Central Coast Watershed Studies

CCoWS

Storm water quality in the Pacheco, Uvas, and Watsonville watersheds, 2003-4

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Executive Summary and Conclusions

- Watershed Working Groups exist in the Central Coast region of California to address continued adoption of water quality improvement practices. These groups are primarily comprised of representatives from the agricultural industry.
- Storm water quality was monitored at two sites in each of three watersheds where Watershed Working Groups have or will be convened: Pacheco, Uvas-Carnadero, and Watsonville.
- Notionally, the sites in each watershed would be above and below sections of the watershed comprising single land uses, such as agriculture. This would allow inference about pollution sources specific to these land uses to be made using the differences in data from the respective above/below sites. However, this ideal is only partly possible - given the limited availability of public-access bridges for storm sampling, and the complex spatial pattern of mixed land uses in the lower portions of most Central Coast watersheds.
- Three storms were monitored throughout the 2003-4 winter - during the beginning, middle, and end of the storm hydrograph. A total of about 17-18 samples were obtained per site.
- Samples were analyzed for suspended sediment concentration (SSC), nitrate, ammonia, orthophosphate, temperature, pH, turbidity, transparency, and total dissolved solids.
- Suspended sediment concentrations during storms were high enough for moderately adverse effects on aquatic biota. While there was some evidence for increased sources in downstream areas, there was also uncertainty about the role of changing sediment transport processes with changing geomorphology as one moves downstream.
- Phosphate concentrations met water quality objectives in Pacheco and Uvas-Carnadero, but failed to meet objectives in the Watsonville watershed. Strong evidence for increased sources between the two sampling sites on Watsonville Slough was tempered by the fact that the majority of this highly heterogeneous watershed (91.4%) occurs between the two sites.
- Nitrate concentrations met objectives at all sites except the lowest Watsonville site, where they were severe. The low concentrations at most sites are not interpreted as indicating that significant sources do not exist, but rather, that large undeveloped upper areas of watersheds can both reduce the detectability of significant lower-watershed sources, and also dilute their effects.
- Pacheco Watershed
    - Sediment and nutrients exceeded objectives infrequently, indicating only minor problems at the site.
    - Peak storm loads are typically around 15 times higher than non-storm loads. So if we assume about 5 storm days occur each year, peak storm loads would account for about half the annual load.
    - 18.9% of watershed lies between the two sampling sites

- There is some evidence for local, short-term pulses of sediment and nutrients being delivered from nearby areas (such as agricultural areas) between the two sampling sites immediately during storms. At all other times, inputs from these areas are either minimal, or are overshadowed by the large discharges from the greater watershed above the upper sampling site.
- The Pacheco Watershed is unusual for small Creeks in the Region because of near-perennial reservoir releases.

- Uvas-Carnadero Watershed
  - As for the Pacheco Watershed, sediment and nutrients exceeded objectives infrequently, indicating only minor problems at the site - at least in terms of sediment and nutrient *concentrations*. Exception is occasional severe sediment spikes during storm peaks - most likely detrimental to salmonid migration.
  - Sampling sites are dry throughout the entire non-winter period, so almost all load is directly associated with storms.
  - Roughly 3% of watershed lies between the two sampling sites
  - No evidence for agricultural inputs between sampling sites - nor would any be detectable given that almost the entire watershed is above the upstream site. Some evidence for seasonal sediment storage and remobilization in sandy/gravelly channel bottom.
- Watsonville Watershed
  - 91.4% of watershed lies between the two sampling sites
  - Phosphate and phosphate concentrations consistently much worse than objectives. Some evidence for increased inputs from sources between the sampling sites (incorporating many land uses). Nitrate concentrations better than objectives at upstream site, but much worse than objectives at downstream site - indicating severe inputs between sampling sites (consistent with tile-drained agriculture, but by no means conclusive, given the wide range of land uses in the watershed). Generally minor suspended sediment concentrations, although one severe spike was sampled.
- Summary & Recommendations
  - Repeat this study every 3 years
  - Based on the present data, Pacheco is a low priority watershed - given its advantage situation of having agricultural inputs being consistently diluted by upper watershed flows
  - Based on the present data, Uvas-Carnadero is a low priority watershed for nutrients, but sources of occasional storm sediment spike should be clarified and monitored. The watershed supports one of the better-known salmonid runs in the greater Pajaro Watershed, and the northern part of the threatened South-Central Coast Steelhead Evolutionary Significant Unit.
  - The Watsonville Slough watershed has severe nutrient pollution, particularly in the downstream reaches (but upstream of the tide gates). While the watershed supports a particularly diverse array of land uses (Hager et al,. 2004), agricultural inputs are a likely source of the high nitrate, phosphate, and ammonia concentrations

observed. The present data offer a substantive baseline against which to measure the effectiveness of future improvements to water quality management in the watershed.

- Since the runoff from all watersheds has the potential to impact downstream areas, including the ocean, it is important to understand pollution *loads* being delivered to downstream areas as well as *concentrations* within the watershed itself. The present data indicate that storm loads account for a significant proportion of the annual load, and that they often cannot be characterized by non-storm sampling. Thus, we emphasize the need to conduct targeted storm sampling in conjunction with ambient sampling in any future efforts to establish baselines, or evaluate future changes.
- A statistical methodology based on locally weighted quadratic regression was developed for comparing storm water quality data between sites, or between years at a given site

1 Introduction

1.1 Background

With the aim of improving water quality over time through the continued adoption of a variety of land management practices, Watershed Working Groups (WWG) are being formed in the Central Coast of California.

The Coalition of Central Coast County Farm Bureaus has developed an agricultural watershed management program for six counties throughout the Central Coast region of California (MBNMS, 1999). The coalition was organized for two primary purposes: to increase agricultural participation in addressing water quality issues and to assist the Monterey Bay National Marine Sanctuary in the implementation of the Water Quality Protection Program Action Plan for Agricultural and Rural Lands (MBNMS, 1999). A major component of each County's program is implemented through the formation and participation of Watershed Working Groups – voluntary networks of landowners, growers, and ranchers. Participants in the program work with technical assistance organizations to monitor water quality, improve management practices, and develop watershed plans to address non-point source pollution (Hager et al., 2003).

This study was modeled after the Chualar Creek Watershed Working Group Pilot Project (Hager et al., 2003). Sediment, nutrients, and discharge were sampled at 6 locations during a number of storms. Sampling locations were chosen to span agricultural portions of watersheds where working groups have already been formed. The present project documents water quality conditions a single point in time – a single storm season. The objective is to provide a baseline. The intention is that these conditions will be compared with sampling at some future point in time, in order to determine the effectiveness of water quality improvement practices. Such a comparison should involve statistical methodology that is able to take into account uncertainty due to climatic and environmental stochasticity (random variation), as well as sampling variability and bias.

1.2 Objectives

The objectives of the present study were to:

- Determine whether storm water quality problems currently exist within the WWG streams
- Establish baseline storm water quality characterization of the selected WWG watersheds – with the intent that the same effort be repeated in the future in order to track water quality changes over time
- Attempt to evaluate potential agricultural influence on present storm water quality through upstream/downstream comparisons

2 Study Area and Site Descriptions

The creeks sampled for this study are tributaries of the Pajaro River. Pacheco Creek enters the San Felipe Lake, which is the source of the Pajaro River. Uvas Creek becomes Carnadero Creek before flowing into the Pajaro River about 4 km before the San Benito River confluence. Watsonville Slough originates in the town of Watsonville and drains into the Pajaro River estuary immediately upstream of the mouth at Monterey Bay (Fig. 2-1). Two sites were monitored on each of these three systems (Table 2.2). Additional sites are referred to in the text (Table 2.1).

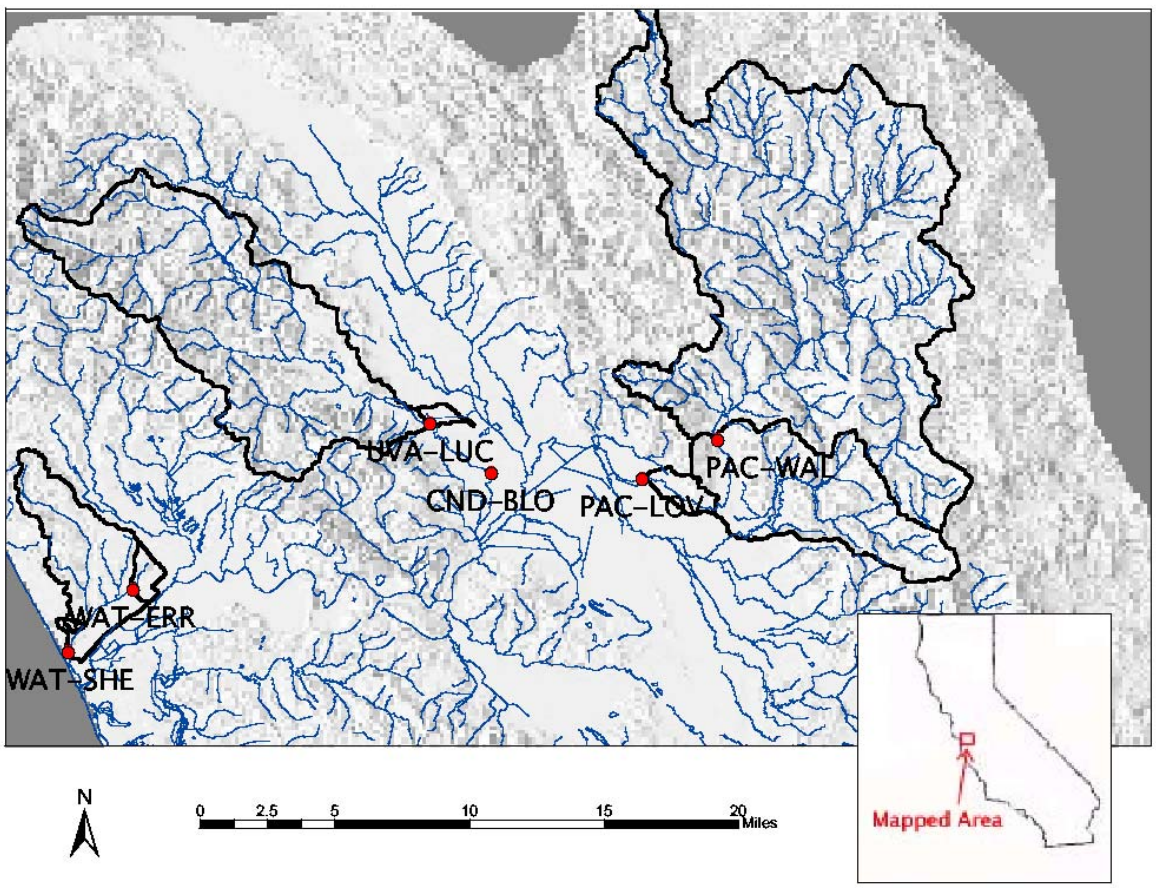


Figure 2-1 Sampling sites and watershed boundaries. Note that the watershed of CND-BLO could not be determined due to flat topography and private access restrictions on field reconnaissance.

Table 2.2 CCoWS monitoring sites. See Fig. 1 for a map of sites.

CCoWS site code	Site description	Watershed area above site (km^2)	Fraction of total watershed that is between the two sampling sites
PAC-WAL	Pacheco Creek at Walnut Ave	373.2	
PAC-LOV	Pacheco Creek at Lover's Lane	460.3	18.9%
UVA-LUC	Uvas Creek and Luchessa Rd	184.4	
CND-BLO	Carnadero Creek and Bloomfield Rd	Roughly 184.4 + 5	Roughly 3%
WAT-ERR	Watsonville Slough at Errington Rd	4.149	
WAT-SHE	Watsonville Slough at Shell Rd	48.16	91.4%

Table 2.1 Non-CCoWS sites referred to in the text and analysis.

Site name	Use	Source	Displayed in figure
Pacheco Creek Reservoir	Reservoir storage	Santa Clara Valley Water District	2
Uvas Creek Reservoir	Reservoir storage	Santa Clara Valley Water District	7
Mt. Madonna	Weather Station (precipitation)	California Data Exchange Center	18
Watsonville West	Weather Station (precipitation)	California Irrigation Management Information System	18
San Luis Reservoir	Weather Station (precipitation)	U.S. Bureau of Reclamation	18
Llagas Creek near Gilroy (USGS 11153650)	Stream discharge	U.S. Geological Survey	22
Pajaro River at Chittenden (USGS 11159000)	Stream discharge	U.S. Geological Survey	22
Uvas Creek near Gilroy (USGS 11154200)	Stream discharge	U.S. Geological Survey	-
San Benito River at HWY 156 near Hollister (USGS 11158600)	Stream discharge	U.S. Geological Survey	22

2.1 Pacheco watershed

2.1.1 PAC-WAL

Pacheco Creek at Walnut Rd is above almost all of the intensive agriculture in the Pacheco Creek Watershed (Fig. 2-2). The channel is well defined with a gravel substrate (Fig. 2-3). Above this site, the predominant land uses are grazing and parks.

This site is located 12 km (7.5 miles) downstream from Pacheco Reservoir. The Reservoir is owned and operated by the Pacheco Pass Water District, with data collection and management performed by the Santa Clara Valley Water District. The capacity of this reservoir is 7577 ML (6,143 af) (SCVWD, 2004). Water releases from this reservoir can influence discharge and water chemistry at PAC-WAL.

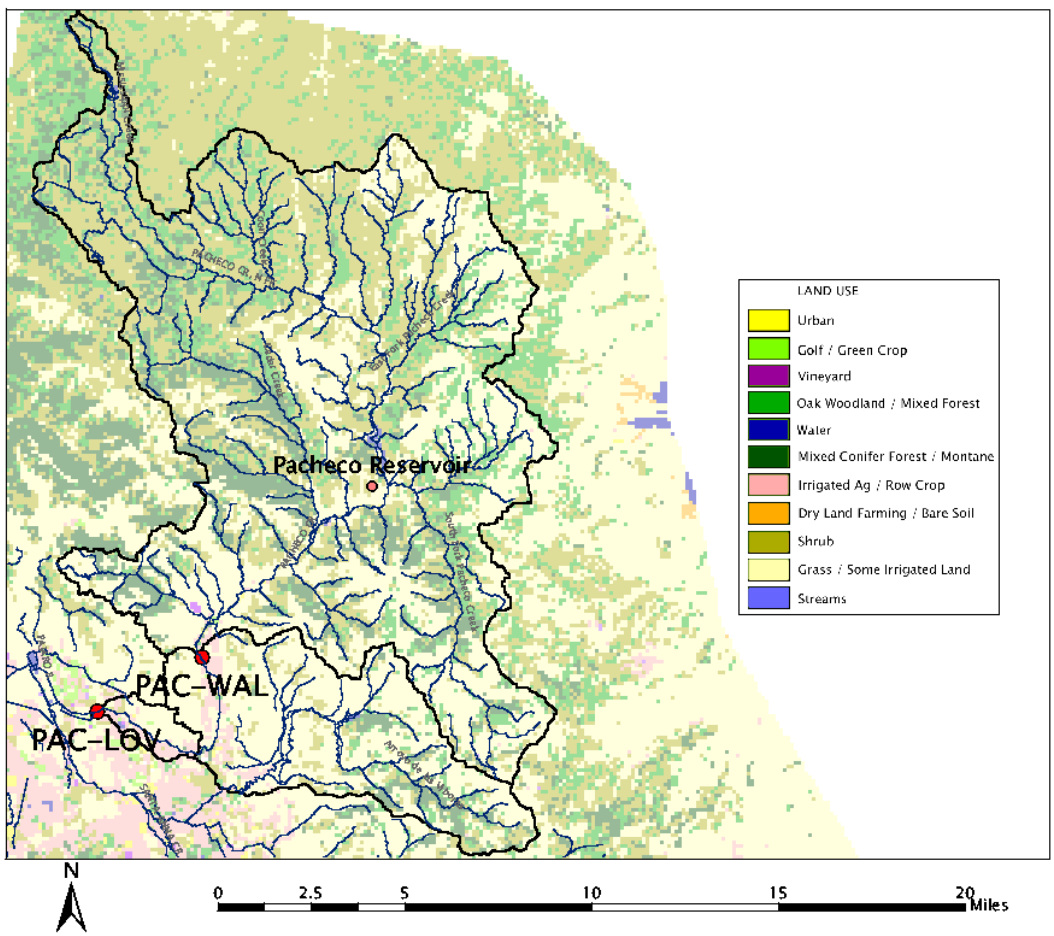


Figure 2-2 Land use in the Pacheco Creek Watershed. PAC-WAL and PAC-LOV in relation to the Pacheco Creek Reservoir (Land use data source: Newman et al., 2003).

Figure 2-3 Pacheco Creek at Walnut Rd (PAC-WAL) from the right bank looking upstream. (Photo: Joy Larson, 4 May 2004)

Figure 2-4 Taking discharge measurements from the bridge at PAC-WAL during high flow. (Photo: Joy Larson, 25 Feb 2004)

2.1.2 PAC-LOV

Pacheco Creek at Lover's Lane is located 9 km (5.5 miles) downstream of PAC-WAL (Fig. 2-5). The predominant land uses between these two Pacheco Creek sites are row crop and other irrigated agricultural land. This site also has a well-defined channel but the substrate is muddy with silts and clays. This reach of the Pacheco Creek also has a lot of in-stream vegetation that could slow water flow and trap sediment with the potential to assimilate nutrients.

Figure 2-5 Pacheco Creek at Lover's Lane (PAC-LOV) as seen from the bridge downstream (left) and upstream (right). (Photos: Joy Larson, 4 May 2004)

Discharge and water chemistry at this site may also be influenced by water releases from the Pacheco Reservoir. Depending on the water level, discharge measurements were made usually immediately upstream from the bridge and occasionally downstream from the bridge. The vegetation in the stream retards much of the total water flow along the right side of the channel. Though velocity measurements across complete cross sections were made, most velocity readings with current meters were from the deeper, faster part of the channel that runs close to the left bank, where the water is not blocked by willows in the channel.

While sampling was in progress, local landowners and residents often stopped to enquire about the sampling crew's activities. The belief was noted that in-stream vegetation exacerbates flooding of their land.

The Central Coast Ambient Monitoring Program (CCAMP) operated by CCRWQCB samples a site at Highway 156 between PAC-WAL and PAC-LOV. We did not sample this site because it is neither upstream nor downstream of the majority of row-crop agriculture in the watershed, and vehicular traffic creates safety issues for measurement of storm discharge from the bridge. A brief review of CCAMP water quality data for this site is in Table 3.1.

Figure 2-6 PAC-LOV at flowing at 18 m³/s. The top of the staff plate is almost 1 meter below the stage. (Photo: Joy Larson, 26 Feb 2004)

2.2 Uvas-Carnadero Watershed

2.2.1 UVA-LUC

Uvas Creek at Luchessa Rd is the site of a former USGS stream gage that was active from Jan 01, 1959 to Sept 30, 1992. There is a large maintained levee and riprap on both sides of the channel that protects the surrounding urban and agricultural land from flooding (Fig. 2-8). The channel substrate is sandy, and subject to shifting during medium to high flows (Ken Stumpf, SCVWD, pers. comm., 2004). In the watershed above this site are numerous construction sites, some agriculture, ranchettes, and forest. This site exhibits flashy behavior associated with urban runoff. There is a large pipe that enters the creek from the right bank immediately downstream of the bridge that drains storm water.

