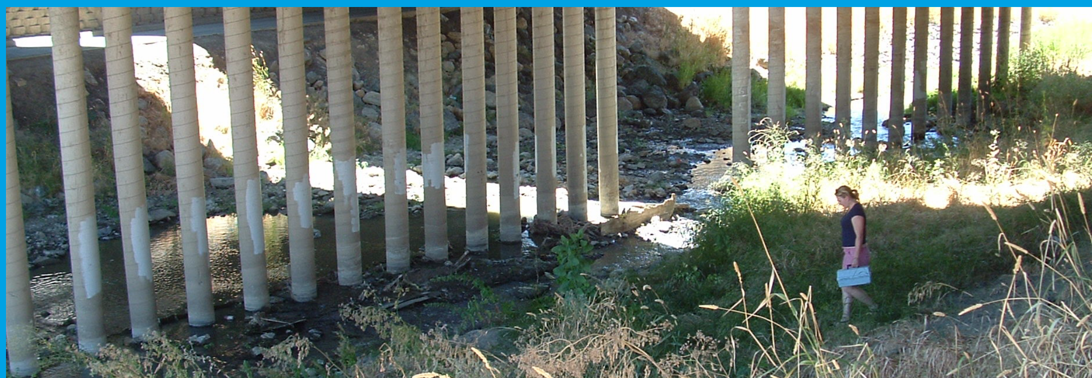

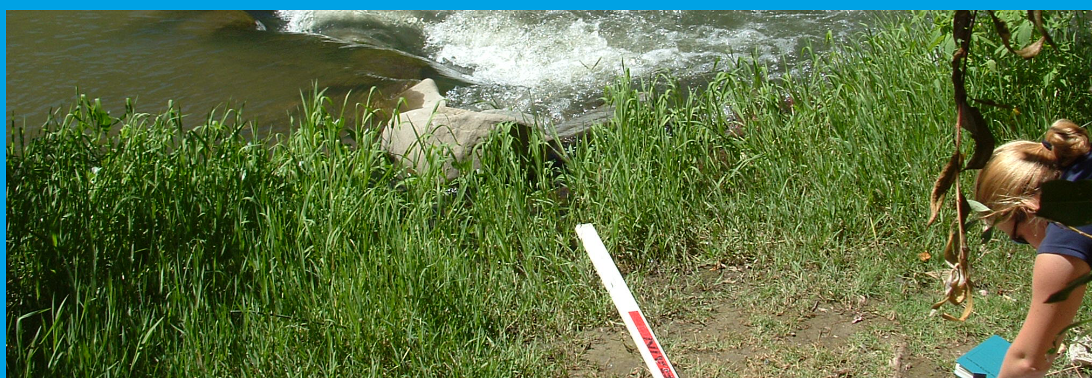

Spatiotemporal Variation of Turbidity in Alameda Creek and Selected Tributaries: August through December 2007

by

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EXECUTIVE SUMMARY

Turbidity is a measurement of the cloudiness of water associated with suspended sediments and organic matter and elevated turbidity in a creek can have deleterious impacts on fish and fauna. If turbidity information is coupled with data on suspended sediment concentrations and flow, an estimate of fine sediment load and potential deposition on sensitive downstream locations can also be modeled. 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. Turbidity was significantly elevated during high flow conditions, but our own monitoring as well as USGS data suggests that the elevated turbidity decreases rapidly after cessation of a high flow event. We also measured temperature and dissolved oxygen on five occasions and found that dissolved oxygen was generally high enough to support anadromous salmonids, however water temperatures may be elevated above optimal rearing temperatures. To provide further insights on sources and variability of turbidity and perhaps fine sediment loads, another year of monitoring under different climatic conditions and monitoring in select locations to understand point source inputs could be completed. In reaches where turbidity nears recommended water quality objectives, a bioenergetics study of the target fish species to understand if they are able to meet their energy requirements for survival and growth would be a vital next step to determine if turbidity or other factors such as dissolved oxygen, food resources, and temperature are limiting.

I. PURPOSE

Despite extensive human development activities, the Alameda Creek watershed still supports a large array of native fish species, and great attention is now focused on restoring the anadromous steelhead (*Oncorhynchus mykiss)* and Chinook salmon (*Oncorhynchus tshawytscha)* populations. Turbidity and suspended sediment are known to negatively impact salmonids and reduce growth rates. The purpose of this study was to collect low-flow turbidity information throughout Alameda Creek and selected tributaries during the months of August-December. We aimed to determine whether and where reaches exist that have chronic and/or sporadic high levels of turbidity in relation to Water Quality (WQ) standards, guidelines or recommendations found in local policy documents and scientific literature. The results of this study may indicate reaches or subwatersheds where excessive sediment may be originating, where research into the effects on the local fish population may be considered, and where if necessary management options to decrease turbidity could be explored.

II. INTRODUCTION

Turbidity is a commonly measured parameter of water quality, and specifically refers to the 'cloudiness' in water. While certain magnitudes and fluctuations of turbidity in creeks may be natural, chronic high turbidity or pulses in excess of natural variation due to human activities in a watershed are undesirable because of how turbidity blocks light transmission to photosynthesizing aquatic vegetation and impairs the respiration and vision of sighted aquatic organisms. In addition, the presence of elevated turbidity in flowing waters indicates downstream transport of fine suspended sediment. A creek, such as Alameda Creek, in a developed watershed may be subject to chronic and/or sporadic pulses of high turbidity. In this report we describe turbidity in Alameda Creek and selected tributaries from observations made from August through early December 2007 and discuss the probable implications for anadromous fish. Since suspended sediment concentrations and flow were not measured, no estimates could be made of the downstream transport of fine sediment loads but it is recognized that this is an important issue to consider in the future in relation to sedimentation in the Alameda County Water District (ACWD) recharge facilities, the ACFC&WCD Fremont Flood Control Channel and sensitive downstream habitats for native or endangered species.

Turbidity Measurement

Turbidity is measured by nephelometry, which measures the side scattering of light off of suspended particles, usually centering on a 90 degree angle. Turbidity is reported in nephelometric turbidity units (NTU), a unit relating the amount of side-scatter of light in a water sample to the amount of side-scatter produced from an arbitrary standard of formazin (Davies-Colley and Smith, 2001). Turbidity measurement is not absolute – it is a function of the optics and design of the instrument, and therefore is unique for each instrument. Studies of turbidity measurement using different nephelometers indicate that different instruments can yield significantly different results (Duchrow and Everhart, 1971; Davies-Colley and Smith, 2001; Lewis et al, 2007; Klein et al., 2008). Therefore, it is important to calibrate and maintain a single instrument during each study and to be cautious when comparing results from different instruments.

Relationship of Turbidity to Suspended Solids and Water Clarity

Turbidity is correlated with suspended sediment concentration (SSC) and is an indirect measure of visual water clarity, both ecologically significant parameters of water quality. Turbidity measurements are correlated with suspended sediment concentrations because increasing suspended sediment in a sample will cause increased light scatter during turbidity measurement. Studies have shown these correlations (Pavanelli & Pagliarani 2002, Lewis et al. 2002), however, the strength and slope of the correlation can differ significantly between watersheds and different locations within the same watershed. These differences have to do with the varying characteristics of sediments as well as the varying amounts of suspended organic particle concentrations (which increase turbidity but not SSC) (Davies-Colley and Smith, 2001). Turbidity is also highly correlated (inversely) with visual water clarity. Visual water clarity, however, is a direct measurement of the visible distance through a water column and can be directly measured using methods such as a Secchi disc (measures visibility along a vertical column) or black disc (measures visibility along a horizontal column) (Davies-Colley and Smith, 2001). Despite some of the inherent complications in interpreting and comparing turbidity measurements, it remains the easiest and cheapest method of indicating water clarity and particle concentrations in the water that may impact fish, leading to its widespread usage in the regulatory and environmental resource management fields.

Impact of Turbidity on Fish

Turbidity and suspended solids are known to impose a variety of negative impacts on fish which may be lethal, sub-lethal, or cause behavioral changes that may result in immediate death or population decline over time (reviews of studies found in: Lloyd, 1987; Newcombe and MacDonald, 1991; Bash et al., 2001; Rosetta, 2004). The impacts of excess suspended solids on fish can be classified* as causing:

<u>Behavioral changes</u> such as avoidance, break down of social structure and territoriality, alteration to foraging activities, slowed reactivity, and impaired migration;

<u>Physiological stresses</u> to fish such as gill trauma, gill flaring, cough frequency, elevated blood sugar, plasma and cortisol, and impaired growth and reproduction; and

<u>Habitat effects</u> including impairment to the prey communities as well as suspended sediment deposition causing increased embeddedness, loss of pool volume, and decreased hyporheic upwelling.

*classification from Bash et al., 2001.

Turbidity, an optical measurement, will directly affect those fish behaviors associated with vision (i.e. foraging, reactive distance, etc.). Turbidity also impacts fish indirectly by decreasing light penetration into the water, which is necessary for plant photosynthesis, and thus has ramifications for the entire aquatic ecosystem. The behavioral alterations caused by turbidity are cumulative with the physiological and habitat effects resulting from increased suspended sediments. These combined effects may further be synergistic with other environmental factors including: duration, frequency and magnitude of exposure; particle size, type, angularity and toxicity; season and water temperature; species and life stage of the fish; natural background turbidity in the area; presence and access to refugia; and other stressors present (Newcombe and MacDonald, 1991; Bash et al. 2001).

Relevant Water Quality Guidelines, Standards or Objectives

In the San Francisco Regional Water Quality Control Board (SFRWQCB) Basin Plan (2007), the turbidity water quality objective (3.3.19) states:

> 'Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases from normal background light penetration or turbidity relatable to waste discharge shall not be greater than 10 percent in areas where natural turbidity is greater than 50 NTU."

The first sentence refers to turbidity within water bodies more generally while the second sentence refers more specifically to waste discharges, or point sources, contributing to turbidity. Interpreting the first sentence for a specific watershed involves considering the beneficial uses of the water body and the turbidity at which those uses are considered to be adversely affected. Interpreting the second sentence involves defining "normal background" turbidity; multiple procedures have been described for doing this, some of which are discussed later.

The SFRWQCB has identified a number of beneficial uses in the Alameda Creek watershed on which elevated turbidity could have negative impacts, including agricultural supply, municipal and domestic supply, recreation, groundwater recharge, warm freshwater habitat and wildlife habitat (SFRWQCB Basin Plan, 2007). Many streams in the watershed have also been identified as having beneficial uses specific to fish. These uses include:

> 2.1.3 COLD FRESHWATER HABITAT (COLD)
> Uses of water that support cold water ecosystems, including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates. Cold freshwater habitats generally support trout and may support the anadromous salmon and steelhead fisheries as well…
>
> 2.1.10 FISH MIGRATION (MIGR)
> Uses of water that support habitats necessary for migration, acclimatization between fresh water and salt water, and protection of aquatic organisms that are temporary inhabitants of waters within the region. The water quality provisions acceptable to cold water fish generally protect anadromous fish as well. However, particular attention must be paid to maintaining zones of passage. Any barrier to migration or free movement of migratory fish is harmful…

2.1.18 FISH SPAWNING (SPWN)
Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. Dissolved oxygen levels in spawning areas should ideally approach saturation levels….

Below is a table of the existing (E) and potential (P) beneficial uses identified in the various streams sampled within this study:

Table 1: Identified Potential and Existing Beneficial Uses in the Alameda Creek Watershed (SFRWQCB, 2007). 'P' indicates a potential beneficial use for the stream reach, and 'E' indicates an existing beneficial use.

	COLD	MIGR	SPWN
Alameda Ck	E	E	E
Arroyo De La Laguna	P	E	E
Arroyo Del Valle	E	P	E
Arroyo Mocho	P	E	E
Tassajara Ck	P	E	E
Arroyo Las Positas	P	E	E
Arroyo Seco	P	E	E
Alamo Canal	P	E	E

Given that the streams sampled in this study have been identified as having potential or existing beneficial uses related to anadromous fish cold freshwater habitat, migration and spawning, the water quality objectives that turbidity not adversely affect these beneficial uses applies. In the absence of quantitative regulations, we rely on the literature to inform turbidity thresholds for causing adverse impact on anadromous fish. Numerous studies have observed the various adverse impacts on fish species at a variety of magnitudes and durations of turbidity exposure (reviews of studies found in: Lloyd, 1987; Newcombe and MacDonald, 1991; Bash et al., 2001; Rosetta, 2004). Deleterious impacts on fish are seen in conditions of as little as 10 NTU and the severity of impacts increase with increased turbidity. Based on Klein et al, (2008), McBain and Trush (2007, pg. 14) propose three ecologically significant turbidity thresholds that could affect juvenile and smolt growth in Alameda Creek. In the absence of quantitatively defined regulations, the turbidity results from this study will be analyzed in relation to those thresholds proposed by McBain and Trush.

The three proposed thresholds* are:

a) 10 NTU for greater than 50% of the time exposed
b) 25 NTU for greater than 20% of the time exposed
and
c) 50 NTU for greater than 10% of the time exposed

* refer to Klein et al. (2008, pp. 50-57) for justification of thresholds.

In identifying these thresholds, Klein et al. (2008) highlight the cumulative effect of elevated turbidity in relation to duration. Negative impacts on fish have been observed even at relatively low turbidity when the exposure is over a longer duration. These are only suggested thresholds and the reader should note the inherent challenges (previously mentioned) of comparing turbidity measurements. Further, it is recognized that these thresholds are recommended for November 15 to June 15 in any one year, while this study occurred from early August to early December. A brief discussion of the applicability of these thresholds to this study will be given in Section V of this report.

III. Methods

Data on spatiotemporal variation of turbidity in Alameda Creek and selected tributaries was collected from twenty-five locations during nineteen field days between August 10 and December 7, 2007.

Site Selection

Alameda Creek watershed boasts the largest drainage area in the nine county San Francisco Bay Area with multiple major and minor tributaries. Sample site selection was an ongoing process, with several alterations to the site list made in the early stages of the sampling period based on feedback from stakeholders, site reconnaissance, and analysis of early results. Site selection was based on the following objectives:

- To sample a minimum of sixteen locations per field day.
- Our ability to complete each round of sampling in a single field day.
- The site accessibility and safety; assumed to be best at road crossings over creeks.
- A wide spatial distribution of sites to acquire understanding of spatial variation of turbidity throughout the creek and selected tributaries and the potential to identify reaches or subwatersheds with relatively elevated turbidity, if any.

