A comparison of the effects of regulated and non-regulated hydrologic regimes on fine sediment deposition and benthic macroinvertebrate distributions

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Abstract This study examines how fine sediments deposited in streams in the Santa Clara Valley of California affect the density and composition of benthic macroinvertebrates commonly used as water quality bioindicators. The focus is on the three insect orders Epheroptera, Plecoptera and Trichoptera (EPT) because they are considered generally intolerant of stream pollution. Excess fine sediments (<2mm) alter the substrate composition by filling in interstitial spaces and coating surfaces, thereby changing habitat suitability for aquatic organisms including salmonids and macroinvertebrates. Dams may affect fine sediment levels in streams because regulated flows have less capacity and competence to move fine sediment. The present study on six streams addresses whether regulated flow and non-regulated flow sites have different amounts of fine sediment and if EPT metrics differ among the two flow regimes. Five collections were made at each site using a Hess sampler with a 500 μm mesh net. A nested analysis of variance showed regulated flow sites to have significantly ($p < 0.05$) higher amounts of fine sediment. EPT richness was also significantly different at regulated flow sites. EPT richness and density were negatively correlated with the amount of fine sediment present. This polygonal distribution shows that fine sediment is a limiting factor in EPT richness and density. In addition, due to the difficulty of measuring fine bed sediments, the study examined whether turbidimeters can substitute as a quick field method for estimating fine bed sediment. Results show a curvilinear relationship between fine bed sediment and turbidity ($r = 0.77$, $p<0.01$).

Introduction

Rivers play a paramount role in shaping the landscape by selectively eroding, transporting and depositing sediments on the land in their journey towards the ocean (Lemly 1982). These sediments range from fine clays up to large boulders. Fine sediments are a category of sediments consisting of fine sand (<2000 to >62 µm), silts (<62 to >4 µm), and clays (<4 µm). Fine sediments occur naturally in streams but are considered a pollutant when they are in excess of natural levels. Sediments are considered one of the top stream pollutants by the U.S. Environmental Protection Agency (EPA 2004). Excess fine sediments are primarily human-induced and can result from disturbances such as dams, surface mines and construction activities (Wood and Armitage 1997) and land use relating to agriculture, forestry, and residential development.

Dams strongly influence sediment transport because they often modify the natural discharge regime (Poff et al. 1997). Dams disrupt the often natural highly variable flow regime, replacing it with a less variable low discharge (Poff and Ward 1989, Mount 1996, Ligon et al. 1995). Reduced peak flows hinder sediment transport capacity and competence (Wilcock et al. 1996). As a result, reaches downstream of dams can accumulate fine sediment deposits without natural scouring. Fine sediment introduced from downstream tributaries may also accumulate on the bed if reservoir storage has sufficiently reduced the river's transport capacity (Kondolf and Wilcock 1996). Bankfull discharge with a recurrence interval of 1.5 yr is often considered the channel forming flow (Dunne and Leopold 1978). Due to flow regulation, bankfull discharge may seldom occur. Resulting fine sediment deposition may change channel morphology and the physical aquatic habitat with deleterious effects on macroinvertebrates, algae, macrophytes, and fish (Wood and Armitage 1997).

Macroinvertebrate health is very important to the aquatic ecosystem because these ubiquitous organisms provide a vital food source for many fish, birds, and insects. Reductions in macroinvertebrate densities can negatively influence fish populations (Wood and Armitage 1997).

The addition of fine sediment to a stream alters the substrate composition by filling in interstitial spaces and coating surfaces which affects substrate suitability for aquatic organisms (Culp and Davies 1985, Erman and Ligon 1988, Wilcock et al. 1996). Fine sediments can increase insect drift, deposit on respiratory structures, and reduce dissolved oxygen availability (Culp et al. 1985, Brittain and Eikeland 1988, Lemly 1982, Wood and Armitage 1997).

The effects of fine sediments on macroinvertebrates in Mediterranean climate streams have not been extensively studied. Hubert et al (1996) studied macroinvertebrate density and substrate relationships in a small, high plains stream in Montana and indicated changes to the macroinvertebrate assemblage from an increase in fine sediment. Erman and Ligon (1988) conducted a study below a water-filtration facility in the San Francisco Bay area, but it was an atypical system in which the pulses of sediment addition to the stream were very high for brief periods of time, whereas my study involved fine sediment deposits that resulted from nearly constant regulated flow year around. Studies of dam-associated fine sediments and macroinvertebrates in the Mediterranean climate region would contribute to better understanding of the impacts of dams.

In addition to the deleterious effects of excess fine sediments on macroinvertebrates, other ecological impacts result from fine sediment deposition and distribution. Fine sediment is an issue of importance in assessing potential habitat for threatened and endangered fish such as steelhead trout and coho salmon on the Pacific Coast. Fine sediments can greatly impact fish spawning grounds by filling in the interstitial spaces of the substrate, which reduces the availability of dissolved oxygen to incubating eggs (Kondolf and Wilcock 1996). Fine sediments can also be important in the transport and fate of many contaminants. In the Bay area, mercury is likely transported by fine sediments from abandoned mercury mining sites in South San Jose to the Bay. Many studies support the widely accepted view that as grain size decreases, the concentration of sediment-associated contaminants increases (Old et al. 2003). These are only a few reasons to study the distribution of fine sediments in local south Bay streams. Nationwide, sediments are recognized as a severe problem, yet no national program exists to study this pollutant.

This study examines how dams might influence excess fine sediment deposition in downstream reaches. The effects of dams and reservoirs are generally well established and may include the flooding of valleys and the retention of coarse sediments by the dam. Dams release sediment-starved water that has greater erosive power directly downstream which coarsens the bed. Other downstream effects include alteration of the natural flow regime, which is a function of the magnitude, frequency, duration, timing and rate of change of hydrological conditions (Poff et al. 1997); water temperature regime, and physical habitat, all of which leads to decreased aquatic ecosystem health. However, little is known about the effects of dams further downstream.