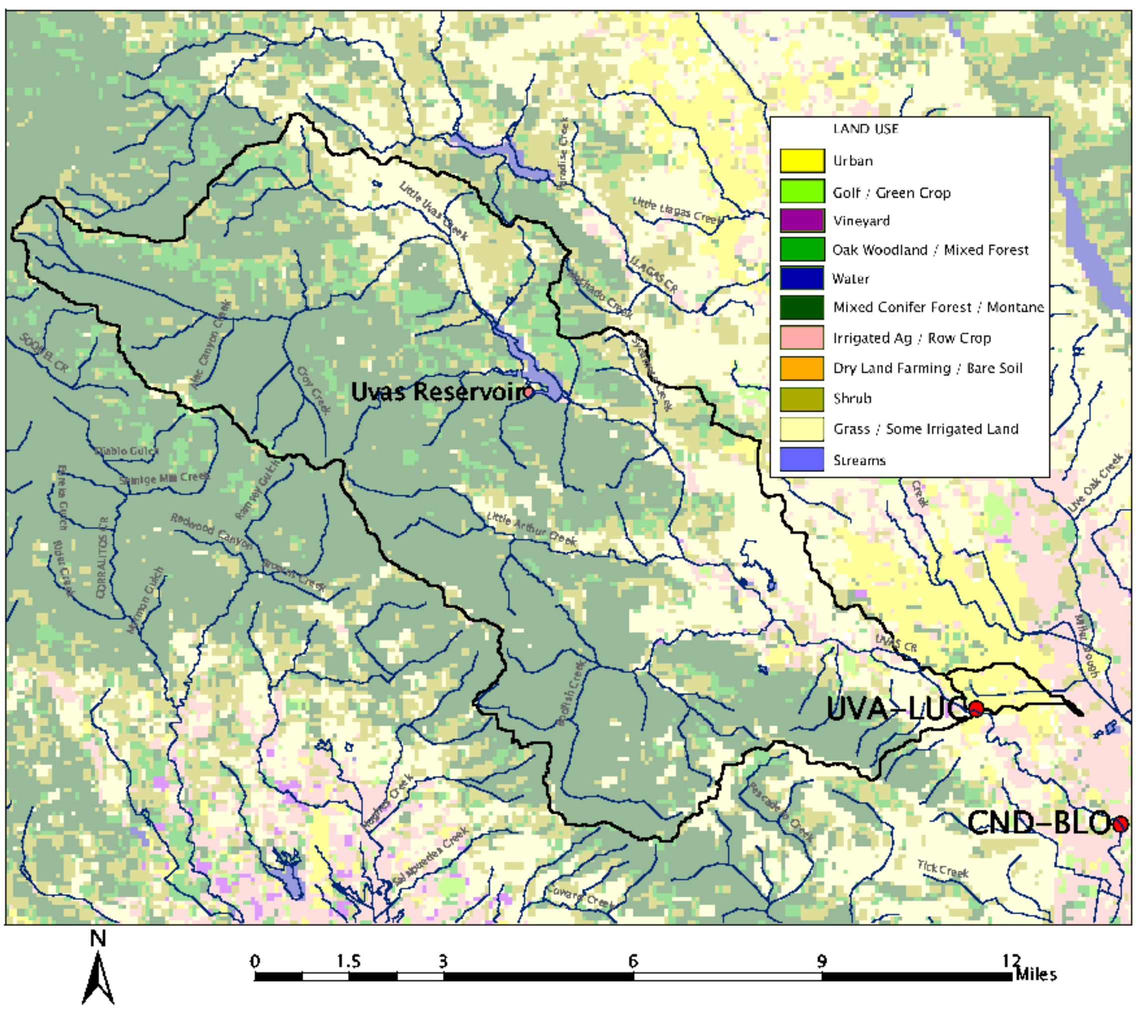


Figure 2-7 Land use in the Uvas-Carnadero Creek Watershed. UVA-LUC and CND-BLO in relation to the Uvas Creek Reservoir. The GIS land use layer was extracted from a data layer created by CCoWS (Newman et al, 2003).

Figure 2-8 Uvas Creek at Luchessa (UVA-LUC) looking downstream from the left bank. (Photo: Joy Larson, 4 May 2004)

It is located 14.6 km (9 miles) downstream of the Uvas Reservoir. The Reservoir was constructed in 1957 and has a storage capacity o 12,255 ML (9,935 af) (SCVWD, 2004). Releases from this reservoir could influence discharge and water chemistry at UVA-LUC.

The bridge at this site has high cyclone fence rails on both sides preventing the use of a bridge crane for high flow discharge measurements. Discharge measurements taken on the first few visits to this site were taken from where the USGS staff plates are upstream of the bridge. At this location, it is not possible to wade across the entire width of the stream during high stages, as the bed drops off to a deep thalweg. In subsequent visits to this site, other areas downstream from the staff plates were found where it is possible to wade across the entire channel.

2.2.2 CND-BLO

At Highway 101, Uvas Creek changes its name to Carnadero Creek. Carnadero Creek at Bloomfield Rd is located 3 miles downstream of UVA-LUC (Fig. 2-9). The predominant land use that is geographically between these two sites is irrigated row crop agriculture with some urban land. However, its unclear how much of this land actually drains into the Uvas-Carnadero stream system between the two sites. Field reconnaissance indicates that the land north of the Creek and east of Highway 101 drains northeast into Llagas Creek or a tributary that drains into Carnadero Creek downstream of CND-BLO. It is unclear whether the land south of the Creek drains into the Creek or not. The two sampling sites are perhaps the best options for safe, public-access sampling 'above' and 'below' the row-crop agriculture of the Uvas-Carnadero watershed. But they are quite limited in this respect, perhaps incorporating only a negligible fraction of the row-crop agriculture of the Carnadero region. This is typical of the constraints to ideal scientific sampling when attempting to monitor land-use-specific sources in mixed land use regions.

The same large, well-maintained levee is present at CND-BLO to protect surrounding agricultural fields from flooding. The channel is well defined with a substrate that is gravely in the middle of the channel with sand along the banks (figure 9). There is a lot of riparian vegetation on both banks of this reach.

The staff plate at this site is mounted to the pillar of the bridge. During low flows, the stage of the water may be underneath the zero ft mark of the staff plate. A low flow plate was installed on a stake driven into the thalweg, but was bent out of shape during a high flow event in January 2004.

This site is also a CCAMP site. A brief review of CCAMP water quality data from this site is in Table 3.1.

Figure 2-9 Carnadero Creek at Bloomfield (CND-BLO) looking upstream. (Photo: Joy Larson, 4 May 2004)

2.3 Watsonville Watershed

2.3.1 WAT-ERR

Watsonville Slough at Errington Rd is a well-defined ditch that mainly drains urban areas of Watsonville and some agricultural areas (Fig. 2-10). There is in-stream aquatic vegetation present and the substrate is mainly riprap debris with some silt deposit.

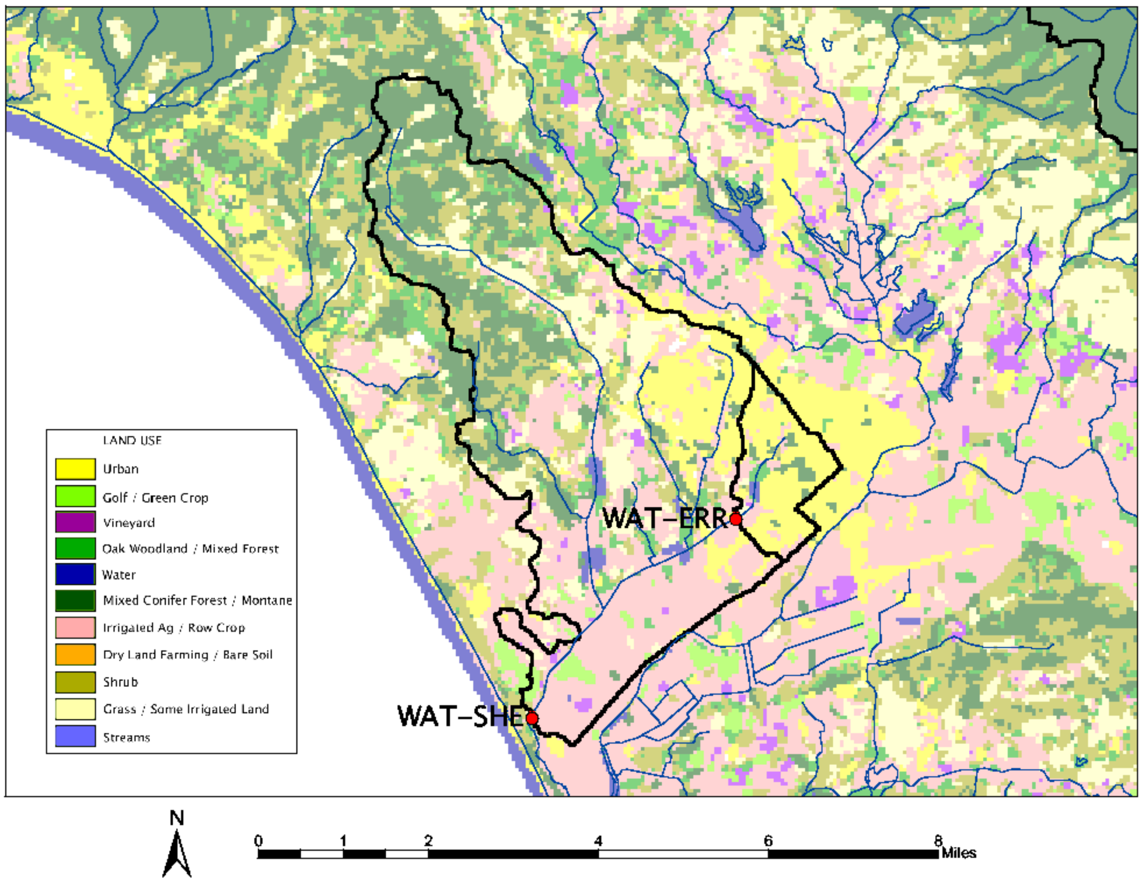


Figure 2-10 Land use in the Watsonville Slough Watershed above sampling sites on the slough. The GIS land use layer was extracted from a data layer created by CCoWS (Newman et al, 2003).

Figure 2-11 Watsonville Slough at Errington Rd (WAT-ERR) looking downstream. (Photo: Joy Larson, 4 May 2004)

Discharge measurements at this site were only measurable for the first storm in the sampling period. High wind velocities push the water surface velocity upstream inconsistently, resulting in a relatively unreliable stage-discharge relationship (appendix B). There is also a large pipe suspended from bank to bank in the channel underneath the bridge that influences water flow through the site (Fig. 2-12).

Figure 2-12 Pipe under the Errington Rd bridge at WAT-ERR. (Photo: Joy Larson, 4 May 2004)

2.3.2 WAT-SHE

Watsonville Slough at Shell Rd is 5 km (3 miles) downstream of WAT-ERR (Fig. 2-13). The land use adjacent to the Slough between the two sites is irrigated row crop agriculture. There are also several major tributaries, draining a mixture of agricultural, urban, rural-residential, and wooded land. Again, this is not an ideal situation for above-and-below sampling of land-use-specific sources, but rather, is reflective of typical constraints.

Discharge measurements were never taken at this site because of the numerous factors influencing flow. One of the factors is the sluggish flow with low, undetectable velocities through the site. There is also a pump station that pumps water from the upstream side to the downstream side of the tide gates and is operated and maintained by the Pajaro Valley Water District (Fig. 2-14). There are also two sets of culverts and leaky tide gates.

During times of high flow, high tides also back water upstream when the channel is full (Fig. 2-14). There is no reliable staff plate. Stages were recorded as inverse stages, or the distance from the bottom of the pump house platform to the water's surface. All samples were collected from the pump house platform using a grab pole.

Figures 2-15 and 2-16 show WAT-SHE looking upstream during low flow and during high flow.

Figure 2-13 Watsonville Slough at Shell Rd looking upstream (left) and pump house (right). (Photos: Julie Hager, 30 Dec 2003)

Figure 2-14 Back flow of water over tide gates at WAT-SHE. Water is flowing from the right to the left of this picture. Picture taken from pump house platform. (Photo: Joy Larson, 25 Feb 2004)

Figure 2-15 WAT-SHE looking upstream at low flow. (Photo: Joel Casagrande, July 2002)

Figure 2-16 WAT-SHE looking upstream during high flow (Photo: Joy Larson, 26 Feb 2004)

3 Existing data: CCAMP

The Central Coast Ambient Monitoring Program sampled Pacheco Creek at Highway 156 (PAC-156, in between PAC-WAL and PAC-LOV), as well as Carnadero Creek at Bloomfield Road (CND-BLO). Sampling took place from December 1997 to December 1998. Parameters that were measured include total ammonia as N, nitrate as N, pH, phosphate as P, total suspended solids, water temperature, and turbidity. It is unknown if any of these samples coincided with storms.

Table 3.1 Summary of water quality data in the study area accessed from the CCAMP website (CCAMP, 2004).

	Pacheco Ck at Hwy 156 (CCoWS site code: PAC-156)				Carnadero Ck at Bloomfield (CCoWS site code: CND-BLO)			
Water Quality Parameter	Max	Min	Mean	n	Max	Min	Mean	n
Ammonia as N, total (mg/L)	0.131	0.004	0.036	12	0.05	0.004	0.028	7
Nitrate as N (mg/L)	5.843	0.674	2.936	12	2.18	0.157	1.117	7
pH	8.35	7.5	7.91	13	8.4	7.56	7.968	8
Phosphate, total as P (mg/L)	0.8	0.033	0.309	12	0.47	0.047	0.225	7
Suspended solids, total (mg/L)	362	N/a	58	15	96	0.3	24.2	10
Water temperature (°C)	27.4	11	17.4	13	21	9.3	13.1	8
Turbidity (NTU)	222	6	48	11	151	5	38	8

4 Methods

The three selected watersheds (Pacheco Creek Watershed, Uvas-Carnadero Creek Watershed, and the Watsonville Slough Watershed) were sampled during three storms in the 2003/2004-storm season.

4.1 Storm prediction

Monitoring was planned around predicted storm events. These predictions were made with satellite images (NOAA), radar images (NOAA and wunderground.com), quantitative precipitation forecasts (QPFs) (NOAA), and 10-day weather forecasts (weather.com) available online. An attempt was made to sample each storm with a QPF of greater than about 13 mm (0.5 inches), up to a maximum of three storms.

4.2 Sites monitored

Two sampling sites were monitored on each creek, one upper (or above significant/targeted land use), and one lower (or downstream of significant/targeted land use).

4.3 Monitoring schedule

Each site was visited at least five times during each of the three storm events with the intention of having sampling times span the storm hydrograph (pre-storm, pre-peak, peak, post-peak, and post-storm).

4.4 Measurements

At each visit to a site, stage was recorded, and velocity measurements were made when conditions were appropriate for the purpose of calculating discharge (Watson et al, 2005-06f). A USGS Type A Crane was used (with Four-Wheel Truck, model 4350) to measure deep, fast flows from bridges when the flow was too deep and fast to wade safely (Fig. 4-1). The crane was only used during the third storm event. It was not fully operational for the first storm event and as a result, some high flows were not measured. The second storm was relatively small and flow measurements were made by wading across the creeks without the use of the crane.

Final discharge estimates were taken from a stage-discharge 'rating' curve hand-fitted to the discharge data for each site. This curve was of the form:

$$Discharge = Scale \times (Stage + Offset)^{Power}$$

Where *Scale*, *Offset* and *Power* are parameters fitted for each site (see Appendix B).

Because individual measurement errors are likely to be smoothed by the curve we make the assumption that discharge estimates based on the curve are more accurate than actual measurements. This practice is also effectively followed by the USGS (although the USGS uses a more complex rating curve).

Figure 4-1 Thor Anderson using the bridge crane at PAC-LOV on 26 Feb 2004. (Photo: Joy Larson)

Figure 4-2 Lowering the weighted fish from the bridge crane into high flow water at PAC-WAL. (Photo: Joy Larson, 26 Feb 2004)

4.5 Sample Collection and Laboratory Analysis

Two samples were collected every time a site was visited. One depth-integrated sample was collected using a DH48 or DH76 sampler and analyzed for suspended sediment concentration (SSC), turbidity, and transparency. In order to keep nutrient sample bottles clean and avoid cross contamination of samples due to sampling equipment, nutrient samples were taken as grab samples directly into the bottle. The grab sample was taken at arm's length from the surface during wadable flows and at arm's length from the bank at high flows. These nutrient samples were then frozen and analyzed for nitrate (NO_3-N), ammonia (NH_3-N), and phosphate (PO_4-P) (Watson et al, 2005-06f).

Other water quality parameters that were measured *in situ* were temperature, pH, and total dissolved solids (TDS). Table 4.1 lists the measured parameters and associated analysis methods.

Where discharge measurements were made, SSC and nutrient concentrations were multiplied by the measured discharge to obtain instantaneous loads. These loads were graphed against measured discharges to identify spikes in concentrations or dilutions associated (or not associated) with increased discharges, and to also potentially identify overall changes in concentration over time.

Table 4.1 Analysis methods and instruments used for measuring water quality parameters. See Watson et al, 2004 for further explanation of each method.

Parameter	Analysis method / instrument
SSC	Vacuum pump and filters
Turbidity	HachTurbidimeter2100P
Transparency	Transparency 60cm Tube
NO_3-N	HACH Spectrophotometer; HR (0.2 to 30 mg/L NO3-N); chromotropic acid method
NH_3-N	HACH Spectrophotometer, LR (0.02 to 2.50 mg/L NH3-N); salicylate method; AmVer Test 'n Tube
PO_4-P	HACH Spectrophotometer, (0.06 to 5.0 mg/L PO4); absorbic acid method; PhosVer 3; AmVer Test 'n Tube
pH	Oakton pH Tester
Temperature	Thermometer
TDS	Oakton TDS Tester

4.6 Water quality objectives

Water quality objectives were defined as a basis to compare observed levels of suspended sediment, turbidity, nitrate, phosphate, ammonia, and pH. These objectives are summarized in Table 4.2 and detailed below.

Table 4.2 Summary of water quality objectives that will be used for comparison to data.

Analyte	Water Quality Objective
Suspended sediment (mg/L)	10, 100, 1000
Turbidity (NTU)	2, 20, 200
NO_3-N (mg/L)	1.2
NH_3-N (mg/L)	0.497 – 6.67
PO_4-P (mg/L)	0.12
PH	6.5 – 9.0

4.6.1 Sediment and turbidity

Water quality objectives for turbidity levels and suspended sediment concentrations are not defined numerically by the RWQCB. Hager et al. (2003) reviewed the literature or suspended sediment impacts to fish and aquatic invertebrates (key data reproduced here in Appendix A). Noting the absence of definitive studies for Central Coast aquatic ecosystems, Hager et al. suggested following guidelines – based primarily or rainbow trout and representing the most applicable objectives available:

- Up to 2 NTU or 10 mg/L: not likely to adversely affect fish and invertebrates
- Up to 20 NTU or 100 mg/L: potential change in behavior and / or slight decrease in survival
- Up to 200 NTU or 1,000 mg/L: stress, physiological changes, and potentially lethal effects

4.6.2 Nutrients

Water quality objectives used for comparison of observed nutrient concentrations in this report are taken from the following two sources.

A study by San Jose State University and Merritt Smith Consulting (1994) examined nutrient problems and sources in the Pajaro River and Llagas Creek. The authors estimated nutrient objectives based on mean concentrations observed at relatively un-impacted sites for nitrate (NO3-N) to be 1.2 mg/L and for phosphate (PO4-P) to be 0.12 mg/L (SJSU & Merritt Smith, 1994).

In *A Compilation of Water Quality Goals* prepared by Jon B. Marshack for the Central Valley RWQCB, both narrative and numeric objectives for water quality are listed (Marshack, 2000). Of the Ambient Water Quality Criteria to Protect Freshwater Aquatic Life for total ammonia nitrogen, criteria that correspond to different temperature and pH are given. The maximum and minimum temperature (14.5°C and 7.88°C respectively) and the maximum and minimum pH (10.3 and 4.5 respectively) that were measured in the field during sample collection were used to specify a range of criteria for comparison. This range is from 0.497 mg/L to 6.67 mg/L (Marshack, 2000. pg 13).

4.6.3 pH

In the Basin Plan it states that: "For waters not mentioned by a specific beneficial use, the pH value shall not be depressed below 7.0 or raised above 8.5." (CCRWQCB,1984). In the CCRWQCB document Compilation of Water Quality Goals, the USEPA national recommended ambient water quality criteria for freshwater aquatic life protection is cited as an instantaneous maximum of 6.5 – 9.0 (CCRWQCB, 2000).

4.6.4 Transparency, TDS, and temperature

To date, there are no explicit published numeric water quality objectives for transparency, TDS, or temperature.

5 Results and Discussion

5.1 Hydrology

5.1.1 Precipitation

Precipitation data were obtained online from numerous websites. A map of the location of precipitation stations is shown in Figure 5-1. Data for the Watsonville West station were taken from the California Irrigation Management Information System (CIMIS, 2004), data for the Mt. Madonna station were taken from California Data Exchange Center (CDEC, 2004), and data for the San Luis reservoir station were taken from the US Bureau of reclamation (USBR, 2004).

Overall, the Mt. Madonna weather station received more precipitation than the other two weather stations. Storms that were monitored occurred 28 Dec 2003 – 5 Jan 2004, 1 – 5 Feb 2004, and 23 Feb – 1 Mar 2004. Figure 5-2 displays precipitation data from three nearby weather stations and sampling dates.