Site selection involved compilation of an original list of approximately twenty-five potential sampling sites throughout the watershed. The first sampling day and chance for site reconnaissance led to modifications after multiple sites in the upper watershed were found to be dry. Discussions with stakeholders led to further refinements in site selection. High turbidity at the “Mocho @ Hopyard” and “Mocho @ Santa Rita” sites early in the study led to the addition of “Line G3 @ Mocho” and “Mocho above Line G3” in the attempt to more narrowly identify the source areas of the high turbidity. Our final list of sample sites was too long to accomplish in one field day, so some sites were sampled on every other sampling date. Figure 1 shows the location of each sample site. Table 2 lists all sites, coordinates and descriptions of sampling locations. Those sites in the table with a (1) or (2) after the name indicates that they were sampled every other time, and all the (1)’s were sampled on the same day, as were all the (2)’s on the alternate day. Those sites with an asterisk (*) after the name were sampled earlier in the study but ultimately dropped during the course of the study. They are still included in this report because, although not critical, the results add support to understanding the spatiotemporal variation of turbidity in the watershed. Figures 2-23 show photos of the sampling locations.

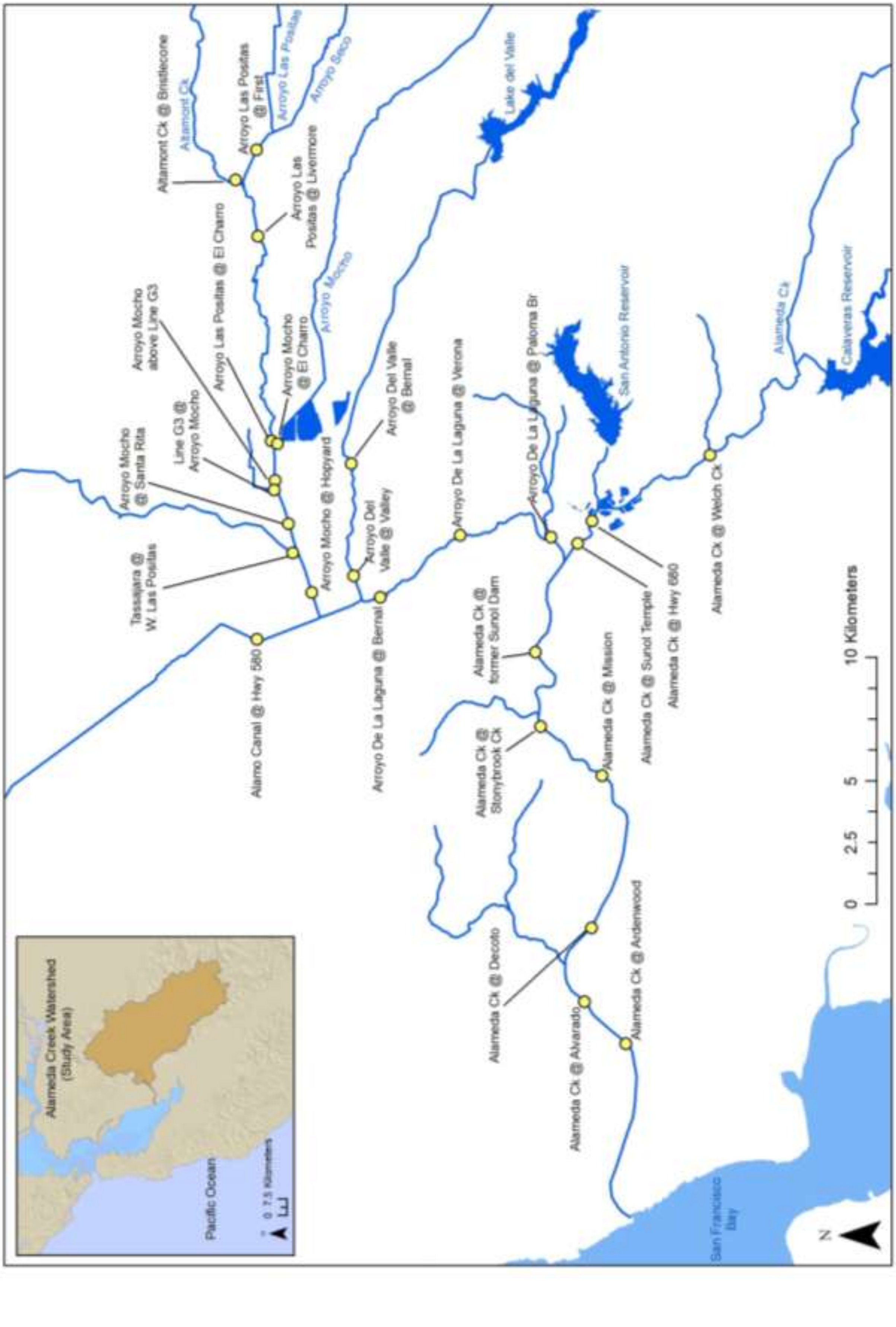

Figure 1: Turbidity Sampling Locations

Table 2: Turbidity sampling locations.

Site Name	Latitude	Longitude	Sample Location Description (Note: "US" means "upstream" and "DS" means "downstream")
Alameda Ck @ Ardenwood	37.5658	-122.0676	Approx. 40 m US of bridge; US third of riprap grade control. Site is tidally influenced. Generally sampled from the edge because it was too deep to wade into.
Alameda Ck @ Alvarado	37.5808	-122.0523	Just DS of DS end of bridge abutments.
Alameda Ck @ Decoto (1)	37.5782	-122.0253	Approx. 20 m US of US bridge abutments. No riffle present, sampled in run.
Alameda Ck @ Mission (2)	37.5744	-121.9700	Approx. 20 m DS of DS bridge abutments
Alameda Ck @ Stonybrook Ck (1)	37.5967	-121.9521	Approx. 10 m US of large cememt structures in stream and about even with DS end of RR crossing abutments.
Alameda Ck @ frmr Sunol Dam (2)	37.5987	-121.9251	Riffle approx. 30 m DS of former dam
Alameda Ck @ Sunol Temple	37.5832	-121.8855	From water temple, walk S past gate and SE along dirt road approx. 200 m. Then turn right onto a dirt road and walk approx. 100 m to a clearing. The creek is on the far side of the clearing.
Alameda Ck @ 680	37.5780	-121.8773	From the end of Athenour Way, walk NE parallel to 680 approx. 250 m. Riffle approx. 25 m US of 680.
Alameda Ck @ Welch Ck (2)	37.5350	-121.8534	Very little flow during sampling period, but fastest flowing area is directly under bridge of Calaveras Rd.
Arroyo De La Laguna @ Paloma Bridge	37.5931	-121.8833	US of bridge; just US of weir
Arroyo De La Laguna @ Verona	37.6262	-121.8825	First riffle DS of bridge, approx. 60 m DS of bridge.
Arroyo De La Laguna @ Bernal	37.6553	-121.9051	Riffle is under bridge.
Arroyo Del Valle @ Valley	37.6651	-121.8973	Riffle under bridge, towards DS edge of bridge.
Arroyo Del Valle @ Bernal *	37.6659	-121.8565	Approx. 20 m DS of bridge.
Alamo Canal @ 580	37.7003	-121.9203	Riffle approx. 80 m DS of bridge.
Arroyo Mocho @ Hopyard	37.6803	-121.9034	Riffle under bridge, towards NE corner of flow.
Tassajara Ck @ W. Las Positas	37.6866	-121.8894	Small riffle approx. 15 m DS of bridge abutments
Arroyo Mocho @ Santa Rita	37.6888	-121.8784	Riffle approx. 10 m DS of bridge
Line G-3 @ Arroyo Mocho	37.6940	-121.8652	Constriction point just US of concfluence with Mocho.
Arroyo Mocho above Line G-3	37.6940	-121.8642	Riffle approx 40 m US of confluence with Line G3.
Arroyo Mocho @ El Charro	37.6940	-121.8484	Sampled flow where it enters the large settling area before it mixes with water from Arroyo Las Positas.
Arroyo Las Positas @ El Charro	37.6940	-121.8483	Riffle just under bridge on DS side of bridge; just US of weir.
Arroyo Las Positas @ Livermore *	37.6999	-121.7737	Riffle directly under bridge.
Arroyo Las Positas @ First St. (1)	37.7005	-121.7423	DS of weir, approx 75 m DS of bridge.
Altamont Ck nr Bristlecone (1)	37.7151	-121.7514	Walk along East side and down from Springtown Blvd. Approx. even with Bristlecone.

Figure 2: Sampling location Alameda Creek @ Ardenwood Blvd. at low tide (2 feet above mean sea level at the Dumbarton Bridge. Site was sampled at tides between 0.1 and 8.2 feet above mean sea level at the Dumbarton Bridge). Photo from right bank.

Figure 3: Sampling location Alameda Creek @ Alvarado Blvd. (from left bank).

Figure 4: Looking downstream toward sampling location Alameda Creek @ Decoto Rd.

Figure 5: Looking upstream toward sampling location Alameda Creek @ Mission Blvd.

Figure 6: Looking downstream from sampling location sampling location Alameda Creek @ Stonybrook Creek.

Figure 7: Looking upstream from sampling location Alameda Creek @ Stonybrook Creek.

Figure 8: Sampling location Alameda Creek @ former Sunol Dam (from right bank).

Figure 9: Looking upstream from sampling location Alameda Creek @ former Sunol Dam. Left bank dam abutment visible slightly right of center in picture.

Figure 10: Looking upstream toward sampling location Alameda Creek @ Sunol Water Temple.

Figure 11: Looking downstream toward sampling location Arroyo De La Laguna @ Paloma Bridge (from left bank).

Figure 12: Looking downstream toward sampling location Arroyo De La Laguna @ Verona (from pedestrian bridge).

Figure 13: Looking downstream toward sampling location Arroyo De La Laguna @ Bernal (from right bank).

Figure 14: Looking downstream toward sampling location Arroyo Del Valle @ Valley Ave.

Figure 15: Looking downstream toward sampling location Alamo Canal @ 580.

Figure 16: Looking downstream from right bank toward sampling location Arroyo Mocho @ Hopyard.

Figure 17: Looking upstream toward sampling location Tassajara Creek @ W. Las Positas.

Figure 18: Looking downstream from right bank toward sampling location Arroyo Mocho @ Santa Rita Road.

Figure 19: Looking upstream on Line G3. Sampling location Line G3 @ Arroyo Mocho is in bottom left corner. Confluence with Arroyo Mocho is just out of view.

Figure 20: Looking upstream toward sampling location (riffle centered in picture) Arroyo Mocho above Line G3.

Figure 21: Confluence of Arroyo Mocho and Arroyo Las Positas. Sampling location Arroyo Las Positas @ El Charro Rd. just above weir. Arroyo Mocho enters via the concrete structure at left center of the picture and samples collected for this location at the entry point.

Figure 22: Looking downstream toward sampling location Arroyo Las Positas @ N. Livermore Ave.

Figure 23: Looking upstream at sampling location Arroyo Las Positas @ First St.

Instrument

We used a Hach 2100P portable turbidity meter (considered the industry standard; Figure 24) calibrated weekly within 24 hours prior to each field excursion. This turbidimeter measures the nephelomtric signal of scattered light at a 90 degree angle to the transmitted light. It has a range of 0-1000 NTU, is accurate to within 2% of the reading plus stray light (<0.02 NTU), and the repeatability is within 1%. The light source is a tungsten filament lamp and the detectors are silicon photovoltaics. The sample cells are Borosilicate glass with screw caps. The standards used for instrument calibration were STABLCAL Stabilized Formazin Standards at four turbidities (<0.1 NTU, 20 NTU, 100 NTU, and 800 NTU). Note that in this study, we report using two significant figures for all measurements under 100 NTU, and three significant figures for measurements 100 NTU or greater. Consistent with the instrument specifications, the accuracy of these measurements is within 2%.

Figure 24: Photo of Hach 2100P turbidimeter.

On October 30, 2007, we verified the accuracy of the turbidimeter instrument used in this project by comparing the results for a set of standard vials to those measured when using a brand new Hach 2100P turbidimeter. The standards used in this instrument verification were Gelex Secondary Standards at values of 0-10 NTU, 0-100 NTU, and 0-1000 NTU. The maximum difference in results (Table 3 below) between the two turbidimeters was 3%.

Table 3. Comparison of turbidity measured using the project turbidimeter and a brand new turbidimeter purchased during the project. Both instruments are the Hach 2100P model.

	Tests Result for (1) Project Turbidimeter	Test Results for (2) New Turbidimeter (purchased 10/2007)	Difference (2-1) / New Turbidimeter Reading (2) (in %)
Test 1 (a)	4.5	4.5	1%
Test 2 (b)	53	55	3%
Test 3 (c)	540	530	-2%
Test 4 (a)	4.5	4.6	1%
Test 5 (b)	53	54	3%
Test 6 (c)	540	530	-1%
Test 7 (a)	4.5	4.6	1%
Test 8 (b)	53	54	3%
Test 9 (c)	540	530	-2%

Field Methods

During primarily low-flow conditions in 2007, i.e., from August-early December, turbidity was sampled at twenty five locations over the course of nineteen field days. The route of travel through the watershed was altered throughout the study period to reduce the potential bias in the results by sampling a site at the same time every sampling event. On site, grab samples were taken from the fastest velocity area observed in the upstream one-third portion of a riffle at each sample location. Where no riffles were present within 100 m of the entry point, samples were taken in the fastest velocity areas of a run. Specific sampling locations for each site are described in Table 2 (page 12 of this report). Where possible, sample locations were approached from downstream and care was taken not to disturb the turbidity upstream before taking each sample. Sampling did not occur when there was either no visible flow, or dangers to field personnel (e.g. feral pigs in SFPUC open space lands near site "Alameda Creek @ Sunol Water Temple") were present near the site. At each site, samples were taken in triplicate using three glass vials, dried with a paper towel, and gently inverted three times before placing each into the Hach 2100P. Measurements were recorded, along with sample time and water depth at the sampling location. After measurement, samples were discarded and the vials rinsed with deionized water. Sample cells were then refilled with deionized water for transport between sites. On five sampling occasions, ancillary temperature and dissolved oxygen (DO) measurements were also taken using a YSI multimeter and recorded for each site. In mid-November, a sighting of the invasive New Zealand Mud Snail was reported in the Alameda Creek Watershed. To prevent spread of this invasive species, beginning on November 20 and through to the end of the project, any field member entering the creek wore 18" boot covers. After each sampling event, the covers were carefully removed inside-out to prevent contamination and then disposed of.