The principal obstacle to understanding fine sediments is their transient nature. They are easily suspended and transported; even at the riffle level, variability is extremely high. Some methods used to measure fine bed sediment include the McNeil sampler, estimated percentage embeddedness, and pebble counts. Quantifying the amount of fine sediments is more difficult because it often involves sampling and lab analysis which is laborious and therefore expensive. In an attempt to simplify the procedure, this study also examined the feasibility of relating turbidimeter readings from suspending the fine bed sediment in the field, to the estimated volume of fine bed sediment determined from water samples collected at the site. Many studies have examined the relationship between turbidity and suspended sediments (e.g. Suk et al 1998; Riley 1997). However, I have found no work that studied the relation between turbidity and fine bed sediments.

Study objectives The present study addressed four questions: first, it examined whether similar amounts of fine bed sediment occur in regulated flow and non-regulated flow sites by comparing field-collected water samples (aliquots) in the laboratory.

Macroinvertebrates are commonly used as bioindicators to indicate water quality and stream health. The three orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) are particularly sensitive to stream pollutants, including fine sediments. Therefore secondly, the study examined EPT metrics including EPT density, EPT richness, percentage of EPT (% EPT), and EPT/ (EPT + Chironomidae) and compared them between regulated and non-regulated flow sites to assess the health and functionality of streams under these two different flow regimes.

Thirdly, to test the effects of fine sediment on macroinvertebrates, EPT density and richness were compared to fine sediment levels from each site.

And lastly, this study assessed whether field-measured turbidity could be correlated with the lab-measured fine sediment from sediment samples.

Methods

Study sites The Santa Clara Valley begins at the southern end of the San Francisco Bay area in California. The Valley has a Mediterranean climate regime with wet winters and dry summers. In the 1930s and 1950s, many dams were constructed in the Valley to capture water from the surrounding watersheds during the wet winter months. Reservoirs in the valley currently provide about 25% of Santa Clara County's water supply (Santa Clara Valley Water District).

The sampling sites were chosen based on similarity of flow regime (regulated or natural), elevation, availability of high gradient riffles for sampling, substrate size, and riparian vegetation. Elevation ranged from 102 to 132 m. The altitudinal range was minimized to reduce the effect of altitude on macroinvertebrate distribution (Carter et al. 1996). All regulated flow sites were approximately 2 km downstream of the dams.

The study was conducted on six streams located in the Santa Clara Valley and Coastal Mountains. Four of the streams are on the western edge of the Santa Clara Valley and two are on the western slope of the Coastal Range (Fig. 1). Alamitos Creek (ac), Guadalupe Creek (gc), and Stevens Creek (sc) are three regulated flow sites that are downstream of dams. Saratoga Creek (sa), Peters Creek (pe), and Pescadero Creek (ps) are non-regulated flow sites with a relatively uninhibited discharge regime. Sampling occurred on October 24, 25 and 31 of 2003. A short sampling period was optimal because macroinvertebrate composition changes rapidly in late fall. Many aquatic macroinvertebrates grow rapidly in the fall. In addition, precipitation typically begins in late October and early November in the Mediterranean climate; high flows from storms in non-regulated streams will affect the distribution of macroinvertebrates. No rainfall occurred between the sampling of non-regulated flow sites.

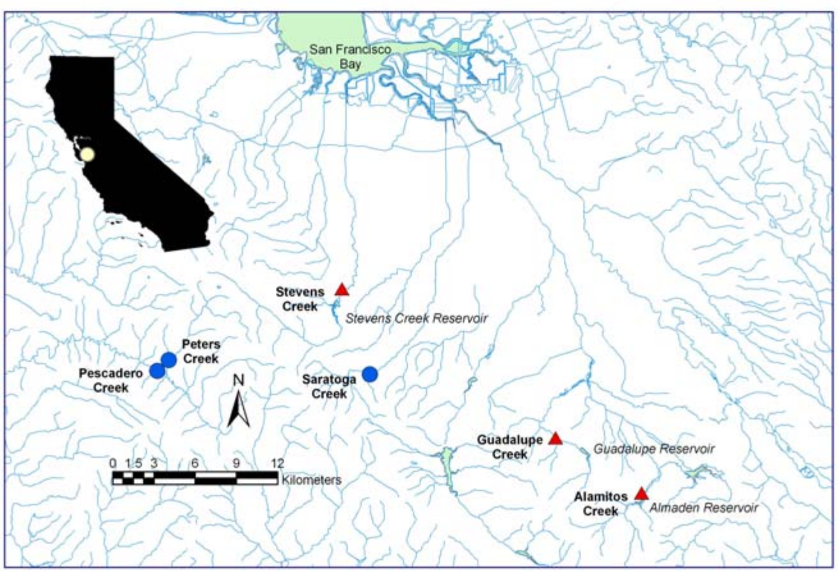


Figure 1. Study sites in the Santa Clara Valley, California.
▲= regulated flow sites. ● = non-regulated flow sites.

An EPA Habitat Assessment for high gradient streams was completed during the sampling at each site to qualitatively assess physical features such as bank stability, riparian vegetation cover, and substrate size. This assessment is commonly used in bioassessment studies to determine if sampling sites have similar habitat characteristics. In addition, water quality parameters such as water temperature, air temperature, dissolved oxygen, pH, and conductance were collected. The habitat assessment helped determine if the six sites in the study are qualitatively similar.

