarse, gravelly soils along Arroyo Mocho and other streams in the southern portion of the Valley enabled surface water to percolate rapidly into the groundwater, while the fine-grained soils along Arroyo Las Positas inhibited groundwater recharge and promoted surface flow. The sediment dynamics of Arroyo Las Positas also differed markedly from those of Arroyo Mocho. While Arroyo Mocho deposited much of its comparatively coarse sediment load at the upper end of its alluvial fan, Arroyo Las Positas transported its finer sediment load further downstream. Water and sediment flowing through Arroyo Las Positas eventually entered the Pleasanton marsh complex in the western portion of the Valley (see Figure 2.3). Arroyo Las Positas was characterized by a single-threaded channel across the Valley. The low stream power and fine sediment load of Arroyo Las Positas (relative to Arroyo Mocho) precluded the formation of a large alluvial fan or extensive braided reaches as on Mocho. Flows were intermittent, with the exception of a short reach downstream of Las Positas springs (near present-day Las Colinas Road) (Stanford et al. 2013).

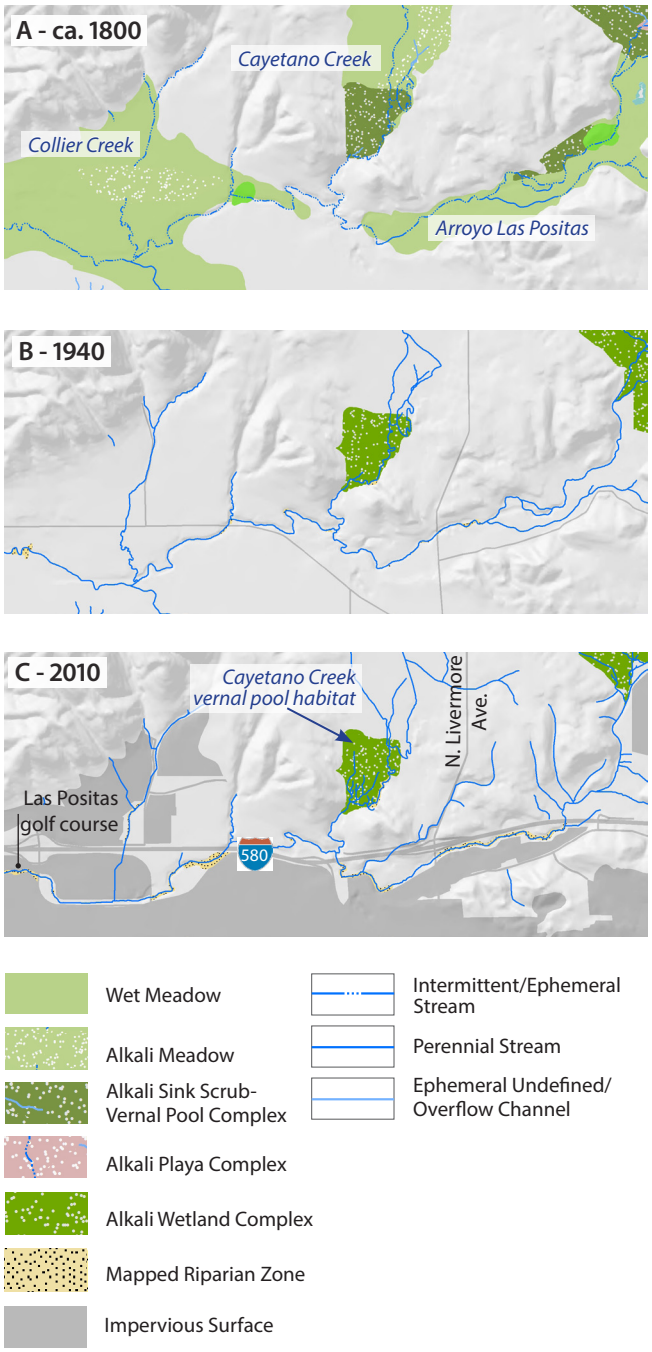


Figure 3.23. Change over time in riparian habitat extent, stream configuration, and extent of impervious surfaces between 1800, 1940, and 2010 on Arroyo Las Positas A. Historical conditions representing ca. 1800 (Stanford et al. 2013). B. Conditions in 1940 (USDA 1940, USGS 1940). C. Conditions in 2010 (USDA 2009, ICF International 2010, SFEI 2011).

For the most part, riparian cover along this reach of Arroyo Las Positas was herbaceous, with occasional oaks. Patches of denser cover, often dominated by willows, occurred less frequently, likely in areas of shallow groundwater (Stanford et al. 2013). Further downstream near Isabel Avenue, the riparian cover was likely dominated by grassland, occasional oaks, and seasonal wet meadow, which was inundated during the wet season but dry during the summer. Since the boundary of the Pleasanton marsh complex varied greatly on a seasonal and interannual basis, at times seasonal wet meadow may have extended as far east as this reach.

HISTORY OF CHANGES OVER TIME

A variety of factors have increased streamflow in Las Positas in recent decades, including the addition of SWP water, ditched connections between northern tributaries and Arroyo Las Positas, urban runoff, and irrigation at Springtown Golf Course. Tectonic movement along a fault in the eastern basin may also have contributed to increased streamflow (Stevens pers. comm.). Consequently, flow is now perennial in Arroyo Las Positas downstream of the Springtown area.

Extensive urbanization has occurred in this area, and along much of this reach Arroyo Las Positas is now bordered by roads, highways (I-580), shopping centers, or other urban development. Much of this development has occurred quite recently. For example, in 1993, much of the area between I-580 and Las Positas Road was still undeveloped (Figure 3.25). The increase in impervious surfaces and surface runoff associated with this widespread urban development has likely contributed to increased streamflow in Las Positas.

Changes in channel planform have also likely impacted stream functioning and contributed to sedimentation

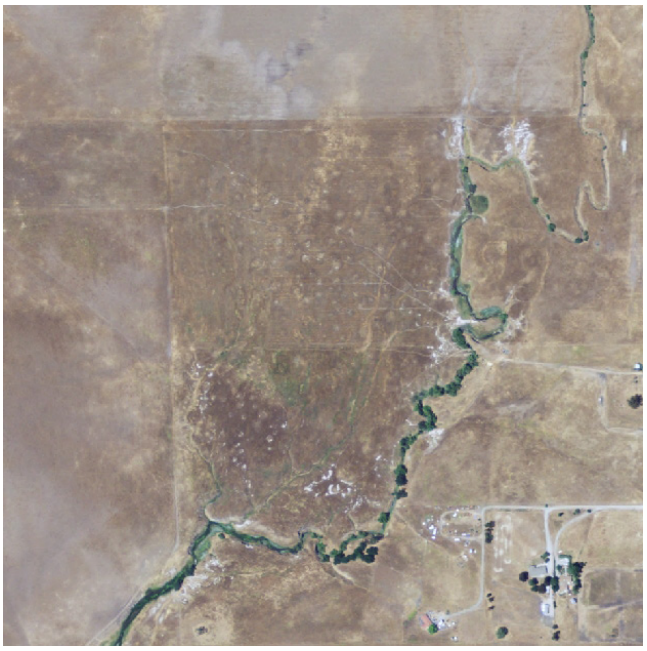


Figure 3.24. Remnant vernal pool complex near Cayetano Creek. The vernal pools can be identified by a mottled pattern of pools, swales, and mounds visible in the aerial photograph, and their presence was confirmed by local experts (Bartosh pers. comm).

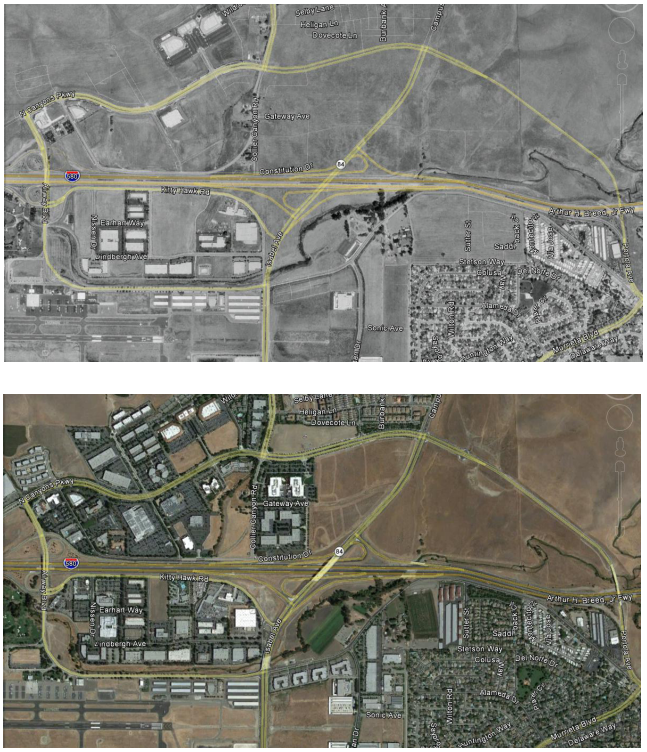


Figure 3.25. Comparison of Isabel Avenue area development between 1993 (top) and 2010 (bottom) showing rapid urbanization throughout the 1990s and 2000s in the northern hills above Arroyo Las Positas. (Google Earth 1993, 2010)

and channel incision. A comparison of USGS topographic quads shows that much of this reach of Arroyo Las Positas was straightened and channelized between 1961 and 1980. Channel straightening tends to increase bed slope by decreasing channel length, and thus leads to increases in flow velocities, which increases shear stress on the bed and banks and can lead to channel incision and widening in weakened areas (Booth 1990). In addition, tributaries such as Collier Creek, which were once discontinuous, have been straightened and extended to connect with the main stem (see Figure 3.23). These connections increase flows in the main stem and may have contributed to downstream incision and erosional patterns.

FUTURE POTENTIAL

Floodplain creation at strategic locations along Arroyo Las Positas could help to alleviate local channel incision and sedimentation occurring at the I-580 and Airway Boulevard crossings. Although sediment storage was not the primary function provided by this stream system historically, channelization, increased streamflow, and road construction have created a need for greater sediment storage capacity along this reach. Potential sites that might be considered for floodplain restoration include the undeveloped parcel just southeast of the Airway Boulevard crossing, the undeveloped parcel just east of the I-580 crossing, and the parcel between the I-580 and Isabel Avenue crossings (Figure 3.26).

Surprisingly, amidst the quick expansion of urban development in this portion of the Valley and the surrounding hills, an area of high quality vernal pool habitat has been left undeveloped and unplanted along Cayetano Creek (see Figure 3.24). Vernal pool habitats are increasingly rare

Figure 3.26. Potential locations for new surface water storage, and inset floodplain habitat (in purple). These sites on the valley floor need to be evaluated for land ownership, slope, and contaminants, but are some of the rare creekside open space still remaining that could be conserved for sediment retention or wetlands to mimic historical wet meadow/willow grove floodplain functions. These sites would need to be excavated down to allow for reconnection to the channel, and thus re-use of the removed dirt will need to be evaluated. These sites are also not the only potential places for inset floodplains on Arroyo Las Positas, and other sites should be evaluated as well. (USDA 2009)

in California: Holland (2009:1) states that within the Great Valley (defined as an 18,000,000 acre area encompassing 30 counties within California, including Alameda), approximately 87% of the pre-agricultural vernal pool complex habitat had been lost by 1997. Within Alameda County, the extent of vernal pool complex decreased by 27.1% between 1986 and 2005 alone (Holland 2009:8). The patch of vernal pool complex along Cayetano Creek is identified as a "key parcel for the protection of biological resources" in the North Livermore Plan Area in the North Livermore Priority Landscape Area Resources Conservation Plan Public Review Draft (Nomad Ecology 2008:135).

Conceptual Models of Arroyo Las Positas Evolution

The case studies isolated for this reach of Arroyo Las Positas are presented as separated sites, but are meant to be taken as a group, and analyzed cumulatively to assess multiple benefits for watershed management. Individually, these actions may have limited local benefit, but taken together they may increase ecological function and improve flood management over the course of the stream and watershed. We use an understanding of historical and current conditions to create a conceptual model of change over time, envisioning a future scenario that builds on historical functions and modern constraints (Figure 3.27). These three oblique views of Arroyo Las Positas are shown conceptually over three time periods: the historical period, the current day conditions, and projecting into the future based on the analyses done in the case studies presented above. Below each graphic, we present gradients of different important physical and ecological controls on the system: seasonality of water flow, type of water transport (recharge or transport, or both), sediment dynamics, and the state of riparian habitat. While many of the underlying physical parameters have stayed the same, these surface expressions of water, sediment and vegetation have vastly changed, and thus provide a window into reconstruction of historical functions back onto the landscape. On Arroyo Las Positas, many of our recommendations are simply to encourage protection of rare wetland areas. The recommended placements of inset floodplains are conceptual: actual floodplain restoration will require a better understanding of land ownership and site drainage, and will require hydraulic modeling to assess the flood storage benefits gained by several small floodplains. Finally, the results of these case studies are meant to be taken as a group, or as a vision for this reach of Arroyo Las Positas. Individually, these actions may increase habitat function, and decrease management problems, but the goal of these conceptual models is to envision the stream as a unit, and to plan cumulative restoration projects and management actions that together add up to a healthier watershed.