IV. RESULTS

A table of summary statistics and the measurements at each site for each sampling event are shown in Table 4 and Figures 25-31. The sampling events can be categorized as taking place during low- and high-flows which correspond to daily mean discharge between 23 and 61 cfs at the Niles Gage for low-flow conditions, and a daily mean discharge of 385 cfs at the Niles Gage for the high flow event. Figure 32 shows the daily average discharge at the USGS Alameda Creek at Niles gauge with the sample dates imposed.

Table 4: Turbidity sampling summary statistics. Note measurement accuracy is ±2%.

	Low Flow Conditions						High Flow Conditions
	Min Turbidity (NTU)	Max Turbidity (NTU)	Mean Turbidity (NTU)	Median Turbidity (NTU)	Standard Deviation (NTU)	Count (n)	Turbidity (NTU)
Alameda Ck @ Ardenwood	22	882	106	56	197	18	357
Alameda Ck @ Alvarado	5.8	20	9.6	9.2	3.3	18	
Alameda Ck @ Decoto	0.6	22	4.7	2.9	6.6	9	
Alameda Ck @ Mission	2.6	15	7.8	6.0	4.3	11	187
Alameda Ck @ Stonybrook Ck	2.9	11	6.1	5.4	2.5	10	
Alameda Ck @ frmr Sunol Dam	3.2	9.1	6.0	6.8	2.1	11	221
Alameda Ck @ Sunol Temple	1.0	11	4.1	1.3	4.5	5	
Alameda Ck @ 680	0.8	1.8	1.4	1.4	0.5	3	
Alameda Ck @ Welch Ck	0.3	2.4	0.9	0.5	0.8	7	1.1
Arroyo De La Laguna @ Paloma Bridge	5.1	17	11	11	3.6	18	249
Arroyo De La Laguna @ Verona	7.0	22	15	15	4.0	18	287
Arroyo De La Laguna @ Bernal	8.5	19	14	14	3.3	18	285
Arroyo Del Valle @ Valley	1.7	4.8	3.1	3.0	1.0	18	15
Arroyo Del Valle @ Bernal	1.4	1.6	1.5	1.5	0.1	3	
Alamo Canal @ 580	4.2	19	9.9	9.6	3.6	16	227
Arroyo Mocho @ Hopyard	20	63	46	49	13	18	360
Tassajara Ck @ W. Las Positas	7.1	151	43	38	34	16	40
Arroyo Mocho @ Santa Rita	10	77	40	38	22	16	309
Line G-3 @ Arroyo Mocho	7.1	392	73	40	106	12	33
Arroyo Mocho above Line G-3	7.6	33	15	14	6.9	12	274
Arroyo Mocho @ El Charro	6.6	6.6	6.6	6.6		1	103
Arroyo Las Positas @ El Charro	4.2	15	7.7	7.7	2.9	18	267
Arroyo Las Positas @ Livermore	1.7	2.1	2.0	2.1	0.2	3	
Arroyo Las Positas @ First St.	2.8	31	9.0	6.2	8.7	10	
Altamont Ck nr Bristlecone	7.0	42	20	16	14	6	

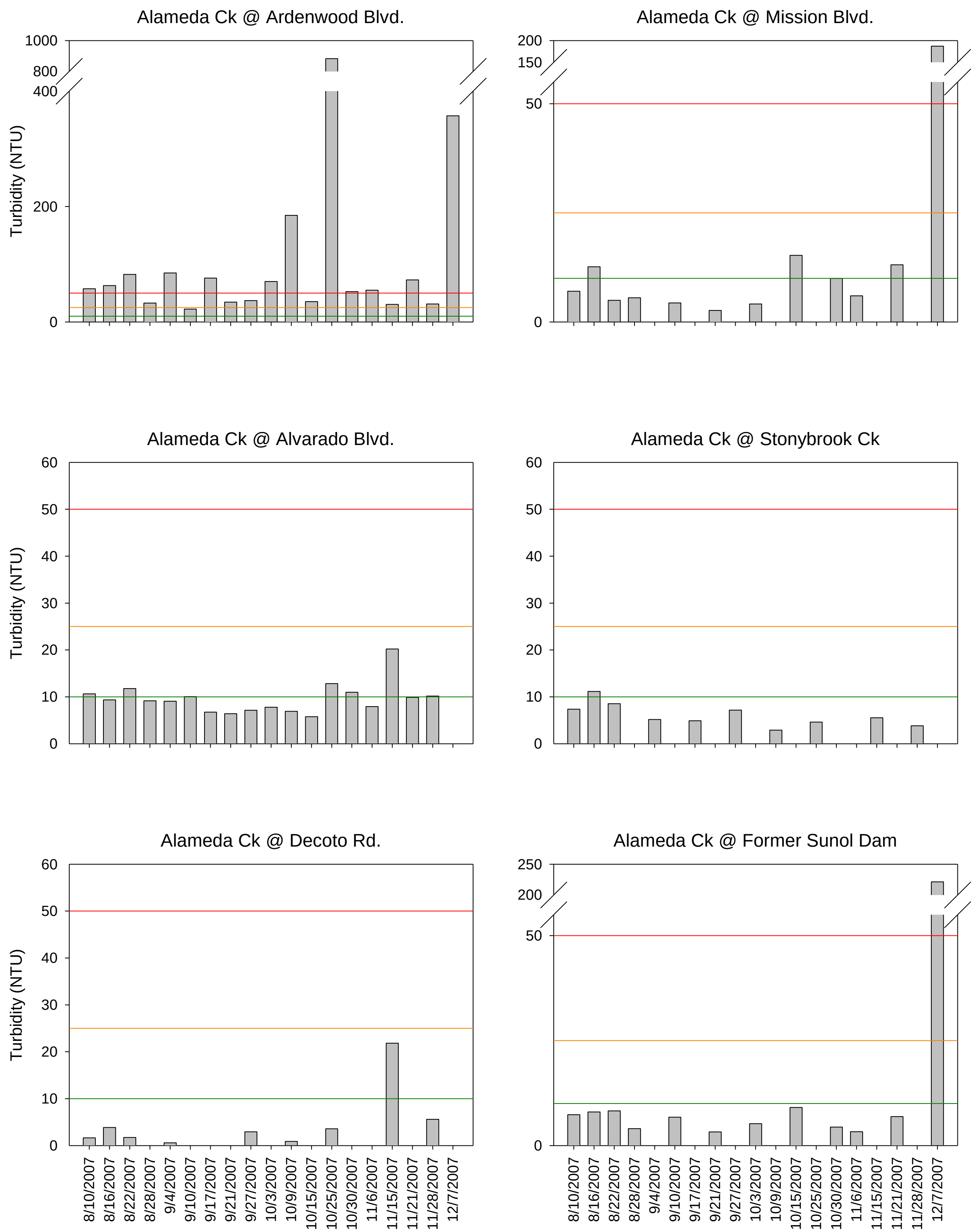

Figure 25: Sampling results for each event at individual sites.

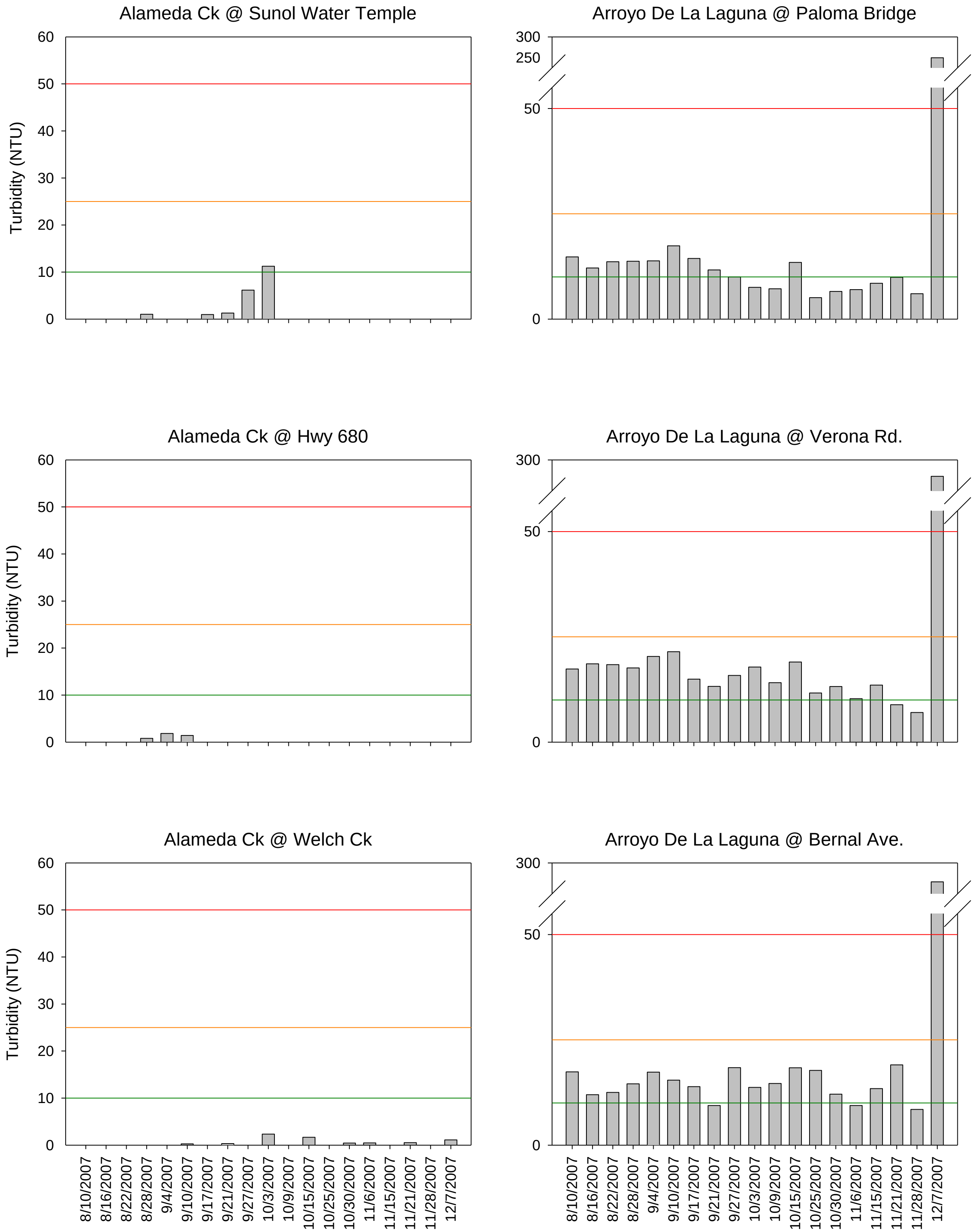

Figure 26: Sampling results for each event at individual sites.

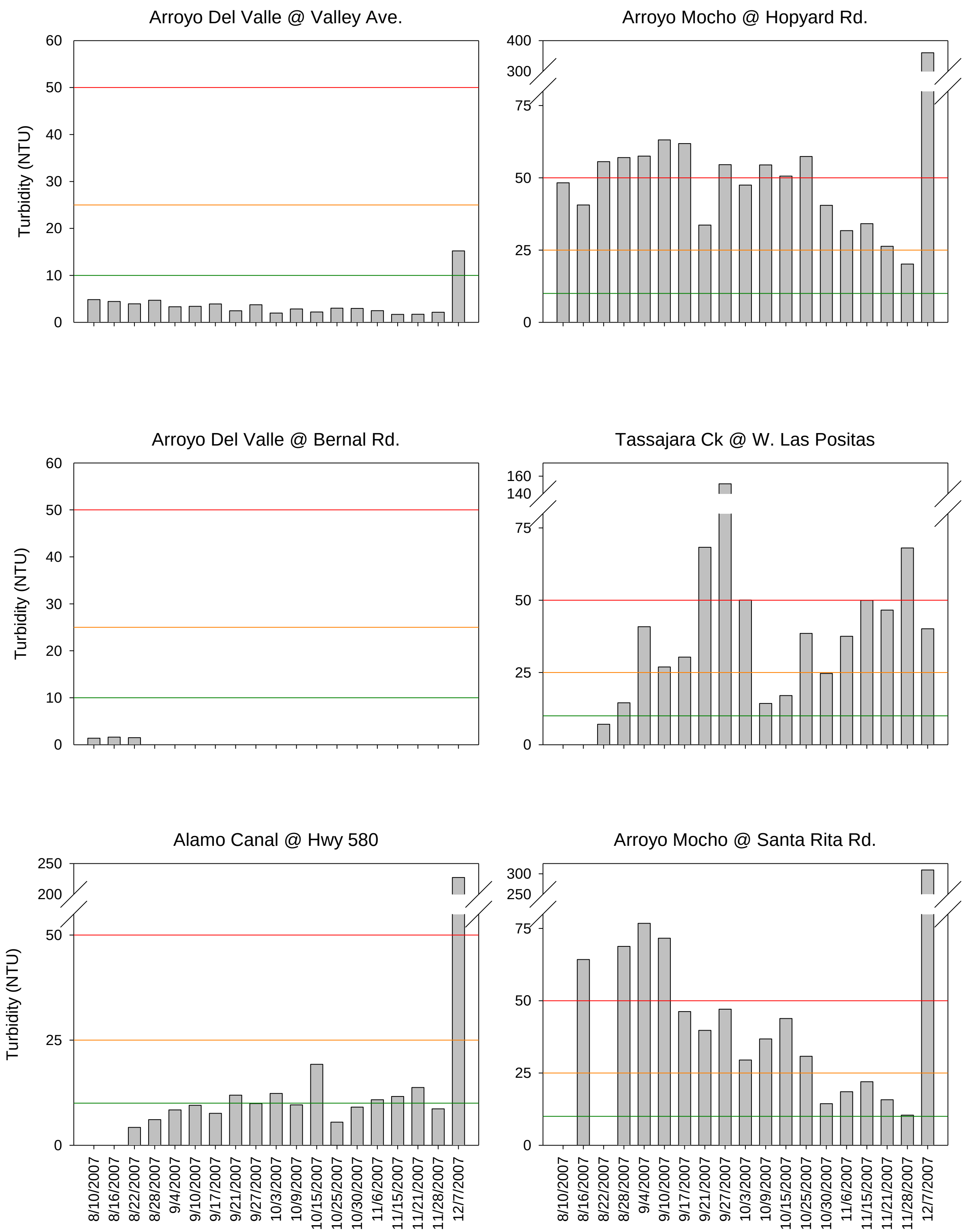

Figure 27: Sampling results for each event at individual sites.