Field Methods Five collections were made at each reach, for a total of 30 samples. Sampling equipment consisted of a Hess sampler with a 500 μm net, a modified bucket, and a turbidimeter with a measuring capacity of 1000 Nephelometric Turbidity Units (NTU). The modified bucket designed for this study has an open bottom with a ring of foam around the bottom edge. The turbidimeter, a Global Water Instrument, Inc. model WQ770, was calibrated using a Formazin standard for 0-1000 NTUs. The bucket fits within the sampler so that the two comprise a unit (Fig. 2). This unit was wedged into the substrate to create an essentially closed cell of water in the stream. If a good seal could not be obtained (i.e. water flow was evident within the unit), another location in the riffle further upstream was chosen. Sampling always occurred from downstream to upstream so that potential collection sites were not disturbed.

With the sampling unit (Hess and bucket) firmly in place, water depth was measured three times to estimate the mean water volume. The probe of the turbidimeter was placed in the stream to get an ambient turbidity reading to later compare with the fine sediment turbidity. The probe was put inside the unit in preparation for the disturbance. To measure the amount of embedded fine sediments, the substrate was dug up by hand, rubbed, and stirred for 30 seconds. A turbidimeter reading was taken and then a 250 ml sample of suspended sediment sample was collected within the bucket. Therefore, two estimates of the amount of fine sediment per area were made; one estimate was obtain by measuring the mass of fine sediment from the sediment samples, and the other estimate was made by suspending fine bed sediment and measuring the resulting turbidity with a turbidimeter in the field. Substrate was disturbed to approximately 10 cm deep, which was similar to the depth macroinvertebrates were collected with the Hess Sampler.

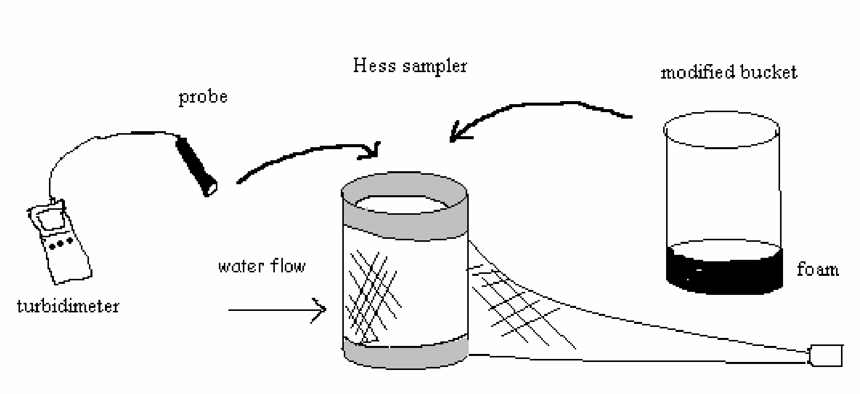


Figure 2. Turbidimeter, Hess sampler and bucket

After fine sediment sampling, the bucket and turbidimeter probe were removed from the Hess Sampler and macroinvertebrates were collected. The rocks within the sampler were washed and rubbed to ensure that the majority of organisms were collected. The macroinvertebrates were washed from the net and preserved in the field with 10% buffered formalin. The faunal samples were taken back to the USGS lab in Menlo Park to be sorted and identified. The fine sediment samples were also taken to the lab and kept refrigerated until they were processed.

Laboratory processing Each faunal sample was examined under a microscope at 7.5X power and all larvae and pupae collected. If the sample contained an abundance of inorganic material making it difficult to sort the macroinvertebrates, the sample was elutriated five times to separate the inorganic material from the organic. The inorganic material was examined under the microscope to ensure that no macroinvertebrates remained. This method worked well since the sand grains are much heavier than the organisms and other organic material. The organisms were initially sorted into EPT, Chironomidae, and Other. The EPT taxa were identified to the lowest practicable level; to species if possible, otherwise to genus or family. The groups Chironomidae and Other were not identified to any greater detail. Each taxon was enumerated. Abundances of collected taxa were scaled to individuals per m^2. Aquatic insects were identified using Merritt and Cummins (1996), Wiggins (1996), and Stewart and Stark (1988).

Lab-measured fine sediment estimates were used to compare treatments (flow regimes). The radius of the modified bucket, r = 120.7 mm, was determined to find the fine sediment sample area. A mean depth was calculated from the three water depths measured during each sample.

The total volume of water in the modified bucket was obtained using the area and mean depth of the water.

To estimate the amount of fine sediment embedded within the area of the modified bucket, the aliquots collected during the disturbance of the substrate were first stirred using a magnetic stirring bar to re-suspend the solids. Three 20 ml aliquot were drawn from each field sample while stirring and then each pipette into separate aluminum trays that had previously been tared. The samples were oven dried at 95°C for >24 hr and then weighed to obtain the amount of fine sediment contained in the tray. The samples were weighed to an accuracy of ±0.1mg. The mean of the three fine sediment masses from each collection were used to compare with field-measured turbidity. Three blank trays were dried and weighed along with the samples as a control.

To examine the relationship between the fine sediment estimated by turbidity and the lab estimated fine sediment, turbidity was multiplied by water volume within the modified bucket. These values were then plotted against fine sediment values estimated from the water samples.

Sampling design This study used a hierarchical (nested) sampling design. Such a design uses replication of experimental units in at least two levels of a hierarchy and allows an estimate of the intrinsic variability among areas that has nothing to do with the differences that might be due to the experimental treatments (Underwood 1997). Nested analyses of variance allow insight into where the variance occurs among the different factors. The goal is to partition the variability observed in the data into each of the three levels of replication. In this study, each treatment (flow regime) contained three replicates (the streams), and each replicate contained five collections sampled from high gradient riffles. Preliminary sampling indicated that fine sediment variation within each reach was high. It is also well known that macroinvertebrate densities vary greatly within reaches (Resh and McElravey 1993); therefore we allocated sampling effort accordingly by collecting five samples per reach to maximize the ability to capture the variation. The nested design of this study maximizes the ability to obtain robust results and detect any significant difference in mean between treatments. The program Statistica (StatSoft 2004) was used to analyze the data. The macroinvertebrate data were transformed. Count data were log transformed and % data were arcsine square root transformed.