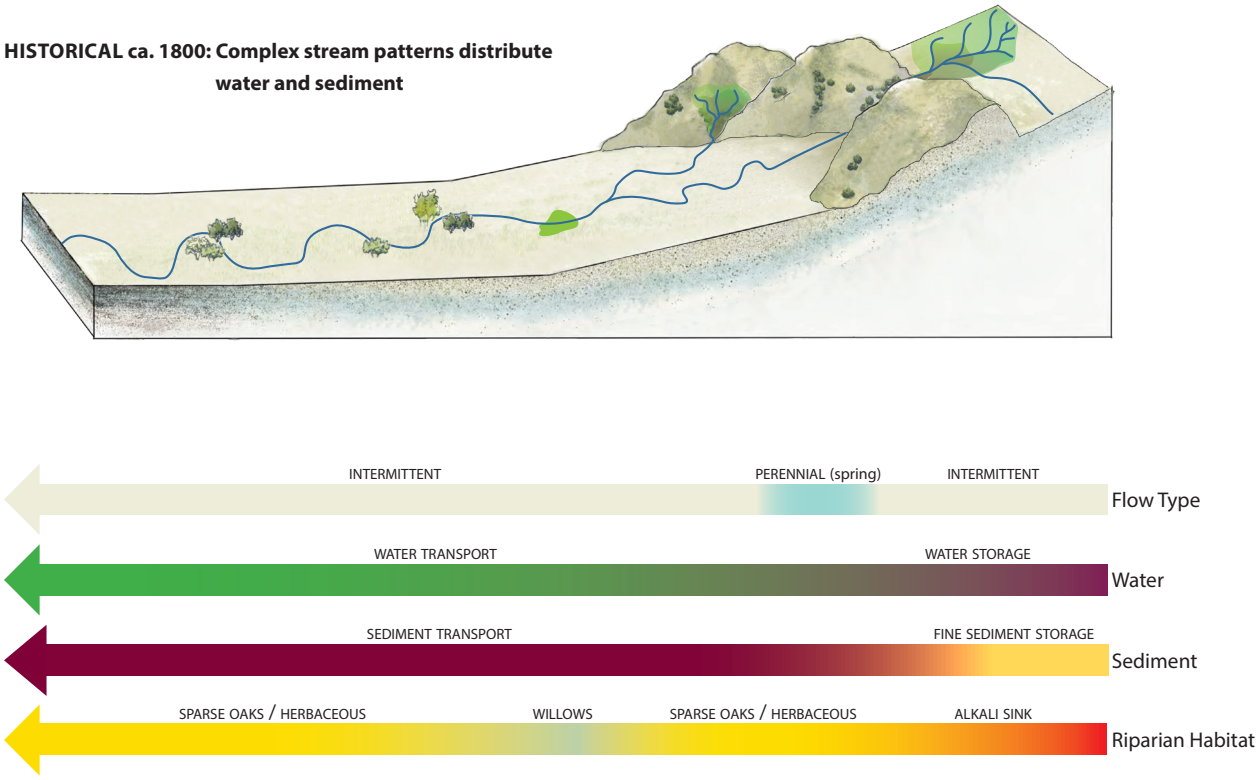
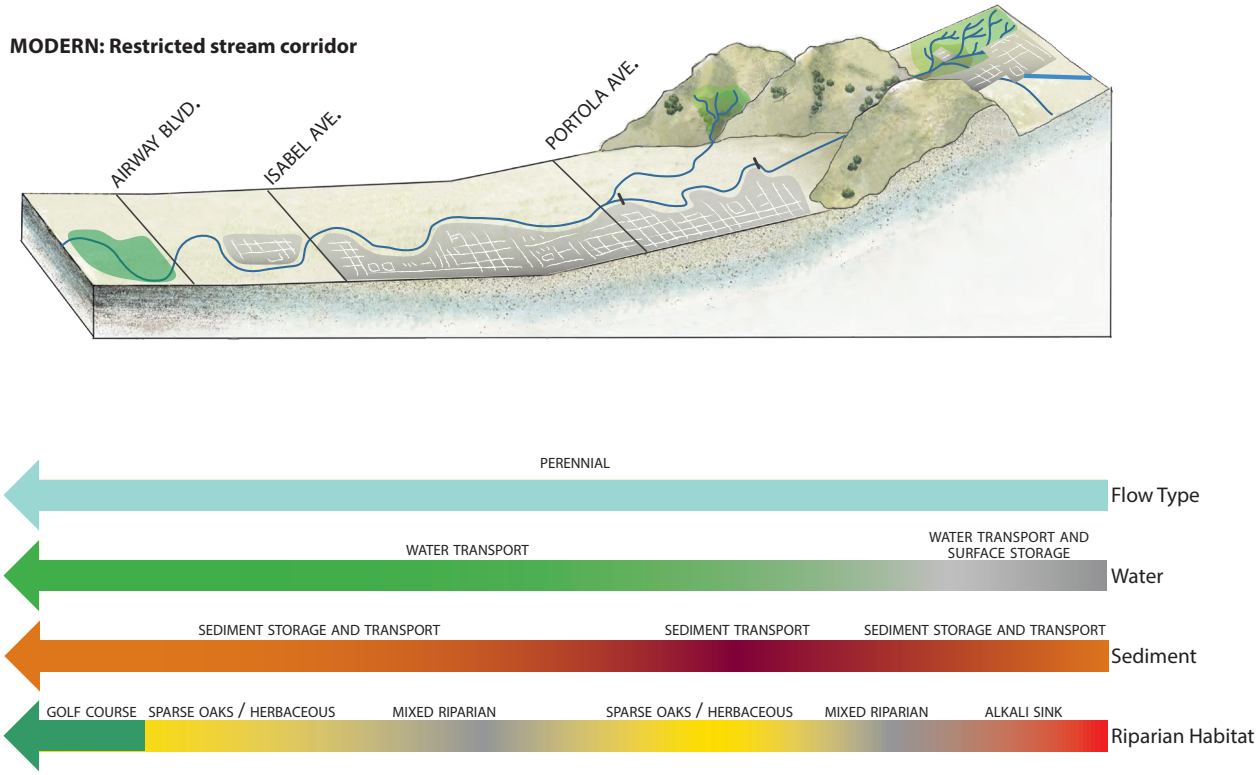
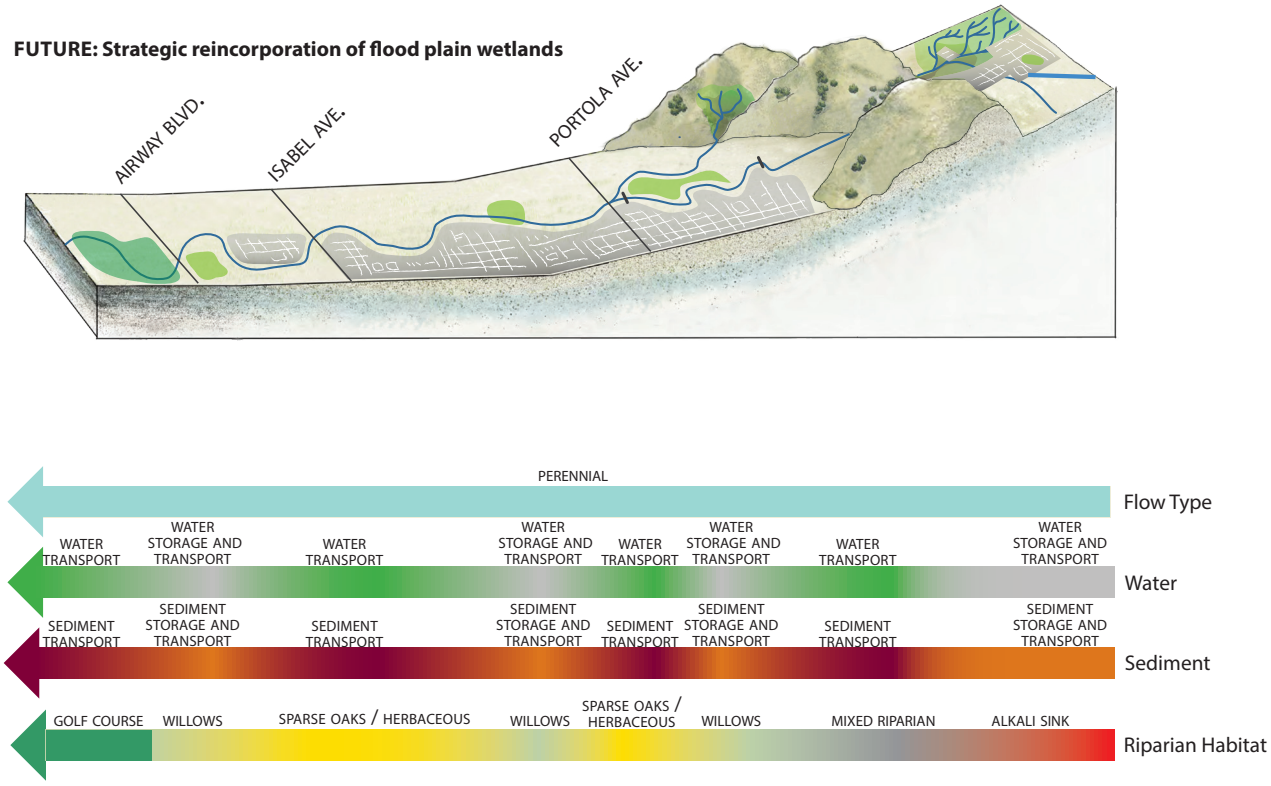


Figure 3. 27. Past, present and future conceptual models of Arroyo Las Positas from Springtown to Las Positas Golf Course.

MODERN: Restricted stream corridor



FUTURE: Strategic reincorporation of flood plain wetlands



4. CONCLUSIONS

Summary of recommendations and next steps

This analysis provides a first step in developing a landscape-scale strategy for addressing multiple challenges and goals in the Zone 7 service area. We first outline a process-based framework for identifying the underlying physical and ecological processes shaping different parts of the system. We then evaluate landscape scale changes and existing potential for modifications to address contemporary challenges. These represent an initial exploration of concepts. Next steps would involve further refinement of a larger vision in concert with Zone 7 staff and additional technical analysis.

This type of assessment, though essential, is often missing from the planning process. Short term projects often move forward without sufficient consideration of how and where they fit into the watershed, or what the cumulative impacts may be of many projects over time. Table 4.1 summarizes the main restoration actions guided by watershed processes, and proposed by this report, listing them as either short term, long term, or both. Next steps may include putting combinations of these proposals together to assess cumulative short and long term benefits that could be gained.

Table 4.1. Short term and long term interventions as opportunities for increased ecosystem function at a watershed scale

Stream	Reach	Intervention	Timescale	Functions
Arroyo Mocho	Southeast	Restore braiding when agricultural land is sold	Long term	Increased sediment deposition and in channel storage, sycamore alluvial woodland
	Holmes Street Bridge to Madeiros Parkway	Restore braiding in parkland	Short term	Increased sediment deposition and in channel storage in parks, decreased sedimentation at Holmes Street Bridge and Stanley Boulevard Bridge, increased diversity in riparian habitat
	Distributaries	Addition of channels to act as distributaries into gravel pits, reconnection of floodplain habitat to channel	Short term and long term	Sediment transport into gravel pits at high flows, reconnection of floodplains, re-introduction of native species
Arroyo Las Positas	Springtown	Preserve remaining vernal pool habitat, discourage development	Short and long term	Important habitat for rare and endangered species, flood attenuation (sink), natural LID
	Cayetano vernal pools	Preserve remaining vernal pool habitat, discourage development	Short and long term	Important habitat for rare and endangered species, flood attenuation (sink), natural LID
	I-580 corridor	Lower floodplain areas to create off channel habitat	Long term	Mimicking wet meadows, LID functions, decreasing impacts of incision (lowering adjacent floodplains), flood attenuation

Long term planning considerations

For practical reasons, streams are often managed in discrete reaches or according to property lines, responding case by case to bank failures or other incidents. However, it behooves managers, planners, and scientists alike to scale up and evaluate the cumulative effects and impacts of restoration efforts and stream management interventions, developing longer term visions to manage at a watershed scale. Historical ecology helps to arrive at that vision, revealing the underlying geologic, geomorphic and hydrologic gradients and processes that are not easily altered, as well as those processes that have changed irrevocably (such as surface and groundwater hydrology, land cover, etc.). A successful vision for a watershed approach to restoration and beneficial management relies on a deep understanding of natural landscape patterns and processes and the degree to which they have changed or remain intact or recoverable.

The site scale actions proposed in this report can be undertaken separately, but if implemented together they have the potential to have a much greater cumulative impact. For example, high sedimentation rates along Arroyo Mocho (which has the highest sediment supply of any stream in the Valley) have necessitated regular sediment removal, which is a costly, ongoing management solution. Interventions on Arroyo Mocho, such as restoring floodplains and braided channel morphology throughout the upper part of the study area (Case Studies 1 and 2), would allow for more naturally-organized in-channel storage along a substantial reach, and would likely lessen sediment delivery to downstream Zone 7 facilities. Further study is needed, including modeling of cumulative impacts of flood retention and sediment transport when combining these components. Determining targets for peak flow reduction and sediment deposition and the costs associated for each scenarios may be effective next steps.

Individual floodplains added to the Arroyo Las Positas stream network may not make a large difference for flood control, but the cumulative effects may include slowing stormwater flows, increasing off-channel sediment storage, and discouraging more development in the Valley. Similarly, maintaining individual wetland habitat patches may not increase populations of particular rare and endangered species, but protecting a network of wetland habitats across the landscape may enhance ecological connectivity and function. Furthermore, wetlands provide surface storage for storm flows - nature's LID.

Although urbanization has irrevocably transformed the Valley and modified hydrologic processes, practical strategies exist to minimize the detrimental impacts of urban development on stream networks and riparian habitats. Greater implementation of LID practices in strategic places to mimic historical stream and watershed function and distribution may help to ameliorate a number of stream management problems in the Valley.

Urbanization has also affected the quality and habitat value of riparian vegetation throughout the Valley. Just along Arroyo Mocho, riparian vegetation ranges from a relatively intact riparian corridor with oak and sycamore near Robertson Park and Madeiros Parkway to highly disturbed non-native grassland and eucalyptus stands west of Stanley Blvd. While we encourage efforts to restore riparian habitats within the Valley, it is important to recognize that the structure and composition of these habitats is controlled by a variety of physical factors that operate at multiple scales. In order to be successful, restoration efforts must take these constraints into account. To the degree possible, efforts should address management problems by working to restore the underlying physical drivers as a way to recruit desired native riparian habitat.

Parrott and Meyer (2012) urge managers to "take advantage of [a] systems's internal memory" - in other words, to restore or mimic the processes and disturbance regimes under which a landscape or ecosystem evolved. In some cases, a system's internal memory may be literally visible - for example, the imprint of past terraces visible in LiDAR scans. It is also useful to assess to what degree a system has retained this internal memory. Which processes that shaped the system historically are still active today? Which have been altered or eliminated? Where have legacy features persisted, and how do these constrain the potential of a particular site?

Trying to reconstruct historical components back onto a landscape is unrealistic, and yet throwing out all historical reference to create 'novel' ecosystems may be equally ineffective (Hobbs et al. 2009, Jackson and Hobbs 2009). Historical legacies set the course for conceptual approaches for designing more resilient systems in the future. Not all "fixes," designs, or landscape-level restoration projects can be completed at once, or even in a short time frame. Yet having the vision for a resilient landscape allows managers to put the "pieces of the puzzle" together in a way that is forward thinking, cumulative, multi-beneficial, and economically prudent, letting nature do the work.

Recommended actions for next steps

- Set measurable goals (e.g., percent reduction in the frequency of sediment removal, percent flow reduction for specific stream reaches) to guide progress towards the design of a more resilient channels that provide multiple benefits and support desired ecosystem functions.
- Further refine proposed conceptual solutions to define specific project locations and management actions, and conduct site inventories as needed
- Model cumulative effects of proposed conceptual projects to identify the most cost-effective approaches for reaching management goals
- Integrate approaches with SMMP development and prioritize next steps

REFERENCES CITED

Allardt, G. (1874). Official map of Alameda County, California.

Allardt, G. F. ([1880] 1907). Pleasanton and vicinity, Alameda County, Cal. Showing the original condition and extent of swamps and tules in the year 1880, subsequently drained by an extensive system of drainage canals. Traced from the original map made from surveys by the late George F. Allardt, Civil Engineer. To accompany report of Otto von Geldern, Consulting Engineer, dated San Francisco, September 1907.

Beagle, J.R., Bigelow, P., McKee, L. J., Pearce, S. 2012. Sediment Source Reconnaissance of Stonybrook and Sinbad Creek Watersheds: A rapid evaluation of two small tributaries near the Alameda Creek Flood Control Channel. Prepared for the Alameda County Flood Control and Water Conservation District.

Beagle, J.R., Eads, R., Pearce, S., Gilbreath, A.N., Gluchowski, D.C., and McKee, L.J., 2011. Suspended and bed sediment transport in Arroyo Mocho and Arroyo Las Positas during Water Year 2011. A Watershed Program report of the San Francisco Estuary Institute prepared for Zone 7 Water Agency, Livermore, CA. San Francisco Estuary Institute, Oakland, CA. 38pp

Beagle JR, AA Whipple, and RM Grossinger. 2013. Landscape Patterns and Processes of the McCormack-Williamson Tract and Surrounding Area: A framework for restoring a resilient and functional landscape. Prepared for The Nature Conservancy. SFEI-ASC Publication #674, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA

Bigelow, P, Pearce, S., Benda, L., McKee, L.,Andras, K. and Kass, J. 2012. Geospatial Terrain Mapping of Sediment Sources within the Arroyo Mocho Watershed. (Revised August 2013). Regional Watersheds Program. Contribution number 665. Bigelow Watershed Geomorphology, Earth Systems Institute and San Francisco Estuary Institute, Richmond, CA.

Bigelow, P., S. Pearce, L. McKee, and A. Gilbreath. 2008. A sediment budget for two reaches of Alameda Creek. Prepared for Alameda Flood Control and Water Conservation District.

Booth D.B. (1990). Stream-channel incision following drainage-basin urbanization. Water Resources Bulletin. American Water Resources Association (26) 3

Bryant, E. ([1848] 1985). What I saw in California: being the journal or a tour; by the emigrant route and south pass of the Rocky Mountains, across the continent of North America, the Great Desert basin, and through California, in the years 1846, 1847. Lincoln, NE & London, UK, University of Nebraska Press.

Burtt Davy, J. (1898). Livermore Valley, beside the county road. Field Notebook 13. Field Notes 4267-4289.

California Legislature Assembly (1854). Journal of the fifth session of the legislature of the state of California, begun on the second day of January, 1854, and ended on the fifteenth day of May, 1854, at the cities of Benicia and Sacramento. Sacramento, BB Redding, State Printer.

California Department of Transportation. (1998). Historic property survey report for the seismic retrofit of Alameda Creek Bridge and overhead (Bridge #33-0039). District 4-Oakland.

Carlton, W. H. (1874). Field notes of the subdivision lines of township 3 and 4 south, range 2 east with lines of Rancho Valle de San Jose Mount Diablo Meridian, California. U.S. Department of the Interior, Bureau of Land Management Rectangular Survey, California. Book 308-6.

Carpenter, D. W., J. J. Sweeney, et al. (1984). Geology of the Lawrence Livermore National Laboratory site and adjacent areas, Lawrence Livermore National Laboratory.

Cash (1875). Survey no. 1624 for E. A. Rose, Murray Township.

Cluer, B., M. Swanson, J. McKeon et al. (2009). Symposium Report: Ecological Opportunities for Gravel Pit Reclamation on the Russian River. Exploring ideas and research for reclaiming old gravel pits adjacent to the Russian River. Assessing ecological opportunities for wetlands and fisheries. January 21, 2009. Santa Rosa, CA.

Coats, R., M. A. Showers, et al. (1988). A management plan for the Springtown alkali sink wetlands and the endangered plant *cordylanthus palmatus*. San Francisco, Phillip Williams & Associates.

Coats, R., M. A. Showers, et al. (1993). "Management plan for an alkali sink and its endangered plant *cordylanthus palmatus*." Environmental Management **17**(1): 115-127.

Collins, B. D. and D. R. Montgomery (2001). Importance of Archival and Process Studies to Characterizing Pre-Settlement Geomorphic Processes and Habitat in the Puget Lowland. In Dorava J. M et al. Eds. (2001). Geomorphic Processes and Riverine Habitats. Water Science and Application 4. AGU.

Crespí, J. and H. E. Bolton (1927). Fray Juan Crespí, missionary explorer on the Pacific coast, 1769-1774. Berkeley, CA, University of California Press.

Day, S. (1853). Copy of field notes of surveys of a part of the 1st Standard Parallel south of Mount Diablo and east of the Principal Meridian, and of townships south of the base and east of the Meridian. **Book 231-7**.

Department of Water Resources (DWR). (2001). South Bay Aqueduct (Bethany Reservoir and Lake Del Valle). http://www.water.ca.gov/pubs/swp/south_bay_aqueduct__lake_del_valle_and_bethany_reservoir_/south-bay-aque.pdf

Department of Water Resources (DWR). (2006). Livermore Valley groundwater basin. San Francisco Hydrologic Region. California's Groundwater Bulletin 118.

Dietz, M. F. (2007). "Low impact development practices: a review of current research and recommendations for future directions." Water, Air, & Soil Pollution **186**: 351-363.

Duerr (1872). Survey No. 1528.

Dunne, T. and L. B. Leopold (1978). Water in environmental planning. New York, NY, W.H. Freeman and Company.

Echo. 1894a. In consequence of making of a large excavation in the bed of the Arroyo Mocho... December 20. *Courtesy of Livermore Heritage Guild*.

Echo. 1894b. The arroyos Mocho and Valle were both, at times, during the late storm, unfordable... December 27. *Courtesy of Livermore Heritage Guild*.

Edwards, P. (1932). The diary of Philip Leget Edwards; the great cattle drive from California to Oregon in 1837. San Francisco, CA, Grabhorn Press.

Edwards SW, Thayer C. 2008. The last days of Livermore. *The Four Seasons* 13(2):1-30.

Elliott, A. H. and S. A. Trowsdale (2007). "A review of models for low impact urban stormwater drainage." Environmental Modelling & Software **22**: 394-405.