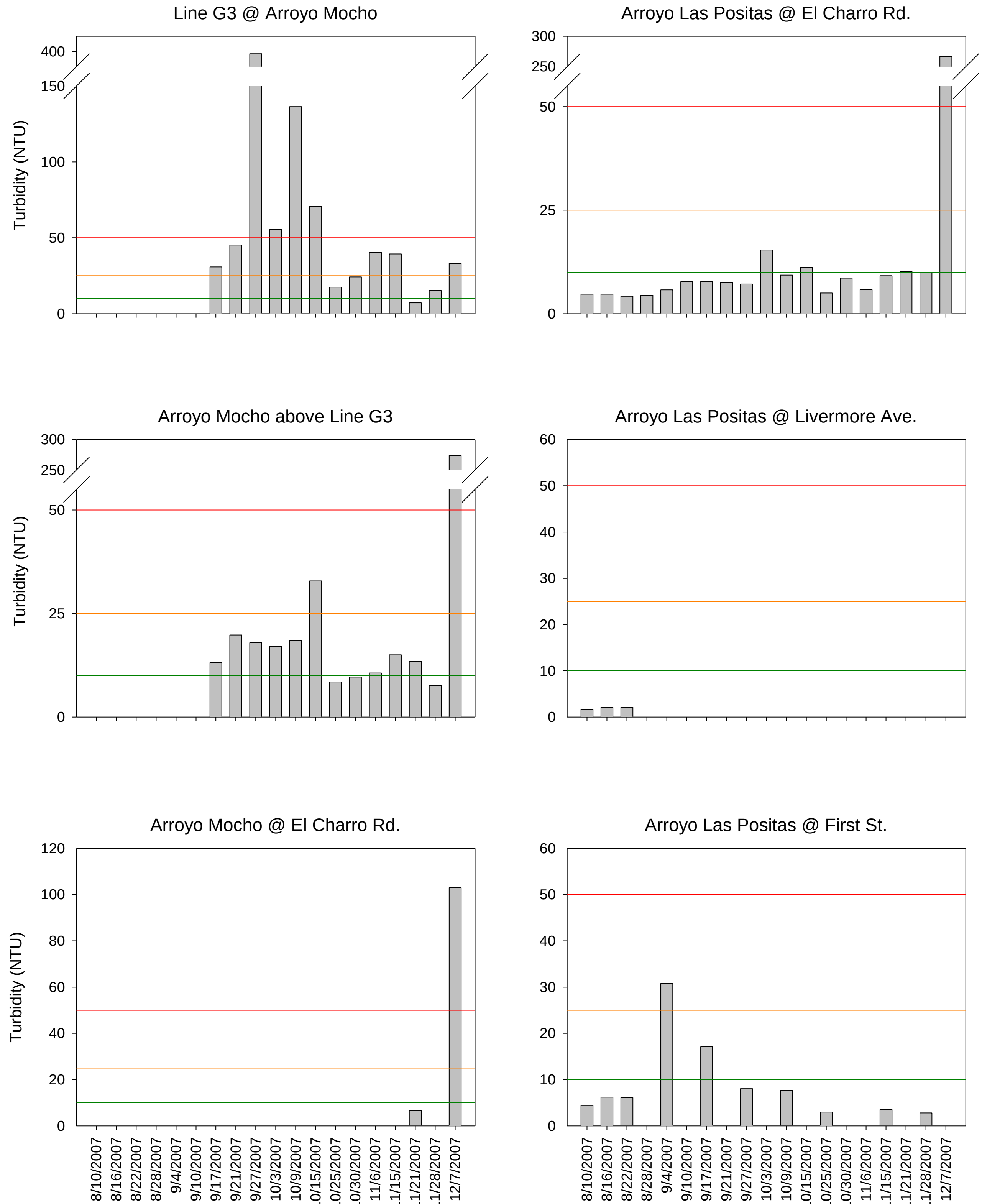

Figure 28: Sampling results for each event at individual sites.

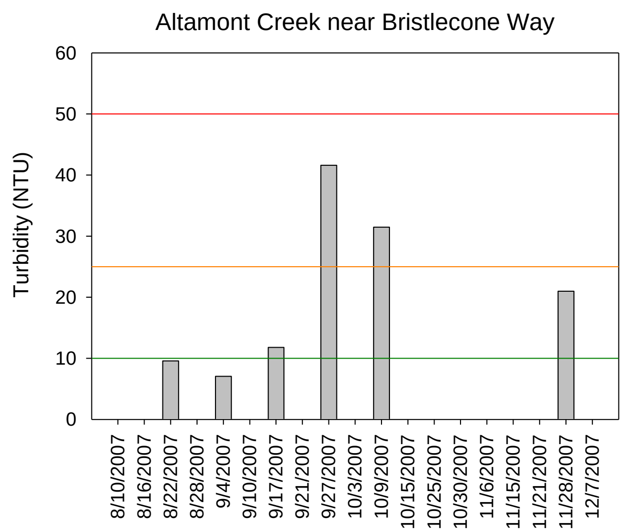

Figure 29: Sampling results for each event at individual sites.

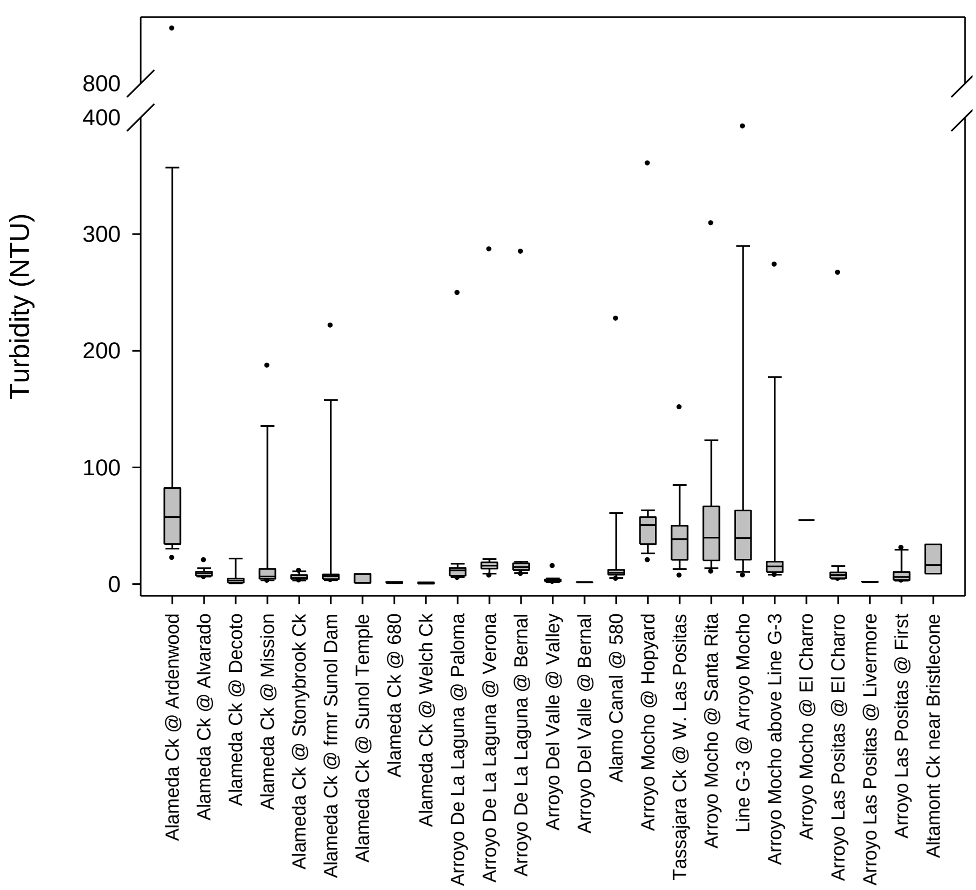

Figure 30: Box plots of turbidity results for each sampling location. In each panel, the top and bottom of the box depicts the 25th and 75th percentiles of the data and the line within the box is the median. Tick marks above and below the box are the 10th and 90th percentiles, and the dots are the data points beyond these percentiles.

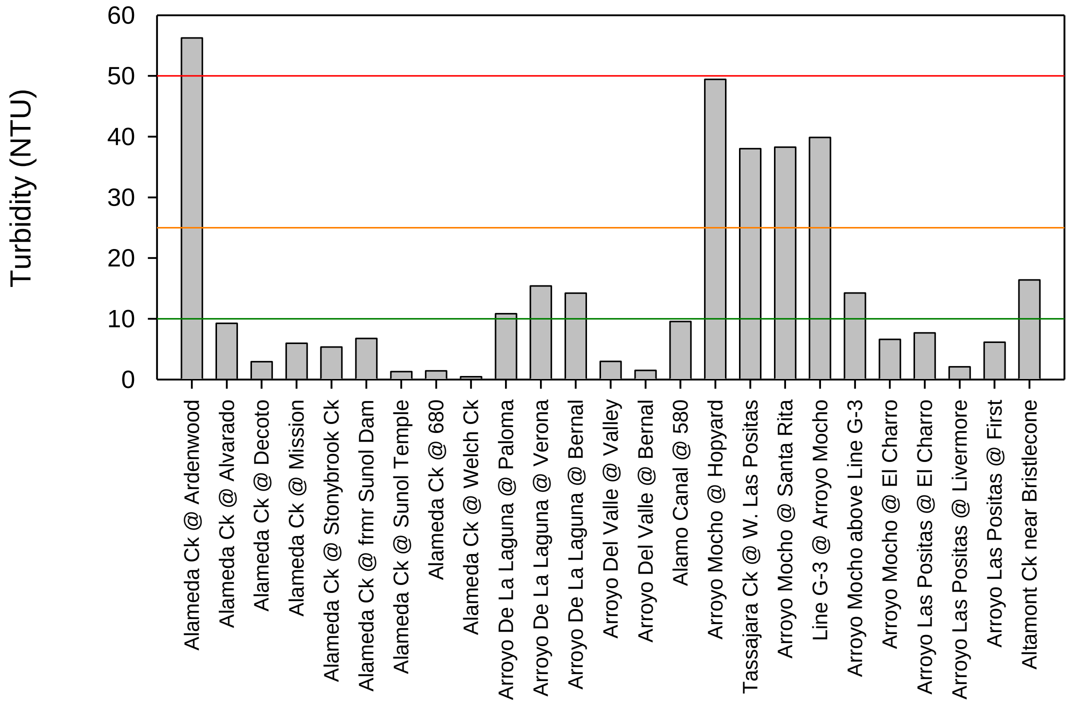

Figure 31: Median turbidity for each sampling location.

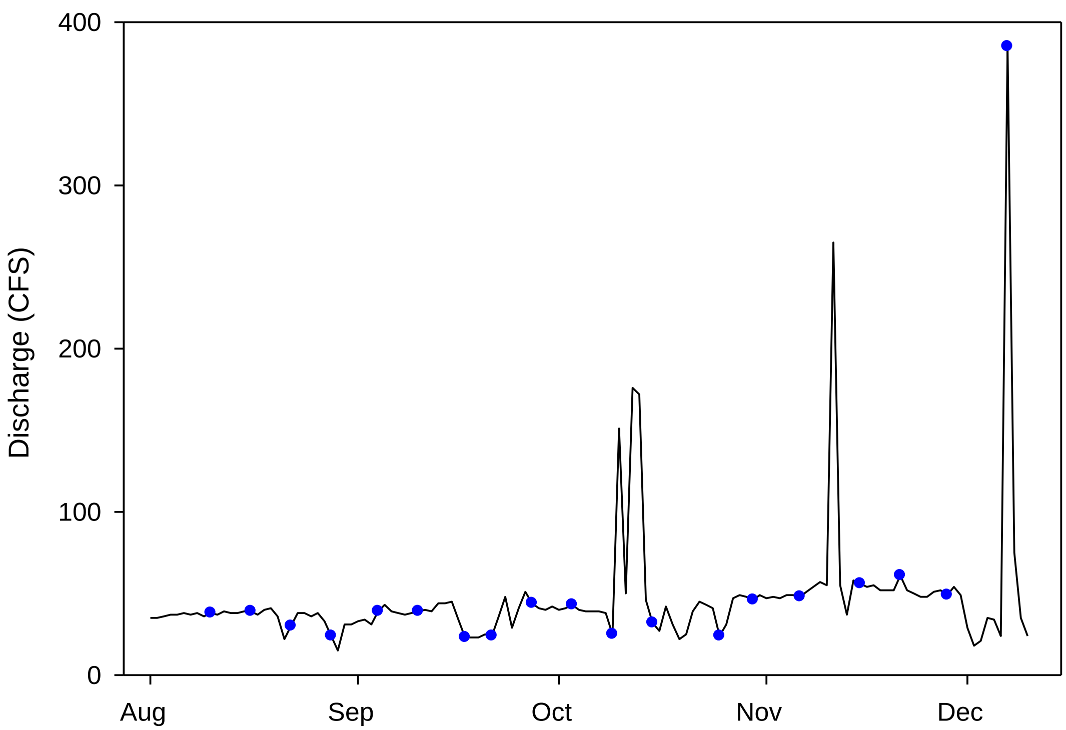

Figure 32: Sample dates imposed on the hydrograph at the USGS Niles Gage (USGS preliminary data subject to revision). Note 400 cfs is a common event with a return period of <1 year.

Low-Flow Turbidity Results

The first eighteen sampling events occurred during relatively low-flows, with average daily discharge ranging between 23 and 61 cfs. At most sites over the course of these eighteen field days, measured turbidity varied little. "Alameda Ck @ Ardenwood Blvd.", the furthest downstream site in the watershed, was a notable exception; however, the fluctuations at this site are linked to the natural tidal flux experienced there. Two tributaries in Arroyo Mocho also fluctuated more significantly during the low-flow period. "Tassajara Creek @ W. Las Positas" varied between 7 and 150 NTU, with a relatively high mean and median of 43 and 38 NTU, respectively. Likewise at "Line G3 @ Arroyo Mocho", turbidity ranged from 7 to 392 NTU and the mean and median were 73 and 40 NTU, respectively. Land use development is occurring in both of these watersheds and may be a contributor to these variable and relatively high turbidities. Interestingly, the Tassajara and Line G3 sites both reached very high low-flow turbidities on the same day, September 27, 2007. The average daily flow at the USGS Niles gauge was 44 cfs and the previous day's average flow was 51 cfs, which was the largest flow in the sampling record up to that point in the study (note USGS preliminary data subject to revision). The median turbidity at each site for the low-flow period is shown spatially in Figure 33.