It rained off and on for almost the entire month of December 2003 leading up to the first sampled storm (Fig. 5-2). The second storm was an isolated event without much precipitation before and after the sampled dates. Rain was intense during the second week of February before the third and final monitored storm. This increased stream flow dramatically (Fig. 5-6), as the streams did not return to low flow conditions between the two storm systems at the end of February.

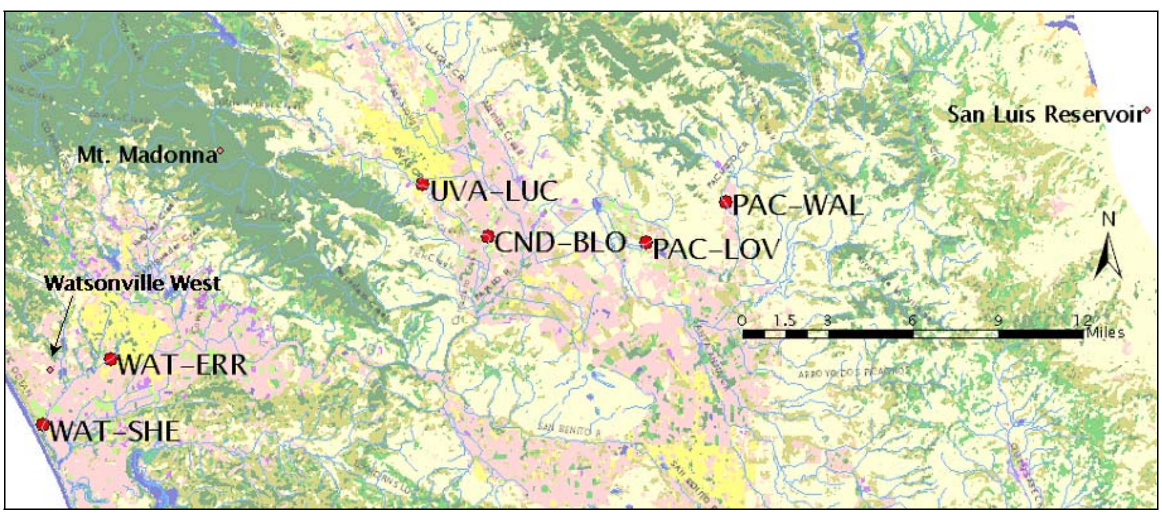


Figure 5-1 Location of precipitation stations in relation to sampling sites.

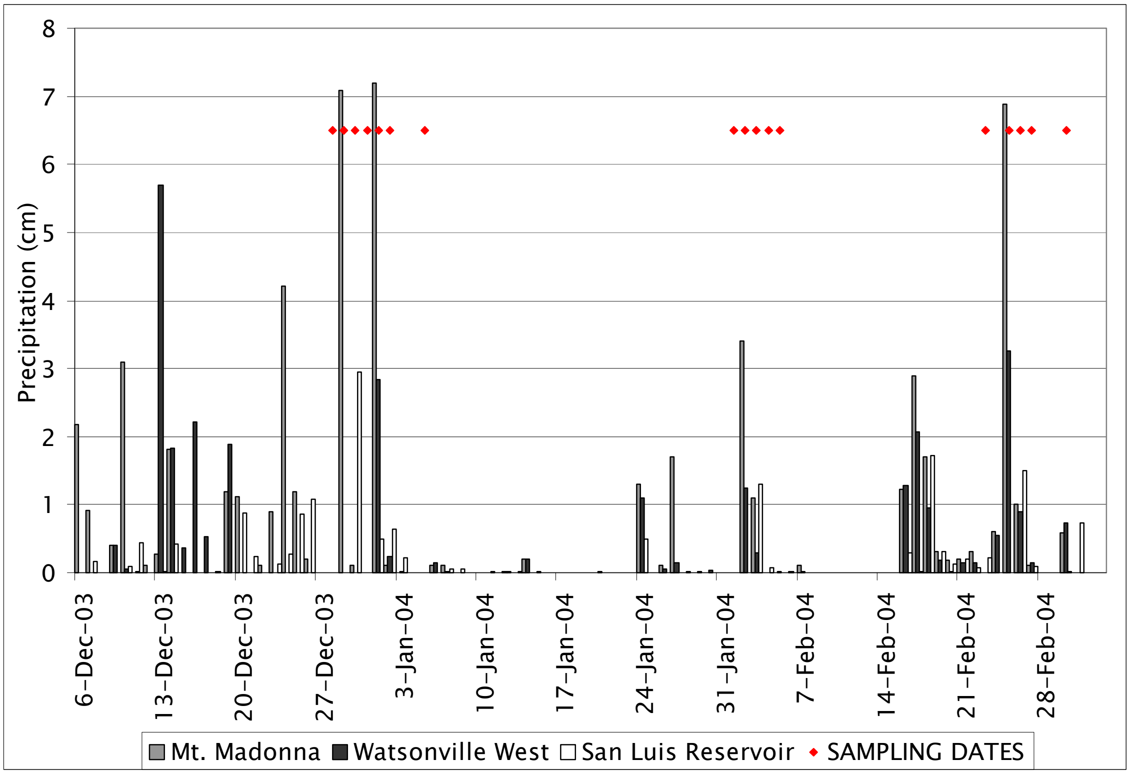


Figure 5-2 Daily precipitation at three weather stations in the study area during the entire monitoring period, including sampling dates. There was no data available from the Watsonville West station from 20 – 30 Dec 2003.

5.1.2 Reservoir releases

Another major influence on discharge and water chemistry is water releases from reservoirs upstream of the sampling sites. See Figures 2-2 and 2-7 for the location of the reservoirs in relation to sampling sites. Figures 5-3 and 5-4 display reservoir storage data that were obtained from the Santa Clara Valley Water District website (SCVWD). These data are displayed with sampling dates.

What is of interest in these charts is the change in storage. This was calculated by subtracting the storage of one day from the storage of the previous day (in acre-ft), and then converting this value into a rate (cubic feet per second). A drop in the change in storage (black line) implies that a net amount of water was released from the reservoir relative to any inflow that was occurring at the time (assuming negligible evaporation and percolation).

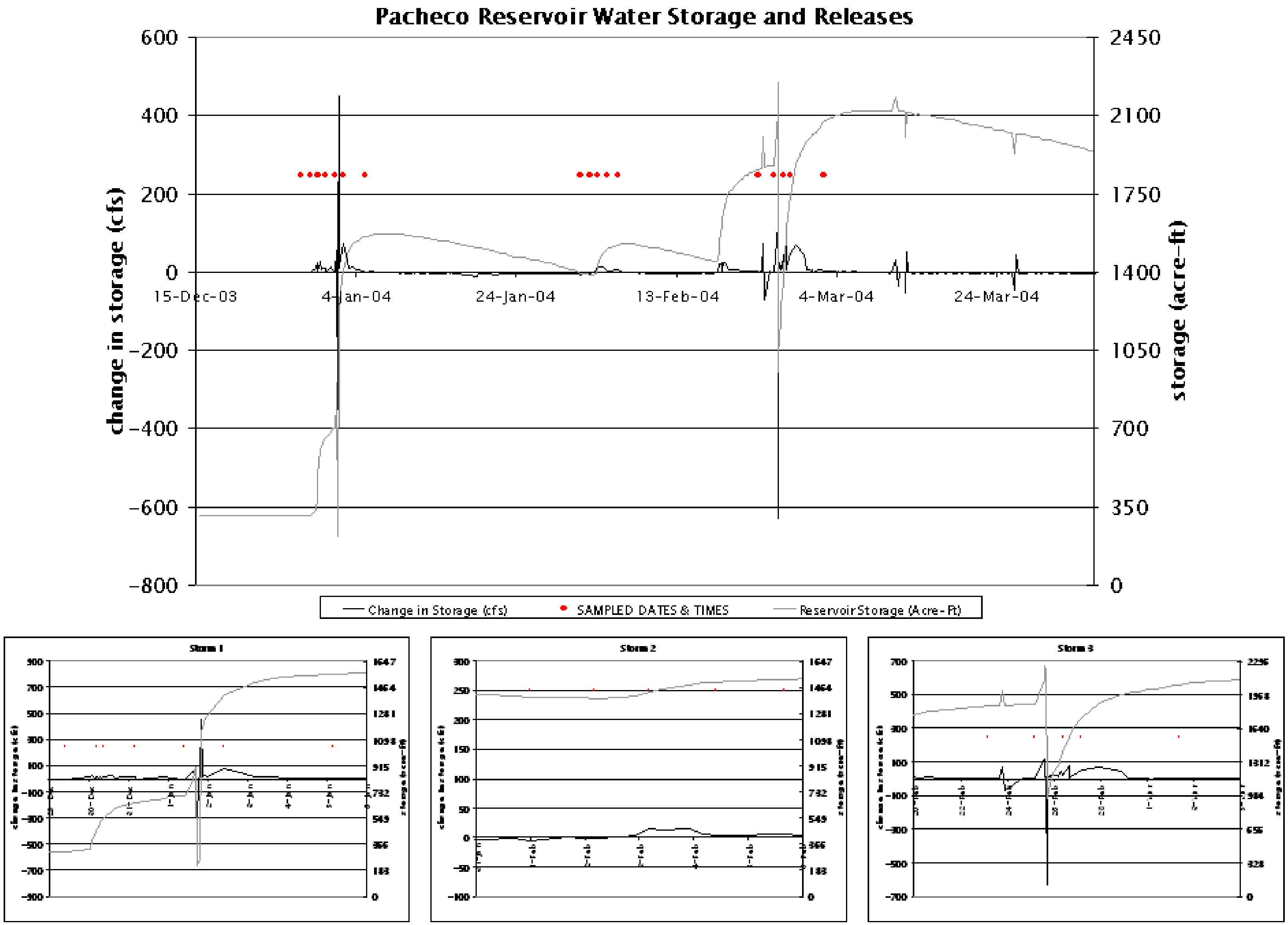


Figure 5-3 Pacheco Creek Reservoir water storage and releases. Bottom three graphs display storage and change in storage during each sampled storm on a smaller scale.

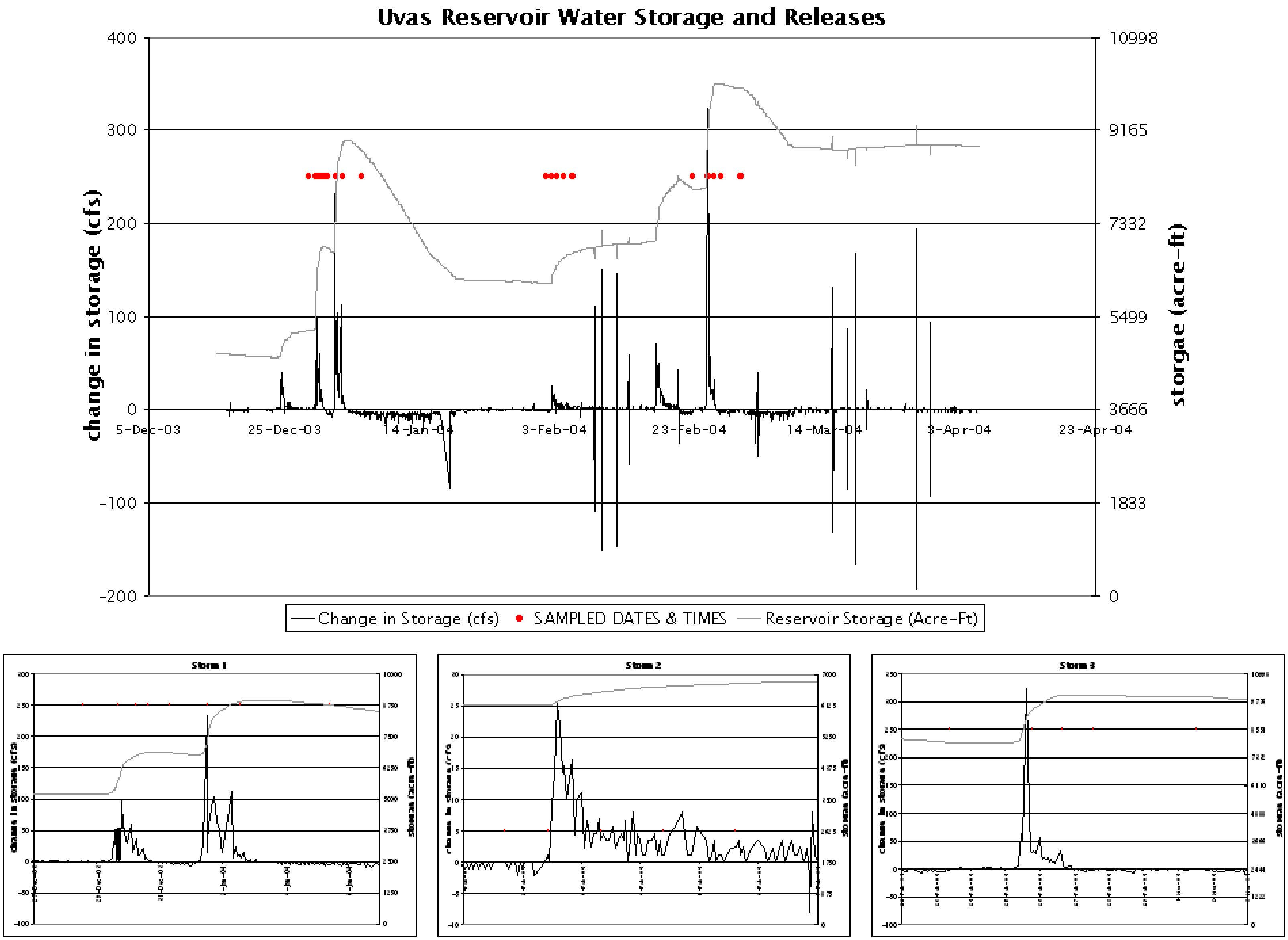


Figure 5-4 Uvas Creek Reservoir water storage and releases. Bottom three graphs display storage and change in storage each sampled storm on a smaller scale.

There were two significant releases from the Pacheco Creek Reservoir during the sampling periods, one during storm 1 on 1 Jan 2003, and one during storm 3 on 25 Feb 2003 (Fig. 20). See Appendix C for data from this reservoir from 1Jan 2003 to 16 June 2004.

There were no significant releases from the Uvas Creek Reservoir during the sampling periods, though there were releases in between sampled storms (Fig. 21).

5.1.3 Stream discharge

Figure 5-5 displays U.S. Geological Survey gauging stations located within the study area. Figure 5-6 displays continuous discharge data from these gauging stations. These data were obtained from the USGS Surface-water Data for California web site (USGS, 2004).

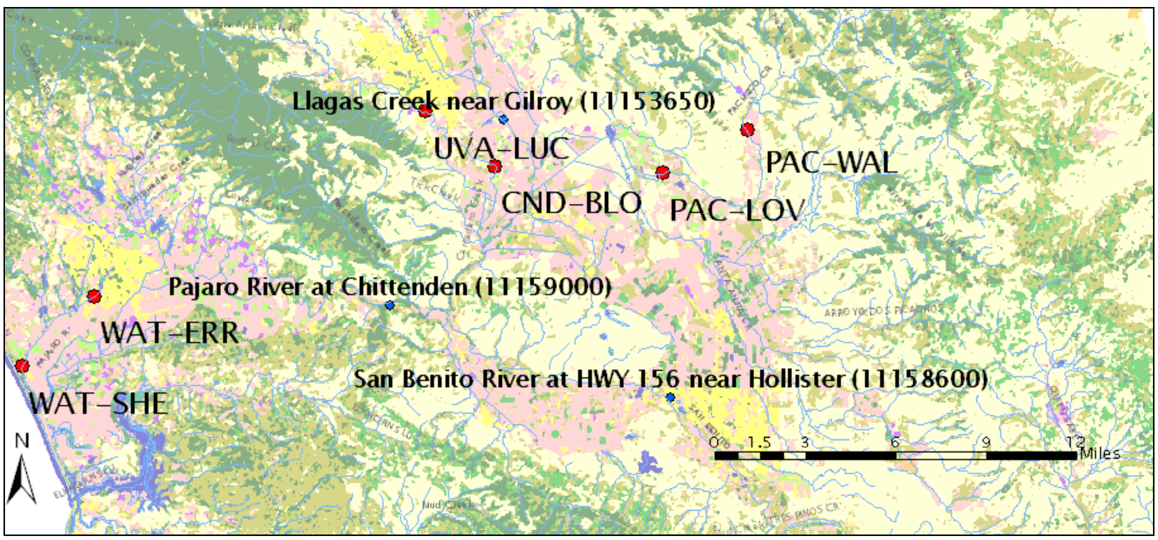


Figure 5-5 Location of USGS gauging stations in relation to sampled sites.

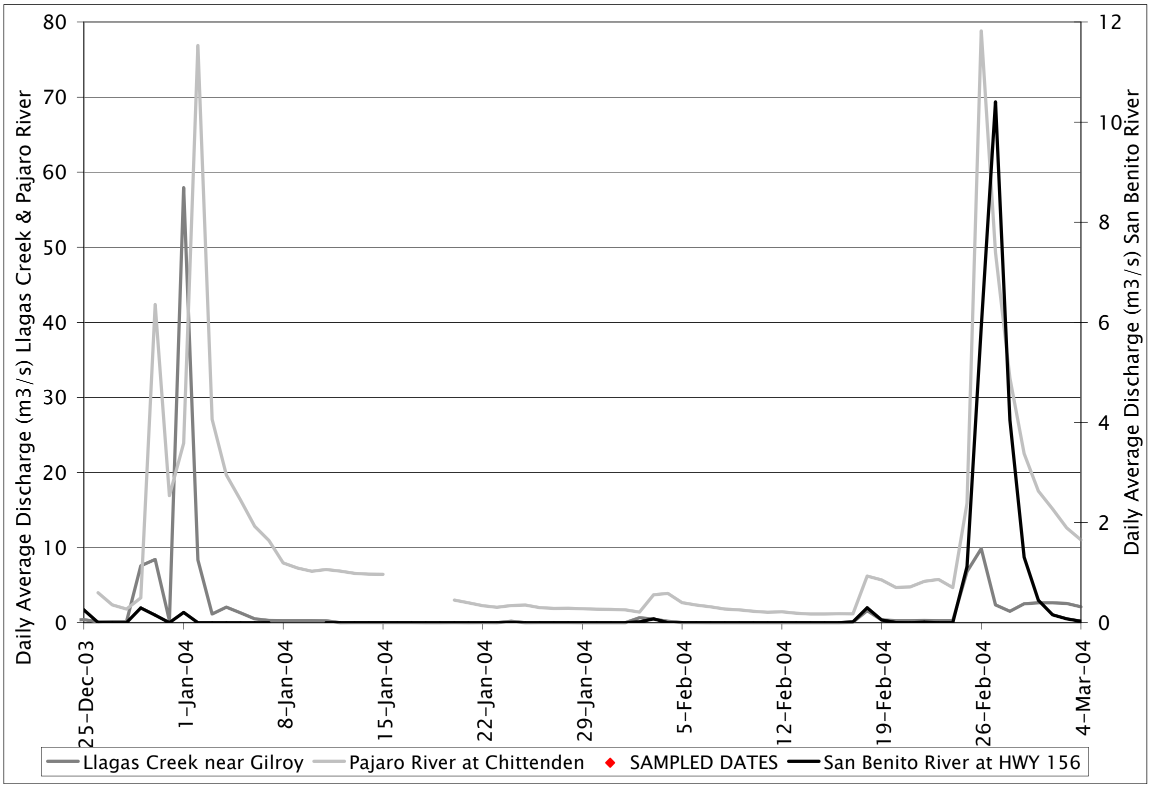


Figure 5-6 Daily average discharge at three nearby USGS gauging stations in the study area including sampling dates. No record was available for the San Benito River at HWY 156 for 8 – 10 Jan 2004 or for the Pajaro River at Chittenden for 16 – 19 Jan.

Discharges measured for the present study area show in Figures 5-7 through 5-9. Stage-discharge rating curves as well as a table of the parameters for each curve for all 5 sites are displayed in Appendix B. Discharges measured by CCoWS on the Pacheco Creek were similar between the two sites (Fig. 5-7). Flows measured during the third monitored storm were much greater than flows measured during the other two storms. These flows would not have been measurable without the use of a bridge crane.