Ferriz, H. (2001). Groundwater resources of Northern California: an overview. Engineering Geology Practice in Northern California: Association of Engineering Geologists Special Publication 12 and California Division of Mines and Geology Bulletin 210. H. Ferriz and R. Anderson.

Figuers, S. and K. D. Ehman (2004). Preliminary stratigraphic evaluation west side of the main basin Livermore-Amador groundwater basin. Prepared for Zone 7 Water Agency.

Fisher, H., E. G. Brown, et al. (1966). Livermore and Sunol Valleys, evaluation of ground water resources, Appendix A: Geology, Department of Water Resources. Bulletin No. 118-2.

Friends of Springtown Preserve Springtown alkali sink ecology, botany, and wildlife notes. Livermore, CA. http://www.springtownpreserve.org/Reference_Materials/FSP-Springtown_Ecology_primer.pdf.

Fuller, M. L. (1912). Preliminary report on the underground waters of the Livermore and Sunol valleys.

Gillies, Eric L., "Effects of regulated streamflows on the Sycamore Alluvial Woodland riparian community" (1998). *Master's Theses. San Jose State University.*Paper 1630.

Goals Project. 1999. *Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project*. USEPA, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland.

Graymer, R. W., D. L. Jones, et al. (1996). Preliminary geologic map emphasizing bedrock formations in Alameda County, California:a digital database, U.S. Geological Survey Open-File Report 96-252.

Greiner, C. M. (2010). Principles for strategic conservation and restoration. Report No. 2010-01, Puget Sound Nearshore Ecosystem Restoration Project: 40.

Grossinger, R. M. (2012). Napa Valley historical ecology atlas: Exploring a landscape of transformation and resilience. Berkeley, CA, University of California Press.

Grossinger, R. M., E. E. Beller, et al. (2008). South Santa Clara Valley Historical Ecology Study: Including Soap Lake, the Upper Pajaro River, and Llagas, Uvas-Carnadero, and Pacheco Creeks. Oakland, CA, San Francisco Estuary Institute.

Gutmann, I. (1919). An agricultural survey of the Pleasanton properties of the Spring Valley Water Co. San Francisco, CA.

Halley, W. (1876). The centennial year book of Alameda County, California. Oakland, CA, William Halley.

Higley, H. A. (1857). Official map of the County of Alameda, California [electronic resource]/ surveyed and compiled by order of the Board of Supervisors. San Francisco, CA, Lith. Britton & Rey.

Hobbs, R., E. Higgs, et al. (2009). "Novel ecosystems: implications for conservation and restoration." Trends in Ecology and Evolution **24**(11): 599-605.

Holland, R. F. (1986). Preliminary descriptions of the terrestrial natural communities of California. Unpublished report. Sacramento, CA, California Department of Fish and Game, Natural Heritage Division.

Holland, R. F. (2009). California's Great Valley vernal pool habitat status and loss: rephotorevised 2005.

Holstein G. 2001. Pre-agricultural grassland in Central California. *Madroño* 48(4):253-264.

Howard, A. D. (1979). Geologic history of middle California. Berkeley, CA, University of California Press.

Howe, R. (1851). Field notes on a meridian line south of Mount Diablo in the state of California, under contract dated October 1, 1851. U.S. Department of the Interior, Bureau of Land Management Rectangular Survey, California. Book 231-3.

ICF International (2010). East Alameda conservation strategy, final draft, prepared for: East Alameda County Conservation Strategy Steering Committee. San Jose, CA, ICF International.

Jackson, S. and R. Hobbs (2009). "Ecological restoration in the light of ecological history." Science 325: 567-569.

Keeler-Wolf, T., D. R. Elam, et al. (1998). California vernal pool assessment preliminary report, State of California Department of Fish and Game.

Keeler-Wolf, T., K. Lewis, et al. (1996). The definition and location of sycamore alluvial woodland in California. Sacramento, CA, State of California, The Resources Agency, Department of Fish and Game.

Knighton, D. (1998). Fluvial forms and processes: A new perspective. New York, Hodder-Arnold.

Kohlmann, S., J. Alvarez, et al. (2008). A baseline assessment of environmental and biological conditions at Five Pillars Farms, Alameda County, California. Castro Valley, CA, Tierra Resource Management.

Kondolf, G.M. and M. Larson. (1995). Historical channel analysis and its application to riparian and aquatic habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems (5) 2:109-126

La Croze, J. (1860). Field Notes of the obsolete survey of the Rancho Santa Rita, Yontz, Administrator, Confirmee. U.S. Department of the Interior, Bureau of Land Management Rectangular Survey, California. Book Obs Santa Rita 37

Lee CH. 1916. *Spring Valley Water Company vs. City and County of San Francisco, et al. Vol. 8. Depreciation, financial, going value, lands, overhead rating base, reservoir values, water rights. District Court of the United States for the Northern District of California.*

Lewis WJ. 1861. *U.S. v. Jose Dolores Pacheco, Land Case 155 ND [Santa Rita], U.S. District Court, Northern District. Courtesy of The Bancroft Library, UC Berkeley*.

Magney, D. L. (1992). "Descriptions of three new Southern California vegetation types: Southern Cactus Scrub, Southern Coastal Needlegrass Grassland, and Scalebroom Scrub." Crossosoma **18**(1): 1-9.

Mikesell LR, Weissmann GS, Karachewski JA. 2010. Stream capture and piracy recorded by provenance in fluvial fan strata. *Geomorphology* 115:267-277.

Moerenhout ([1849]1935) The inside story of the gold rush. First Person Narratives

Nomad Ecology (2008). North Livermore priority landscape area resource conservation plan public review draft. Prepared for Tri-Valley Conservancy. Livermore, CA.

Nusbaumer, G. L. (1889). Official Map of Alameda County. Oakland, CA, Tribune publishing company.

Parrott, L. and W. S. Meyer (2012). "Future landscapes: managing within complexity." Frontiers in Ecology and the Environment **10**(7): 382-389.

Pearce, S., Bigelow, P., and McKee, L. 2009. Dry Creek Watershed Sediment Source Reconnaissance Technical Memorandum. Prepared for the Alameda County Flood Control and Water Conservation District, Hayward, CA. Regional Watershed Program, San Francisco Estuary Institute, Oakland, CA. 27 pp.

Ryan, W. R. (1850). Personal adventures in Upper and Lower California, in 1848-9; with the author's experience at the mines. Illustrated by twenty-three drawings taken on the spot. California as I saw it: first person narratives of California's early years, 1849-1900. London, William Shoberl. 1 & 2.

Sanborn Mapping. 2007. Alameda County LiDAR data. Alameda County, CA.

San Francisco Estuary Institute (SFEI). 2011. Bay Area aquatic resources inventory. SFEI. http://www.californiawetlands.net/tracker/ba/map.

Sawyer, J. O., T. Keeler-Wolf, et al. (2009). A manual of California vegetation, second edition. Sacramento, CA, California Native Plant Society.

Sawyer, T. L. (1999). Assessment of contractional deformation rates of the Mt. Diablo fold and thrust belt, eastern San Francisco Bay region, Northern California, U.S. Geological Survey National Earthquake Hazards Reduction Program.

Sawyer, T. L. and J. R. Unruh (2004). Characterization of late Quaternary deformation of the Mt. Diablo fold-and-thrust best, eastern San Francisco Bay Area, California, AGU meeting.

Sharsmith, H. K. (1945). "Flora of the Mount Hamilton Range of California (a taxonomic study and floristic analysis of the vascular plants)." American Midland Naturalist **34**(2): 289-367.

Simenstad, C., D. Reed and M. Ford. (2006). When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecological Engineering 26 (2006) 27-39.

Sloan, D. (2006). Geology of the San Francisco Bay region. Berkeley, CA, University of California Press.

Smith MB. (1934). Ground water in Livermore Valley. A thesis submitted to the Department of Geology and the Committee on Graduate Study of the Leland Stanford Junior University in partial fulfillment of the requirements for the degree of Master of Arts. Stanford University, CA.

Sowers, Janet M. 2003. Historical Geomorphology of Arroyo Valle and Arroyo Mocho with notes on steelhead migration, Livermore-Amador Valley. Prepared for Zone 7 Water Agency by Janet M. Sowers, William Lettis & Associates. November 26, 2003.

Stanford, B., R. Grossinger, et al. (2013). Alameda Creek Watershed historical ecology study. Richmond, CA, San Francisco Estuary Institute-Aquatic Science Center.

Thompson and West (1878). Official and historical atlas map of Alameda County, California Oakland, CA,

Tibbetts, F. H. (1907). Report on artesian basin of Livermore Valley.

Treutlein, T. E. and P. Fages (1972). "Fages as Explorer, 1769-1772." California Historical Society **51**(4): 338-356.

U. S. Census Bureau (2010). 2010 Census Data, 2010.census.gov/2010census.

U. S. Department of Agriculture (USDA), Western Division Laboratory. 1940. [Aerial photos of Alameda County]. Scale: 1:20,000. Agricultural Adjustment Administration (AAA). *Courtesy of Earth Sciences & Map Library, UC Berkeley, and the Alameda County Resource Conservation District (ACRCD) and National Resources Conservation Service (NRCS).*

U. S. Department of Agriculture (USDA). 2009. [Natural color aerial photos of Alameda County]. Ground resolution: 1m. National Agriculture Imagery Program (NAIP). Washington, D.C.

U. S. Department of Energy (US DOE). 2004. *Draft site-wide environmental impact statement for continued operation of Lawrence Livermore National Laboratory and supplemental stockpile*

stewardship and management programmatic environmental impact statement, Appendix H: Seismicity. National Nuclear Security Administration, Livermore, CA.

U. S. Geological Survey (USGS). 1940. Livermore Quadrangle, California : 15-minute series (Topographic). 1:62,500.

U. S. Geological Survey (USGS). 1942. Altamont Quadrangle, California : 15-minute series (Topographic). 1:62,500.

U. S. Geological Survey (USGS). 1980. Livermore Quadrangle, California : 7.5-minute series (Topographic). 1:24,000.

U. S. Geological Survey (USGS). 1981. Altamont Quadrangle, California : 7.5-minute series (Topographic). 1:24,000.

U. S. Geological Survey (USGS). 2005. National Hydrography Dataset.

U. S. Geological Survey (USGS). San Francisco Bay Region Urban Dynamics Data Set.

Unruh, J. and S. Sundermann (2006). Digital compilation of thrust and reverse fault data for the northern California map database: collaborative research with William Lettis & Associates, Inc., and the U.S. Geological Survey, U.S. Geological Survey National Earthquake Hazards Reduction Program.

Unruh, J. R. and T. L. Sawyer (1997). Assessment of blind seismogenic sources, Livermore Valley, eastern San Francisco Bay region, U.S. Geological Survey National Earthquake Reduction Program.

von Geldern, O. (1907). Investigation of the hydrography of Livermore Valley and the adaptability of the valley lands to the culture of hops. San Francisco, CA.

von Geldern O. 1912. *Report on Alameda Creek yield. Courtesy of San Francisco Public Utilities Commission Archives.*

Westover, H. L. and C. V. Duyne (1911). Soil survey of the Livermore area, California. B. o. S. United States Department of Agriculture, Government Printing Office.

Westover, H. L. and C. Van Duyne (1910). Livermore Soil Map, U. S. Department of Agriculture, Bureau of Soils.

Whitney, J. D. (1873). Map of the region adjacent to the Bay of San Francisco. Sacramento, CA, State Geological Survey.

Wiens, J. D., G. D. Hayward, H. D. Safford, C. M. Giffen. (2012). Historical Environmental Variation in Conservation and Natural Resource Management. John Wiley & Sons, Ltd. Oxford, UK.

Williams, C., Jr. (1912). Report on the water supply of the Alameda Creek watershed with particular reference to the Livermore Valley underground supply, prepared at the request of Percy V. Long. San Francisco, CA.

Wood, M. W. (1883). History of Alameda County, California: including its geology, topography, soil, and productions: together with a full and particular record of the Spanish grants. Oakland, CA, Pacific Press.

Zone 7 Water Agency (Zone 7). (2006). Zone 7 Stream Management Master Plan. Prepared by RMC Water and Environment. August 2006.

Zone 7 Water Agency (Zone 7). (2010). Semi-annual fall groundwater contours.

Zone 7 Water Agency (Zone 7). (2011). Annual report for the groundwater management program. 2010 water year. Livermore Valley groundwater basin. Livermore, CA.

APPENDIX A: METHODS

Several of the methods used in this report incorporated information from the Alameda Creek Historical Ecology Report (Stanford et al. 2013). We synthesized this historical data and added contemporary information to examine physical gradients and drivers; analyze hydro-geomorphologic, ecological, and land use changes over time; devise landscape-level restoration/intervention strategies; and develop conceptual models illustrating potential landscape scale trajectories. This involved compiling SFEI studies examining sediment dynamics in the watershed, conducting SFEI riparian vegetation surveys, compiling Zone 7 reports and the currently-in-revision Zone 7 Stream Management Master Plan (SMMP), gaining local expertise from Zone 7 staff, utilizing USGS topographic quadrangles, aerial photographs, and a variety of other reports and data inputs.

Several new GIS data layers were developed for this project in order to assess interim time periods and evaluate change over time, focusing on impervious surfaces, road networks, and riparian vegetation extent.

GIS LAYERS

GIS layers were developed to represent various aspects of the Valley's ecology, hydrogeomorphology, and land use at four time periods: 1800s, 1940s, 1980s, and 2009.

Channel network

The channel network data layers were created for each of the four time periods using data compiled from a variety of sources. For the 1800s, we used the channel network layer developed for the Alameda Creek Watershed Historical Ecology Study (Stanford et al. 2013). This layer was developed by modifying the Bay Area Aquatic Resource Inventory (BAARI; SFEI 2011) mapping where historical sources showed a clear divergence from modern sources. Historical sources used included 1940 aerial photographs (USDA 1940), historical USGS topographic quads, other early maps of the Valley, and GLO surveys.

The 1940s channel network layer was developed using the 1800s channel network layer as a starting point. The channel network was modified where necessary based on the 1940 aerial imagery. For the 1980s, we used the National Hydrography Dataset (NHD) Flowline data for the channel network layer (USGS 2005). For 2009, we used the BAARI mapping.

Gravel pits

Gravel pits data layers are only included for two time periods: 1980s and 2009. For the 1980s, we used the National Hydrography Dataset (NHD) Waterbodies layer to represent the gravel pits. For 2009, the gravel pits were digitized from the National Agriculture Imagery Program (NAIP) imagery (USDA 2009). Only gravel pits with a distinct boundary visible in the NAIP imagery were digitized. We compared the digitized gravel pits to existing maps of the Zone 7 service area.

Impervious surfaces

Impervious surfaces data layers were created for the 1940s, 1980s, and 2009, and include areas occupied by urban areas and major roads and highways. For the 1940s and 1980s, urban areas were mapped by modifying the 1940 and 1974 USGS San Francisco Bay Region Urban Dynamics Data Set layers (USGS n.d.) based on USGS topographic quads from the 1940s and 1980s, respectively (USGS 1940, 1942, 1980, 1981). For the 1940s, major roads and highways were digitized from 1940 aerial imagery, and a 15 m buffer was created around both roads and highways. For the 1980s, major roads and highways were digitized from the 1980s USGS quads, or where possible from the NAIP 2009 imagery using the 1980s USGS quad for interpretation. For 2009, major

roads and highways were digitized from the NAIP 2009 imagery. For both the 1980s and 2009, a 20 m buffer was created around major roads and a 40 m buffer was created around highways.

Riparian vegetation

We created riparian vegetation data layers for the 1800s, 1940s, and 2009. Areas classified as riparian include both wooded and sparsely-vegetated areas within or adjacent to the stream channel.

The 1800s riparian vegetation layer includes riparian land cover types from the Alameda Creek Watershed Historical Ecology Study habitat mapping (Stanford et al. 2013). For our area of interest, these include Sparsely Vegetated Braided Channel, Sycamore Alluvial Woodland, Pond, Valley Freshwater Marsh, and Willow Thicket. For areas along Arroyo Mocho where riparian vegetation was not mapped in the historical ecology report, we used a 130-m wide riparian corridor which had been previously mapped as the 'active channel'. The layer also includes non-riparian wetland habitats from the Alameda HE study habitat mapping, including Alkali Meadow, Alkali Sink Scrub-Vernal Pool Complex, Alkali Playa Complex, and Wet Meadow.

The 1940s riparian vegetation layer was digitized from the USDA 1940 aerial imagery. For the 2009 riparian vegetation layer, we started with the ICF riparian vegetation mapping (ICF International 2010) and modified the boundaries based on NAIP 2009 imagery. Within our area of interest, ICF riparian vegetation types included Mixed Riparian Forest and Woodland and Mixed Willow Riparian Scrub. Where ICF did not map riparian vegetation, we created a 10-m riparian buffer along Arroyo Mocho, Arroyo Las Positas, Altamont Creek, and Arroyo Seco. For the 1940s and 2009 layers, we attributed the riparian corridor using a generic classification called Mapped Riparian Zone.

We also digitized wetland habitats in the Springtown area for 1940s and 2009 using the USDA 1940 imagery and NAIP 2009 imagery, respectively.

RIPARIAN WIDTH CLASS ANALYSIS: ARROYO MOCHO

We analyzed the change in riparian corridor width along the portion of Arroyo Mocho within our study area between the 1800s, 1940s, and 2009. For each time period, the riparian corridor was divided into three width classes: <60 m, 60-200 m, and 200-400 m. A division was created wherever a new width class started or ended, so that each segment of riparian corridor fell within a single width class. For each segment, the average width was estimated using the Measure tool in ArcMap. Stream reaches were coded with the width class and average width of the corresponding riparian corridor segment. We then calculated the proportion of total stream length for each width class for each time period.