Table 5 shows the percentage of sampling events at each site in which turbidity was greater than the three magnitude thresholds (10, 25 and 50 NTU) proposed by McBain and Trush (2007, based on Klein et al, 2008). Percentages shown in red exceed the proposed magnitude-duration thresholds. Some stream reaches stand out having elevated turbidities relative to other reaches. The results of these sections are systematically discussed below, beginning with the most upstream section:

<u>Arroyo Las Positas and Altamont</u>
The low-flow median turbidity at the Arroyo Las Positas sites was generally under 10 NTU; slightly higher turbidities were encountered at "Altamont Ck @ Bristlecone". Turbidity at "Altamont Ck @ Bristlecone" exceeded the 10 NTU for greater than 50% exposure, and the 25 NTU for greater than 20% exposure thresholds.

<u>Arroyo Mocho</u>
Arroyo Mocho upstream of it's confluence with Arroyo Las Positas was low during the entire low-flow sampling period except on one day when the average reading was 7 NTU. Downstream of the confluence with Arroyo Las Positas and just above Line G3, the median turbidity was moderate at 14 NTU and exceeded the proposed threshold of 10 NTU for greater than 50% of the samples. Downstream of the Line G3 input, Arroyo Mocho sites have moderately-high medians in the 25-50 NTU range, which may be partly or completely attributable to the turbid inputs from Line G3 and Tassajara Creek (sites previously discussed). All of these sites exceeded all three of the magnitude-duration thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008) (Table 5).

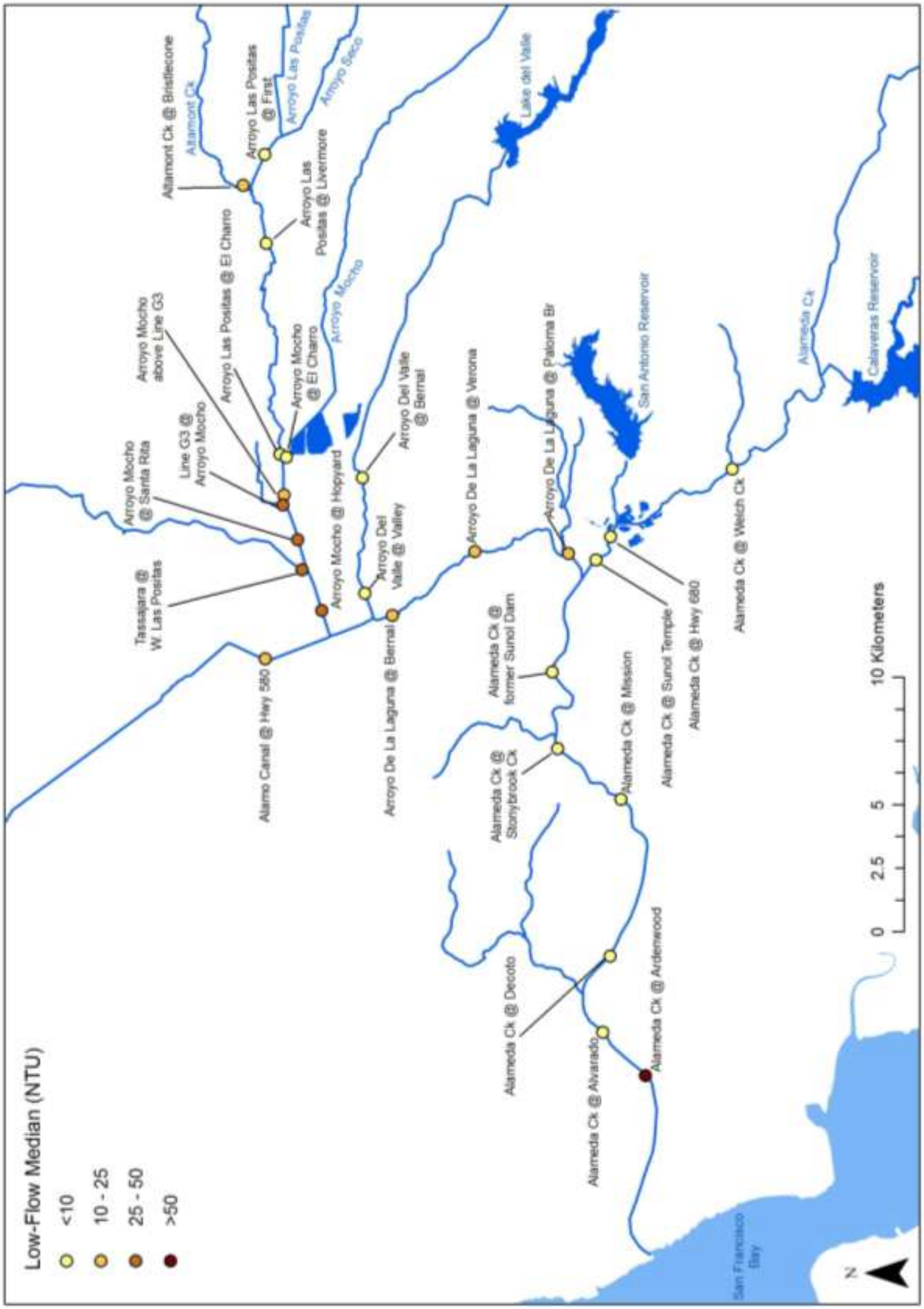

Figure 33: Median Low-Flow Turbidity

Table 5: Turbidity results as related to the three magnitude-duration thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008). The italicized numbers (also in red) indicate the magnitude-duration thresholds that were exceeded in the results of this study. The color code applied to each reach and illustrated in Figure 34 corresponds with the number of thresholds crossed, where red is applied to sites in which three thresholds were crossed, yellow is applied to sites where one or two thresholds are crossed, and green is applied to sites where no thresholds were crossed. Sites visited on less than five sampling occasions were removed from this analysis.

	Percentage of Sampling Events:				
	≥ 10 NTU	≥ 25 NTU	≥ 50 NTU	Count (n)	Color Code
Alameda Ck @ Ardenwood*	*100%*	*95%*	*63%*	19	Red
Alameda Ck @ Alvarado	39%	0%	0%	18	Green
Alameda Ck @ Decoto	11%	0%	0%	9	Green
Alameda Ck @ Mission	33%	8%	8%	12	Green
Alameda Ck @ Stonybrook Ck	10%	0%	0%	10	Green
Alameda Ck @ frmr Sunol Dam	8%	8%	8%	12	Green
Alameda Ck @ Sunol Temple	20%	0%	0%	5	Green
Alameda Ck @ Welch Ck	0%	0%	0%	8	Green
Arroyo De La Laguna @ Paloma Bridge	*53%*	5%	5%	19	Yellow
Arroyo De La Laguna @ Verona	*89%*	5%	5%	19	Yellow
Arroyo De La Laguna @ Bernal	*84%*	5%	5%	19	Yellow
Arroyo Del Valle @ Valley	5%	0%	0%	19	Green
Alamo Canal @ 580	41%	6%	6%	17	Green
Arroyo Mocho @ Hopyard	*100%*	*95%*	*53%*	19	Red
Tassajara Ck @ W. Las Positas	*94%*	*71%*	*24%*	17	Red
Arroyo Mocho @ Santa Rita	*100%*	*71%*	*29%*	17	Red
Line G-3 @ Arroyo Mocho	*92%*	*69%*	*31%*	13	Red
Arroyo Mocho above Line G-3	*77%*	15%	8%	13	Yellow
Arroyo Las Positas @ El Charro	21%	5%	5%	19	Green
Arroyo Las Positas @ First St.	20%	10%	0%	10	Green
Altamont Ck near Bristlecone	*67%*	*33%*	0%	6	Yellow

* tidally influenced reach

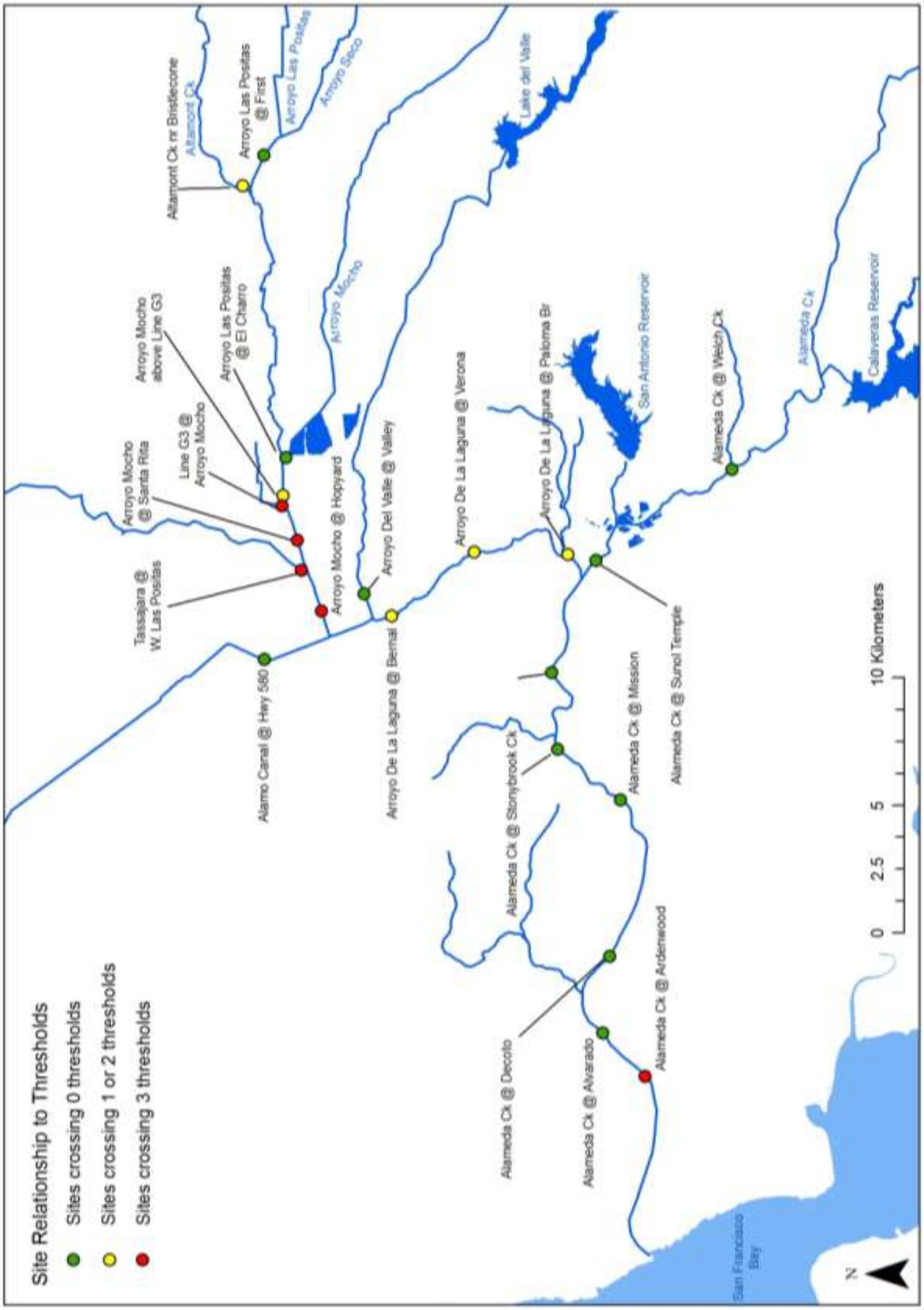

Figure 34: Relationship to Turbidity Thresholds

Arroyo Del Valle

Both Arroyo Del Valle sites had very low turbidity throughout the low-flow sampling period. Out of 18 sampling events, the maximum turbidity at "Arroyo Del Valle @ Valley Ave." was 4.8 NTU. None of the thresholds were exceeded in Arroyo Del Valle.

Arroyo De La Laguna

The three sites in Arroyo De La Laguna have moderate median turbidity readings in the 10-25 NTU range and each exceeds the proposed threshold of 10 NTU for greater than 50% of the samples. Unless there is a point source discharge we are not aware of, Arroyo Mocho is partly or completely the source of this turbidity since Arroyo Del Valle and Alamo Canal appear to be contributing low turbidity. Vallecitos Creek is a significant tributary to Arroyo De La Laguna and enters immediately above the "Arroyo De La Laguna @ Paloma Bridge" site. Although we did not sample Vallecitos Creek directly, the turbidity measurements at "Arroyo De La Laguna @ Paloma Bridge" were generally 2-5 NTU lower than the two upstream Arroyo De La Laguna sites, indicating that Vallecitos Creek is probably not contributing to turbidity in Arroyo De La Laguna during under the sampled flow conditions.

Alameda Creek

Turbidity in Alameda Creek was generally low during the low-flow conditions of the sampling period. Upstream of the confluence with Arroyo De La Laguna, many reaches of the creek were dry or had very low flow. The few samples we were able to collect had extremely low turbidity, and fish were observed at the Sunol Temple site on multiple occasions. Downstream of the confluence with Arroyo De La Laguna, turbidity in Alameda Creek increased slightly with medians all between 3 and 9 NTU but maximum turbidities of 22 NTU. We observed tidal inundation at the most downstream site in the watershed, "Alameda Creek @ Ardenwood". Turbidity was quite varied and high at this site, ranging between 22 and 882 NTU and having a median of 56 NTU. Data collected by other researchers in the region indicates that turbidity in the Bay at Dumbarton Bridge (the closest Bay location where there is systematic turbidity data collection) generally fluctuates throughout the day in relation to tides and wind driven sediment resuspension and largely ranges between 0 and 300 NTU, averaging approximately 75-100 NTU (Buchanan and Ganju 2004; Buchanan and Lionberger 2007; CICORE 2007). Therefore, we attribute the elevated and varied turbidities at this site to tidal influence. With the exception of "Alameda Creek @ Ardenwood", none of the Alameda Creek sites exceed the thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008).