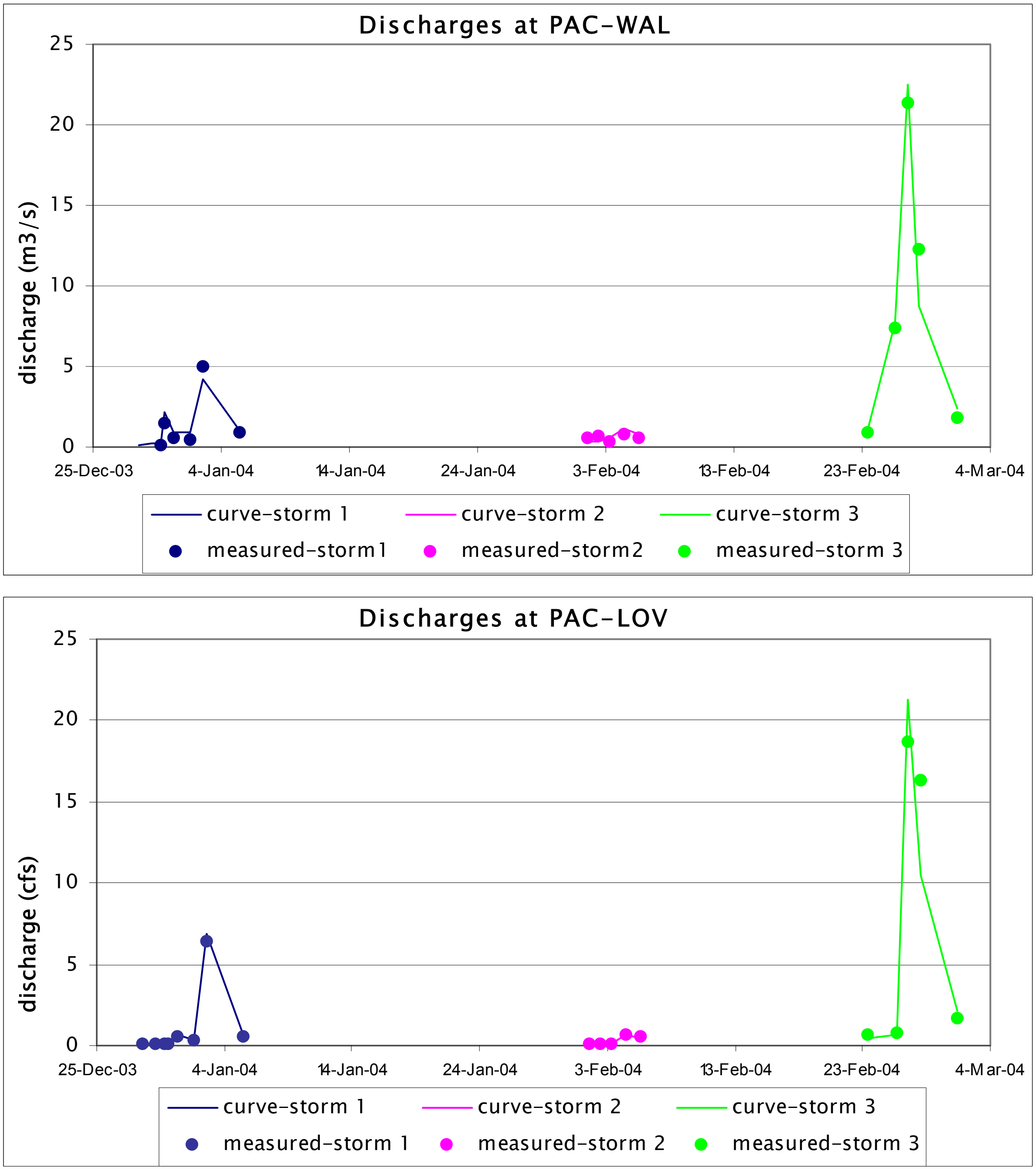
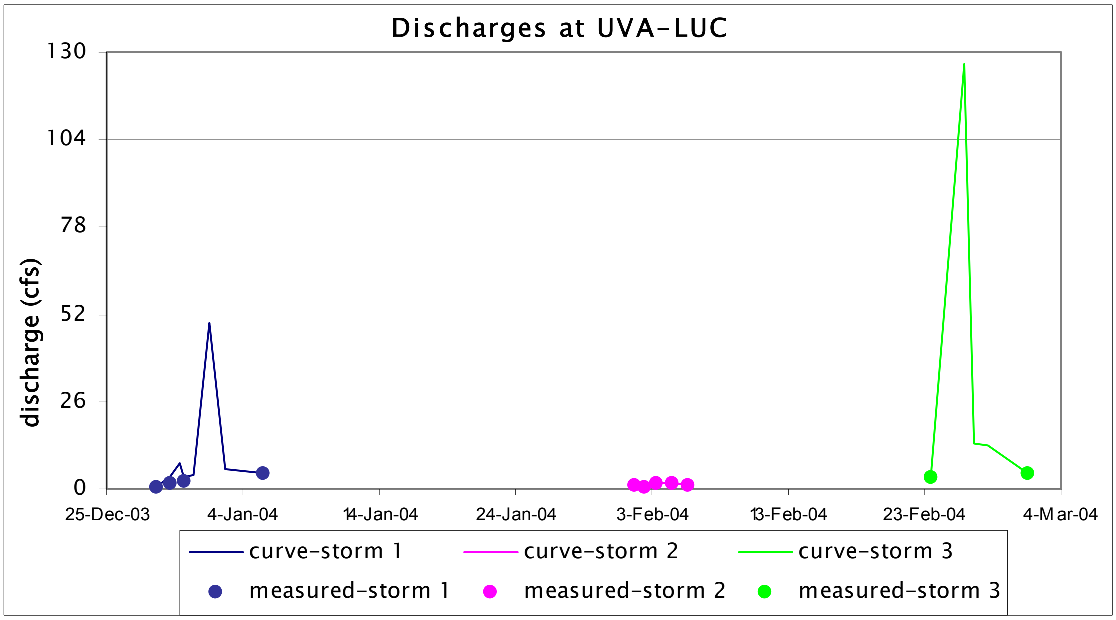


Figure 5-7 Time series of discharges calculated from stage-discharge curves (lines) and measured discharges (dots) on the Pacheco Creek.

The same storm pattern was measured on the Uvas-Carnadero Creek (Fig. 5-8), though it was not possible to use the bridge crane at UVA-LUC, so high flows that were to deep and fast to wade safely were not measured.



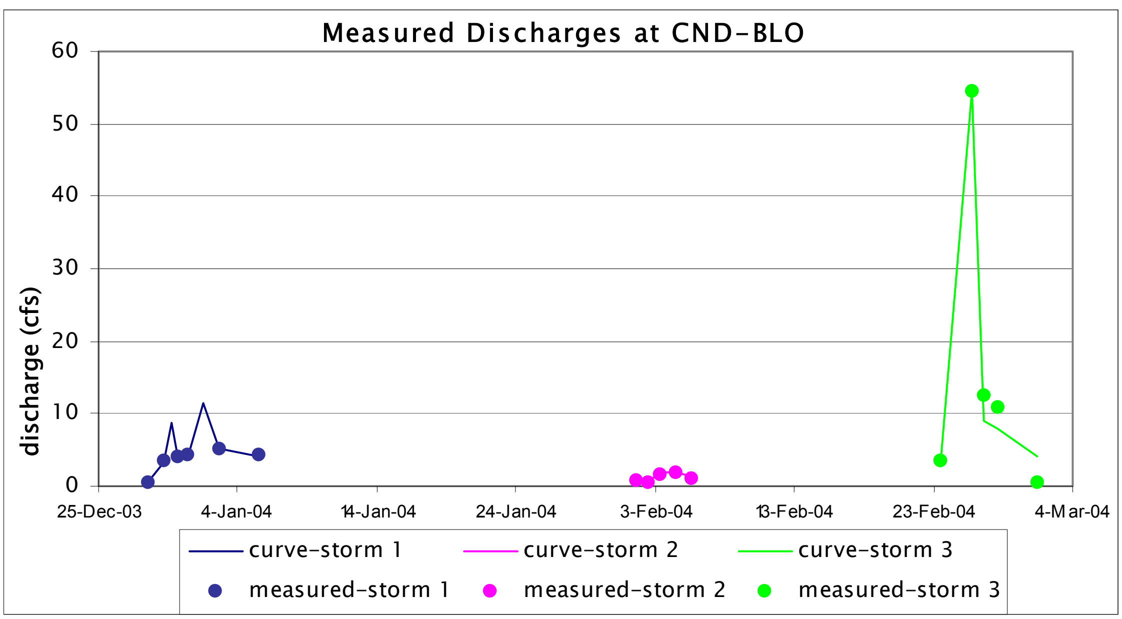


Figure 5-8 Time series of discharges calculated from stage-discharge curves (lines) and measured discharges (dots) on the Uvas-Cranadero Creek.

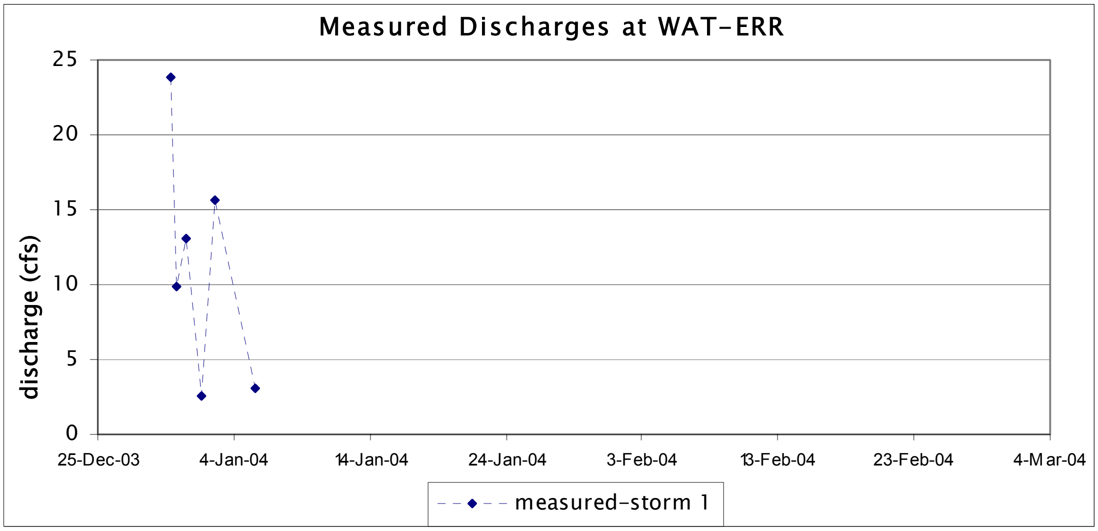


Figure 5-9 Time series of discharges measured for WAT-ERR. Discharges for storm 2 & 3 were not measurable. More than 6 points are necessary for a reliable stage-discharge curve; dashed line does not represent discharges calculated from a curve.

5.2 Suspended sediment and nutrient concentrations

Concentration data were summarized using box-and-whisker plots, with linear interpolation used to estimate percentiles (Figs 5-10 through 5-15). See figure 27 for a graphical explanation of box-and-whisker plots. Included in each plot is the water quality objective for each parameter.

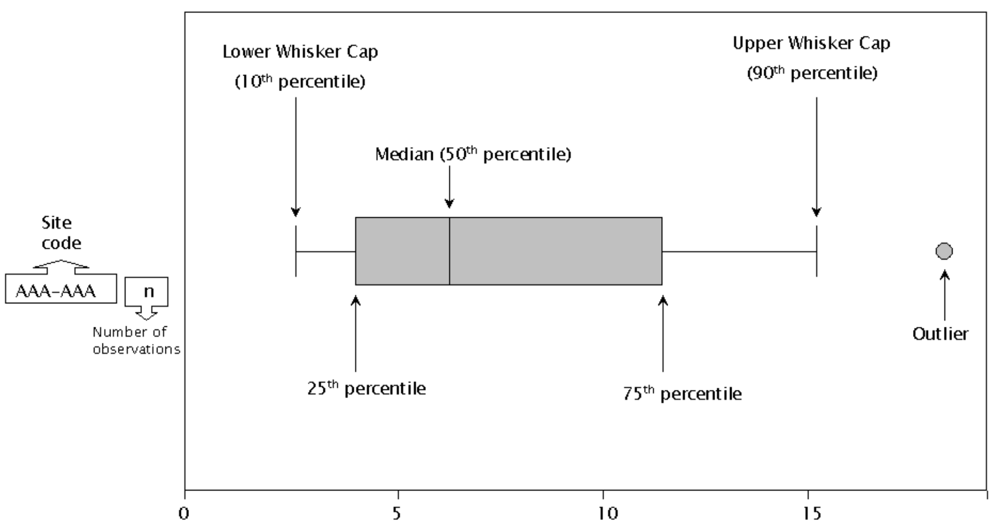


Figure 5-10 Box-and-whisker plot schematic.

5.2.1 Sediment

The median SSC concentration at all sites ranged from 30 - 50 mg/L (Fig. 5-11). This range is in between 10 and 100 mg/L, which are concentrations that could potentially change fish behavior and/or slight decrease in fish survival. All 90th percentiles were above 100 mg/L, which is the concentration that has the potential to cause stress, physiological changes, and potentially lethal effects. There was an increase in SSC concentration from PAC-WAL to PAC-LOV, potentially indicating a sediment source such as agriculture between the two sites. Sediment concentrations observed at UVA-LUC were higher than those observed downstream at CND-BLO. As discussed later in Section 5.3.2, this does not appear to be due to a difference in sediment loads. It may be an artifact of diffusion of the hydrograph peak (and thus the instantaneous sediment transport capacity per unit stream width) - which would be expected to be very abrupt at UVA-LUC immediately downstream of the City of Gilroy, and more diffuse further downstream due to friction. There was also decrease in SSC concentration from WAT-ERR to WAT-SHE, most likely for similar reasons.

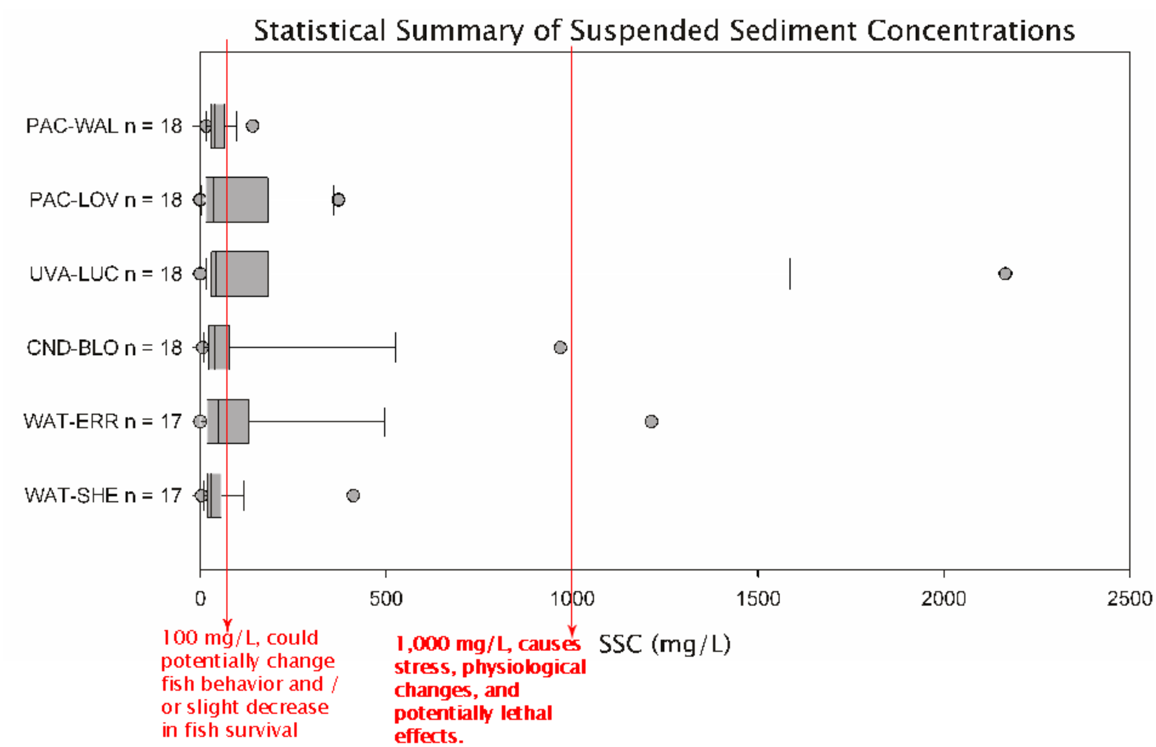


Figure 5-11 Statistical distribution of suspended sediment concentrations of all samples collected at all 6 sites in the study area.

5.2.2 Phosphate

In general, the median phosphate concentrations from Pacheco Creek and Uvas-Carnadero Creek were below the water quality objective of 0.12 mg/L for phosphate with a few exceptions (Fig. 5-12). Most of the observed concentrations exceeding the water quality objective are from the first monitored storm during the end of December 2003 and the beginning of January 2004, though this storm may not have been the first flush as it was not the first storm of the season (Fig. 5-2). While the median values do not differ greatly between upstream and downstream sites, there is some evidence for a greater frequency of high phosphate concentrations at the downstream sites. This is consistent with but not conclusive of agricultural and urban sources mobilized primarily by the higher flows.

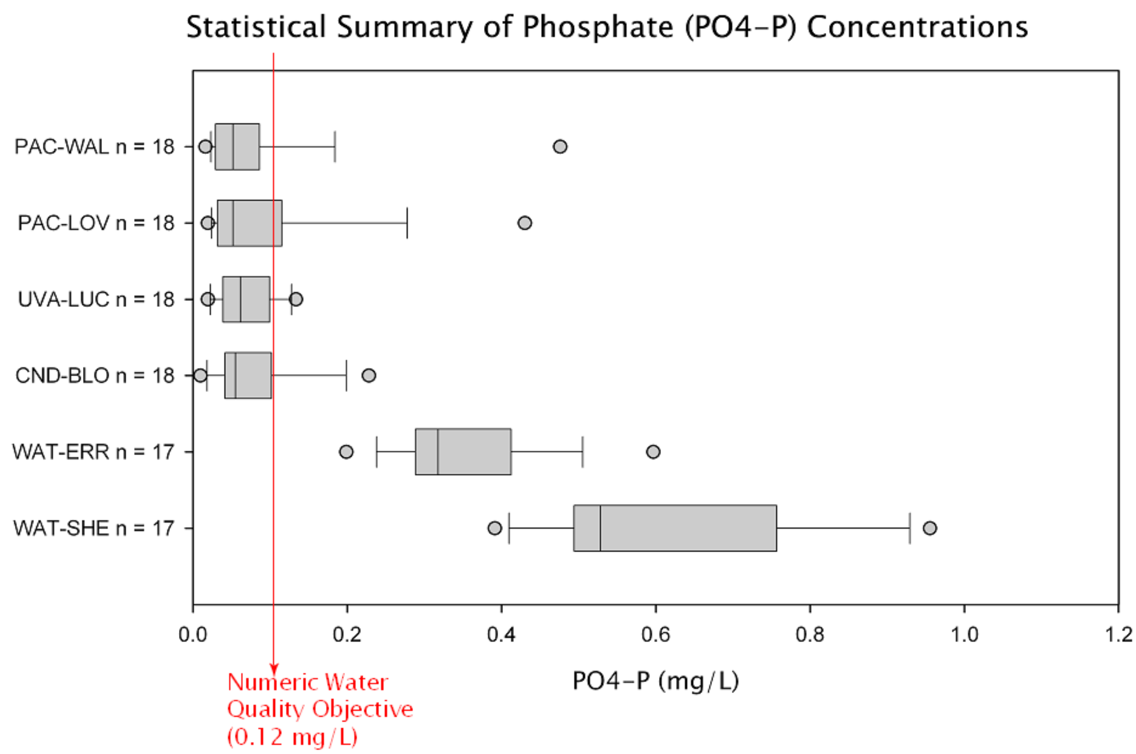


Figure 5-12 Statistical distribution of phosphate concentrations of all samples collected at all 6 sites in the study area.

All samples collected from the Watsonville Slough exceed the phosphate water quality objective, with strong evidence for additional sources in the reach between the two sampling sites. These sources could equally be from urban, agricultural, or other land uses.