Results

The six sites in this study are similar in habitat. All had dense canopy cover, similar riparian species (alders, bays, maples), and comparable substrate type (cobble/gravel). Water quality parameters presented in Table 1 below indicate no major differences in water quality between sites.

stream	Saratoga	Peters	Pescadero	Guadalupe	Stevens	Alamitos
air temp C	18.9	12.5	18.5	17.5	12.4	12
velocity m/s	0.4	0.4	0.5			0.6
water temp C	13.4	11.1	11.6	16.7	15.0	9.8
conductance	531.0	810	737.0	422.0	503.0	413.0
DO %sat.	96.1	94.3	94.1	94.4	77.4	88.0
DO mg/L	10.0	10.3	10.2	9.1	7.8	10.0
pH	6.09	7.9	7.9	6.9	7.4	7.5

Table 1. Water quality parameters at each site. Velocity values were not collected for Guadalupe and Stevens Creek.

Sediment and flow regime The difference in mean estimated fine sediments between flow regimes was significant (F= 96.5300, p<0.001), with the regulated flow sites having approximate 19 g of fine sediment compared to 8 g at non-regulated flow sites (Table 2, Fig. 3). The flow regime and reach factors accounted for nearly all of the variation, with 54.6% and 45.4%, respectively (Table 3).

		Non-regulated Flow				Regulated Flow			
Streams		**sa**	**pe**	**ps**	mean	**al**	**gc**	**sc**	mean
EPT richness									
	Mean	8.20	8.00	9.80	8.67	2.00	5.80	3.60	3.80
	S.D.	4.09	3.67	2.17		1.22	1.79	0.55	
	CV	49.84	45.93	22.12	39.30	61.24	30.84	15.21	35.76
Total EPT									
	Mean	414.54	488.65	1197.30	700.16	83.37	465.49	405.27	318.04
	S.D.	284.39	256.24	221.77		36.98	162.61	198.88	
	CV	68.60	52.44	18.52	46.52	44.36	34.93	49.07	42.79
% EPT									
	Mean	0.38	0.64	0.66	0.56	0.03	0.56	0.40	0.33
	S.D.	0.12	0.06	0.08		0.03	0.14	0.16	
	CV	32.70	9.48	11.96	18.05	110.09	24.47	39.98	58.18
EPT/EPT+C									
	Mean	0.87	0.90	0.89	0.89	0.04	0.94	0.76	0.58
	S.D.	0.10	0.07	0.09		0.05	0.05	0.06	
	CV	11.39	8.08	9.60	9.69	119.93	5.48	8.21	44.54

Sediment (g)									
	Mean	7.08	7.62	8.31	7.68	17.81	18.65	21.55	19.34
	S.D.	2.09	3.03	2.96		9.48	6.51	13.47	
	CV	29.56	39.78	35.63	34.99	53.24	34.91	62.49	50.21

Table 2. Mean, Standard Deviation (S.D.), and Coefficient of Variation (CV) for selected metrics at each stream site.

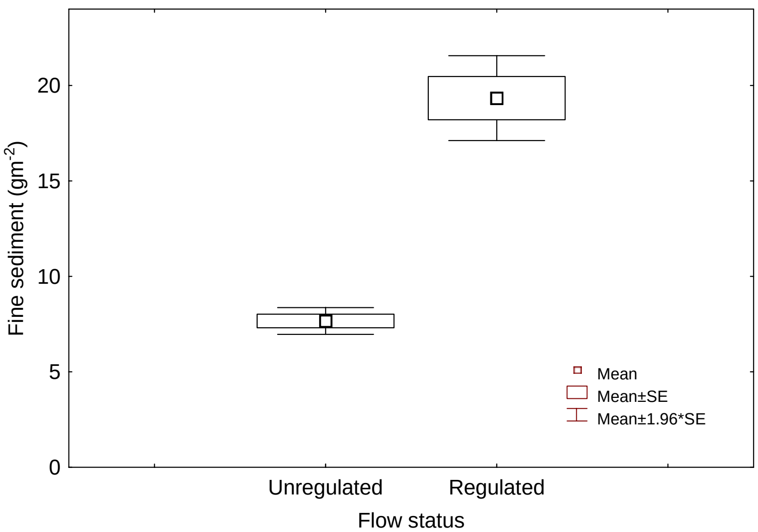


Figure 3. Estimated mean fine sediments between flow regimes. Regulated flow regime sites having a significantly higher mean (p<0.001, F= 96.5300).