Turbidity following Higher Flows

There were two low-flow sampling events that followed within days of higher discharges at the USGS Alameda Creek at Niles gage (our flow indicator gage site). The first event involved two successive higher daily average discharges of 176 and 172 cfs on October 12th and 13th, respectively. Turbidity was measured in the watershed two days later on October 15th. Although a few locations (Alamo Canal @ Hwy 580, Alameda Creek @ Mission, Arroyo Mocho above Line G3) showed slightly higher turbidities, there was no systematic and/or significant elevated turbidity within the watershed relative to other low-flow samples. The second higher flow event occurred on November 11, 2007, when the daily average discharge was 265 cfs at the Niles gage. Turbidity was measured throughout the watershed four days later and, again, there was no systematic and/or significant elevated turbidity within the watershed. These results suggest that most tributaries and the main stem recover quickly following storm flow; turbidity diminishes rapidly in less than 2-4 days. However, McBain and Trush (2008) graphed the turbidity and discharge at the Alameda Creek near Niles USGS Gaging Station for the 2006 water year and illustrated that turbidity rarely dropped below 10 NTU from November to June, and that it took multiple days for turbidity to decrease below 25 NTU following storm events during the same time period. Therefore, these results indicate that turbidity diminishes rapidly following a dry or early winter season storm event, but may act differently after storm events during latter months in a given wet season.

High-Flow Turbidity Results

On December 7, 2007, the daily average discharge at the USGS Alameda Creek at Niles gage was 385 cfs and turbidity was measured on the same day at sixteen of the sampling sites. The results from our high-flow turbidity observations are listed in Table 4, shown in Figures 25-29 for each sampling site, and illustrated spatially in Figure 35. Turbidity increases over the low-flow results were significant at virtually all sites and exceeded 300 NTU in Arroyo Mocho. “Alameda Creek @ Welch Creek” was the exception with turbidity as low as during the low-flow period likely because the relative increase in flow was less here than in the northern arm of the watershed. “Arroyo Del Valle @ Valley” was also low in turbidity at 15 NTU, however this result was approximately three times the median for that site. Interestingly, the two sites that regularly had high turbidity during the low-flow sampling period, “Tassajara Creek @ W. Las Positas” and “Line G3 @ Arroyo Mocho”, both had turbidities that approximated the median of the dry-flow period and were significantly lower than the maximum low-flow turbidities recorded. These results indicate that perhaps point sources in these two creeks are diluted with higher flows.

USGS Continuous Turbidity Monitoring

The USGS monitors turbidity continuously in 15 minute intervals at three locations in the watershed, Alameda Creek near Niles (11179000), Alameda Creek below Welch Creek near Sunol (11173575), and Arroyo De La Laguna at Verona (11176900). The USGS uses submersible turbidimeters (FTS DTS 12) with infrared lights to measure light scatter, as opposed to the Hach 2100P used in this study, which utilizes a tungsten lamp, or white light (USGS 2005). USGS turbidity data presented here is reported in formazin nephelometric units (FNU) rather than NTUs, and although correlations can be made, the relationship is not 1:1 (USGS 2005). These cautions considered, the continuous datasets offer important insight into the temporal variation at these few locations. Turbidity at the Alameda Creek near Niles gage (Figure 36) ranged from 0 to 600 FNU and averaged 30 FNU during the study period for which USGS data was available (August 27 – December 7, 2007)[1]. As observed in the differences between this study’s low-flow and high-flow results, turbidity at the USGS Niles gage responded significantly to discharge and recovered quickly after high flows (however, note that this data appears noisy and is preliminary and subject to USGS revision).

[1] All USGS turbidity data presented here is raw data and has not been quality checked at this time.

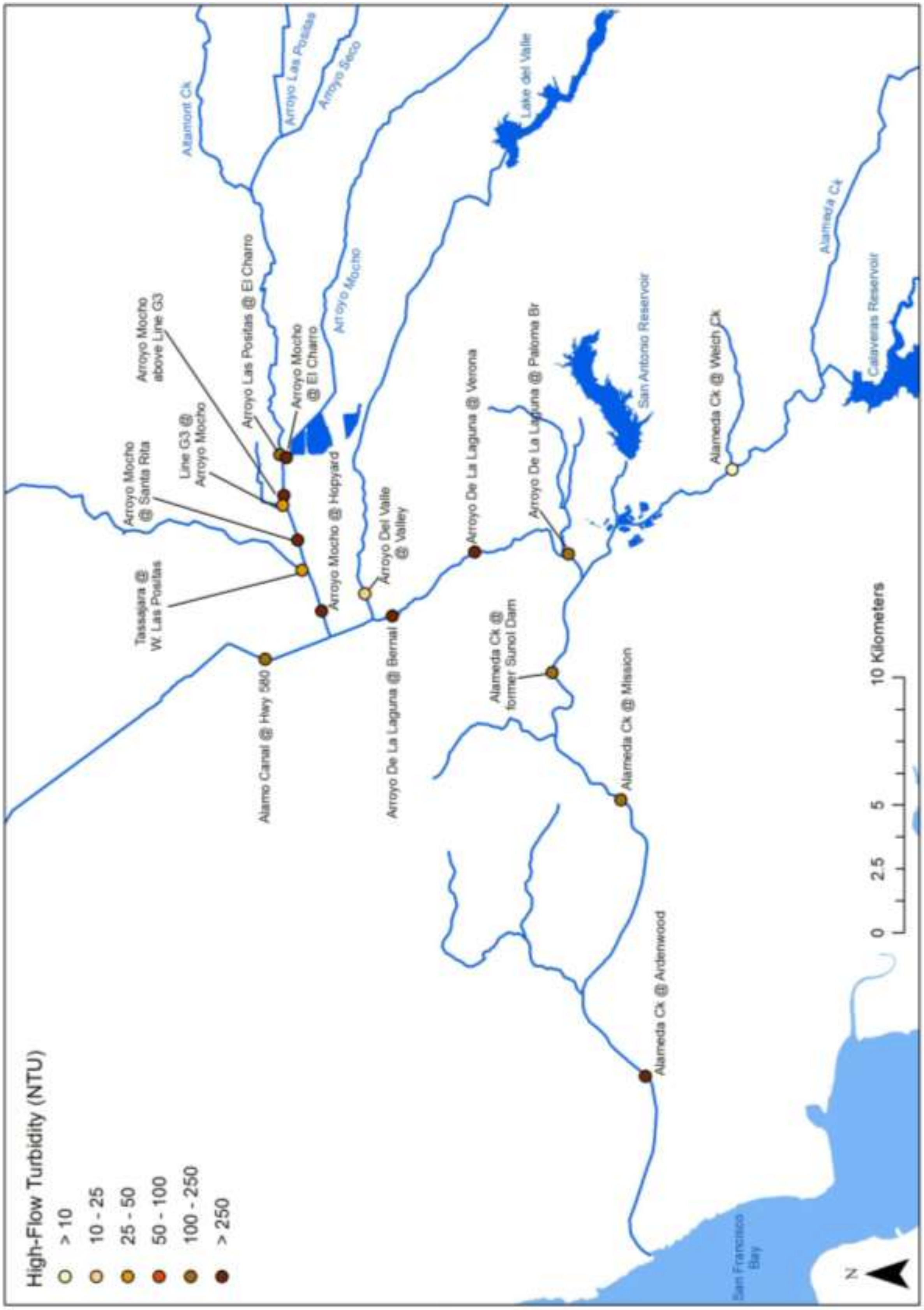

Figure 35: High-Flow Turbidity on 12/07/2007

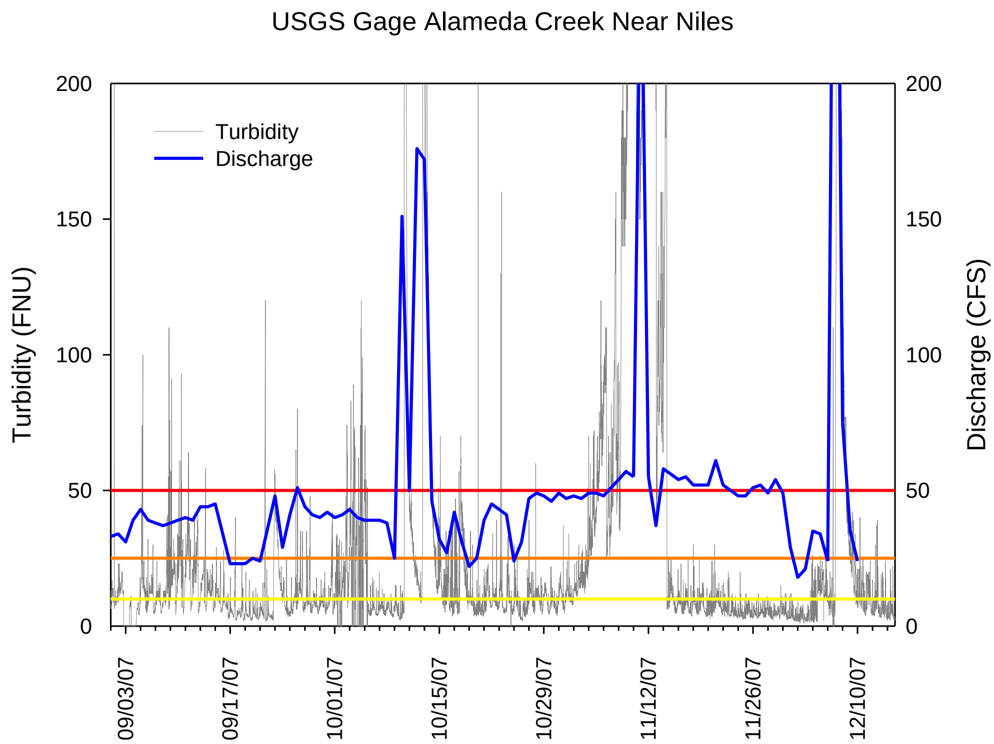

Figure 36: Turbidity at the USGS Gage Alameda Creek near Niles for the period of August 27 – December 7, 2007 (USGS preliminary and subject to revision).

The USGS gage Arroyo De La Laguna at Verona began recording turbidity during the fall 2007, and the location of measurement is approximately 60 m upstream of our own sampling site, Arroyo De La Laguna @ Verona. Although direct comparison between the two types of measurement should not be made, a strong correlation exists (Figure 37). At lower turbidities, the data are similar, but at higher turbidities the Hach 2100P turbidimeter tends to measure turbidity (in NTU) greater than the USGS turbidimeter (measured in FNU). These observations are consistent with other SFEI data for the Guadalupe watershed in Santa Clara County.

A continuous plot of turbidity and discharge at the USGS Arroyo De La Laguna at Verona gage is shown in Figure 38. The continuous record shows much greater variation in turbidity than what our sampling regime captured. Like at the Niles gage previously discussed, turbidity at Verona responds significantly to discharge but recovers quickly after high flows. For the period of September 12 through December 7, 2007, turbidity was greater than 10 FNU 75% of the time, greater than 25 FNU 13% of the time, and greater than 50 FNU 7% of the time. Again, although the measurement methods are not directly comparable, they are similar at lower readings (averaging 4.8% difference between samples under 20 NTU/FNU; with the percent difference calculated as the difference between the SFEI and USGS measurements for the same sample time divided by the average of the two measurements). These results as related to the proposed thresholds provide further support for the conclusion that the chronic background stressor threshold of 10 NTU for greater than 50% exposure is exceeded at this location.

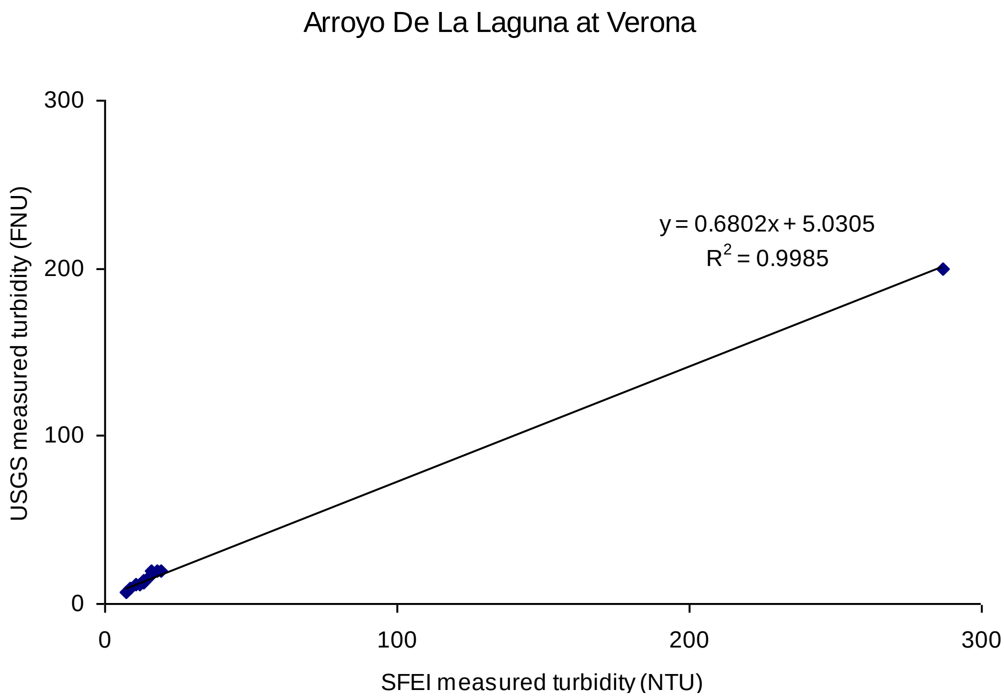

Figure 37: Regression of USGS turbidity measurements versus SFEI turbidity measurements at the Arroyo De La Laguna at Verona USGS gage and SFEI sampling location.