RIPARIAN VEGETATION FIELD MAPPING METHODS

To obtain a better picture of the current condition of riparian habitats within the study area, we conducted vegetation surveys along a portion of Arroyo Mocho from Concannon Blvd to approximately ¾ mile west of Isabel Avenue. In GIS, we segmented the riparian areas into field polygons corresponding to three stream reaches ("Robertson Park," "Holmes," and "Stanley") and four geomorphic zones (channel, inner bench, outer bench, and floodplain). Within each field polygon, we counted the number of each tree species and recorded tree size class. For detailed information on our vegetation mapping methods and results, see Appendix B.

APPENDIX B. RIPARIAN MAPPING ON ARROYO MOCHO

INTRODUCTION

Ideally, restoration efforts are guided by an integrated understanding of regional historical ecology, landscape processes, and contemporary site-specific conditions. Combining insights from these varied perspectives provides a more comprehensive picture of restoration opportunities and constraints, and hopefully leads to more successful restoration outcomes. Within our study area, and particularly within the Arroyo Mocho case study areas, riparian habitats represent both important restoration targets as well as key drivers of hydrogeomorphic processes such as channel stabilization and groundwater recharge. Thus, in order to develop effective restoration strategies and to prioritize sites for possible management interventions along Arroyo Mocho, it was necessary to assess the current condition of riparian vegetation.

We conducted riparian vegetation surveys along the Arroyo Mocho corridor from Concannon Blvd to approximately ¾ mile west of Isabel Avenue. Surveys were conducted between November 1 and 15, 2012. The goals of the surveys were to provide further insight into the current condition of riparian vegetation within our case study areas, and to help identify priority areas for preservation or restoration. Information collected through the surveys was intended to help address the following specific questions:

1. What is the size distribution of riparian trees? Where have mature trees survived? Where are they regenerating?
2. How does the density of riparian vegetation vary by reach and geomorphic setting?
3. How does species dominance vary by reach and geomorphic setting?

Sycamores, as the dominant tree in what was once a widespread but is now a relatively uncommon riparian habitat type, were the focus of particular interest in our riparian mapping.

METHODS

Pre-field

In GIS, we segmented the riparian area into polygons corresponding to their reach and geomorphic zone. The survey area included three reaches: Robertson Park (from Concannon Boulevard to Arroyo Road), Holmes (from Arroyo Road to Holmes Street), and Stanley (from N Murrieta Boulevard to approximately ¾ mile west of Isabel Avenue).

Geomorphic zones were determined using aerial and LiDAR imagery, and included channel, inner bench, outer bench, and floodplain. The channel was defined as the area immediately surrounding the active channel up to the first distinct bench visible in LiDAR imagery. The inner bench was defined as the area extending from the channel to the next distinct change in elevation, and the outer bench was defined as the area extending from the inner bench to the boundary of the stream corridor (identified by a distinct topographic change or by the interface with developed urban areas). The floodplain geomorphic zone was assigned to two large polygons in the Holmes reach separated from the mainstem by a walking trail. The four geomorphic zones were further segmented into a series of field polygons small enough to sample within. Each field polygon was assigned a unique ID number. In some cases, the polygons were modified in the field to better represent geomorphic conditions on the ground.

Field

In the field, we visually established the extent of each field polygon on the ground using aerial photographs, and conducted vegetation surveys within each polygon sequentially. Within each field polygon, we attempted to count each tree and record species name and size class. We also noted the dominant understory species in each field polygon. In areas where the vegetation was too thick permit access or to allow counting of individual trees, we estimated tree abundance and size class. Recorded tree species included:

- Sandbar willow (Salix hindsiana)
- Willow species (Salix laevigata and/or Salix lasiolepis)
- Fremont cottonwood (Populus fremontii)
- California black walnut (Juglans hindsii)
- Western sycamore (Platanus racemosa)
- Valley oak (Quercus lobata)
- Coast live oak (Quercus agrifolia)
- Eucalyptus (Eucalyptus spp.)
- California buckeye (Aesculus californica)
- Tanbark oak (Lithocarpus densiflorus)
- Other

We classified each tree into one of four size classes, designated C1 through C4 (Figure B1). C1 was used to represent trees in the smallest size class, which included seedlings and small saplings. C2 included medium to large size saplings. C3 included small to medium-sized trees, and C4 was reserved for mature trees.

In addition to surveying riparian vegetation, we recorded the location of notable geomorphic features such as inactive side channels and gravel bars.

SOURCES OF ERROR

Our findings may have been affected by several sources of error. First, there were likely small (<5 m) discrepancies between the boundaries of the field polygons created in GIS and the boundaries of the field polygons identified on the ground; these discrepancies may have had a small impact on the number of trees counted for a given polygon. Second, portions of the field polygons where vegetation was especially dense were difficult to access, and in some cases trees in these areas had to be identified and counted from a distance. Third, in areas of especially high tree density, we were unable to count individual trees, and thus had to estimate tree abundance and size class. Fourth, although an effort was made to standardize size class definitions, tree size class was determined by visual estimate rather than direct measurement, and thus there was likely some inconsistency in how sizes classes were assigned. Finally, mulefat (Baccharis salicifolia) was inadvertently included in the counts of sandbar willow, artificially inflating estimates of willow density. To correct for this, sandbar willow counts on benches and floodplains in the Holmes and Robertson reaches were reduced by 75%, and counts in channels in the Stanley reach were reduced by 25%.

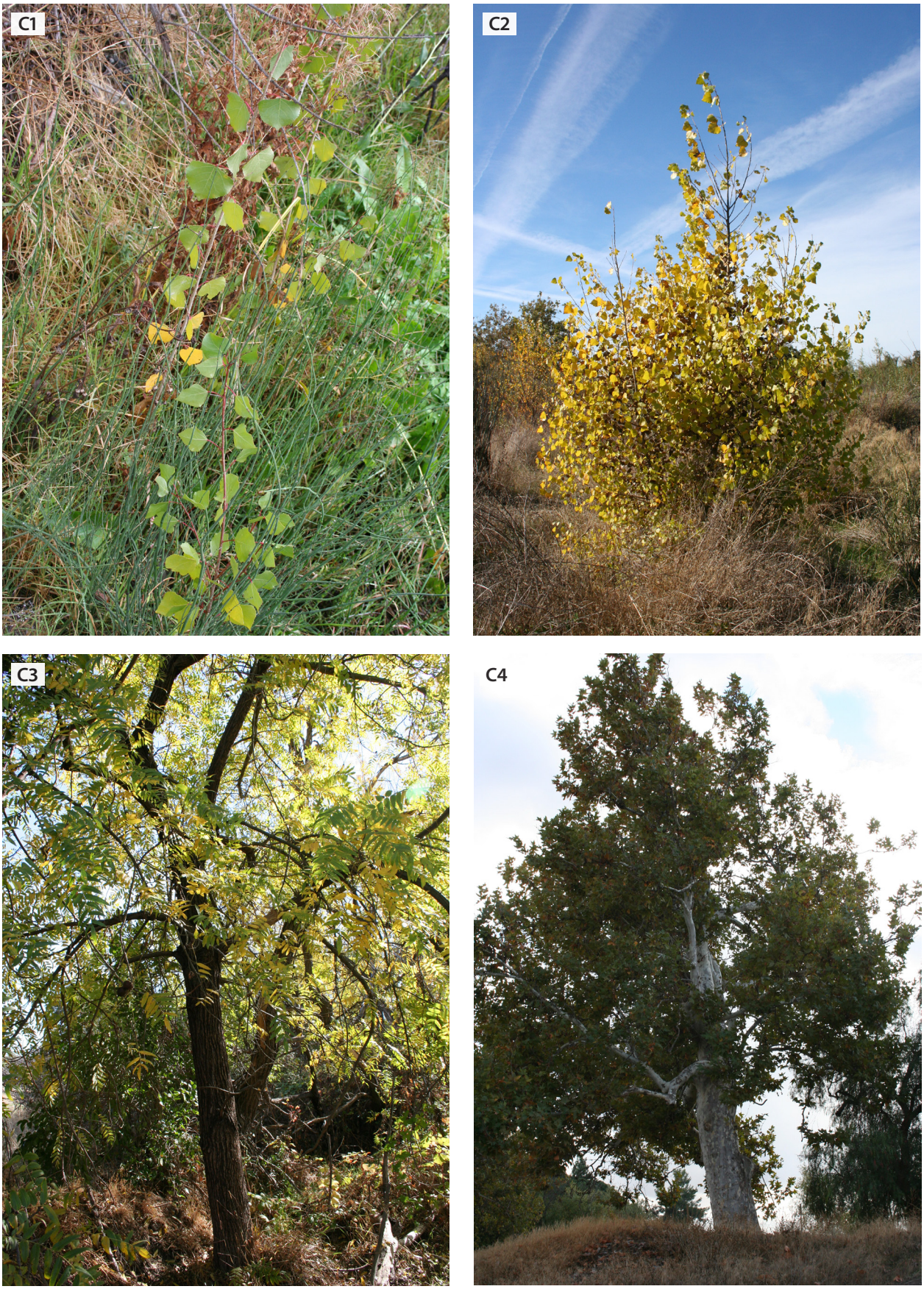


Figure B1. Representative photographs of trees in each of the four size classes used in the field surveys. C1 includes seedlings and small saplings, C2 includes medium to large size saplings, C3 includes small to medium-sized trees, and C4 includes mature trees. (photos by Sean Baumgarten and Julie Beagle, November 2012)

RESULTS

Results from the field surveys are shown in Table B1.

Total Tree Density

Overall tree density was highest in the Stanley reach (302.94 trees/acre), followed by the Holmes reach (78.81 trees/acre) and the Robertson Park reach (54.4 trees/acre) (Table B1 and Figure B2). Densities ranged from 203.32 to 485.79 trees/acre in the Stanley reach, from 8.8 to 400.55 trees/acre in the Holmes reach, and from 4.54 to 256.79 trees/acre in the Robertson Park reach.

In terms of geomorphic zone, tree density was highest in the channel (248.88 trees/acre), followed by the inner bench (78.69 trees/acre), the floodplain (22.15 trees/acre), and the outer bench (21.04 trees/acre). Tree densities ranged from 66.22 to 485.79 trees/acre in the channel, 41.06 to 212.23 trees/acre in the inner bench, 8.8 to 34.05 trees/acre in the floodplain, and 4.54 to 120.15 trees/acre in the outer bench.

Total sycamore density was highest in the Holmes reach (3.93 trees/acre), followed by the Robertson reach (1.79 trees/acre) and the Stanley reach (1.22 trees/acre). In terms of geomorphic zone, sycamore density was highest in the outer bench (3.34 trees/acre), followed by the inner bench (3.06 trees/acre), the floodplain (1.42 trees/acre), and the channel (1.28 trees/acre).

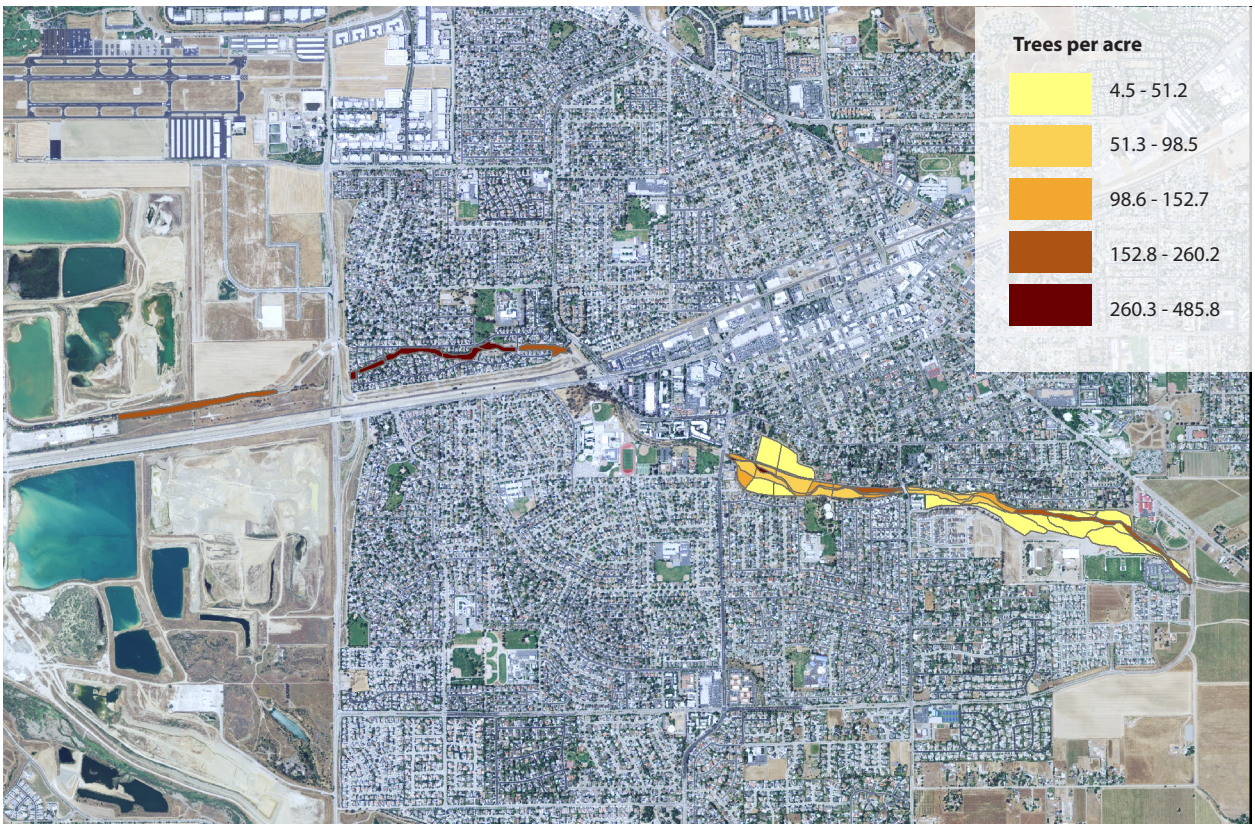


Figure B2. Total tree density in the field survey area.

Table B1. Riparian vegetation survey results. The four geomorphic zones are channel (Ch), inner bench (IB), outer bench (OB), and floodplain (FP). C1-C4 correspond to the four size classes (see Figure B1). Total Density includes all surveyed tree species; Total Density Excluding "Other" includes all willow species, cottonwood, walnut, sycamore, valley oak, live oak, tanbark oak, buckeye, and eucalyptus.