5.2.3 Nitrate

Nitrate concentrations are shown in two Figures (5-13 & 5-14). The first Figure mainly illustrates levels in the Watsonville Watershed, since they are much higher than in the other watersheds. There was a marked increase in nitrate concentrations from WAT-ERR to WAT-SHE. This indicates a distinct, significant source that was not notably present above WAT-ERR. Note that the area above WAT-ERR represents only 8.6% of the total watershed area above WAT-SHE. The additional sources between the two sites could be associated with a wide range of land uses extending throughout the Watsonville area. All samples collected from WAT-SHE exceeded the water quality objective of 1.2 mg/L.

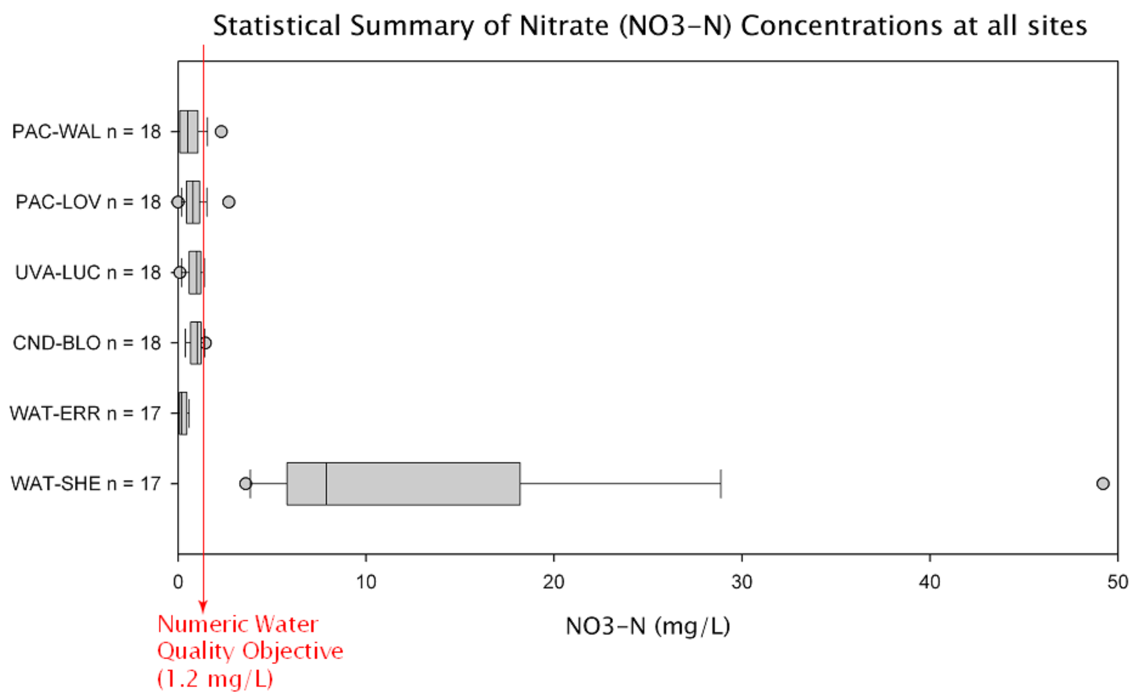


Figure 5-13 Statistical distribution of nitrate concentrations of all samples collected at all 6 sites in the study area.

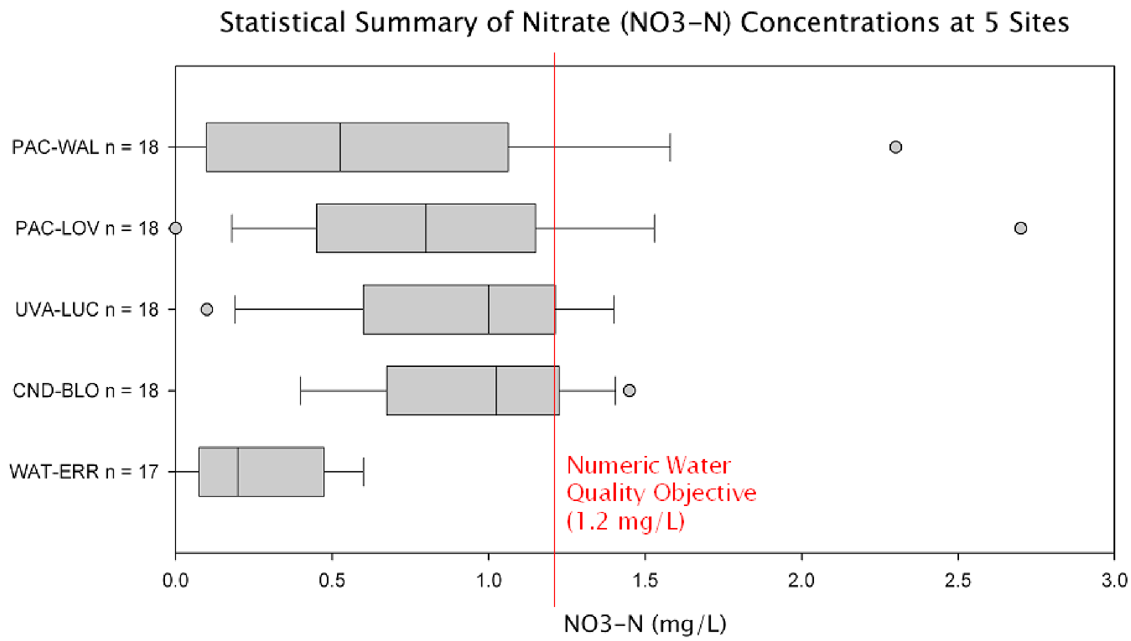


Figure 5-14 Statistical distribution of nitrate concentrations at all site except WAT-SHE.

All of the samples collected from WAT-ERR were below the water quality objective of 1.2 mg/L for nitrate. The majority of nitrate concentrations observed at all five of these sites were below the water quality objective (Fig. 5-14). The distribution of nitrate concentrations increased slightly between PAC-WAL and PAC-LOV, and between UVA-LUC and CND-BLO. A possible interpretation of these data is that the majority of the flow in these watersheds originates from the large, relatively undeveloped upper parts of these watersheds, with low nitrate concentrations. The high concentrations typically associated with agriculture and urban land uses may be being discharged into the stream, but are immediately diluted by the upstream watersheds. Thus the observed effect of these more intense land uses is minimal. The interpretation raises the possibility that a given discharge from a pollution source can have either a significant or an insignificant effect depending on whether or not it lies below a large, relatively undeveloped watershed.

5.2.4 Ammonia

Figure 5-15 displays total ammonia concentrations at all sites. Water quality objectives are not included in this graph because all samples that were collected from Pacheco Creek, Uvas-Carnadero Creek, and the Watsonville Slough met the lower objective value for ammonia (0.497 mg/L) (Marshack, 2000; briefly described in section 4.6.2 of this document).

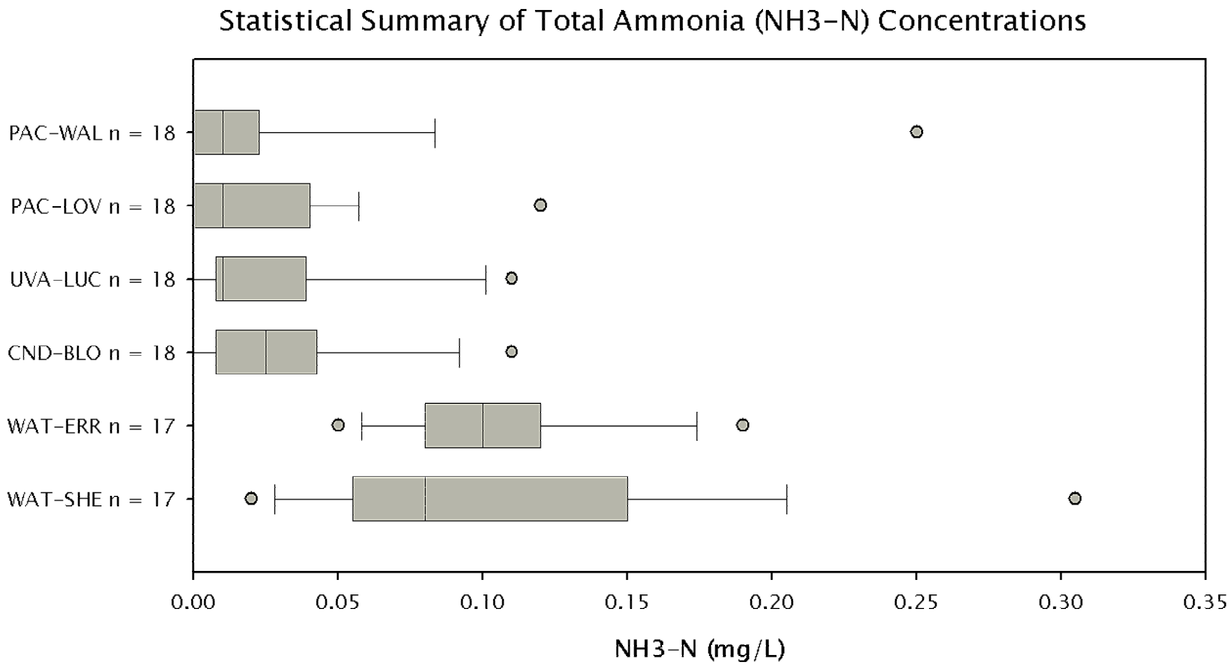


Figure 5-15 Statistical distribution of ammonia concentrations of all samples collected at all sites in the study area.

5.3 Suspended sediment and nutrient loads

The amount of sediment or nutrient moved through a waterway per unit of time is the load, the product of concentration and discharge. Figures 5-16 through 5-20 examine the variation in SSC and nutrient concentration and load with respect to discharge. Because phosphate is known to bind to fine suspended sediment, SSC and PO4-P loads are plotted together. Because nitrate and ammonia are related in nitrogen cycling in aquatic systems, NO3-N and NH3-N are plotted together. Each figure compares an upstream/downstream pair of sites. Not enough discharge measurements were taken on the Watsonville Slough to make such comparisons.

5.3.1 Pacheco Creek

Qualitatively, there are few differences in SSC or nutrient loading between PAC-WAL and PAC-LOV (Figs 5-16 & 5-17). We interpret this to be due to the fact that only 18.9% of the watershed occurs between these two sites. During storms in particular, any inputs between the two sampling sites are overshadowed by the large volume of water coming from the upper watershed, and are thus almost impossible to detect.

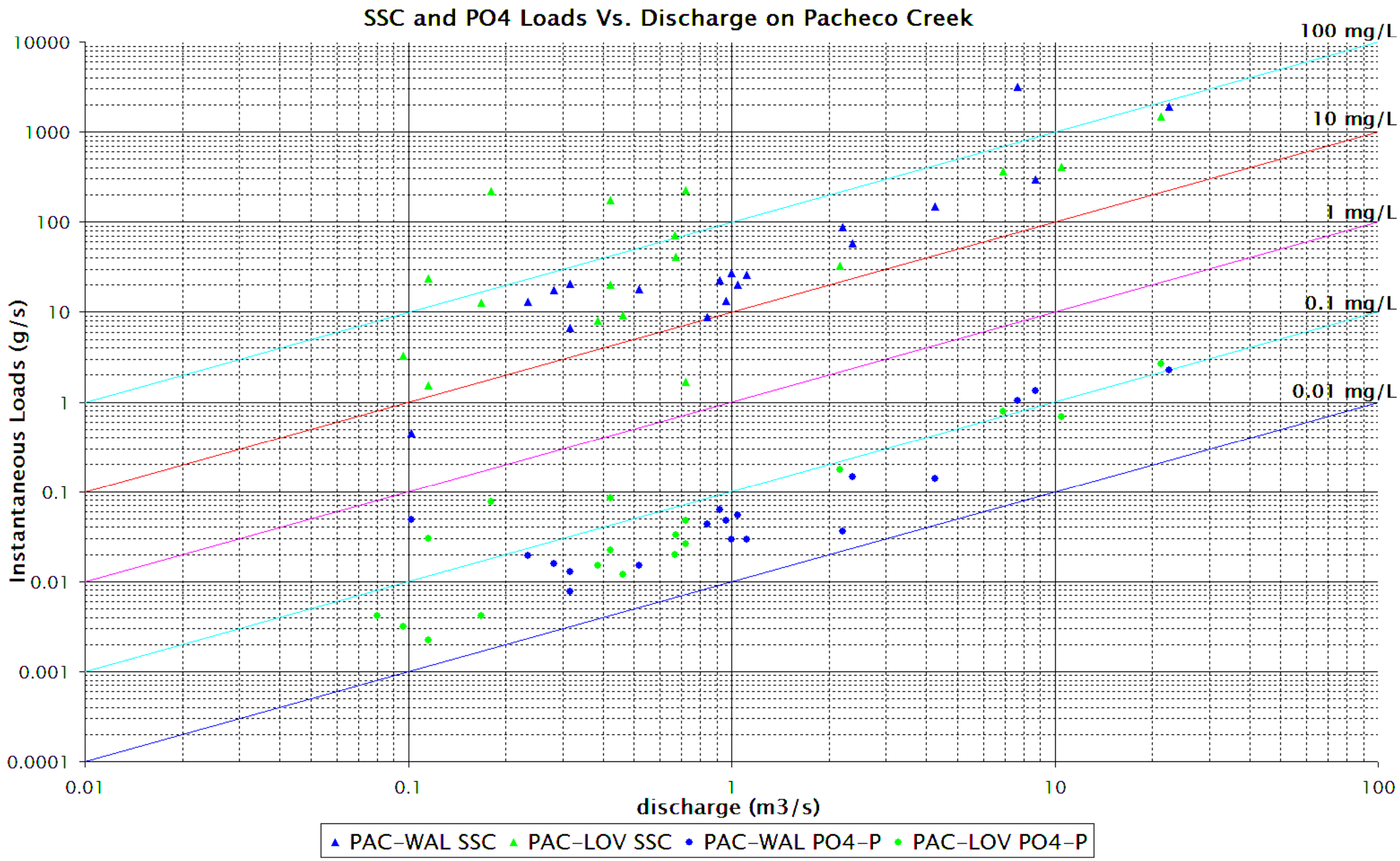


Figure 5-16 A comparison of SSC and PO4-P loads and measured discharges between the upper and lower sampling sites on Pacheco Creek. Diagonal lines are lines of equal concentration.

As expected, suspended sediment loads increased with increasing discharge in Pacheco Creek, with some slight evidence for higher concentrations at higher discharges at the upper site (PAC-WAL). There was little difference between upper and lower sites, except for a flush of anomalously high loads during the rising limb of the hydrograph on 30-Dec-2003 at the lower site (PAC-LOV). This is evidence for marked short-term localized sediment inputs from adjacent land uses during the early storms of the season.

Also as expected, PO_4-P loads increased with increasing discharge, with some evidence for increased concentration at the highest discharges. There were some anomalously high loads at low discharges at both sites during the rising-limb of hydrographs on 30-Dec-2003 and 1-Jan-2004. Again, this is evidence for localized sources near the sampling sites.

NO_3-N and NH_3-N loads were largely determined by variations in discharge, as opposed to variations in concentration. There was little or no relationship between concentration and discharge for NO_3-N, and perhaps a slight negative correlation (i.e. a 'dilution effect') between concentration and discharge for NH_3-N. As with SSC and PO_4-P, some exceptions occurred during the rising limb of the 30-Dec-2003 hydrograph, where anomalously high concentrations of NO3-N and NH3-N were observed at the lower site. This adds to the evidence for sources local to the sampling sites.

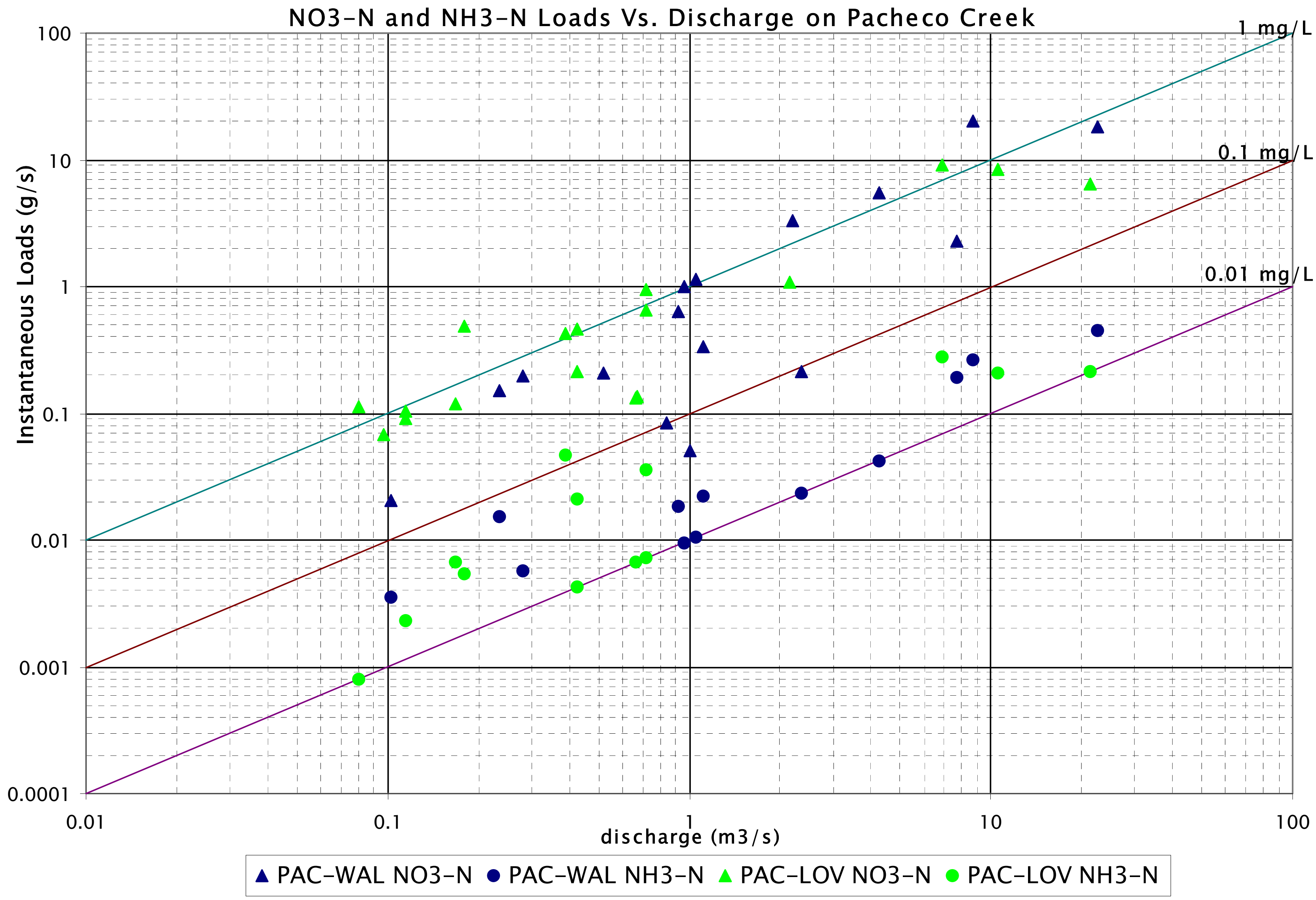


Figure 5-17 A comparison of NO3-N and NH3-N loads vs. measured discharges between the upper and lower sampling sites on Pacheco Creek. Diagonal lines are lines of equal concentration.

5.3.2 Statistical comparison: Pacheco

A objective of many water quality sampling exercises is to detect a difference in water quality between two sites or two periods of time, based on a sample of water quality measurements. If water quality varied randomly, a simple t-test or related method could be used. When major covariates are suspected a more complex method is required. In storm water quality sampling, the pollutant load is the key property of interest. This is strongly determined by discharge, and partly determined by additional dependence of concentration on discharge.

We present a method for change detection that recognizes this covariance. It assumes that sampling is stratified by discharge, so that samples are obtained at a range of discharges. It allows for non-uniform sampling with respect to discharge, where perhaps fewer samples are obtained from the higher discharges. It assumes that for a given discharge or narrow range of discharges, pollutant load is log-normally distributed and sampled in an unbiased way. It does not make any assumptions about the relationship between load and discharge, or between concentration and discharge. Rather, it provides any objective means of evaluating whether such relationships exist.