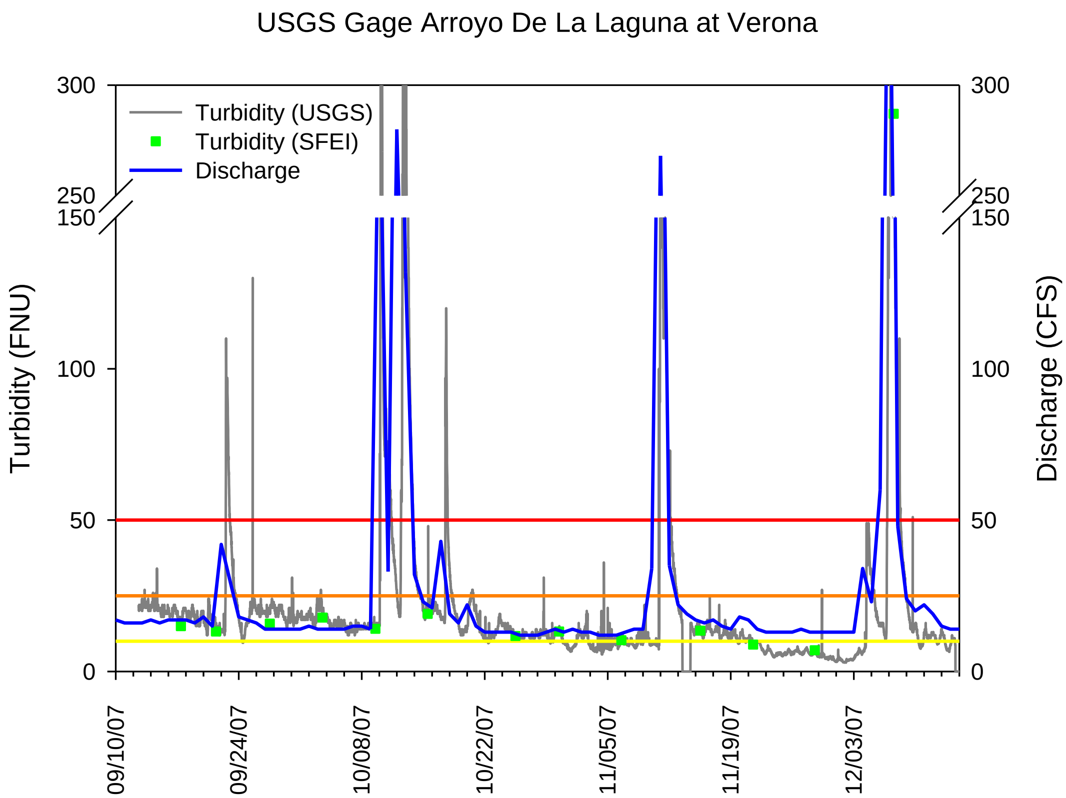

Figure 38: Turbidity at the USGS Gage Arroyo De La Laguna at Verona for the period of September 12 – December 7, 2007.

As mentioned above, the USGS continuous gauges capture greater variation in the turbidity measurements than our point sampling methods. As a result, the USGS turbidity data at the three gages can better offer insight into duration of exposure to various magnitudes of turbidity, and therefore better capture whether or not the magnitude and duration thresholds are crossed. At Arroyo De La Laguna at Verona, our sampling slightly over-predicts the percentage of time that the turbidity is greater than 10 FNU, and slightly under-predicts that percentage of time that the turbidity is greater than 25 and 50 FNU (Table 6 below). Our sampling at this site does accurately indicate that the one threshold (10 NTU for greater than 50% exposure) is crossed, while the others are not. The comparison is not as strong between the other two USGS gages and this study's closest sampling sites to those gages. In both cases, this study's measurements under-predict the duration of exposure to various turbidities at the sites. This poorer comparison may be attributed to the greater spatial discrepancy between sampling locations or the smaller number of sampling events at these sites (10 at Stonybrook Ck and 8 at Welch Ck) as compared to the Arroyo De La Laguna at Verona comparison (19 sampling events). Further, a look back at Figures 36 and 38 shows that the low-flow to high-flow ratio of sampling events in this study (18:1) does not accurately reflect the duration of low-flow and high-flow conditions during the sampling period. Consequently, our results will under-predict the percentage of time that higher turbidities exist at the sampling locations.

Table 6. Comparison of turbidity as related to the three magnitude-duration thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008) between USGS continuous monitoring and the point samples in this study.

			Percentage of time:		
USGS Gage	Period Start	Period End	>10 FNU	>25 FNU	>50 FNU
1) Arroyo De La Laguna @ Verona	9/12/07 14:15	12/7/07 23:45	*75*	13	7
2) Alameda Creek Nr Niles	8/27/07 14:30	12/7/07 23:45	46	*20*	*12*
3) Alameda Creek Below Welch Creek Nr Sunol	10/2/07 17:30	12/7/07 23:45	10	0.5	0.1

	Percentage of time:		
Nearest Sample Site to each USGS Gage	>10 NTU	>25 NTU	>50 NTU
1) Arroyo De La Laguna at Verona	*89*	5	5
2) Alameda Creek at Stonybrook Creek	10	0	0
3) Alameda Creek at Welch Creek	0	0	0

Temperature and Dissolved Oxygen

On five sampling events (four during low-flow conditions and once during high-flow conditions) temperature and dissolved oxygen measurements were recorded using a YSI multimeter. Temperature was largely affected by the time of day the measurements were recorded, and the sampling progression on all five of these sampling events began at the top of the watershed and ended at the Alameda Creek @ Ardenwood Blvd. location. Therefore, we would expect to see a bias in water temperatures increasing in the downstream direction and this is the general trend in the results (Table 6), with temperatures averaging between 12 and 16 degrees Celsius in the tributaries to Arroyo De La Laguna, and averaging between 14 and 22 degrees Celsius in Arroyo De La Laguna and Alameda Creek mainstems. McBain and Trush (2008) recommend an upper daily average water temperature threshold of 68º F (20.0 ºC) for favorable juvenile/smolt growth, while 72º (22.2º C) is considered stressful. They note in their analysis that water temperatures exceeded juvenile growth thresholds in Niles Canyon and farther downstream by mid-June. The results of our study do not refute their conclusion that temperature may be a limiting factor for steelhead during the summer months, but the temperature measurements in this study are instantaneous and cannot be extrapolated to represent daily averages.

The San Francisco Water Quality Control Board's Basin Plan states that for nontidal waters, the dissolved oxygen (DO) water quality objective for cold water habitat is a minimum concentration of 7.0 mg/l. Minimum concentrations measured throughout the watershed were occasionally below 7.0 mg/l, but averages for each site (two to five point samples) were generally higher (Table 7). The Arroyo De La Laguna mainstem had average concentrations between 9.5 and 11.2 mg/l, and Alameda Creek between 9.8 and 12.3 mg/l except in the two lower most sites (Alameda Creek @ Alvarado and Ardenwood) and the uppermost Welch Creek location. The Welch Creek site had extremely low, almost stagnant flows, and the lowermost Ardenwood Blvd. location is tidally influenced. The Alvarado Blvd. location may not meet the SFWQCB quality objective. Of course these measurements were only point measurements taken during the daytime and do not represent worst-case DO scenarios that occur in the morning hours around dawn.

V. Discussion

Alameda Creek is the largest watershed in the San Francisco Bay Area and current efforts are ongoing to understand, restore, and improve anadromous Chinook salmon and steelhead trout populations. The current primary limitations to restoring anadromous fish runs are migration barriers throughout the watershed, but work is being done to remove or mitigate these barriers. After barriers are removed, secondary concerns about limiting habitat conditions emerge including flow, turbidity, water temperature, cover elements and predation, competition with other species, food resources, and dissolved oxygen. As anadromous fish spawn and rear in the Alameda Creek watershed, it is important that elevated turbidity and suspended sediments do not decrease their spawning success and/or growth prior to returning to the ocean, where size is of extreme importance to their performance and survival.

Table 6: Results of Temperature Measurements

	Low Flow Conditions						High Flow Condition*
	Min (°C)	Max (°C)	Mean (°C)	Median (°C)	Standard Deviation (°C)	Count (n)	Temperature (°C)
Alameda Ck @ Ardenwood	14	22	17	16	3.7	4.0	12
Alameda Ck @ Alvarado	13	21	17	17	3.1	4	ND
Alameda Ck @ Decoto	19	24	21	21	3.6	2	ND
Alameda Ck @ Mission	13	17	15	15	2.2	2	12
Alameda Ck @ Stonybrook Ck	15	19	17	17	2.6	2	ND
Alameda Ck @ frmr Sunol Dam	13	16	14	14	2.0	2	12
Alameda Ck @ Sunol Temple	20	20	20	20	NA	1	ND
Alameda Ck @ 680	ND	ND	ND	ND	ND	ND	ND
Alameda Ck @ Welch Ck	16	17	17	17	0.7	2	12
Arroyo De La Laguna @ Paloma Bridge	14	21	17	17	2.8	4	12
Arroyo De La Laguna @ Verona	12	21	16	16	3.6	4	12
Arroyo De La Laguna @ Bernal	11	18	15	15	3.0	4	12
Arroyo Del Valle @ Valley	10	17	13	13	2.6	4	11
Arroyo Del Valle @ Bernal	ND	ND	ND	ND	ND	ND	ND
Alamo Canal @ 580	9.8	18	14	14	3.3	4	11
Arroyo Mocho @ Hopyard	9.7	19	14	14	3.8	4	11
Tassajara Ck @ W. Las Positas	7.4	17	12	13	3.8	4	11
Arroyo Mocho @ Santa Rita	9.5	16	12	12	2.6	4	11
Line G-3 @ Arroyo Mocho	8.9	14	13	14	2.7	4	12
Arroyo Mocho above Line G-3	11	17	14	14	2.5	4	11
Arroyo Mocho @ El Charro	12	12	12	12	NA	1	11
Arroyo Las Positas @ El Charro	10	17	14	14	3.0	4	11
Arroyo Las Positas @ Livermore	ND	ND	ND	ND	ND	ND	ND
Arroyo Las Positas @ First St.	14	17	15	15	2.2	2	ND
Altamont Ck near Bristlecone	16	16	16	16	NA	1	ND

*Only one high flow sampling event on 12/7/2007.
**ND = No data; NA = Not Applicable

Table 7: Results of Dissolved Oxygen Measurements

	Low Flow Conditions						High Flow Condition*
	Min (mg/l)	Max (mg/l)	Mean (mg/l)	Median (mg/l)	Standard Deviation	Count (n)	DO (mg/l)
Alameda Ck @ Ardenwood	*4.9*	8.2	6.2	5.9	1.5	4	9.2
Alameda Ck @ Alvarado	*5.8*	8.8	6.9	6.5	1.4	4	ND
Alameda Ck @ Decoto	11	13	12	12	1.6	2	ND
Alameda Ck @ Mission	12	13	12	12	0.6	2	11
Alameda Ck @ Stonybrook Ck	10	10	10	10	0.2	2	ND
Alameda Ck @ frmr Sunol Dam	9.7	10	10	10	0.5	2	10
Alameda Ck @ Sunol Temple	9.8	9.8	9.8	9.8	NA	1	ND
Alameda Ck @ 680	ND	ND	ND	ND	ND	ND	ND
Alameda Ck @ Welch Ck	*3.3*	3.6	3.5	3.5	0.2	2	9.4
Arroyo De La Laguna @ Paloma Bridge	9.4	11	10	9.9	0.7	4	10
Arroyo De La Laguna @ Verona	7.9	11	9.5	9.6	1.4	4	10
Arroyo De La Laguna @ Bernal	8.5	14	11	11	2.4	4	9.8
Arroyo Del Valle @ Valley	6.6	8.2	7.4	7.3	0.7	4	8.7
Arroyo Del Valle @ Bernal	ND	ND	ND	ND	ND	ND	ND
Alamo Canal @ 580	9.3	13	12	12	1.7	4	11
Arroyo Mocho @ Hopyard	7.3	12	9.9	10	2.0	4	10
Tassajara Ck @ W. Las Positas	*5.3*	10	8.1	8.4	2.1	4	9.5
Arroyo Mocho @ Santa Rita	*6.1*	11	8.6	8.5	2.1	4	9.9
Line G-3 @ Arroyo Mocho	7.5	11	9.4	9.7	1.3	4	9.3
Arroyo Mocho above Line G-3	10	14	13	13	1.8	4	10
Arroyo Mocho @ El Charro	10	10	10	10	NA	1	11
Arroyo Las Positas @ El Charro	9.3	13	11	11	1.6	4	11
Arroyo Las Positas @ Livermore	ND	ND	ND	ND	ND	ND	ND
Arroyo Las Positas @ First St.	7.8	10	9.1	9.1	1.9	2	ND
Altamont Ck near Bristlecone	*4.7*	4.7	4.7	4.7	NA	1	ND

*Only one high flow sampling event on 12/7/2007.
**ND = No data; NA = Not Applicable

Chinook salmon and steelhead have different life histories in the watershed, and it is important to keep in mind the life stage of each species when relating the results from this study. Chinook salmon would presumably swim into the watershed during November and December to spawn and their offspring would head back out to the ocean in later spring and early summer (pers. comm., J. Miller, Alameda Creek Alliance). The young are not likely to oversummer, and thus turbidity may be a lesser concern for Chinook salmon during the period represented by this study (late summer and fall). Spawning adults in November and December, however, may choose to avoid areas of heightened turbidity, although studies of adult avoidance indicate that they are much less sensitive than juveniles and turbidity is more likely to delay migration to natal waters than deter it completely (Bash et al., 2001). More concerning is the potential increased embeddedness caused by the settling of suspended particulates, depleting the intragravel flow of oxygen rich waters necessary for successful spawning, egg incubation, and waste product removal. Suspended sediment deposition is beyond the scope of this study and would require further investigation.

Steelhead can employ a wide range of life tactics and are more likely to be affected by turbidity during the late summer to fall. Typically steelhead will spawn from December to March, the young will rear in freshwaters up to two years or more, and then smolt and head out to the ocean during spring. For those juveniles that remain in the watershed a year or more, August through early December can be a challenging time for them bioenergetically due to lower flows and increased water temperatures. Therefore, excess turbidity at this time could be an important stressor and inhibitor to the growth success of oversummering steelhead due to lack of food as turbidities greater than 10 NTU decrease primary stream productivity.

McBain and Trush, working with the Alameda Creek Fisheries Restoration Workgroup, have identified a number of probable life history tactics that steelhead may have employed historically in the Alameda Creek watershed. Some of these tactics involve juvenile steelhead oversummering in lower Alameda Creek and Niles Canyon reaches of Alameda Creek. While Arroyo De La Laguna, Arroyo Mocho and the other tributaries where turbidity was measured are not indicated as providing probable habitat for oversummering steelhead, the turbidity from these upstream areas is important in terms of how it translates down through the watershed.