Reach	Polygon	Geomorphic Zone	Area (acres)	C1 Density	C2 Density	C3 Density	C4 Density	Total Density	"Total Density Excluding ""Other"""	"C4 Sycamore Density"	"C1 + C2 Sycamore Density"	"Total Sycamore Density"	"Total Willow Density"	"C1 Willow Density"	"C4 Willow Density"
Holmes	44	FP	4.66	1.72	4.93	2.15	0.00	8.80	0.64	0.00	0.00	0.00	0.00	0.00	0.00
Holmes	43	FP	5.23	14.35	13.20	6.31	0.19	34.05	8.23	0.00	0.96	2.68	0.00	0.00	0.00
Holmes	39	OB	3.01	4.99	25.62	5.99	0.00	36.60	24.96	0.00	4.66	7.32	6.32	0.00	0.00
Holmes	38	OB	1.53	5.22	25.47	1.31	1.31	33.31	26.78	0.00	0.00	0.00	20.90	0.00	1.31
Holmes	40	OB	1.61	25.39	74.94	16.10	3.72	120.15	42.11	3.72	2.48	11.15	8.05	0.00	0.00
Holmes	36	IB	1.65	23.03	35.15	5.46	0.00	63.64	60.01	0.00	15.15	15.15	27.88	8.49	0.00
Holmes	42	OB	0.69	11.57	57.87	7.23	0.00	76.68	62.21	0.00	8.68	10.13	26.04	0.00	0.00
Holmes	41	IB	3.11	28.60	24.42	13.49	3.86	70.36	65.86	0.00	0.32	2.89	25.70	11.89	1.61
Holmes	31	IB	1.95	13.82	49.66	15.87	8.19	87.55	69.12	0.00	0.00	0.00	20.48	5.63	0.00
Holmes	34	IB	1.22	16.36	53.99	10.63	1.64	82.62	75.26	0.00	0.00	0.00	15.54	0.82	1.64
Holmes	37	IB	1.61	16.11	68.14	13.63	0.62	98.50	97.88	0.00	0.62	6.81	26.02	2.48	0.62
Holmes	30	IB	0.30	26.67	56.67	26.67	6.67	116.68	106.68	0.00	0.00	0.00	56.67	3.33	0.00
Holmes	45	Ch	0.57	45.57	50.83	12.27	0.00	108.67	106.92	0.00	1.75	8.76	71.86	29.80	0.00
Holmes	29A	Ch	0.45	15.72	60.62	38.17	4.49	118.99	110.01	0.00	0.00	0.00	65.11	8.98	4.49
Holmes	31A	IB	0.72	24.99	69.41	51.36	6.94	152.70	118.00	2.78	0.00	6.94	62.47	4.16	2.78
Holmes	33	IB	1.01	49.29	55.20	19.72	6.90	131.11	119.28	3.94	0.00	4.93	44.36	6.90	0.00
Holmes	35	Ch	0.65	98.61	30.82	0.00	0.00	129.43	126.35	0.00	0.00	0.00	92.45	66.25	0.00
Holmes	32	Ch	0.40	83.01	45.28	0.00	0.00	128.29	128.29	0.00	0.00	0.00	85.53	42.76	0.00
Holmes	28	IB	1.70	34.68	78.77	50.56	11.76	175.77	154.02	0.59	2.35	5.88	52.91	10.58	2.94
Holmes	29	Ch	0.41	134.25	58.58	12.20	2.44	207.48	197.71	0.00	0.00	0.00	175.74	124.49	2.44
Holmes	46	Ch	0.83	340.23	60.32	0.00	0.00	400.55	396.93	0.00	0.00	0.00	283.52	235.26	0.00
Robertson Park	21	OB	2.86	1.05	0.70	2.79	0.00	4.54	4.54	0.00	0.00	2.44	2.09	1.05	0.00
Robertson Park	27	OB	7.71	1.04	3.50	0.00	0.39	4.93	4.93	0.00	0.00	0.00	0.13	0.00	0.00
Robertson Park	20	OB	3.14	5.10	0.64	0.32	0.00	6.05	5.41	0.00	0.00	0.00	0.00	0.00	0.00
Robertson Park	25	OB	5.94	0.17	1.68	6.40	1.85	10.10	10.10	0.84	1.01	4.21	0.84	0.00	0.34
Robertson Park	25A	OB	2.47	12.53	5.66	7.68	0.00	25.86	25.46	0.00	1.21	2.02	2.02	0.00	0.00
Robertson Park	20A	OB	1.30	4.61	9.99	7.69	4.61	26.91	26.14	4.61	0.77	13.07	0.77	0.00	0.00
Robertson Park	19A	IB	6.14	7.17	28.68	4.40	0.81	41.06	41.06	0.00	0.00	0.16	22.65	6.36	0.65
Robertson Park	19	IB	0.97	3.09	29.88	8.24	1.03	42.25	41.22	0.00	0.00	0.00	27.82	3.09	0.00
Robertson Park	18	IB	1.04	4.80	24.94	14.39	0.00	44.12	43.16	0.00	0.00	0.00	27.81	3.84	0.00
Robertson Park	22	IB	1.72	14.56	28.53	2.91	5.24	51.24	51.24	0.00	0.00	0.00	39.59	11.64	2.91
Robertson Park	26	Ch	2.22	18.47	45.50	1.80	0.45	66.22	66.22	0.00	2.70	3.15	48.20	15.77	0.45
Robertson Park	24	IB	1.63	20.28	47.92	6.76	2.46	77.42	76.19	0.61	1.84	4.92	17.20	4.92	1.84
Robertson Park	20B	IB	1.38	35.62	41.44	14.54	2.91	94.51	89.43	0.73	2.91	5.09	43.62	21.81	0.73
Robertson Park	23A	Ch	1.76	31.19	58.98	18.71	1.13	110.01	107.75	0.00	0.00	0.57	90.73	31.19	1.13
Robertson Park	17	IB	0.33	21.53	123.03	49.21	18.45	212.23	178.39	0.00	0.00	0.00	144.56	12.30	15.38
Robertson Park	16	Ch	0.56	51.73	128.44	12.49	1.78	194.44	194.44	0.00	1.78	1.78	169.46	37.46	0.00
Robertson Park	16A	Ch	1.47	84.43	119.83	10.21	0.68	215.16	213.79	0.00	1.36	1.36	192.69	78.30	0.68
Robertson Park	23	Ch	2.59	165.87	58.25	5.79	0.77	230.68	230.29	0.00	0.39	0.39	202.52	155.46	0.39
Robertson Park	16B	Ch	0.57	167.70	89.09	0.00	0.00	256.78	256.78	0.00	0.00	0.00	214.86	157.21	0.00
Stanley	47	Ch	2.19	52.46	99.44	71.16	15.96	239.02	180.63	0.00	6.39	8.21	15.05	8.21	0.00
Stanley	49	Ch	2.51	159.49	116.93	31.02	16.70	324.15	184.55	0.00	0.00	0.00	24.26	7.16	0.40
Stanley	52	Ch	3.56	24.71	100.82	64.31	13.48	203.32	202.76	0.00	0.00	0.00	9.27	4.49	0.00
Stanley	53	Ch	4.03	53.12	122.63	75.71	8.69	260.16	259.42	0.00	0.25	0.25	56.60	19.61	0.99
Stanley	51	Ch	0.38	76.74	148.19	95.26	7.94	328.13	296.37	0.00	0.00	0.00	7.94	5.29	0.00
Stanley	50	Ch	1.03	197.41	222.57	50.32	15.48	485.79	299.02	0.00	0.00	0.00	19.35	0.00	4.84
Stanley	48	Ch	1.57	143.67	120.79	78.19	19.71	362.36	305.78	0.00	0.00	0.00	3.18	1.91	0.00
Stanley	48A	Ch	1.87	186.67	176.01	94.94	17.07	474.68	408.01	0.00	0.53	1.07	0.53	0.53	0.00

Size Class Density

Figure B3 shows the density of each tree size class by geomorphic zone. The channel had the highest tree density for every size class, while the floodplain and outer bench had the lowest densities for each size class. However, when willows, eucalyptus, and "other" were removed from the analysis, the inner bench had the highest density of C2, C3, and C4 trees (the channel still had the highest density of C1 trees) (Figure B4).

The C2 size class had the highest density in every geomorphic zone (Figure B3). However, when willows, eucalyptus, and "other" were removed from the analysis, C1 trees were the most abundant size class within channels and on the floodplains (C2 was still the most abundant size class in the inner and outer benches) (Figure B4). Likewise, when Robertson Park and Holmes reaches were analyzed separately (i.e., the Stanley reach was excluded from the analysis), C1 trees were the most abundant size class within channels (Figures B5 and B6).

Figure B3. Total tree density by size class within each geomorphic zone in the field survey area.

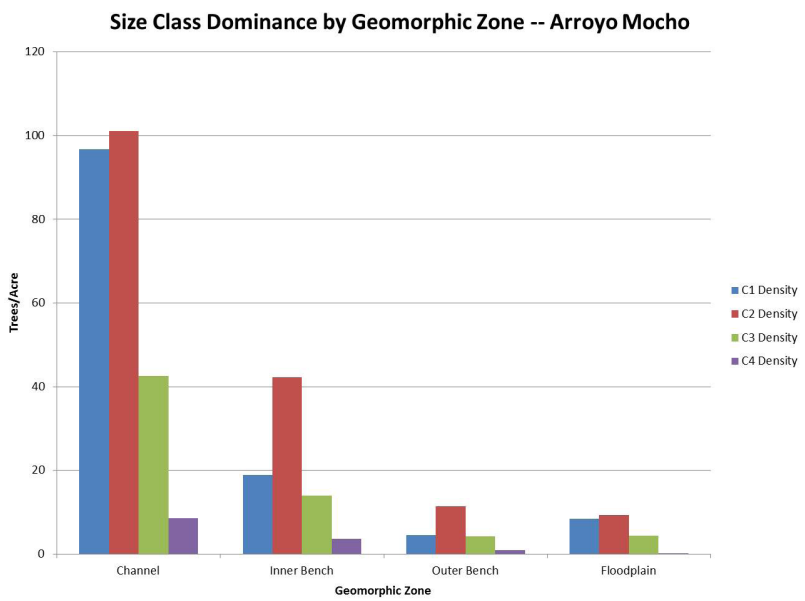
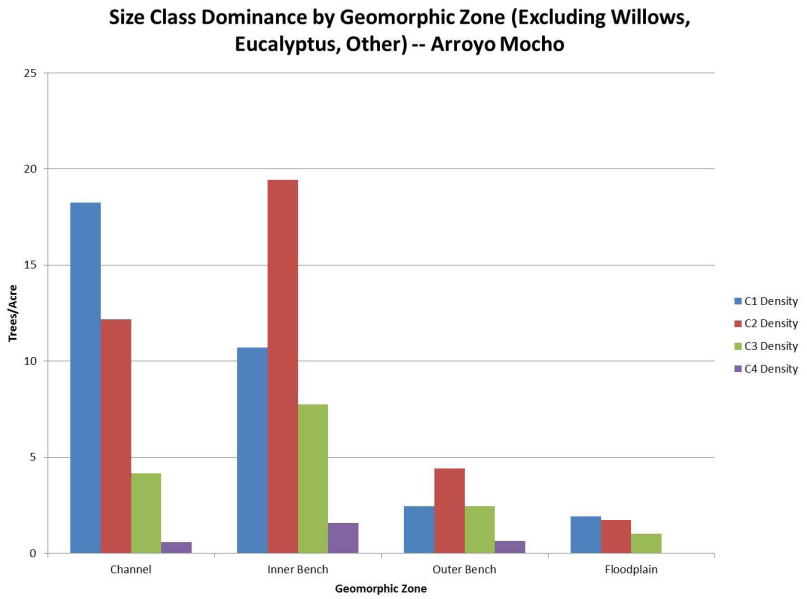


Figure B4. Tree density by size class (excluding willows, eucalyptus, other) within each geomorphic zone in the field survey area.



C4 sycamore density was highest in the Holmes reach (0.39 trees/acre), followed by the Robertson Park reach (0.28 trees/acre) (Figure B7). No C4 sycamores were observed in the Stanley reach. Combined C1 and C2 sycamore density was also highest in the Holmes reach (1.83 trees/acre), followed by the Stanley reach (0.93 trees/acre) and the Robertson Park reach (0.59 trees/acre) (Figure B8).

C1 sycamore density was highest in the inner bench (0.76 trees/acre), followed by the channel (0.44 trees/acre) and the outer bench (0.36 trees/acre) (Figure B9). C2, C3, and C4 density were highest in the outer bench (0.76, 1.65, and 0.56 trees/acre, respectively), followed by the inner bench (0.68, 1.28, and 0.34 trees/acre, respectively). No C4 sycamores were found in the channel or the floodplain.

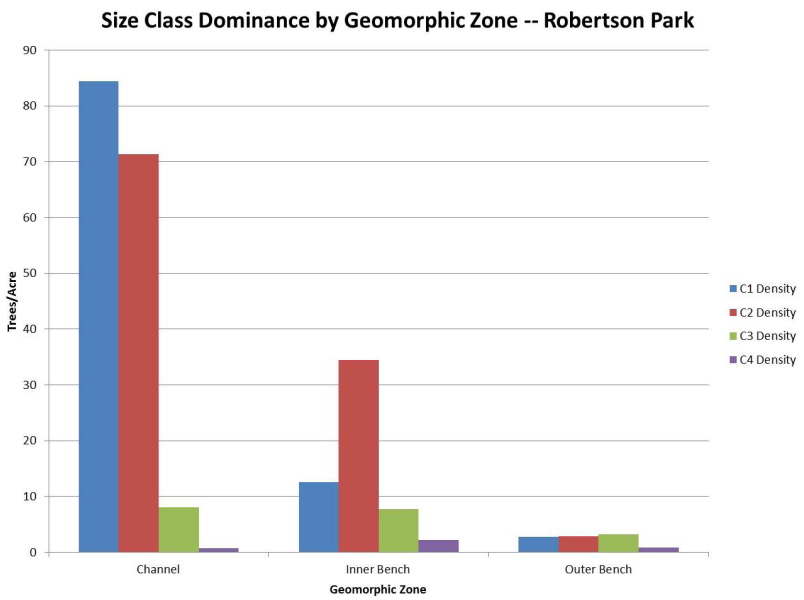


Figure B5. Total tree density by size class within each geomorphic zone in the Robertson Park reach.

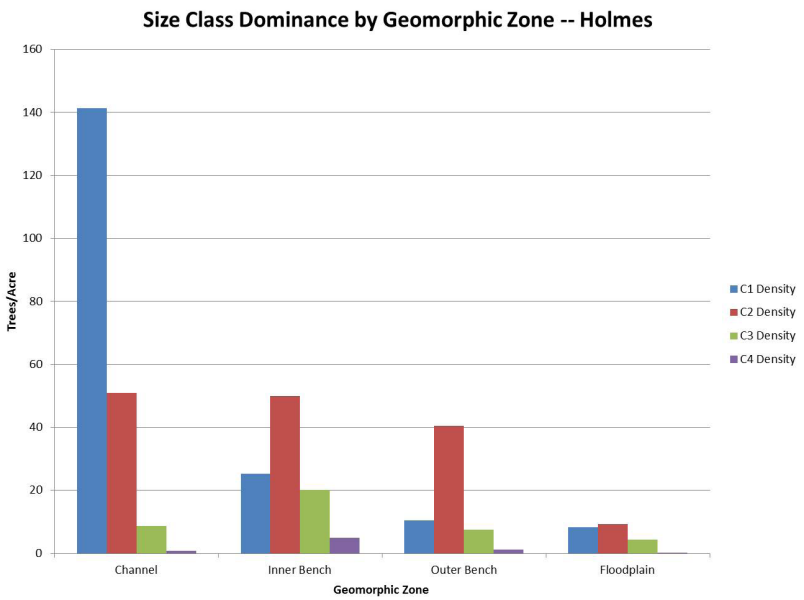


Figure B6. Total tree density by size class within each geomorphic zone in the Holmes reach.

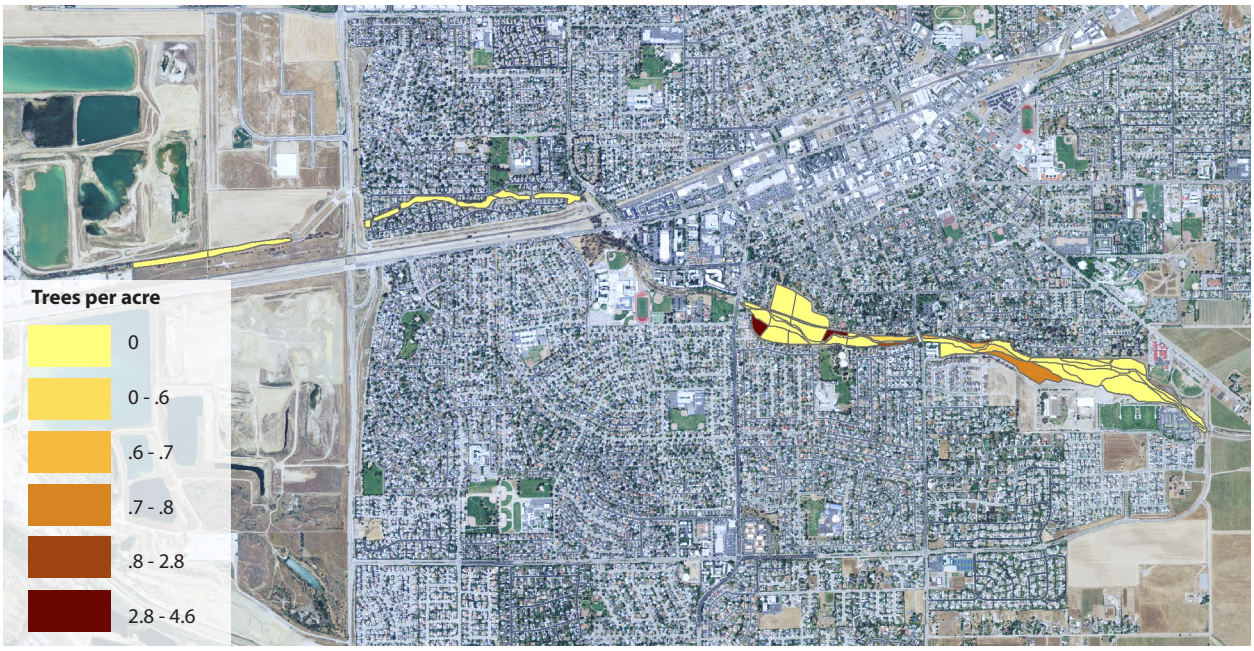


Figure B7. Density of C4 sycamores within the field survey area.

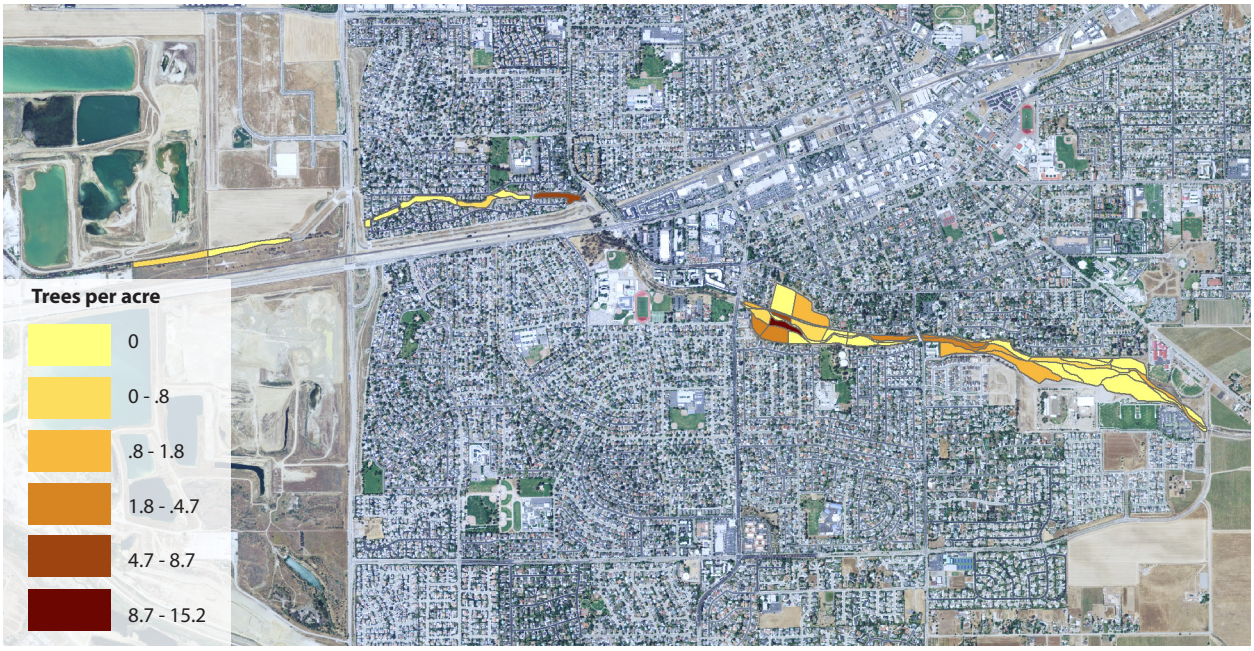


Figure B8. Density of C1 and C2 sycamores within the field survey area.