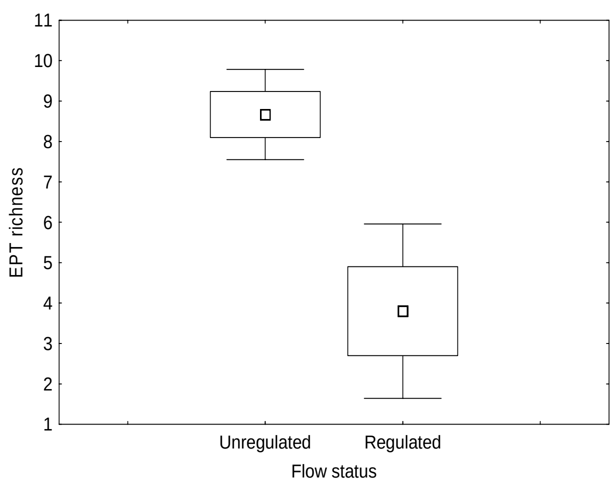
Source	**SS**	**df**	**MS**	**F**
EPT richness				
flow regime	177.633	1	177.6333	15.4017
stream	46.133	4	11.5333	1.7343
reach	159.600	24	6.6500	
total	383.367	29	13.2195	
Total EPT				
flow regime	0.923	1	0.9226	1.3460
stream	2.742	4	0.6854	7.1401
reach	2.304	24	0.0960	
total	5.968	29	0.2058	
% EPT				
flow regime	0.407	1	0.4069	1.6738
stream	0.972	4	0.2431	20.7438
reach	0.281	24	0.0117	
total	1.660	29	0.0573	
EPT/EPT+C				
flow regime	0.707	1	0.7072	1.2469

stream	2.269	4	0.5672	108.2860
reach	0.126	24	0.0052	
total	3.102	29	0.1070	
Sediment (g)				
flow regime	1021.415	1	1021.4152	96.5300
stream	42.325	4	10.5813	0.1889
reach	1344.161	24	56.0067	
total	2407.901	29	83.0311	

Table 3. Summary statistics of the Single factor ANOVAs run on an n=3 per level (based on the means of 5 within-site subsamples at each site).

Macroinvertebrate metrics EPT richness was significantly different between regulated and non-regulated flow sites (F=15.4017, p<0.05) with a mean richness of 8.67 in non-regulated flow sites compared to 3.80 at regulated flow sites (Table 2 and 3, Fig. 4a). EPT density was not significantly different between flow regimes because of the high stream effect (F=1.3460, p< 0.05) (Table 2 and 3, Fig. 4b); streams and riffles collectively accounted for over 90% of the total variation (Table 3). Although EPT densities were not shown to be significantly different, the mean density in non-regulated flow sites was higher (estimated 700 individuals m^{-2}) than regulated flow sites (318 individuals m^{-2}) (Table 2). % EPT did not vary significantly between flow regime (F=1.6738, p>0.05) (Table 2 and 3, Fig. 4c), however the stream factor accounted for >65% of the variation (Table 3). The relationship of EPT/ (EPT+Chironomidae) was explored because many studies have found certain Chironomidae to dominate the benthic assemblage with increasing input of sediments (Lenat et al 1981). However, this metric should not be tested because the variances were so different (Table 2 and 3, Fig. 4d).

4a.



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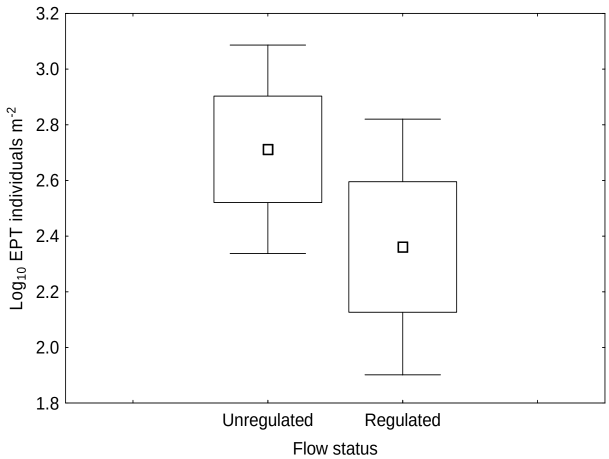

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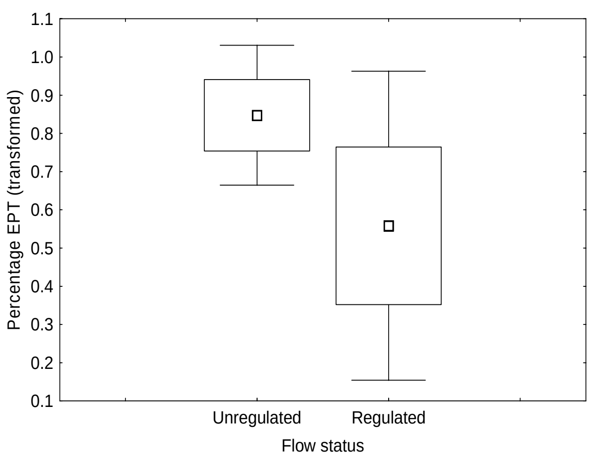

4d.

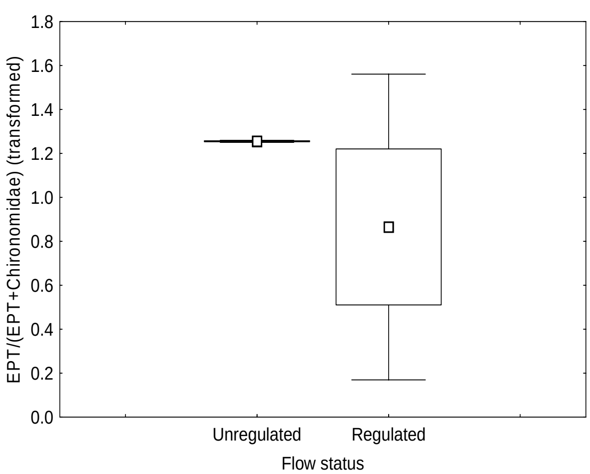

Figure 4 a-d. box contains ±1 standard error, bars are ±2 SE. a. EPT richness was significantly different between regulated and non-regulated flow sites (F=15.4017, p<0.05). b. However, EPT density was not significantly different between flow regimes (F=1.3460, p< 0.05) . c. % EPT was

not significantly different between flow regimes
(F=1.6738, p>0.05). d. EPT/ (EPT+Chironomidae) showed
extremely different variances.