The method utilizes quadratic local regression (Cleveland, 1979; Loader, 1999) (with smoothing parameter $\alpha=1$). A curve is fitted to the relationship between load and discharge in a manner that is not affected by non-uniformity in the sampling distribution. 95% confidence limits for the curve are also computed. Two data sets may then be compared by examining the degree to which the confidence bands for their curves overlap. Non-overlapping confidence bands would indicate a statistically significant difference between the data sets with probability $\geq$ 95%. The discharge and load data were log-transformed before curve fitting. In order to avoid non-zero values that could not be log-transformed, non-detects were replaced with very low non-zero concentrations (1 mg/L SSC, 0.01 mg/L PO4, 0.05 mg/L NO3, 0.005 mg/L NH3).

Figure 5-18 shows the results of this comparison procedure in the Pacheco watershed. The confidence bands almost completely overlap each other for each of the four analytes. There is clearly no statistically significant difference between the sites, and thus no statistically significant evidence of increased pollution sources (such as from agriculture) between the two sites. This is not surprising given the small fraction of the total watershed area that lies between the sites.

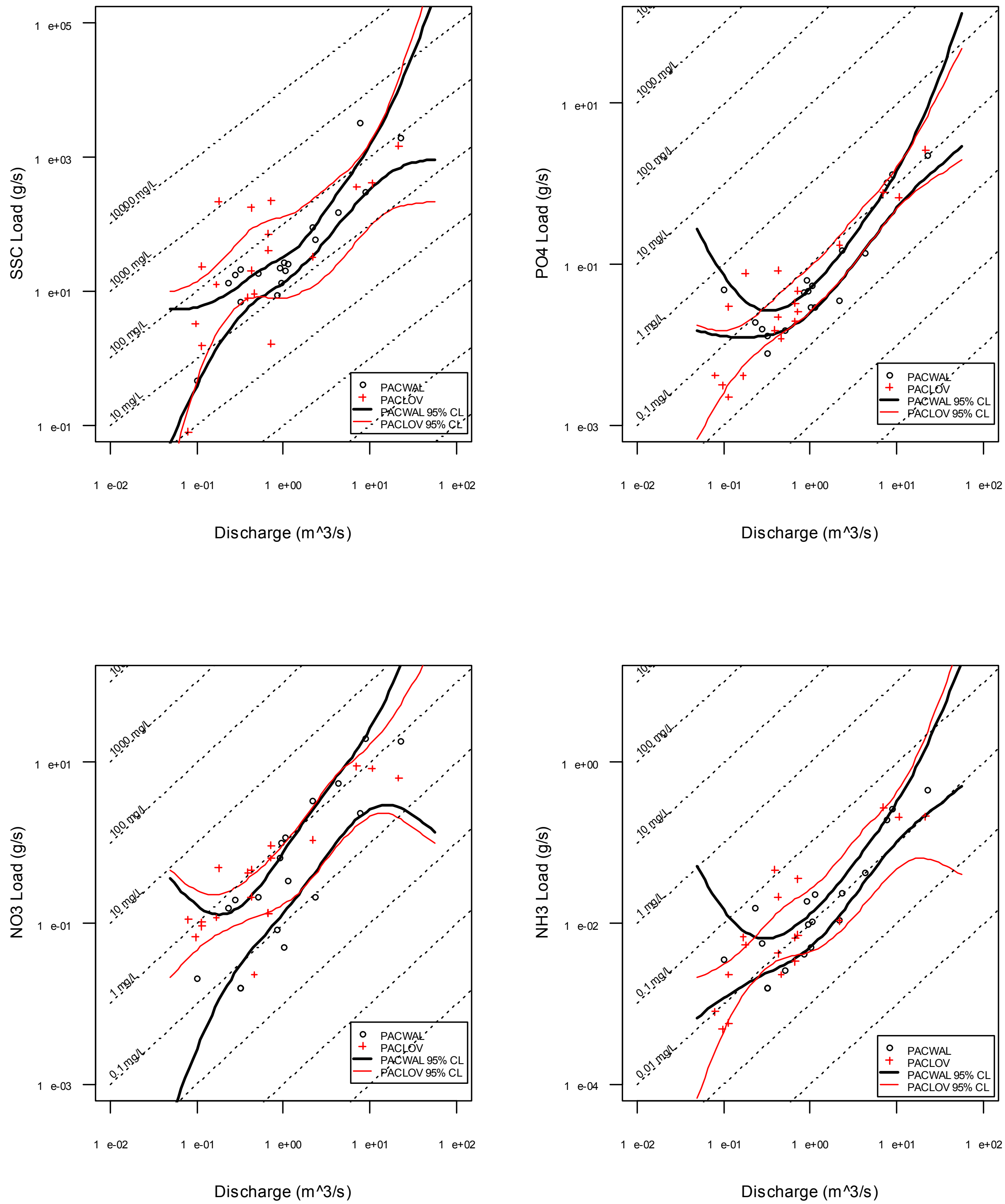


Figure 5-18 Statistical comparison of loads at sites above and below agriculture in the Pacheco watershed.

5.3.3 Uvas-Carnadero Creek

In the Uvas-Carnadero watershed, SSC increased with increasing discharge, leading to a strong dependence of suspended sediment load on discharge (Figs 5-19 & 5-20). There is some evidence for higher SSC concentrations and loads at the downstream site (CND-BLO), although some of the high-flow data are missing for the upstream site due to the impossibility of sampling from a fenced bridge at high flow. Given the minimal watershed area between the two sampling sites, only about 3% of the total watershed area, we suggest that some increases in suspended sediment load between the two sites could be due to re-mobilization of sediments from the dry channel bottom - a process documented in detail by Watson et al. (2003) for the Salinas River watershed. It is probable that sediment is deposited by flows that pass UVA-LUC but do not reach CND-BLO, and are then re-mobilized by higher flows later in the season that make it past CND-BLO.

For all nutrients sampled in the Uvas-Carnadero system, there is no evidence of concentration or dilution effects with respect to changes in discharge over time, and only slight evidence of additional sources between the upper and lower sites (Figs 5-19 & 5-20). As with the Pacheco sampling, this is interpreted as being due to the fact that the vast majority of the watershed is above, rather than between the two sampling sites. It is possible that concentrated agricultural inputs occur between the sites on a per-land-area basis, but that the total agricultural area involved is minimal.

A useful conclusion that can be drawn from the undetectable differences between distributions of data at the upper and lower sites in the Uvas-Carnadero system is that the sampling design is sound. If the sampling design were inadequate, we would see differences between the sites that were sampling artifacts, rather than indications of real differences between the sites.

5.3.4 Statistical comparison: Uvas-Carnadero

Figure 5-21 shows the results of the statistical comparison procedure in the Uvas-Carnadero watershed. As with the Pacheco watershed, the confidence bands almost completely overlap each other throughout most of the discharge range for each of the four analytes. An exception was observed for SSC during mid-range discharges, where the lower site exhibited higher loads for a given discharge than the uppers site, with a not insubstantial degree of statistical significance (as evidenced by almost non-overlapping 95% confidence intervals). For the other analytes, there is no statistically significant difference between the sites, and thus no statistically significant evidence of increased pollution sources between the two sites. Again, this is not surprising given the small fraction of the total watershed area that lies between the sites.

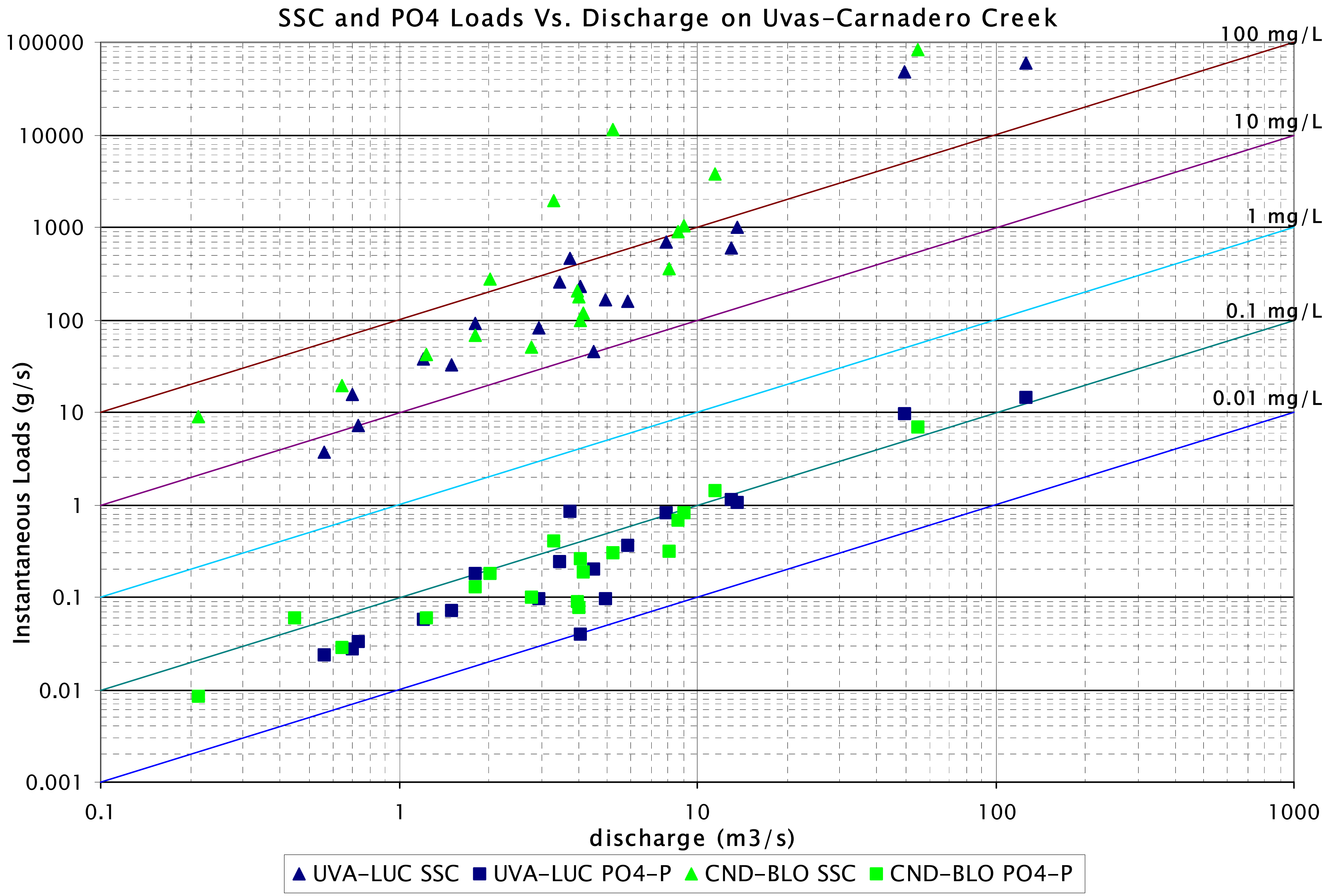


Figure 5-19 A comparison of SSC and PO4-P loads vs. measured discharges between the upper and lower sampling sites on the Uvas-Carnadero Creek. Diagonal lines are lines of equal concentration.

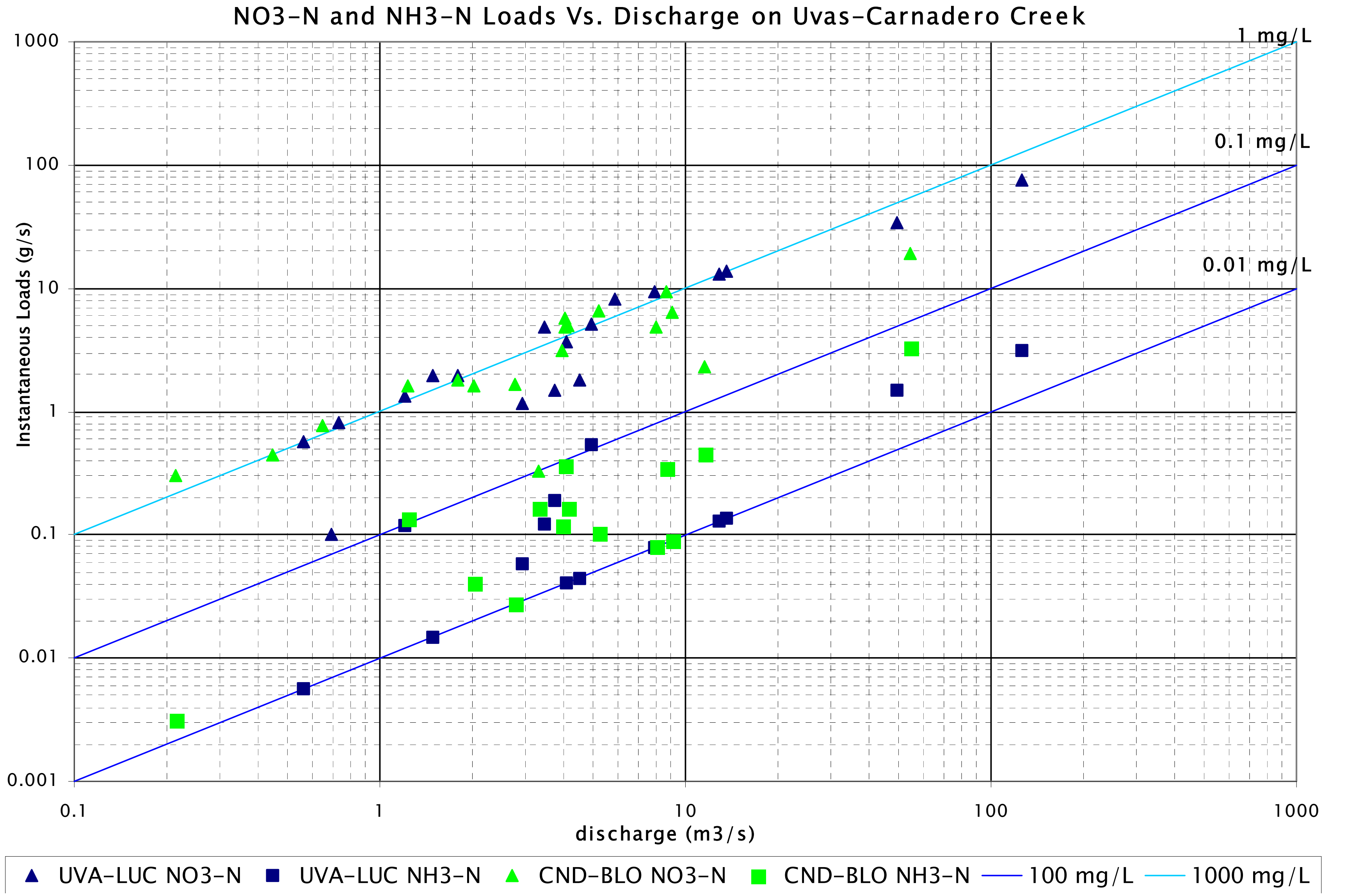


Figure 5-20 A comparison of NO3-N and NH3-N loads vs. measured discharges between the upper and lower sampling sites on the Uvas-Carnadero Creek. Diagonal lines are lines of equal concentration.

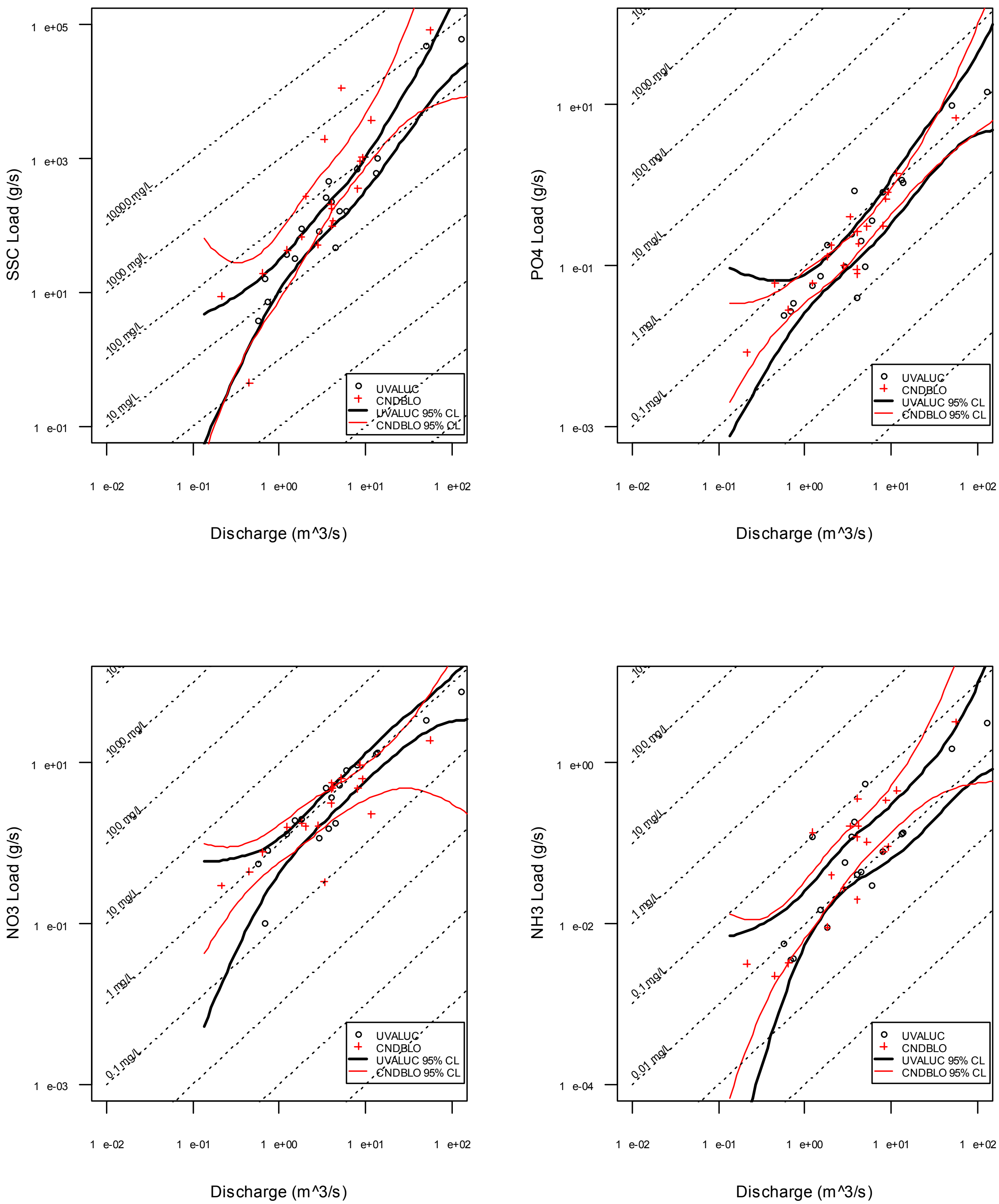


Figure 5-21 Statistical comparison of loads at sites above and below agriculture in the Uvas-Carnadero watershed.

5.4 Turbidity, pH, TDS, temperature, and transparency

5.4.1 Turbidity

Most turbidity levels were below the level that could cause stress, physiological changes, or have potentially lethal effects for fish (Fig. 5-22). Few observed turbidity levels were below the level that could potentially change behavior and/or cause a slight decrease in fish survival. Slight increases are evident between upstream and downstream sites in the Pacheco and Uvas-Carnadero watersheds. A downstream decrease is evident in the Watsonville watershed, perhaps due to settling, or hydrograph diffusion in the temporal domain.