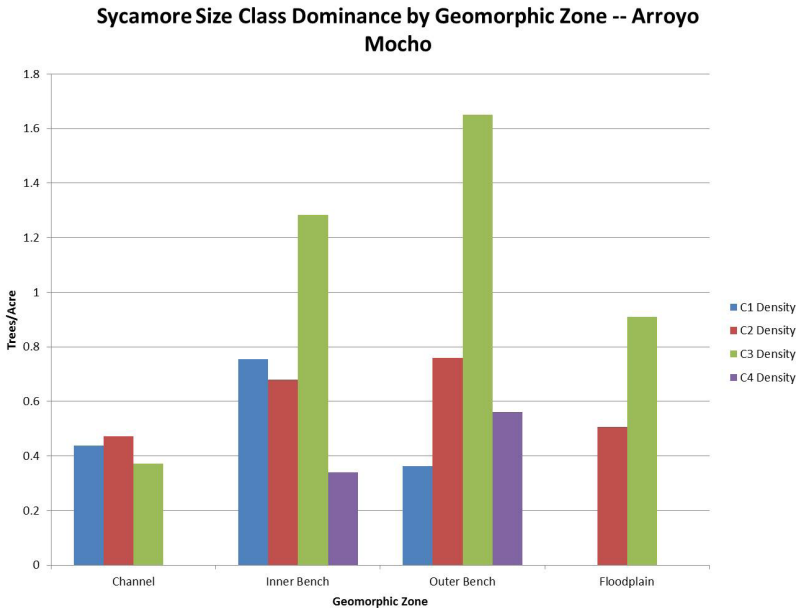


Figure B9. Density of sycamores by size class within each geomorphic zone in the field survey area.

Species Dominance

Species dominance was substantially different in the Stanley reach compared with the Robertson Park and Holmes reaches. Eucalyptus was the overwhelmingly dominant species within the Stanley reach (especially west of Isabel Avenue), which made it by far the most dominant tree species within the channel overall (Figures B10 and B11). In addition to eucalyptus, the Stanley reach also had significant numbers of other non-native species as well as live oak and sandbar willow. Native species abundance and diversity was greater in the portion of the Stanley reach east of Isabel Avenue.

In the Robertson Park and Holmes reaches, sandbar willow was the most common species in the channel (Figures B12 and B13). Within the channel there was also a relatively high density of other willow species (Robertson Park and Holmes reaches) and Fremont cottonwood (Holmes reach). Willow and walnut were common species on the inner bench in both the Robertson Park and Holmes reaches; sandbar willow was also common in the Holmes reach. “Other” was the most common category on the outer bench and floodplain in the Holmes reach (the outer bench and floodplain had a relatively high proportion of non-native ornamental trees, which were recorded in the “other” category).

Figure B10. Tree density by species within each geomorphic zone in the field survey area.

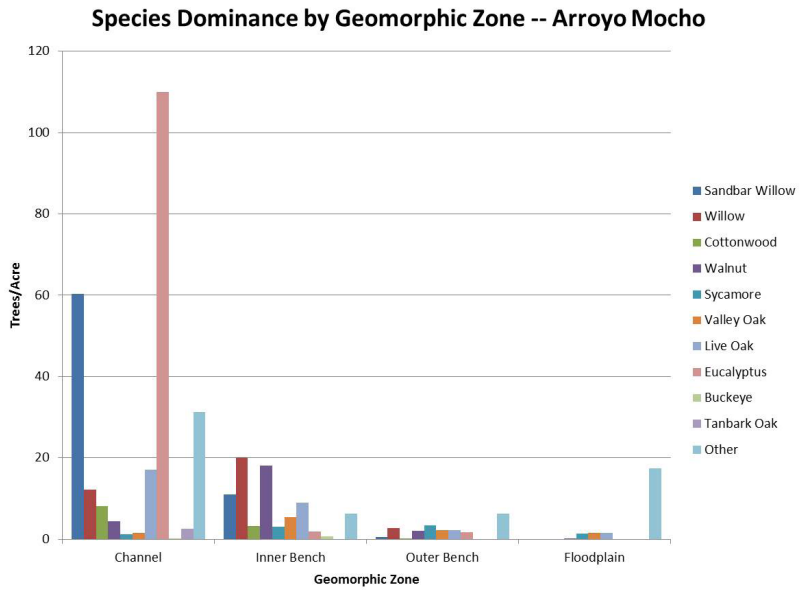
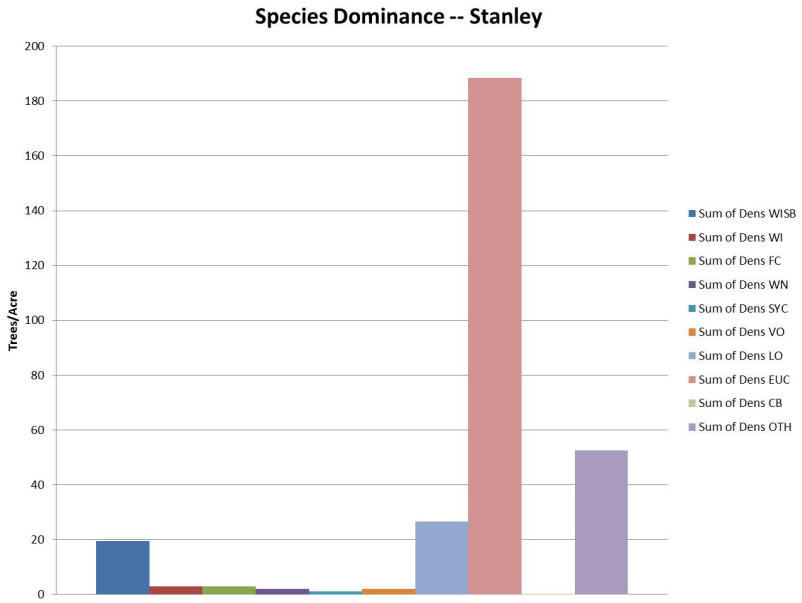


Figure B11. Tree density by species within the Stanley reach (note: "Channel" was the only geomorphic zone in the Stanley reach).



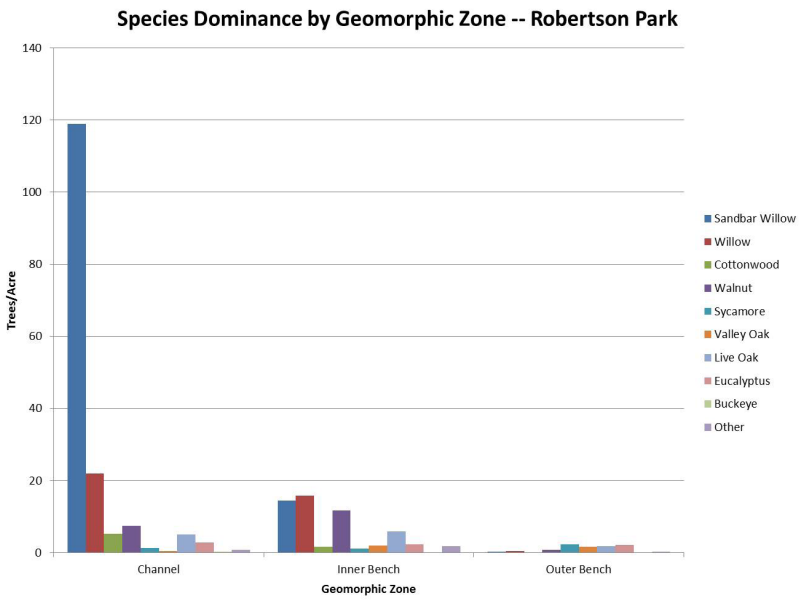


Figure B12. Tree density by species within each geomorphic zone in the Roberston Park reach.

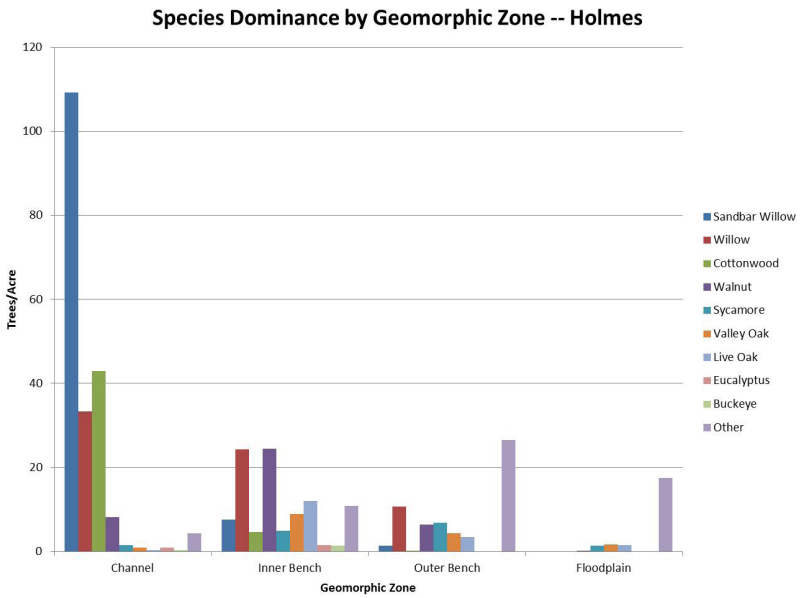


Figure B13. Tree density by species within each geomorphic zone in the Holmes reach.

DISCUSSION

The current condition of riparian vegetation within the Arroyo Mocho case study areas varies considerably by reach as well as by geomorphic zone. The Robertson Park and Holmes reaches support a moderate density mixed riparian forest comprised of native species such as willow, cottonwood, walnut, valley oak, and sycamore, as well as smaller numbers of non-native trees such as plum, pepper, and olive. Riparian vegetation in the Stanley reach is substantially denser. The portion of the Stanley reach east of Isabel Avenue is composed of a dense mixture of native and non-native tree species, while the flood control channel to the west of Isabel Avenue is dominated by dense stands of eucalyptus.

In all three reaches, riparian vegetation is likely much denser than it was historically, and is composed of different plant associations. The change is most apparent in the Stanley reach, where the very high density vegetation that exists today is in marked contrast to the sparse oaks and grasses that dominated the riparian corridor in this reach historically (the historical channel was also in a slightly different location than the modern channel). Riparian vegetation in the Robertson Park and Holmes reaches historically consisted of somewhat denser sycamore alluvial woodland, but this was still less dense than the mixed riparian forest that occurs in these reaches today. Augmented streamflows resulting from urban runoff and the addition of SWP water upstream are likely responsible for much of the vegetation encroachment within the stream corridor. Vegetation encroachment causes the channel to become more confined and stabilized, and thus restoration of a braided channel may require active intervention to reduce vegetation density.

Relatively high densities of mature (C3 and C4) sycamores were observed on the inner and outer benches of the Robertson Park and Holmes reaches (see Figures B7 and B9). Historically, these were braided reaches with intermittent flows that supported sycamore alluvial woodland, and were in turn stabilized by the presence of sycamores. The remnant mature sycamores in these reaches probably established following a flood event when these areas were still part of the active floodplain. Many of these sycamores are “perched” on mounds of dirt above the floodplain, which have become isolated as sediment deposition on these benches has decreased.

As evidenced by the presence of C1 trees, sycamores are regenerating to some degree in all three reaches that we surveyed. The majority of C1 sycamores that we observed were in the Holmes reach. Sycamore recruitment rates appear to be relatively low, however, and given the lack of recent flood events in areas where sycamores are regenerating, the new recruits are likely the result of vegetative reproduction.

Appendix 7.6

Arroyo Mocho Bulk Sediment Sampling

Sarah Pearce
Alicia Gilbreath
Lester McKee

November 2015

SFEI | AQUATIC SCIENCE CENTER
SAN FRANCISCO ESTUARY INSTITUTE & THE AQUATIC SCIENCE CENTER

Appendix 7.6

Arroyo Mocho Bulk Sediment Sampling

Sarah Pearce, Alicia Gilbreath, and Lester McKee

San Francisco Estuary Institute
Richmond, CA

Prepared for:
Zone 7 Water Agency
Livermore, CA

November 2015

Acknowledgements

The San Francisco Estuary Institute would like to extend our gratitude to Zone 7 staff Andy Chamberlain and James Creek for their help in collecting the bulk sediment samples.

Introduction

The Zone 7 Water Agency (Zone 7) owns and maintains a portion of the 11.56 miles of channel with the Arroyo Mocho/Las Positas channel network, and is charged with maintaining the channel and providing protection from flooding for the cities of Livermore, Pleasanton and Dublin. However, since construction, reaches within the Arroyo Mocho flood control channel have experienced net sediment deposition, which has reduced flood capacity within the channel. Information about the grainsize is currently lacking. However such data would assist managers in learning more about the deposition processes, and thus reducing the total amount of sediment in storage. In addition, this data could also be used in future 2-D sediment transport modeling as an input parameter or as a calibration dataset.

In the Fall of 2015, Zone 7 contracted with the San Francisco Estuary Institute (SFEI) to conduct in-channel bulk sediment sampling in the Arroyo Mocho watershed. Bulk sediment sampling is a well-documented methodology (USDA, 2007; Bunte and Abt, 2001) based around removing a predefined volume of material from a representative location on the channel bed, and quantifying the grain size distribution within the sample. The sample is intended to represent surface and subsurface sediment presently in storage in the channel. Although bulk sediment sampling is a fairly simple analysis, the results can be quite powerful. The composition of bed sediment, including its size and gradation, can affect pollutant transport, aquatic habitat, resource management, channel morphology, and stream restoration (USDA, 2007).

The objectives of this study were to quantify the size distribution of surface and subsurface sediment in the Arroyo Mocho system, as it relates to in-channel morphologic changes related to deposition or erosion of sediment. The data will provide insight on potential sources of coarse sediment supplied to the mainstem channel by tributaries, and will elucidate longitudinal patterns or trends in sediment deposition. In addition, the grain size distributions can serve as input data for future sediment transport modeling, shear stress calculations, and hydraulic roughness calculations.

Methods

To meet the objectives of the study, SFEI staff worked with Zone 7 staff to create a sample design to adequately sample the study area, with a sample density that will allow spatial patterns to be detected. The project team chose 24 locations, balancing the need to sufficiently describe the spatial variability of grainsize with the need to remain within the fixed project budget. The locations were carefully chosen to include samples at the upstream and downstream ends of the study area, upstream and downstream of each tributary confluence, and at gauge locations. The general location of each sample was chosen in advance, however the exact location was chosen in the field based upon observed channel characteristics.

Published guidance suggests carefully selecting sample locations that are morphologically stable, representative of the hydraulic and sedimentation processes that are occurring in that reach, and that avoid anomalies that would bias the grain size distribution (USDA, 2007). The coarsest material in a reach has the greatest effect upon channel morphology, and is found at riffle locations or upstream ends of bars. The field team targeted riffles for sample locations because they provide a consistent morphologic unit to sample, are stable, and represent the coarsest material that will be the most difficult (requiring the highest velocities) for the channel to transport. In the field, at each location, approximately 100m of channel length was observed during the process of selecting a representative

riffle. Within the riffle, the channel bed was inspected and the exact sample location was selected using best professional judgment. Whenever possible, the sample was placed at the riffle head (Figure 1). The site was photographed and marked with field flagging or with the sampling device.

It is well documented that coarse channel beds are characterized by significant vertical, spatial, and temporal bed-material variability (USDA, 2007). Thus, capturing the variability within a discrete sample can be difficult. The sample volume must be large enough so that the largest clast within the sample does not affect the distribution. Some authors suggest that the depth of bulk samples must be at least twice the diameter of the maximum particle size and the weight of the largest clast must not be greater than 0.05% of the total sample weight (Diplas and Fripp, 1992). However this can lead to very large sample volumes that would be economically prohibitive to process by the laboratory. Instead, Bunte and Abt (2001) provide guidance on the minimum sample weight needed for sediment of various sizes. For instance, at sites with a maximum clast diameter of 64mm (observed at the Holmes Street Bridge, the coarsest location), in order for the largest clast to only represent <1% of the total sample weight, at least 25 kg (55 pounds) of material should be sampled.

To collect a consistent weight of material, samples were collected in one of three ways, dependent upon the presence of water in the channel. For dry sites, using hand trowels, field staff carefully excavated all material within a 25x25 cm square, to a depth of 20-25 cm, placing all of the sediment into clean, labeled five gallon buckets. Existing vegetation within the square was carefully removed, ensuring that the majority of the fine sediment trapped in the roots was included in the sample. Any large clasts that were more than 50% inside the plot were included in the sample, with those less than 50% removed. The surface and subsurface material (armor layer) was not separated, thus producing an unstratified sample. However, at the two coarsest sites, the armor layer was carefully removed and the length of the intermediate axis was recorded. For wet sites with a shallow water depth, a 30cm diameter metal cylinder[1] was inserted into the bed of the channel to block the flow of water across the sample location (preventing the loss of fine sediment) and all material within the duct was excavated to a depth of approximately 20 cm. For wet sites with a greater water depth (up to 1m deep), field staff utilized a petite ponar dredge sampler to collect material from the bed. The ponar collects bed sediment within its 13.5 x 17 cm opening, but can only sample up to approximately 6 cm depth. This required field staff to collect multiple grabs (approximately 10-15) to obtain a similar volume of bed material. This method does not sample to the same depth, however the ponar was only used at two locations, which happened to be near the downstream end of the study area and thus had generally finer grain sizes than upstream reaches. In addition, field staff dug the toes of their boots into the bed, to qualitatively determine if the subsurface had functionally similar textural properties as the surface.