Sediment and macroinvertebrates To examine the relationship between fine bed sediments and ecological health as indicated by the macroinvertebrate assemblage, EPT density and richness were compared with the estimated amount of fine sediment at each site. Both showed a similar relationship: EPT richness and density were highest at sites with lowest amounts of fine sediment. The upper limit of both measures decreased almost linearly with corresponding increased sediment sites (Figs 5 and 6).

Sediment and turbidity All ambient turbidity readings were very low compared to the fine bed sediment readings, therefore no corrections to the data were made. The amount of fine sediment estimated by field-measured turbidity correlated positively with the mass of fine sediment obtained from aliquots. Higher turbidity corresponds with higher amounts of fine bed sediment, although the relationship is somewhat curvilinear (Fig. 7).

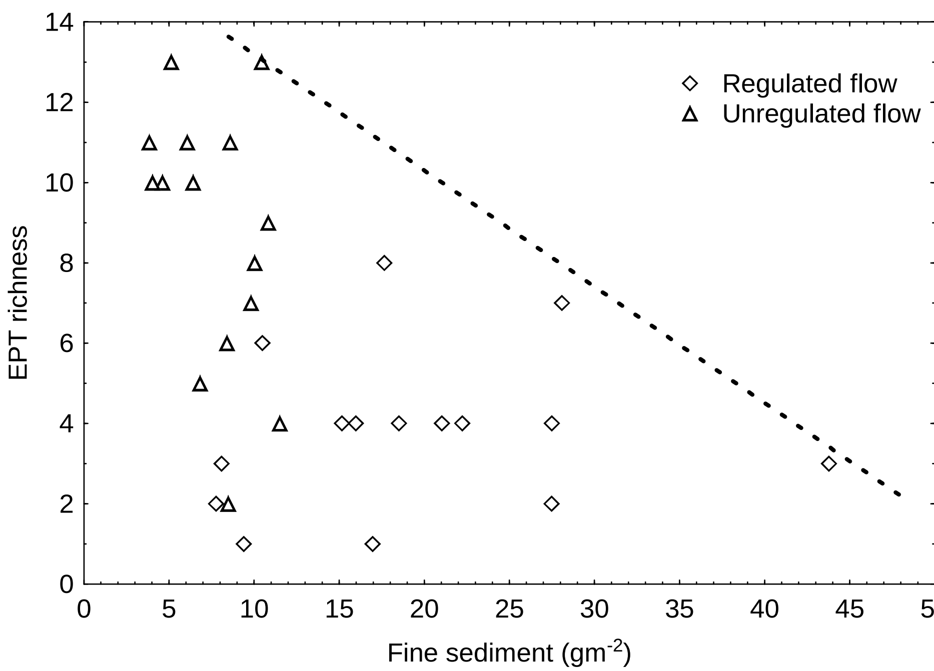

Figure 5. EPT richness and fine sediment at regulated and non-regulated flow sites.
The polygonal distribution suggests that fine sediment is a factor that limits
EPT richness at a given site. The upper limit is fitted by eye.

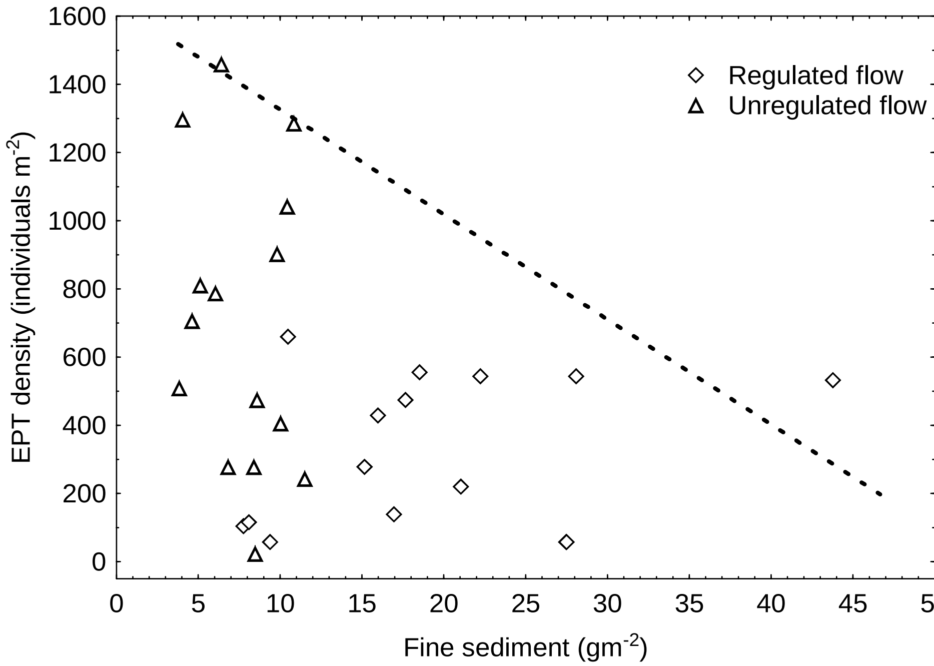

Figure 6. The EPT density and fine sediment relationship shows fine sediment as a factor imposing an upper limit on EPT density . The outlying point on the bottom right is from a Stevens Creek sample that contained one of the highest densities of *Baetis tricaudatus*. *B. tricaudatus* distribution is patchy.