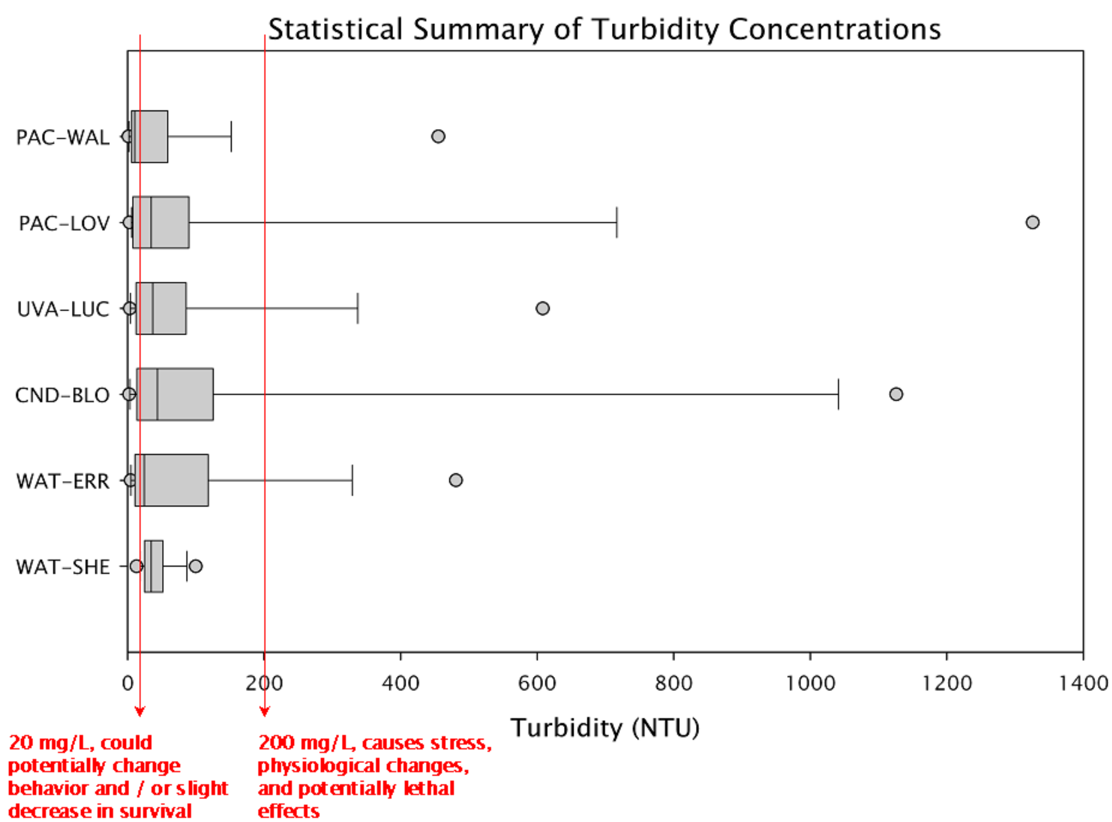


Figure 5-22 Statistical distributions of turbidity levels of all samples collected at all 6 sites.

5.4.2 pH

Most pH measurements fell within the USEPA national recommended ambient water quality criteria for freshwater aquatic life protection. There are few differences in pH between sites. There is a slight decrease between PAC-WAL and PAC-LOV, an increase between UVA-LUC and CND-BLO, and little difference between WAT-ERR and WAT-SHE (Fig. 5-23).

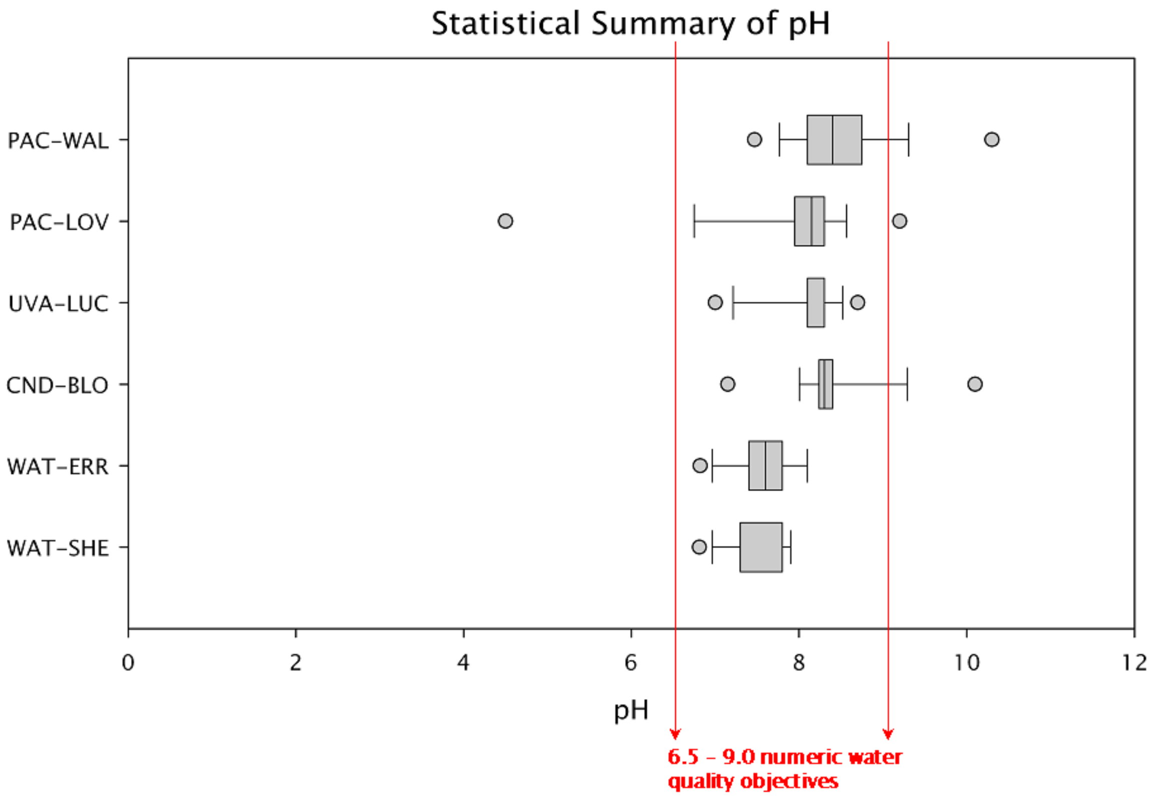


Figure 5-23 Statistical Distribution of pH levels measured *in situ* during each visit to each site.

5.4.3 Total Dissolved Solids

The most obvious increase in TDS concentrations is between WAT-ERR and WAT-SHE (Fig. 5-24), which is consistent with observed increases in nutrients (Section 5.2). Because of the large difference in TDS concentrations at WAT-SHE, statistical distributions at the other 5 sites are displayed in Figure 5-25 without WAT-SHE for easier interpretation of the data.

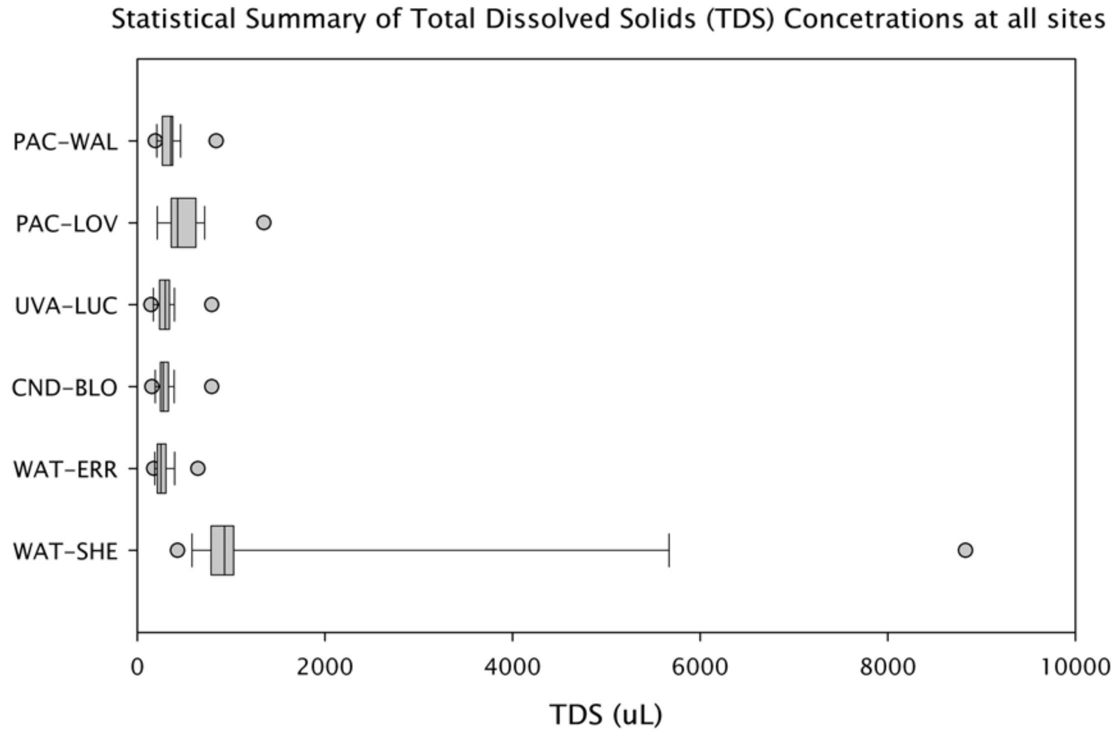


Figure 5-24 Statistical distribution of total dissolved solids levels measured *in situ* at each visit to each site.

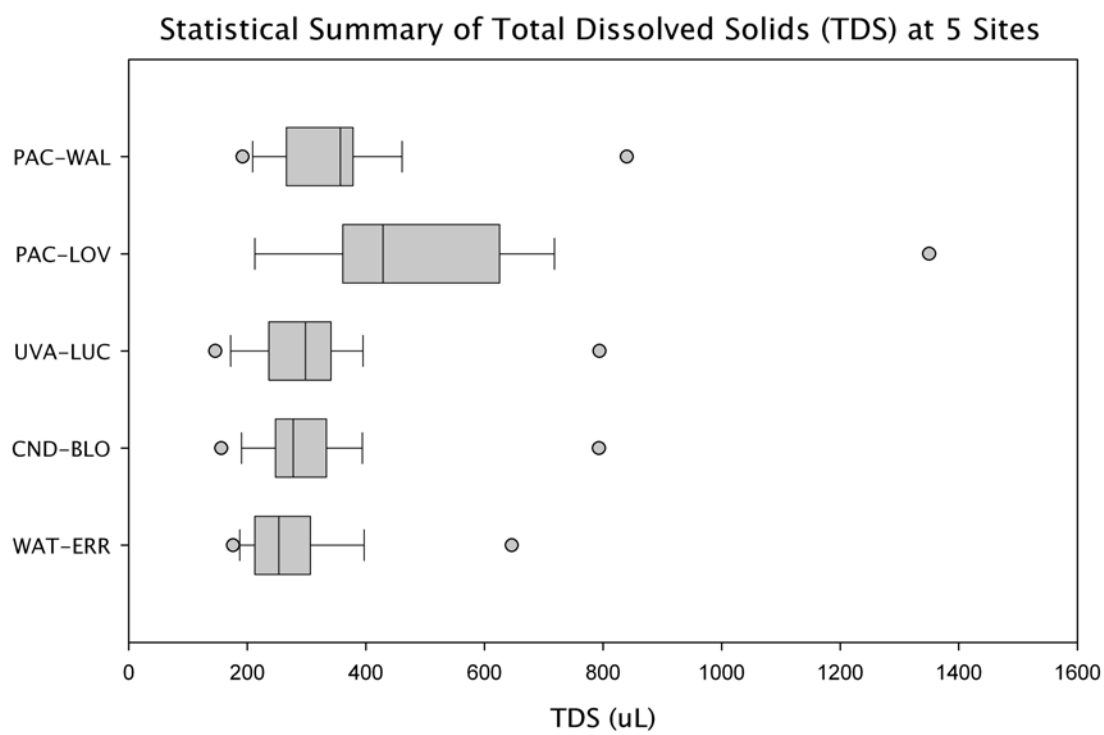


Figure 5-25 Statistical distribution of total dissolved solids levels measured in situ at each visit to all sites except WAT-SHE.

There is a marked increase in TDS concentrations between PAC-WAL and PAC-LOV. There is little difference in TDS concentrations between UVA-LUC and CND-BLO, though the median from CND-BLO is slightly less than the median from UVA-LUC (Fig 40). As stated earlier, there are no explicit water quality objectives for TDS to compare this data to.

5.4.4 Temperature

Measured temperatures did not fluctuate very much between 7°C and 15°C (Fig. 41). There were slight decreases in temperature between PAC-WAL and PAC-LOV and between UVA-LUC and CND-BLO, and a slight increase between WAT-ERR and WAT-SHE. As stated earlier, there are no explicit water quality objectives for TDS to compare this data to.

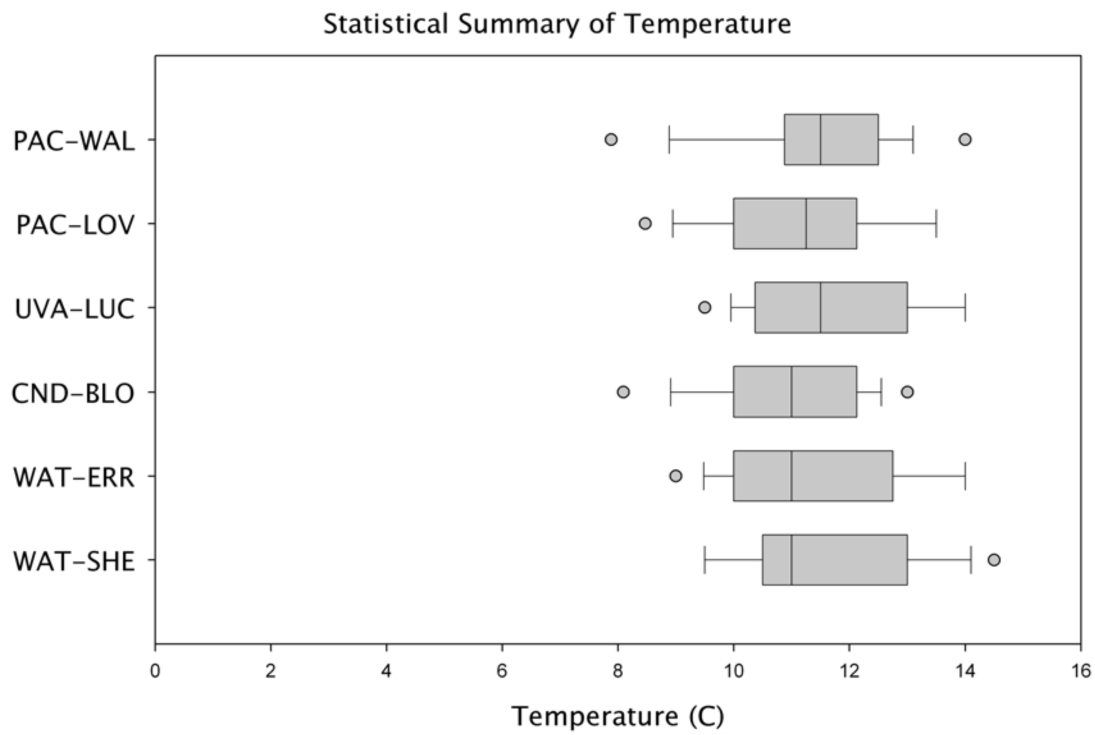


Figure 5-26 Statistical distribution of temperatures measured in situ at each visit to each site.

5.4.5 Transparency

Transparency measurements were made with 60cm transparency tubes where the sample is poured out from a spout at the bottom of the tube until a black and white disk is visible trough the sample at the bottom of the tube. Most of the samples collected did not have enough volume to yield a definite transparency value (i.e. The sample was gone before the black and white disk was visible). Most transparency measurements resulted in greater levels of transparency than there was sample to measure. For this reason, it was not possible to display transparency data in a graphical form. This data is included in the raw data table in Appendix D.

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http://www.wrh.noaa.gov/satellite/4km/WR/VIS4.GIF

http://www.wrh.noaa.gov/radar/loop/DS.80stp/si.kmux.shtml

Weather Underground

http://www.wunderground.com/radar/radblast.asp?ID=MUX&region=c1&lat=36.58769989&lon=-121.84919739&label=Monterey%2c%20CA

weather.com

http://www.weather.com/weather/local/93933?lswe=93933&lwsa=WeatherLocalUndeclared

7 Appendices

7.1 **Appendix A** Suspended sediment toxicity to fish (Hager et al, 2003).

Source (as cited in Hager et al, 2003)	**Species**	**Life Stage**	**Exposure Concentration (mg/L)**	**Exposure Duration (h)**	**Fish Response**	**Reference (as cited in Hager et al, 2003)** (as cited in Hager et al, 2003)
Newcombe and Jensen 1996	Smelt (rainbow)	Adult	3.5	168	Increased vulnerability to predation	Swenson (1978)
	Steelhead	Adult	500	3	Signs of sublethal stress	Redding and Schreck (1982)
	Steelhead	Adult	500	9	Blood cell count and blood chemistry change	Redding and Schreck (1982)
	Trout	Adult	16.5	24	Feeding behavior apparently reduced	Townsend (1983); Ott (1984)
	Trout	Adult	75	168	Reduced quality of rearing habitat	Slaney et al. (1977b)
	Trout	Adult	270	312	Gill tissue damaged	Herbert and Merkens (1961)
	Trout	Adult	525	588	No mortality (other end points not investigated)	Griffin (1938)
	Trout	Adult	300	720	Decrease in population size	Peters (1967)
	Trout (rainbow)	Adult	66	1	Avoidance behavior manifested part of the time	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	665	1	Overhead cover abandoned	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	100	0.10	Fish avoided turbid water	Suchanek et al. (1984a,1984b)

Source (as cited in Hager et al, 2003)	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference (as cited in Hager et al, 2003) (as cited in Hager et al, 2003)
Newcombe and Jensen 1996	Trout (rainbow)	Adult	100	0.25	Rate of coughing increased	Hughes (1975)
	Trout (rainbow)	Adult	250	0.25	Rate of coughing increased	Hughes (1975)
	Trout (rainbow)	Adult	810	504	Gills of fish that survived had thickened epithelium	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	17,500	168	Fish survived; gill epithelium proliferated and thickened	Slanina (1962)
	Trout (rainbow)	Adult	50	960	Rate of weight gain reduced	Herbert and Richards (1963)
	Trout (rainbow)	Adult	810	504	Some fish died	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	270	3240	Survival rate reduced	Herbert and Merkens (1961)
	Trout (rainbow)	Adult	200	24	Test fish began to die on first day	Herbert and Richards (1963)
	Trout (rainbow)	Adult	18	720	Abundance reduced	Peters (1967)
	Trout (rainbow)	Adult	4,250	588	Mortality rate 50%	Herbert and Wakeford (1962)
	Trout (rainbow)	Adult	49,838	96	Mortality rate 50%	Lawrence and Scherer (1974)
	Trout (rainbow)	Adult	80,000	24	No mortality	D. Herbert, personal comm. to Alabaster and Lloyd (1980)
	Trout (rainbow)	Adult	3,500	1,488	Catastrophic reduction in population size	Herbert and Merkens (1961)

Source (as cited in Hager et al, 2003)	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference (as cited in Hager et al, 2003) (as cited in Hager et al, 2003)
Newcombe and Jensen 1996	Trout (rainbow)	Adult	160,000	24	Mortality rate 100%	D. Herbert, personal comm. to Alabaster and Lloyd (1980)
	Trout (rainbow)	Yearling	90	456	Mortality rates 0-20%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	90	456	Mortality rates 0-15%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	270	456	Mortality rates 10-35%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	810	456	Mortality rates 35-85%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	810	456	Mortality rates 5-80%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	270	456	Mortality rates 25-80%	Herbert and Merkens (1961)
	Trout (rainbow)	Yearling	7,433	672	Mortality rate 40%	Herbert and Wakeford (1962)
	Trout (rainbow)	Yearling	4,250	672	Mortality rate 50%	Herbert and Wakeford (1962)
	Trout (rainbow)	Yearling	2,120	672	Mortality rate 100%	Herbert and Wakeford (1962)
	Trout (rainbow)	Juvenile	4,887	384	Hyperplasin of gill tissue	Gouldes (1983)
	Trout (rainbow)	Juvenile	4,887	384	Parasitic infection of gill tissue	Gouldes (1983)
	Trout (rainbow)	Juvenile	171	96	Particles pentrated cells of branchial epithelium	Gouldes (1983)

Source (as cited in Hager et al, 2003)	Species	Life Stage	Exposure Concentration (mg/L)	Exposure Duration (h)	Fish Response	Reference (as cited in Hager et al, 2003) (as cited in Hager et al, 2003)
Newcombe and Jensen 1996	Trout (rainbow)	Juvenile	4,315	57	Mortality rate ~100%	Newcombe et al. (1995)
	Carp (common)	Adult	25,000	336	Some mortality	Wallen (1951)
	Sunfish (green)	Adult	9,600	1	Rate of ventilation increased	Horkel and Pearson (1976)
	Stickleback (threespine)	Adult	28,000	96	No mortality in test designed to identify lethal threshold	LeGore and DesVoigne (1973)
Lloyd 1987	Rainbow Trout (Great Britain)	Juvenile	270 (ppm)		Reduced survival (marked)	Herbert and Merkens (1961)
	Rainbow Trout (Great Britain)	Juvenile	200 (ppm)		Reduced survival (marked)	Herbert and Richards (1963)
	Rainbow Trout (Oregon)	Juvenile	1,000–2,500 (ppm)		Reduced survival (marked)	Campbell (1954)
	Rainbow Trout (Great Britain)	Juvenile	90 (ppm)		Reduced survival (slight)	Herbert and Merkens (1961)
	Rainbow Trout (Great Britain)	Juvenile	50 (ppm)		Reduced growth (slight)	Herbert and Richards (1963)
	Rainbow Trout (Arizona)	Juvenile	<70 (JTU)		Reduced food conversion	Olson et al. (1973)