Sampling to a depth of 20-25 cm produced enough sediment to fill one-half to three-quarters of a five gallon bucket. Each bucket weighed approximately 50-70 pounds, capturing enough sample following the guidance of Bunte and Abt (2001). Once the appropriate volume of sediment had been removed, the sample bucket was sealed, labeled, and carried out of the channel. A final photograph of the sample site was taken, and the exact location of the sample was marked on the high-resolution aerial photographs.

Samples were sent to Consolidated Engineering Laboratories (primary contact Wilson Ye) in Oakland, CA for grain size sieve analysis. The lab requested approximately 50 pounds of sediment for each sample. Each sample was dried and sieved using the following sieve sizes: 3”, 2”, 1.5”, 1”, ¾”, 3/8”, #4, #10, #20, #40, #60, #100, #200. Data is reported as the cumulative weight caught on each sieve, and the percent

[1] A 40cm tall piece of air conditioning duct was utilized because it was strong, yet lightweight.

finer than. In addition, the lab reported the percentage of material in each size category: cobble, coarse and fine gravel, coarse medium and fine sand, silt, and clay as well as D85, D60, D50, D30, D15, and D10.

Results

Each sample was given a unique sample ID, ranging from A up to X, increasing downstream to upstream (Table 1 and Figure 2). The exact location of each sample is shown in Figure 3 in a series of zoomed-in aerial photographs. The grain size distribution of each sample is reported by the lab, including D85 (85% of the sample is finer than this grain size), D50 (the median grain size), D15 (15% of the sample is finer), % finer than 0.25mm (the size distinction between bedload and suspended load), % finer than 0.06 mm (often reported as suspended load), % gravel, % sand, % silt, and % clay (Table 2). A plot of distance upstream from the Arroyo Mocho and Alamo Canal confluence versus grain size illustrates the spatial variation in grain size distribution across the study area (Figure 4). With some variation, in general the samples do display a fining downstream trend, as is common for alluvial channels (Leopold, 1994). The variation is due to a few factors; a tributary confluence pattern is observed, whereas the sample immediately downstream of the tributary is coarser compared to the upstream sample (see samples B-C, D-E, G-H, P-Q, V-W). Sample I is located in a reach that has been restored, with a clay layer exposed in the bed; the sediment in this reach is much finer than elsewhere likely due to the created channel dimensions encouraging sediment transport. Sample N is the coarsest sample, and is upstream of the sediment budget boundary on Arroyo Mocho in a gravel and cobble depositional reach. There is less variation in grain size within the fining downstream trend for sample O through X on Arroyo Las Positas, likely reflecting the overall dominance of gravel and sand in that reach. Figure 5 describes the distribution of material in each broad size class (silt, clay, sand, gravel, cobble). Similarly to Figure 4, for samples A-N the fining downstream trend is visible by the downstream increase in sand content. Figure 6 plots the fine component (finer than 0.25 mm) of each sample, where no apparent trend is observable. Figure 7 illustrates field conditions during sampling.

Discussion

This bulk sediment data set is important as it represents the only systematic quantification of active channel sediment within the Arroyo Mocho system. It is spatially well distributed, and by sampling riffle locations, aims to quantify the coarsest material currently deposited in the channel. The data illustrates the general fining downstream trend, visible in the D50 and D85 grainsizes. Also, it describes the localized coarsening of the bed immediately downstream from tributary inputs, suggesting that they are in fact sources of coarse sediment deposition. The D50 of the downstream samples were 1.3 to 5.5 mm larger, and the D85 of the downstream samples were 0.3 to 21.4mm larger than their immediately upstream counterparts. Also, it is interesting to note that with the exception of Cottonwood Creek, the D85 values for the larger non-urban watersheds (Tassajara Creek, Collier Creek, Cayetano Creek) are higher than those for the urban watersheds (Chabot Canal and Line G-3). This allows us to develop the hypothesis that the non-urban watersheds are delivering coarser grain size material than the urban watersheds, as would conceptually be expected. Cottonwood Creek had the finest D85 grainsize of all the samples taken just downstream of a tributary confluence, and likely is reflecting the channel morphology of that particular sampling location.

The average D50 is 7mm (fine gravel) for the whole study area, ranging from 1 to 18mm between individual sites, suggesting that current bed sediment should be fairly easily mobilized by ordinary flow events. For comparison, in looking at the entire set of bedload samples collected during WY11-15, all

samples were greater than 50% gravel. The average bulk sediment D85 is 21mm (coarse gravel), ranging from 5mm near the confluence with Alamo Canal, up to 77mm at Arroyo Mocho at Holmes Street. This is the material that creates the coarser framework of each individual riffle, and also requires more stream power to mobilize.

These general interpretations accepted, with only 24 samples, some details of the spatial pattern are not captured. For instance, we do not know how far downstream the coarsening due to tributary input extends. Also, we do not know if there is a significant variation in grain size laterally across the channel, or within different channel features (e.g. bars, inner benches). This information could be gathered with additional sampling in the future if the need arises.

Conclusions

This bulk sediment data set illustrates:

1) An average D50 of 7mm (fine gravel) and an average D85 of 21mm (coarse gravel) for the study area based on the 24 sample sites.
2) A fining downstream trend, with the finest sediment at Sample Site A at the confluence with Alamo Canal, and the coarsest sediment in Sample N at Arroyo Mocho at Holmes.
3) A general coarsening of sediment in the mainstem in relation to contribution from side tributaries, with coarser sediment immediately downstream from the confluence.
4) No trend in the fine sediment (<0.25mm) component of the samples.

As Zone 7 Water Agency faces increased costs of maintaining the flood control channel network, including potentially removing sediment to increase flood capacity, the grain size distribution of active sediment is valuable for multiple purposes. This data is a key input parameter for channel roughness calculations and sediment transport numerical modeling. This spatially balanced data set is the only data currently available for these purposes. And while the data set is limited to 24 samples, it does provide a good understanding of the character of sediment currently in channel, and allows further hypotheses about sediment inputs and transport to be generated.

References

Bunte, K., and Abt, S.R., 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics and streambed monitoring. Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p.

Diplas, P., and Fripp, J., 1992. Properties of various sediment sampling procedures. Journal of Hydraulic Engineering, v. 188, n. 7, pp 955-970.

Leopold, L., 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts. 298p.

USDA, 2007. Natural Resources Conservation Service National Engineering Handbook. Part 654- Stream Restoration Design; H-210-NEH-654. Technical Supplement 13A: Guidelines for Sampling Bed Material. Directives.sc.egov.usda.gov

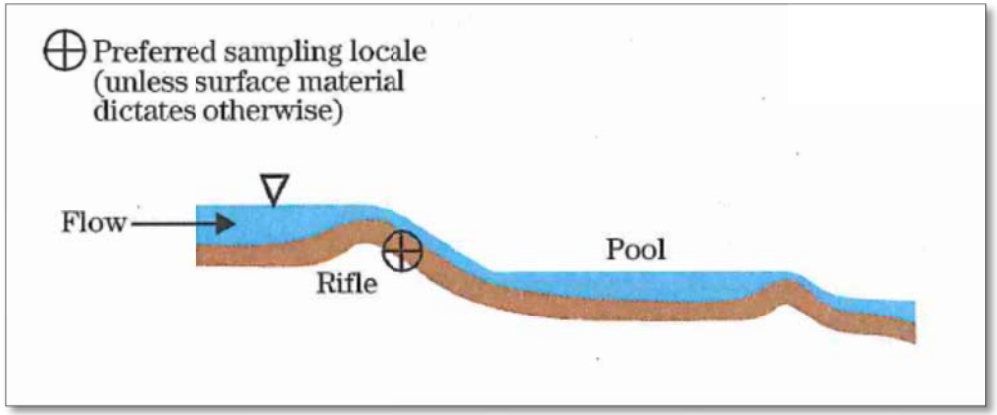


Figure 1. Preferred sampling location (USDA, 2007).

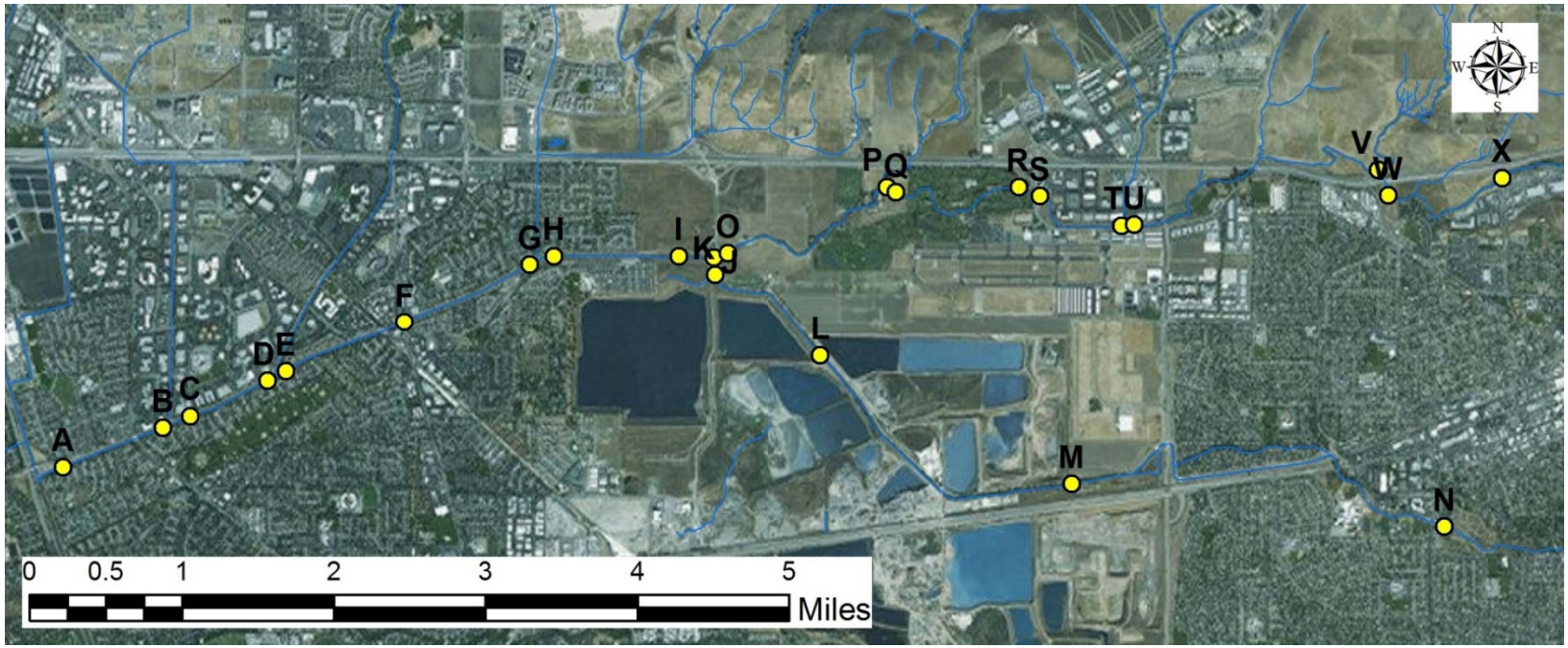
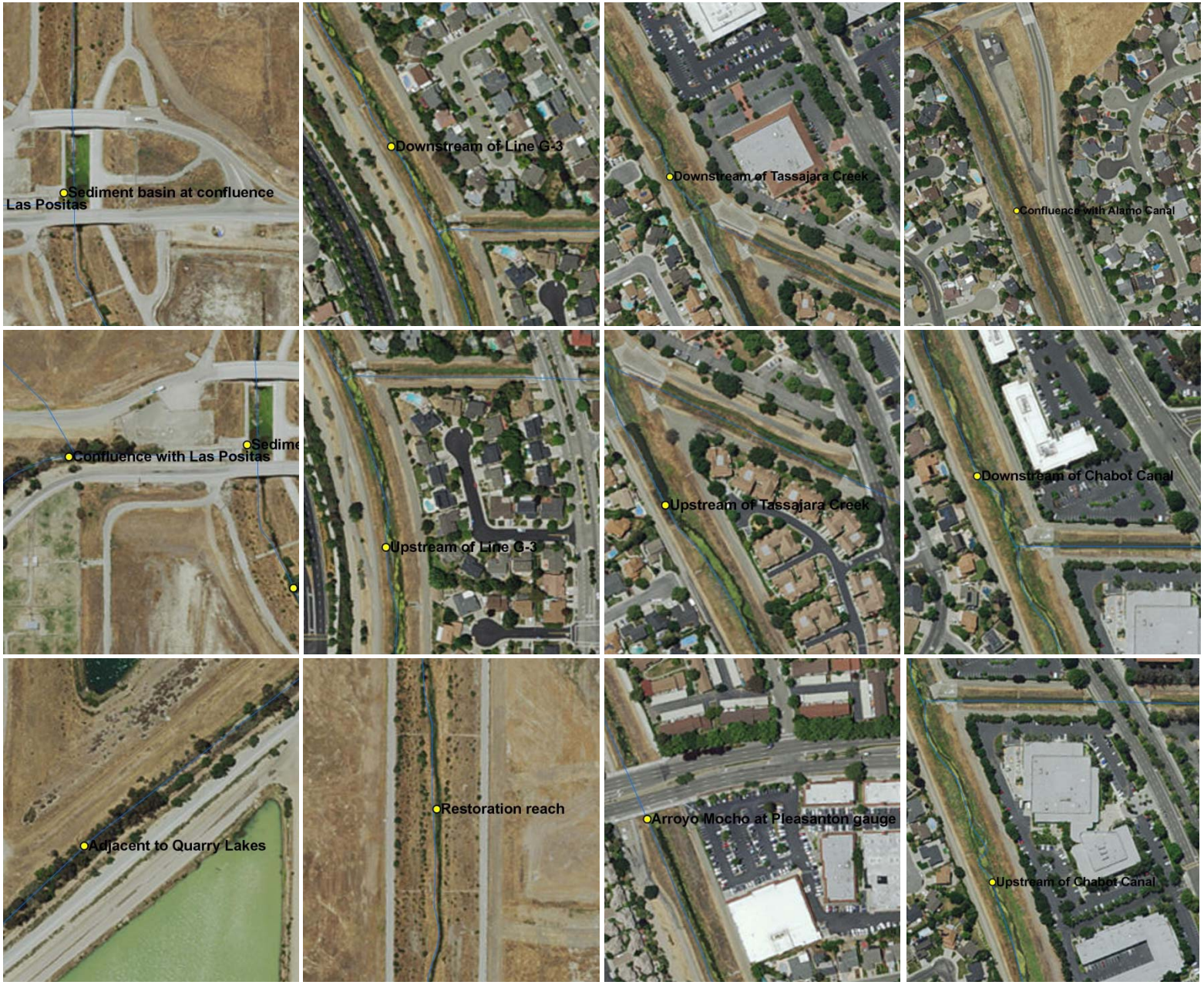


Figure 2. Bulk sediment sampling locations in the Arroyo Mocho watershed. See Figure 3 for close-up locations.


Sediment basin at confluence
Las Positas
Downstream of Line G-3
Downstream of Tassajara Creek
Confluence with Alamo Canal
Confluence with Las Positas
Upstream of Line G-3
Upstream of Tassajara Creek
Downstream of Chabot Canal
Adjacent to Quarry Lakes
Restoration reach
Arroyo Mocho at Pleasanton gauge
Upstream of Chabot Canal

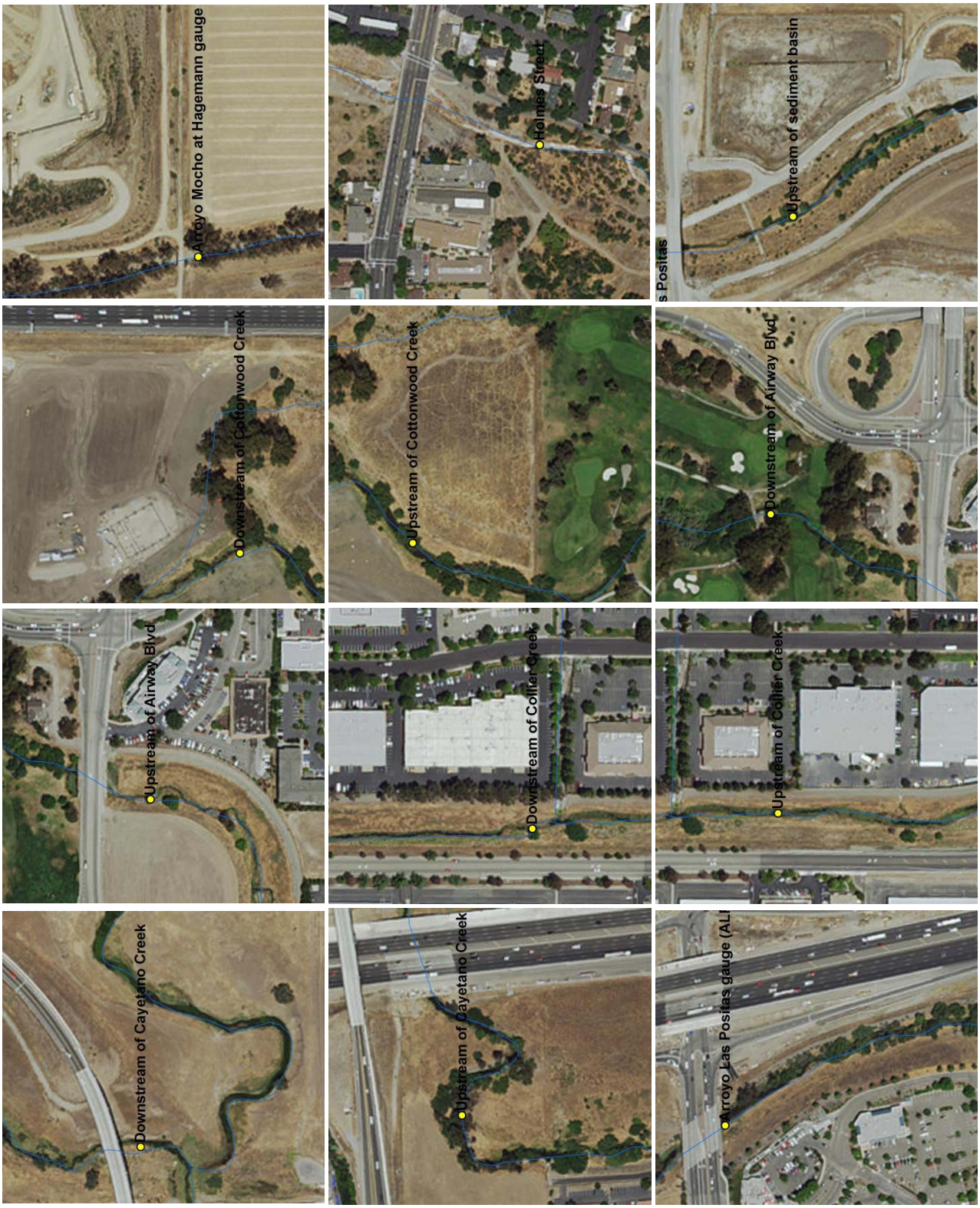


Figure 3. Close up views of each bulk sediment sampling location. Panels show A through L (first page) and M through X (second page), moving left to right, and top to bottom.