Turbidity in the upper reaches of the watershed that were measured was unseasonably high. Particularly in the flowing section of the Arroyo Mocho downstream of the Line G3 tributary, median turbidity was in the high thirties and forties. Line G3 and Tassajara Creek consistently contributed turbid waters around 40 NTU to Arroyo Mocho, and sporadically contributed very turbid waters with maximum low-flow turbidity measured at 392 and 151 NTU, respectively. Figure 39 shows the turbidity measured in Arroyo Mocho approximately 50 m upstream of the Line G3 tributary, the turbidity in Line G3 immediately before the confluence with Arroyo Mocho, and the turbidity measured at the first sampling location on Arroyo Mocho downstream of the Line G3 confluence, “Arroyo Mocho at Santa Rita Rd.”. We also calculated the percent of increase in turbidity at “Arroyo Mocho at Santa Rita Rd.” over the turbidity measured above Line G3. In all thirteen sampling events, the percent increase between the two sites is greater than 10% (the black reference line), and in multiple cases the increase is greater than 100%.

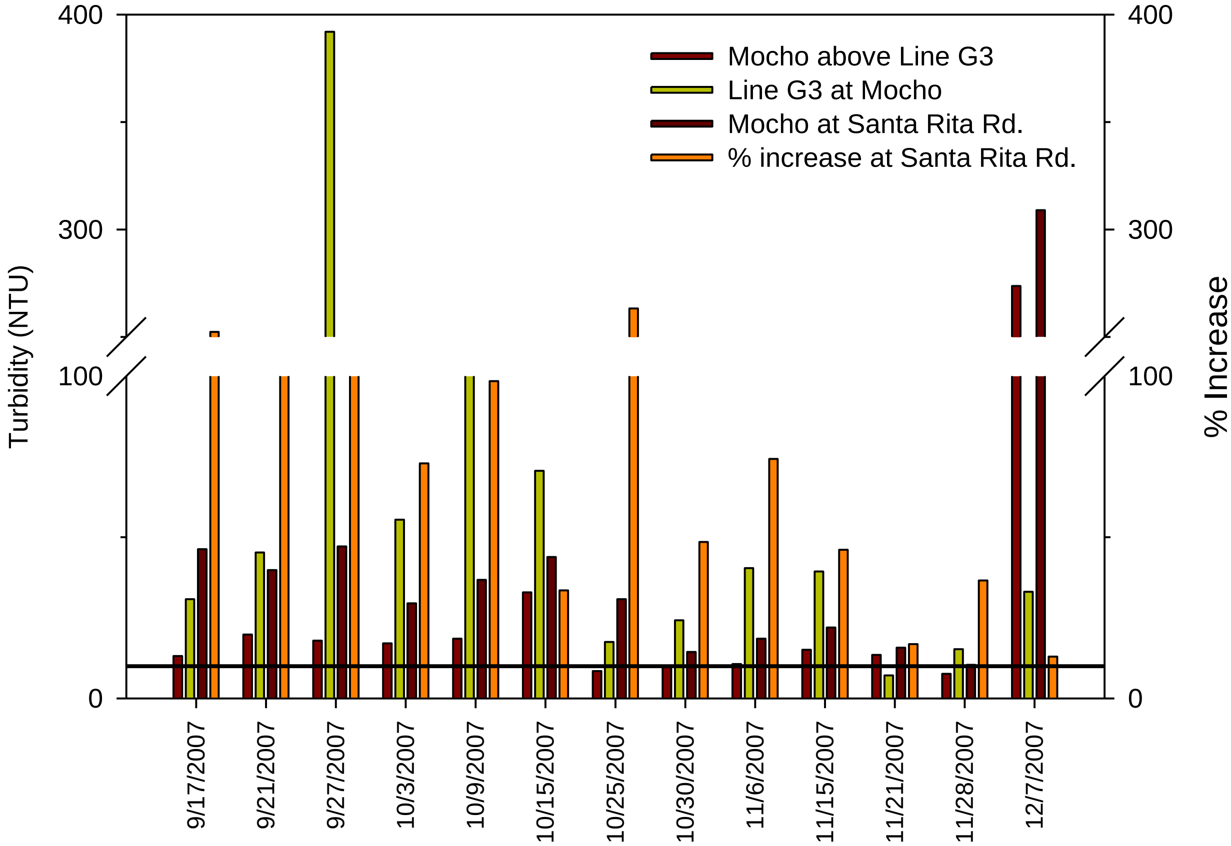

Figure 39: Comparison of turbidity measured in Line G3 and at sites above and below this tributary on Arroyo Mocho. The black line corresponds to a 10% increase in turbidity between sites above and below Line G3, and you can see in the graph that results from every sampling event exhibited greater than a 10% increase between the two sites.

This same comparison of turbidity in Arroyo Mocho upstream and downstream of the confluence with Tassajara Creek would not be quite as extreme since that confluence is downstream of the Line G3 confluence and therefore the turbidity in the Mocho is already impaired. Nevertheless, the turbidities measured in these tributaries suggest that point sources may exist in the Line G3 and Tassajara Creek subwatersheds. Development to the north of Highway 580 in this area was observed by field personnel, and may be the source of this elevated turbidity. Further, the turbidity measured during high flow conditions at these two sites was relatively low (unlike the high turbidities measured elsewhere in the watershed), indicating that the sources of the low-flow turbidity at these sites may be point sources that become diluted during high flows.

This study is unable to determine whether or not point sources in excess of the SFRWQCB objectives exist in the Line G3 and Tassajara Creek subwatersheds. The SFRWQCB Basin Plan water quality objective states that "increases from normal background light penetration or turbidity relatable to waste discharge shall not be greater than 10 percent in areas where natural turbidity is greater than 50 NTU". Defining the natural turbidity for an area is said to be "a difficult endeavor" (Bash et al. 2001, pg. 7). Two suggestions for defining natural or background turbidity include either measuring turbidity in an unmanaged area of the basin, or measuring turbidity at a location immediately upstream of the turbidity causing activity (Bash et al 2001).

Turbidity was not measured in upstream or unmanaged areas of the Line G3 and Tassajara Creek watersheds and therefore we cannot say conclusively whether or not the water quality objective was breached.

Although McBain and Trush (2008) did not propose Arroyo Mocho through the study area as a target area of good rearing habitat, the turbid waters from this tributary may be causing chronic background turbidity in Arroyo De La Laguna. McBain and Trush (2007, based on Klein et al, 2008) have proposed a chronic background turbidity threshold of 10 NTU, in combination with duration of exposure for more than 50% of the time, because studies have shown that salmonid reactive distance, BMI densities, and periphyton productivity are all significantly decreased at turbidity greater than or equal to 10 NTU. Chronic exposure to these deleterious impacts could lead to diminished growth success for rearing juveniles. The mainstem Arroyo De La Laguna may be considered to provide good potential rearing habitat for oversummering steelhead as a means of improving the viability of one or more of the potential life history tactics identified by McBain and Trush (2008). Our study indicates that fish in this reach would be subjected to chronic background turbidity levels in excess of 10 NTU, and with maximum turbidity reaching above 20 NTU during low-flow periods.

This study presents evidence that turbidity is an unlikely limiting factor for salmonids in the Niles Cone and Niles Canyon portions of Alameda Creek during the period of this study. In Alameda Creek upstream of the confluence with Arroyo De La Laguna turbidity was very low, averaging 1-4 NTU at the three sampling locations during lower flows. Through the Niles Canyon, turbidity during low-flow averaged 6 NTU, with medians of 5.4 and 6.8 at the two sites. Downstream of the canyon in Niles Cone and above the tidally influenced Alameda Creek @ Ardenwood Blvd. location, turbidity averaged 4.7 to 9.6 NTU at three sites. Turbidity in this lower section did register above 10 NTU between 10 and 40% of the sampling events, which is below the McBain and Trush (2007, based on Klein et al, 2008) proposed threshold of 10 NTU for greater than 50% exposure, but it may warrant continued monitoring in this section to ensure detection if turbidity does increase above the recommended threshold.

There is weak evidence to accept the hypothesis that Alameda Creek, from the confluence with Welch Creek downstream through Alvarado Blvd. has elevated turbidity from August through early December 2007 relative to water quality thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008) (Note this reach did not have perennial flow throughout the duration of our study). There is no implication that rearing juvenile steelhead will be significantly impacted by the turbidity in the portions of the watershed they are most likely to inhabit (Niles Canyon and Niles Cone) during the period of the study, based on these proposed thresholds. As noted earlier, the thresholds were specifically proposed for the period of November 15 through June 15, which has only a slight overlap with the time-frame of this study, and therefore it is important to address the appropriateness of these thresholds for analyzing the results of this study.

During August to early December, juvenile steelhead oversummering in the watershed minimally need to survive, and growth would be beneficial. This is a challenging time bioenergetically for steelhead because of the warmer water temperatures. Steelhead can survive these months if they can consume enough food to support the increased metabolic rate they experience in warmer waters, so it is extremely important that elevated turbidity does not impair fish feeding activities during this time period. The thresholds proposed by McBain and Trush (2007, based on Klein et al, 2008) are indicated to protect juvenile and smolt *growth*, but during a time period in which water temperatures are generally cooler. If the food consumption requirements for steelhead survival with increased metabolic rates are greater than the consumption rates necessary for steelhead to grow during less stressful temperature conditions, then the thresholds may not be stringent enough and the conclusions of this study could be different. A bioenergetics study of fish in the targeted rearing areas would inform this outstanding question.

In the absence of unambiguously defined thresholds by the SFRWQCB, the McBain and Trush proposed thresholds (based on Klein et al., 2008), with their attention to effects on fish based on magnitude of turbidity and duration of exposure, are utilized for analysis in this report in order to maintain consistency of turbidity evaluation in the watershed. These thresholds are also in line with other nearby state and provincial turbidity standards. In Washington, turbidity cannot exceed 5 NTU over background when the background turbidity is less than 50 NTU, and cannot exceed a 10% increase when background turbidity is greater than 50 NTU (Bash et al 2001). While focusing on the requirements of salmon as an indicator species, the State of Idaho does not allow instantaneous increases in turbidity of 50 NTU, nor a prolonged exposure of a 25 NTU increase for 10 days or more (Bash et al, 2001). In a review of Alaska's turbidity water quality standards and based on effects of turbidity in fish demonstrated in the literature, Lloyd (1987) suggested that standards allowing turbidity increases of 25 NTU above ambient would provide moderate protection for salmonids, while increases no greater than 5 NTU above ambient would provide relatively high protection.

As mentioned, warm water temperatures during the summer months can have important deleterious impacts on salmonids by affecting their metabolic requirements, making them more susceptible to disease, and impacting the dissolved oxygen levels within the creek. The temperature results of this study are inconclusive as to the potential impacts on anadromous fish. Some measurements recorded in this study indicate that an upper threshold of 20 degrees Celsius was exceeded during the period of this study, but the measurements are limited to instantaneous records and do not offer daily averages. Continuous monitoring is recommended and can provide a better understanding of potential impacts of temperature on fish.

Steelhead need high dissolved oxygen (DO) concentrations to maintain a desirable metabolic rate, growth, swimming performance, and overall survival. Davis (1975) found that salmonids function normally at 7.75 mg/l, exhibit distress symptoms at 6.00 mg/l, and are negatively affected at 4.25 mg/l of DO, and the SFRWQB forwards a water quality objective of 7.0 mg/l DO concentration at a minimum for cold water habitats. This study indicates that the portions of Alameda Creek most likely to serve as habitat for oversummering steelhead generally had concentrations higher than 7.0 mg/l. The Alameda Creek @ Alvarado Blvd. site was the exception, though the average concentration at this site was just under the 7.0 mg/l threshold.

McBain and Trush (2008) recommend habitat-streamflow quantification in order to understand the instream flow releases necessary to create and maintain good habitat for oversummering steelhead. Although the results of our study do not indicate that instream flow releases are necessary to mitigate significantly negative impacts of turbidity on anadromous fish in the Niles

Canyon and Niles Cone sections of Alameda Creek, should reservoir releases be considered necessary to mitigate other concerns such as water temperature, the affect on turbidity would likely be in a positive direction.

V. Recommendations

The Alameda Creek watershed has been identified for potential restoration and improvement of the anadromous Chinook salmon and Steelhead Trout populations, and elevated turbidity is known to detrimentally impact anadromous fish spawning and rearing. Some locations in the study area have consistently elevated turbidities, but generally, turbidity is not great enough or in long enough duration to significantly impact the stream reaches indicated for good steelhead rearing. These conclusions, however, are reached on the basis of analysis in relation to proposed turbidity thresholds, while it is recognized that impacts of turbidity on fish are likely synergistic with other environmental factors such as particle size, type, angularity and toxicity, water temperature, natural background turbidity, and presence and access to refugia. Based on our observations, we make the following recommendations.

1) Turbidity could be monitored a second season to explore inter-annual variation associated with significantly different climatic or geomorphic conditions, and/or variations in watershed management.

2) If watershed resource managers are concerned about the elevated turbidity in Arroyo Mocho, efforts should be established to further investigate the sources of these inputs, followed by exploration of management options to decrease this turbidity. Reconnaissance and/or an intensive sampling procedure can be established to investigate sources from Arroyo Mocho at El Charro Rd. downstream to its confluence with Arroyo De La Laguna, as well as upstream along Line G3 and Tassajara Creeks from their confluences with Arroyo Mocho.

3) In areas with the highest turbidity that correspond to proposed rearing habitats, a bioenergetics study could be completed to understand if salmonids are able to meet their energy requirements for survival and growth. Such a study would be a possible next step to determine if turbidity or other factors such as dissolved oxygen, food resources, and temperature are limiting. This would include Niles Canyon and Niles Cone reaches in Alameda Creek, as well as the mainstem Arroyo De La Laguna, if that portion of the creek is re-evaluated to provide good oversummer rearing habitat for steelhead.

4) Temperature should be monitored continuously during the coming spring, summer and fall from May through October in proposed rearing habitats to determine whether average daily temperatures are exceeding critical levels for oversummering steelhead. Elevated temperatures would stress fish, possibly enhancing their sensitivity to turbidity.

5) Increase summertime flow volumes in the reaches targeted for steelhead rearing to improve both water temperatures and turbidity during the summer months. Decreasing water temperatures may represent the most significant improvement for rearing juveniles, but these releases would

likely have net positive impact on turbidity as well. This may need to be monitored depending on the source of released water.

6) A habitat assessment may be conducted to determine whether excessive suspended sediment is settling and depositing on spawning areas. Embeddedness could deplete the intragravel flow of oxygen rich waters necessary for successful spawning, egg incubation, and waste product removal.

7). If there is a desire to determine downstream transport of fine sediment during low or high flow, during a subsequent sampling season, collection of water samples for suspended sediment analysis could be completed along with measurements of velocity. In addition, a qualitative assessment of sediment sources during high flow could be completed by collecting similar spatiotemporal data during and after floods next wet season.

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