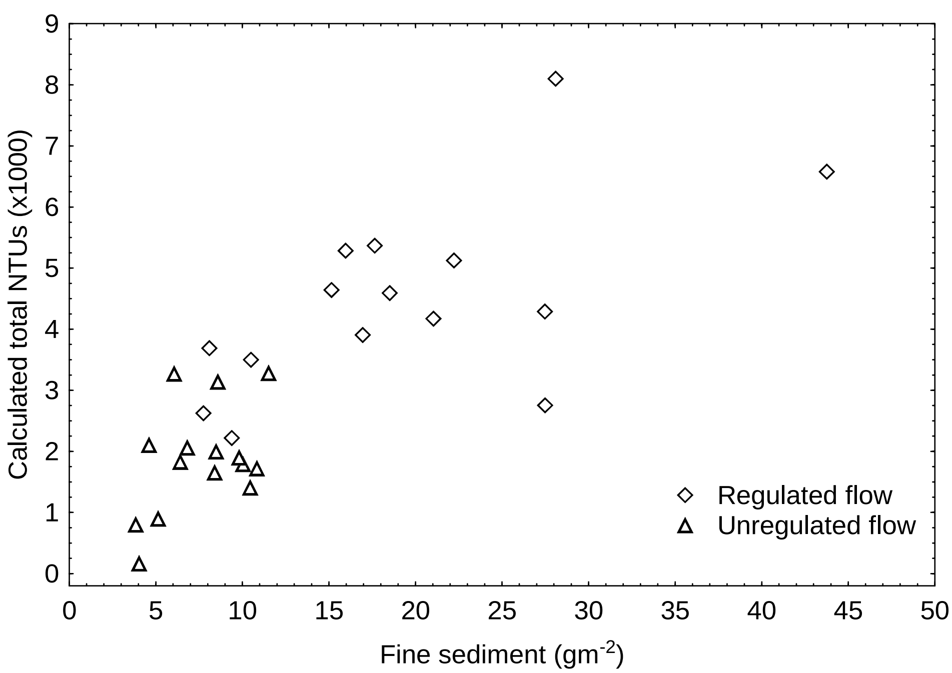

Figure 7. The relationship between lab-measured fine sediment and field-measured turbidity (NTU) is shown. Note the scatter at higher fine sediment values. ($r = 0.77$, $p < 0.01$)

Discussion

The distribution of fine sediment in streams necessitates an understanding of regional climatic conditions. The Santa Clara Valley, as part of the Mediterranean climate regime, receives nearly all its annual precipitation from November through March. Peak flows occur during the wet period and most sediment is transported only during these events. After winter storms, the hydrograph slowly declines and falls throughout the year until it is replenished by storms once again in late fall. This discharge regime strongly suggests that sediments accumulate in streams during the dry period of the year. The accumulated sediments need annual peak flows to be flushed out. This natural system is disrupted when humans build dams in streams. Dams may severely regulate peak flows, depending on the storage capacity of the reservoir relative to the drainage area. For example, the discharge of two study streams were compared in Figure 8. Saratoga Creek (top) is a non-regulated stream with relatively high peak flows during the wet winter season (Fig. 8 shows the period from Jan. 2002 to Dec. 2003). In comparison, regulated Stevens Creek had much reduced peak flows. Both are similarly sized channels. Where once annual peak flows flush out the sediment buildup, it may now take decades for a sufficiently large storm to exceed the capacity of the dam and flush the buildup of sediments that have accumulated in the channel for many years. Thus it is not surprising that this study found regulated flow sites to have more accumulated fine sediments. Peak flows are much less likely to occur and flush out accumulated sediments at regulated flow sites.

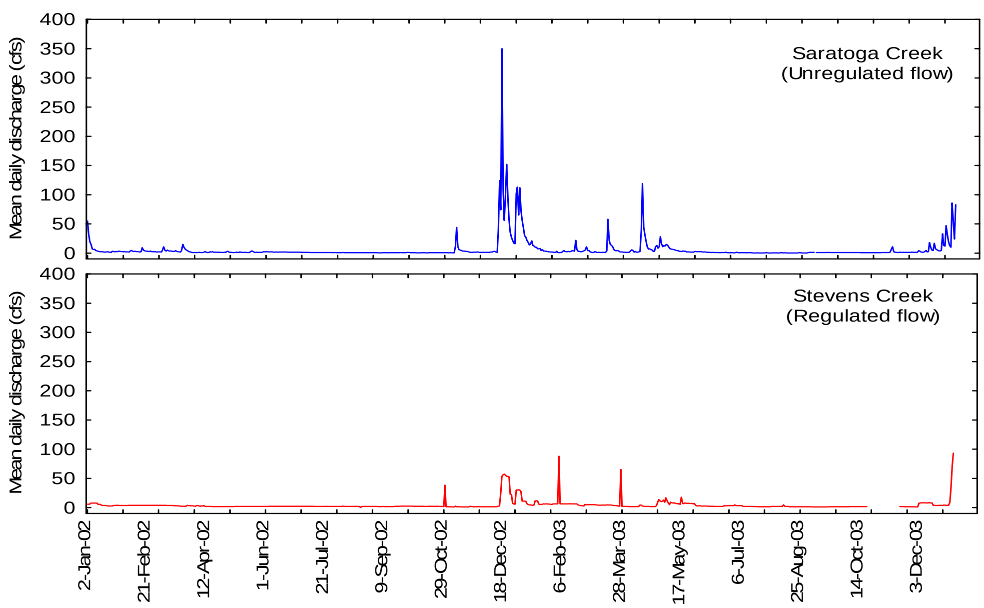

Figure 8. Saratoga Creek (top) is a non-regulated flow stream while Stevens Creek (bottom) is regulated by Stevens Creek Reservoir. Note the reduced peak flows at Stevens Creek.