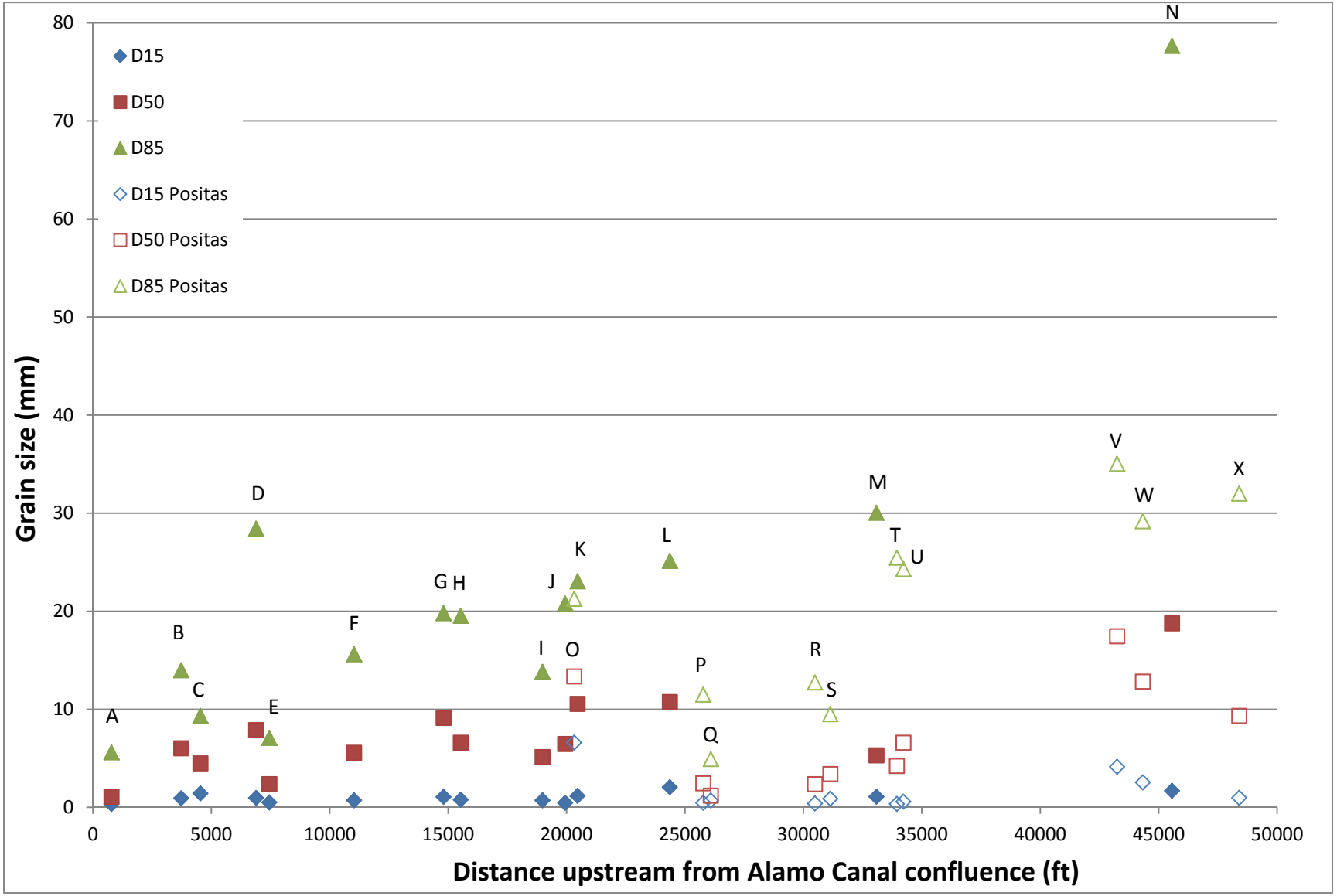


Figure 4. Grain size distribution (D85, D50, and D15) for each sample plotted with channel distance (feet) upstream from the Alamo canal confluence.

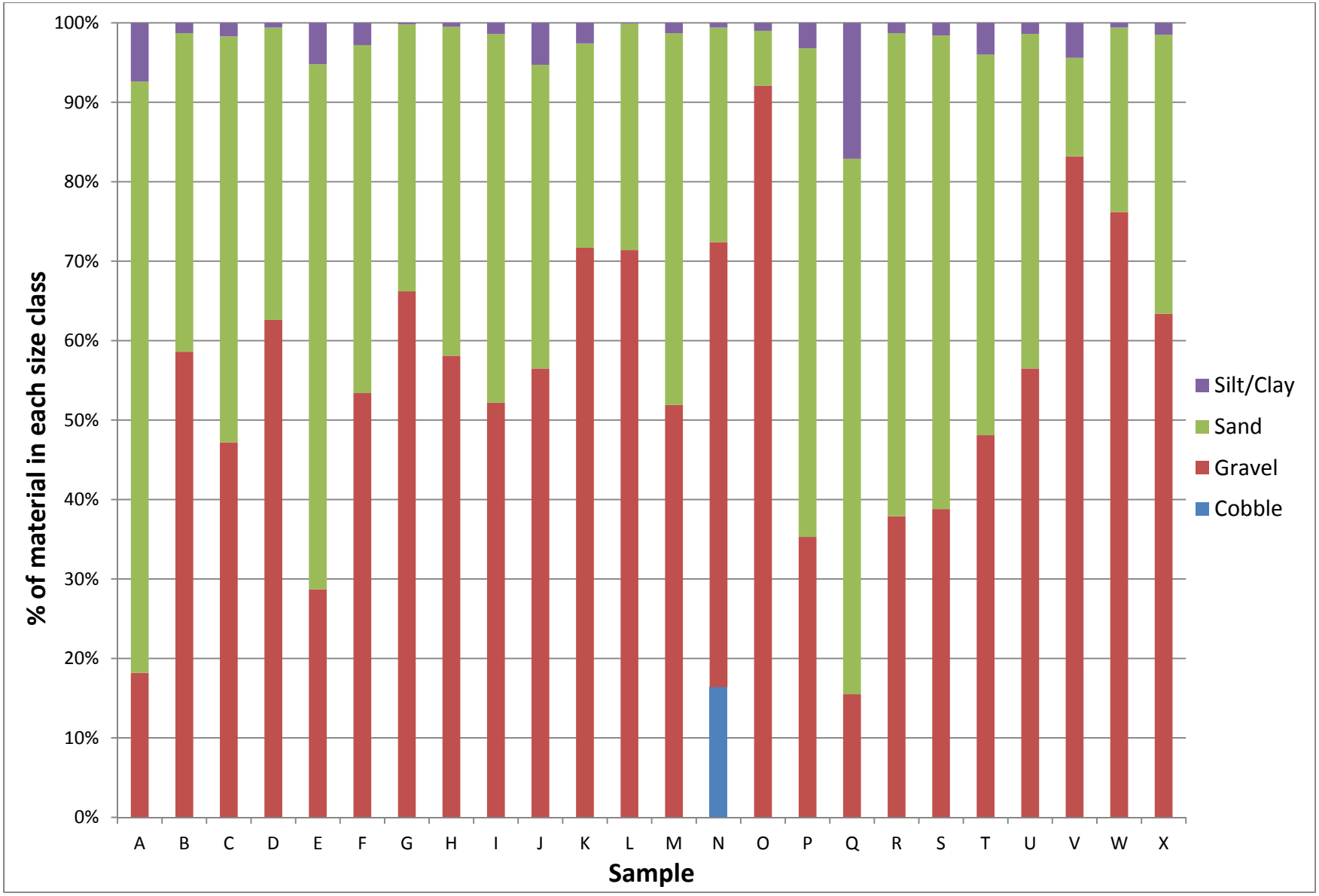


Figure 5. Percent of material in each size class (gravel, sand, silt, clay) for each sample.

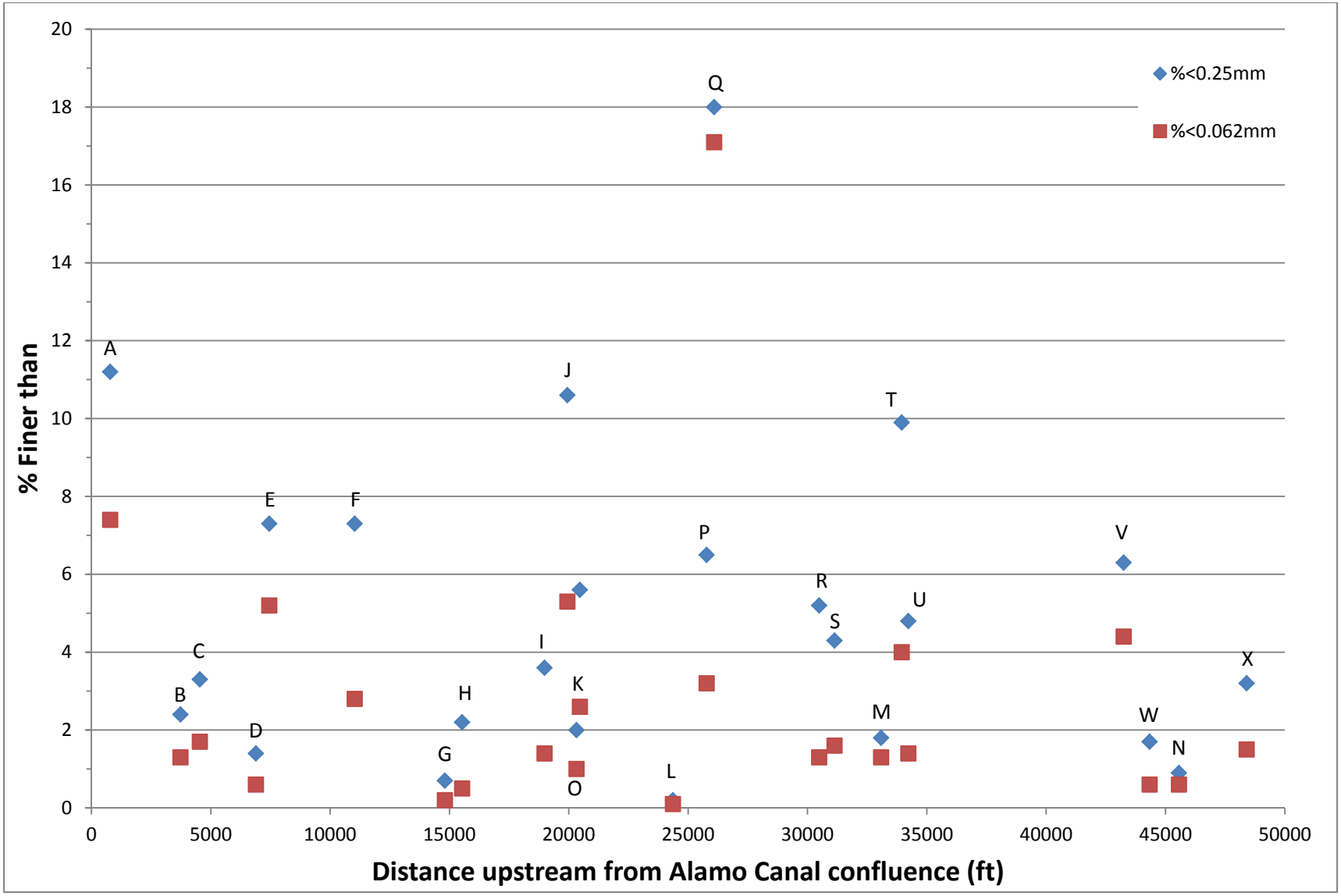


Figure 6. The fine component (finer than 0.25mm) that represents suspended sediment in each sample.

Figure 7. Field photographs of bulk sediment sampling. A) Typical riffle. B) Sampling using the flow barrier in locations with low water levels. C) Resulting void approximately 25cm in depth. D) Typical sediment sample.

Table 1. Location of the 24 bulk sediment samples.

Sample	Location	Latitude	Longitude
A	Arroyo Mocho at confluence with Alamo Canal	37.86442	-121.91032
B	Arroyo Mocho downstream of Chabot Canal	37.86736	-121.90084
C	Arroyo Mocho upstream of Chabot Canal	37.86824	-121.89827
D	Arroyo Mocho downstream of Tassajara Creek	37.87090	-121.89089
E	Arroyo Mocho upstream of Tassajara Creek	37.87161	-121.88917
F	Arroyo Mocho at AMP gauge	37.87534	-121.87784
G	Arroyo Mocho downstream of Line G-3	37.87967	-121.86599
H	Arroyo Mocho upstream of Line G-3	37.88032	-121.86367
I	Arroyo Mocho in restoration reach	37.88033	-121.85182
J	Arroyo Mocho in sediment basin at Las Positas conf.	37.88020	-121.84850
K	Arroyo Mocho upstream of Las Positas confluence	37.87891	-121.84838
L	Arroyo Mocho adjacent to Quarry Lakes	37.87282	-121.83831
M	Arroyo Mocho at AMH gauge	37.86316	-121.81443
N	Arroyo Mocho upstream of Holmes Street	37.85995	-121.77900
O	Arroyo Las Positas upstream of sed basin at Mocho conf.	37.88053	-121.84719
P	Arroyo Las Positas downstream of Cottonwood Creek	37.88553	-121.83199
Q	Arroyo Las Positas upstream of Cottonwood Creek	37.88513	-121.83114
R	Arroyo Las Positas downstream of Airway Blvd	37.88551	-121.81947
S	Arroyo Las Positas upstream of Airway Blvd	37.88484	-121.81746
T	Arroyo Las Positas downstream of Collier Creek	37.88261	-121.80975
U	Arroyo Las Positas upstream of Collier Creek	37.88268	-121.80856
V	Arroyo Las Positas downstream of Cayetano Creek	37.88681	-121.78530
W	Arroyo Las Positas upstream of Cayetano Creek	37.88488	-121.78433
X	Arroyo Las Positas at ALP gauge	37.88620	-121.77355

Table 2. Bulk sediment sample grain size distribution. D85, D50, and D15 are reported in mm.

Sample	D85	D50	D15	%<0.25mm	%<0.06mm	% cobble	% gravel	% sand	% silt/clay
A	5.6106	1.0793	0.3373	11.2	7.4	0	18.2	74.4	7.4
B	13.9814	6.0297	0.9359	2.4	1.3	0	58.6	40.1	1.3
C	9.3287	4.4883	1.4231	3.3	1.7	0	47.2	51.1	1.7
D	28.4231	7.879	0.9504	1.4	0.6	0	62.6	36.8	0.6
E	7.0897	2.3671	0.5046	7.3	5.2	0	28.7	66.1	5.2
F	15.6177	5.5715	0.7135	7.3	2.8	0	53.4	43.8	2.8
G	19.8032	9.1322	1.0737	0.7	0.2	0	66.2	33.6	0.2
H	19.5353	6.5887	0.7793	2.2	0.5	0	58.1	41.4	0.5
I	13.8217	5.1334	0.7152	3.6	1.4	0	52.2	46.4	1.4
J	20.8039	6.4637	0.4683	10.6	5.3	0	56.5	38.2	5.3
K	23.0567	10.5545	1.1732	5.6	2.6	0	71.7	25.7	2.6
L	25.1344	10.7416	2.0589	0.2	0.1	0	71.4	28.5	0.1
M	30.0405	5.3042	1.0784	1.8	1.3	0	51.9	46.8	1.3
N	77.6631	18.7725	1.6916	0.9	0.6	16.4	56	27	0.6
O	21.268	13.3609	6.6116	2	1	0	92.1	6.9	1
P	11.5003	2.454	0.4581	6.5	3.2	0	35.3	61.5	3.2
Q	4.9321	1.1955	0.7094	18	17.1	0	15.5	67.4	17.1
R	12.7408	2.3709	0.4007	5.2	1.3	0	37.9	60.8	1.3
S	9.5146	3.4072	0.8818	4.3	1.6	0	38.8	59.6	1.6
T	25.4652	4.2191	0.3521	9.9	4	0	48.1	47.9	4
U	24.3067	6.6	0.577	4.8	1.4	0	56.5	42.1	1.4
V	35.0435	17.4525	4.1305	6.3	4.4	0	83.2	12.4	4.4
W	29.1863	12.8263	2.5416	1.7	0.6	0	76.2	23.2	0.6
X	32.0049	9.3339	0.967	3.2	1.5	0	63.4	35.1	1.5