Not only do more fine sediments occur in regulated flow sites, but the variability as shown by both the standard deviation and the coefficient of variation is higher as well (Table 2). Many factors could have contributed to this variability, including differences in dam management and water release mandates. The amount of fine sediment coming from the watershed could differ based on factors such as localized geology, land use, and construction activities as well. Also at the site level, local hydraulics contributes to areas of increased deposition (e.g. backwater areas, patches downstream of cobbles and boulders).

A heterogeneous substrate habitat can support a more diverse macroinvertebrate assemblage because of greater niche availability. Non-regulated flow sites supported a significantly richer EPT assemblage. The excessive deposition of fine sediments may create a less diverse physical habitat that is no longer suitable for some aquatic insects.

EPT density varied significantly between the streams factor, however, no difference in means could be detected between flow regimes. Macroinvertebrates such as EPTs, which exist primarily on substrate surfaces and interstitial spaces, require greater heterogeneity in habitat (Waters 1995). One would therefore expect a decrease in EPT density at regulated flow sites which have been shown in this study to have significantly higher amounts of deposited fine sediment. However, there are different levels of sediment tolerance within the EPT. Heptageniidae, a mayfly (Ephemeroptera) family, belongs to the functional feeding group scrapers because they scrape algae and diatoms from substrate surfaces in high gradient riffles as food sources. If substrate surfaces are coated with fine sediment, as in many regulated flow sites, we would expect heptageniids to be lower in density. Indeed, Heptageniidae density was estimated to be 603 individuals m^{-2} in regulated flow sites compared to 4396 individuals m^{-2} in non-regulated flow sites.

Certain species within the EPT appeared similarly abundant at both flow regimes, while some occurred in greater density at regulated flow sites. *Baetis tricaudatus* is an ephemeropteran that occurred at most sites, regardless of flow regime. *Hydropsyche californica,* a trichopteran, and Nemouridae, a plecopteran, are two EPT taxa found primarily in regulated flow sites (Table 4). Although the EPT are relatively pollution-intolerant compared to other taxa, the group encompasses a number of insects that can tolerate varying levels of sediment and other pollutants.

Species	non-regulated flow	regulated flow
Hydropsyche californica	23	708
Baetis tricaudatus	1021	1346
Nemouridae	835	1485

Table 4. Estimated total individuals m^{-2} of selected EPT taxa that were more abundant at regulated flow sites.

An additional reason why EPT density means were not found to be significantly different between flow regime could be due to the high error which would decrease the power to detect any difference in means. The mean EPT density in non-regulated flow sites was 10,521 individuals m^{-2}; in contrast, regulated flow sites had an estimated 4779 individuals m^{-2}. The trend suggests that EPT density is greater in non-regulated flow sites, although there is likely insufficient power to detect it using an n of only three.

The nested analysis of variance showed that the mean % EPT between flow regimes was not significantly different. % EPT varied significantly between streams, which accounted for the majority of variation present in the analysis (Table 2). This metric was not significantly different because certain species within the EPT were abundance at regulated flow sites or at both types of sites. As stated above in explaining EPT abundance, certain EPT taxa such as *Baetis tricaudatus* occurred across both flow regimes and were highly variable.

The metric EPT/ (EPT+Chironomidae) analyzed the relationship of the abundances of EPT to Chironomidae across sites. No significant difference between flow regimes was detected. The effect of increased fine sediment deposition on Chironomidae has been explored by previous studies, but many authors have drawn conflicting conclusions. For example, Lenat et al (1981) suggested dominance by Chironomidae with increasing sediment input, while Angradi (1999) indicated that Chironomidae abundance declined with increasing % fine sediment. Note the large error range of this metric in regulated flow sites compared to non-regulated flow sites. It may not be surprising to see no significant difference because a 500 μm net cannot effectively sample for Chironomidae, even though most bioassessments use 500 μm nets (Carter and Resh 2001). In studies focusing on Chironomidae, they are typically sampled with <100 μm nets due to their small size.

Although highly variable, both EPT density and richness decreased with increasing fine sediment. The upper bound of the polygonal distribution implies that fine sediment is a limiting factor in the density and richness of macroinvertebrates. Thomson et.al. (1996) suggests that looking at the edges of clouds of data in ecological studies could provide insight into limiting factors even if analyzing correlations and regressions reveal no relationship. Although many factors such as food availability and quality, competition, and predation exist which contribute to the abundance and diversity of organisms at a site, the polygonal distribution implies that fine sediment is a limiting factor among other confounding factors which might also influence EPT densities and richness.

The comparison of lab-measured sediment samples with field-measured turbidimeter readings indicated that a fair correlation exists between the two methods. The relationship appears to be curvilinear. At high levels of fine sediment, the turbidimeter likely loses some ability to detect light attenuation in water. Other factors contributing to inaccurate turbidimeter readings could be leakage from the water in the bucket due to an inadequate seal, and up-welling or down-welling of the sediment. It is important to know the spatial extent of fine sediment, and thus far, this method appears to be a quick way to provide fairly accurate data. This method could be explored in future studies with greater sample sizes to provide more conclusive results.

The severity of the fine sediment problem has not been defined for this study. As indicated by the metrics results, however, degradation of aquatic habitat has likely occurred. Substantially more studies are required to further explore the distribution of fine sediments and how fine sediments impact macroinvertebrates. Extensive mitigation for the negative effects of dams may be involved, especially where endangered and threatened species occur. In many places, excess deposited fine sediments have been implicated in fish habitat degradation and channel morphology changes. In the Trinity River of northern California, the streambed filled with fine sediments after Trinity Dam closed upstream and effectively captured peak flows. Flushing flows have been used in different rivers to scour out deposited fine sediments. Perhaps it may become necessary to use flushing flows in some of our regulated flow sites such as Stevens Creek to reduce excess fine sediments to improve the overall ecological health of the stream.

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