Source (as cited in Hager et al, 2003)	**Species**	**Life Stage**	**Exposure Concentration (mg/L)**	**Exposure Duration (h)**	**Fish Response**	**Reference (as cited in Hager et al, 2003)** (as cited in Hager et al, 2003)
Lloyd 1987	Rainbow Trout (Arizona)	Juvenile	70 (JTU)		Reduced feeding	Olson et al. (1973)
	Rainbow Trout (Great Britain)	Juvenile	110		Reduced condition factor	Scullion and Edwards (1980)
	Rainbow Trout (Great Britain)	Juvenile	110		Altered diet (terrestrial instead of aquatic)	Scullion and Edwards (1980)
	Steelhead (Oregon)	Juvenile	2,000		Stress (increased plasma cortisol, hematocrit, and susceptibility to pathogens)	Redding and Schreck (1980)
	Rainbow Trout (Great Britain)	Juvenile	270 (ppm)		Disease (fin rot)	Herbert and Merkens (1961)
	Rainbow Trout (Great Britain)	Juvenile	100 (ppm); 200 (ppm)		Disease (fin rot)	Herbert and Merkens (1961)
	Steelhead (Idaho)	Juvenile	22–265 (NTU)		Avoidance	Sigler (1980), Sigler et al. (1984)
	Steelhead (Idaho)	Juvenile	40–50 (NTU)		Displacement	Sigler (1980)
	Rainbow Trout (Great Britain)	Juvenile	110		Displacement	Scullion and Edwards (1980)
	Trout		25 JTU		Altered behavior (feeding)	Langer (1980)

Source (as cited in Hager et al, 2003)	**Species**	**Life Stage**	**Exposure Concentration (mg/L)**	**Exposure Duration (h)**	**Fish Response**	**Reference (as cited in Hager et al, 2003)** (as cited in Hager et al, 2003)
Newcombe and MacDonald (1991)	Rainbow trout		68	720	25% reduction in population size	Peters (1967)
	Rainbow trout		1,000–6,000	1,440	85% reduction in population size	Herbert and Merkens (1961)
	Steelhead		84	336	Reduction in growth rate	Sigler et al. (1984)
	Rainbow trout		50	1,848	Reduction in growth rate	Sykora et al. (1972)
Bell (1986)	Mosquitofish			181,500 (average)	fatal	Bell (1986)
	Largemouth bass			101,000 (average)	fatal	Bell (1986)
	Black crappie			145,000 (average)	fatal	Bell (1986)

7.2 **Appendix B** Stage-discharge rating curves

Recall from Section 4.4 that stage-discharge curves were fitted to discharge measurements according to the following equation:

$$Discharge = Scale \times (Stage + Offset)^{Power}$$

Where *Scale*, *Offset* and *Power* are parameters fitted for each site. The resulting data and curves are as follows.

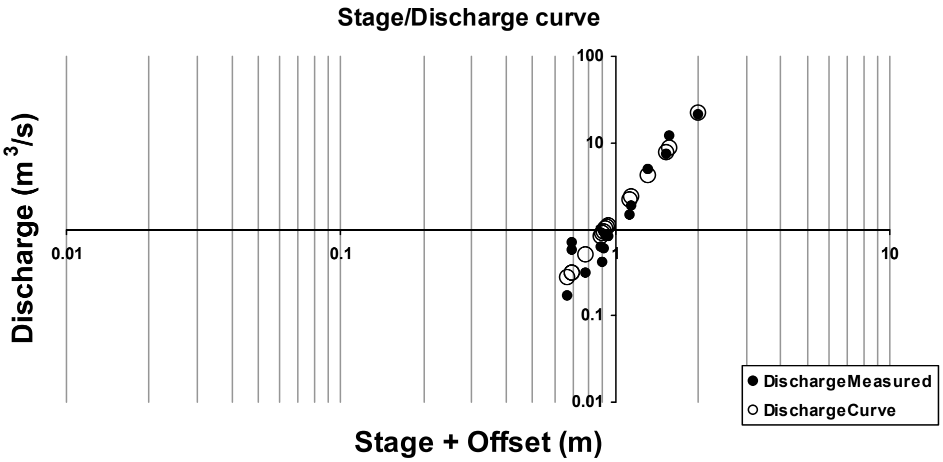


Figure 7-1. PAC-WAL. Scale = 1.4, Offset = -0.5, Power = 4.

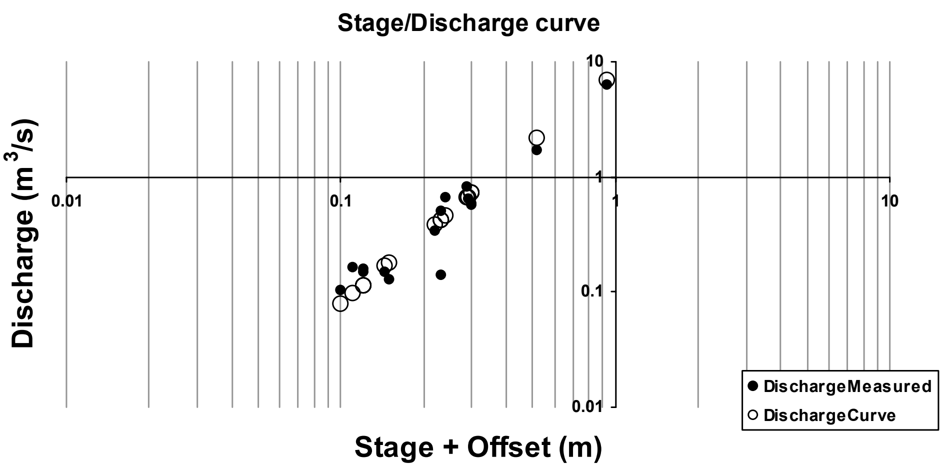


Figure 7-2. PAC-LOV. Scale = 8, Offset = 0, Power = 2.

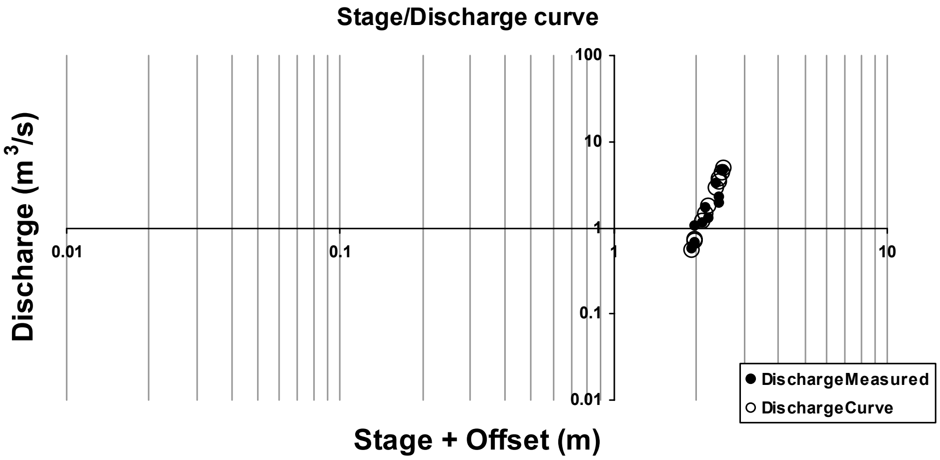


Figure 7-3. UVA-LUC. Scale = 0.003, Offset = -1, Power = 8.

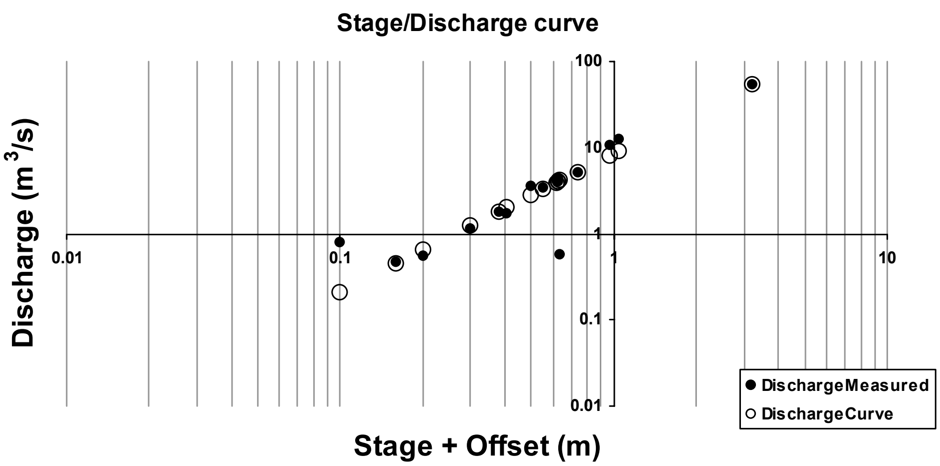


Figure 7-4. CND-BLO. Scale = 8.5, Offset = -0.4, Power = 1.6.

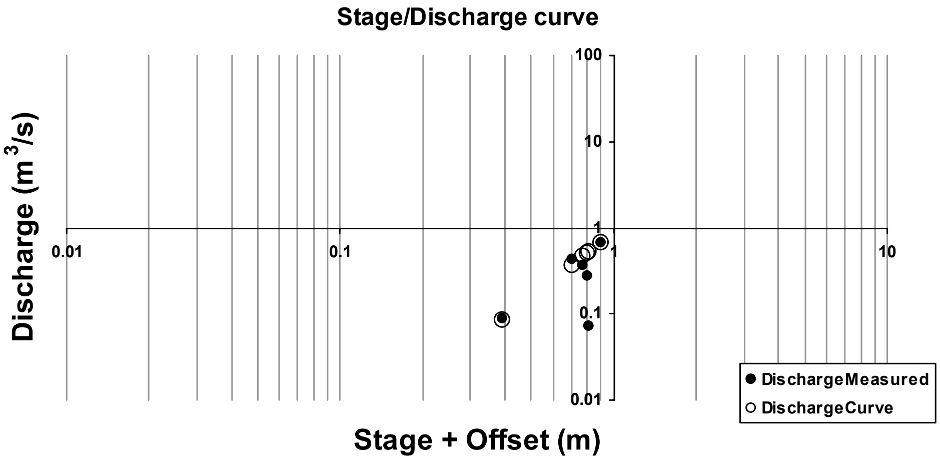
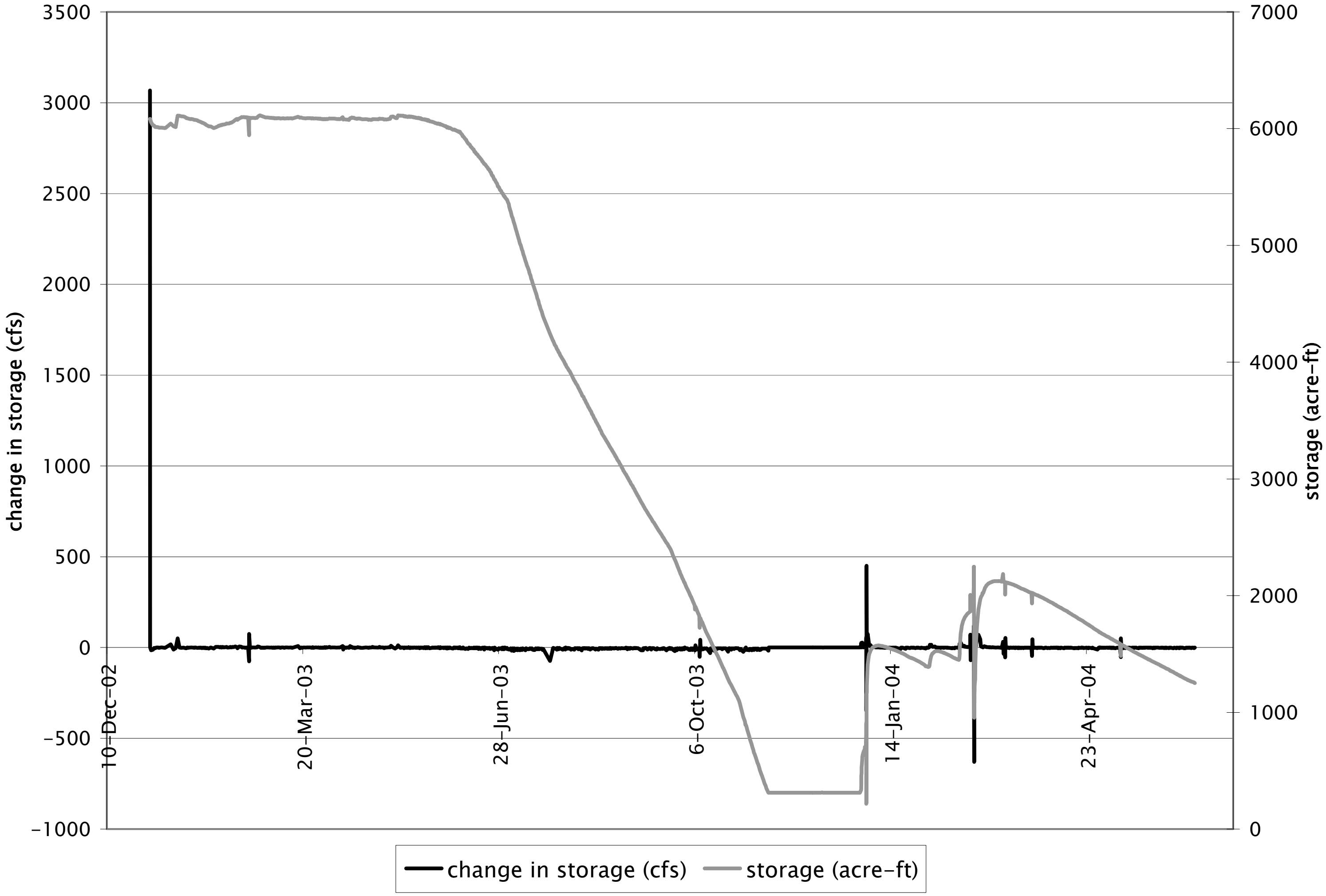


Figure 7-5. WAT-ERR. Scale = 0.9, Offset = 0, Power = 2.5.

7.3 **Appendix C** Pacheco Creek reservoir 2003-4



7.4 **Appendix D** Data table of all measurements

date	time	stage (m)	discharge (m3/s)	temp C	pH	TDS (uS)	SSC bottle #	sample method	Transp (cm)	Turb (NTU)	SSC >63um	SSC <63um	Suspended Solids Concentration (mg/L)	lab analysis date	field notes
PAC-WAL															
28-Dec-03	12:44	0.0	0	7.88	7.47	840	562	grab	> 60	8.62	0	4.469	4.469	6-Jan-04	no flow, stagnant pools
29-Dec-03	14:44	0.1	nmf	9	8.1	372	689	grab	12	109	2.202	52.836	55.038	6-Jan-04	
30-Dec-03	5:30	0.2	0.169	9	8.7	266	496	DH48	9.6	118	10.345	51.727	62.073	6-Jan-04	high water mark at 0.26 - 0.27 m
30-Dec-03	14:31	0.6	1.445	12.5	8.1	287	686	DH48	>19.6	26.3	9.982	29.946	39.928	6-Jan-04	high water mark at 0.69 m
31-Dec-03	8:30	0.4	0.602	10.5	8.4	324	650	DH48	>22.4	8.15	0	13.831	13.831	6-Jan-04	
1-Jan-04	12:16	0.4	0.414	11	8.4	266	609	DH48	18.8	45.7	2.714	21.712	24.426	6-Jan-04	
2-Jan-04	12:54	0.8	4.951	11	7.9	281	569	DH48	>24.2	25.1	0	34.973	34.973	6-Jan-04	high water mark at 0.92 - 0.93 m
5-Jan-04	9:44	0.4	0.868	11	7.8	354	641	DH48	>27	6.85	0	19.302	19.302	6-Jan-04	
1-Feb-04	14:53	0.2	0.588	12.5	10.3	377	496	DH48	>22.0	2.19	0	21.207	21.207	12-Feb-04	
2-Feb-04	9:18	0.2	0.703	12	9.2	419	444	grab	>21.6	7.67	18.12	47.103	65.219	12-Feb-04	high water mark at 0.21m
3-Feb-04	5:56	0.3	0.318	11	9.2	384	655	DH48	>24.4	12.1	0	34.803	34.803	12-Feb-04	
4-Feb-04	10:20	0.4	0.850	12	8.9	374	564	grab	>23.6	5.11	0	23.122	23.122	12-Feb-04	high water mark at 0.5 m
5-Feb-04	13:45	0.4	0.618	14	8.6	369	470	DH48	>28.6	2.08	0	10.433	10.433	12-Feb-04	
23-Feb-04	9:02	0.4	0.855	12.5	8.6	382	463	DH48	>24.2	1.47	8.048	18.778	26.826	25-Mar-04	
25-Feb-04	14:45	1.0	7.386	13	8.6	256	654	DH76	2.3973	455	57.1	354.8	411.910	25-Mar-04	
26-Feb-04	12:22	1.5	21.374	11	8.4	211	647	DH76	10.5	98	12.1	72.587	84.685	25-Mar-04	
27-Feb-04	11:03	1.1	12.311	12	8.2	192	691	DH76	>19.3	37.6	0	33.681	33.681	25-Mar-04	
1-Mar-04	10:50	0.6	1.842	13	8.1	360	658	DH48	>26.3	5.82	4.935	19.741	24.676	25-Mar-04	
PAC-LOV															
28-Dec-03	14:01	0.1	0.105	8.47	7.02	1350	441	DH48	34	22.4	0	0	0.000	6-Jan-04	braided channel, small channel flowing to the right of Q measurements not measured.
29-Dec-03	15:13	0.1	0.153	9	8	645	558	DH48	>60	5.9	0	13.171	13.171	6-Jan-04	braided channel, small channel flowing to the right of Q measurements not measured.
30-Dec-03	6:09	0.2	0.143	10	8	437	565	DH48	2.7	649	88.26	328.98	417.242	6-Jan-04	high water mark at 0.92 m
30-Dec-03	15:11	0.2	0.131	12	7.8	427	612	DH48	2.3	1326	7.399	1206	1213.413	6-Jan-04	
31-Dec-03	8:50	0.3	0.584	10.5	8.1	343	577	DH48	6.6	171	2.738	306.71	309.447	6-Jan-04	
1-Jan-04	13:00	0.2	0.336	11	8.1	440	575	DH48	19.7	50.3	0	20.814	20.814	6-Jan-04	
2-Jan-04	13:45	0.9	6.430	10	8.3	260	594	DH48	12	79.2	0	52.288	52.288	6-Jan-04	
5-Jan-04	10:11	0.3	0.587	9.5	8.1	367	408	DH48	28.2	7.98	2.304	0.000	2.304	6-Jan-04	high water mark at 0.34 m

nmf = no measurable flow

date	time	stage (m)	discharge (m3/s)	temp C	pH	TDS (uS)	SSC bottle #	sample method	Transp (cm)	Turb (NTU)	SSC >63um	SSC <63um	Suspended Solids Concentration (mg/L)	lab analysis date	field notes
PAC-LOV															
1-Feb-04	15:24	0.1	0.162	11.5	9.2	627	635	DH48	>21.0	5.84	7.459	26.106	33.564	12-Feb-04	
2-Feb-04	9:50	0.1	0.161	12	4.5	648	535	grab	17.3	46.6	53.01	151.46	204.471	12-Feb-04	high water mark at 0.13 m
3-Feb-04	6:50	0.1	0.152	11	7	625	575	DH48	>22.2	14	32.02	42.690	74.707	12-Feb-04	high water mark at 0.27 m
4-Feb-04	11:00	0.3	0.647	12	8.5	420	669	grab	>22.0	17.6	21.47	39.368	60.842	12-Feb-04	high water mark at 0.34 m
5-Feb-04	14:30	0.2	0.514	13.5	8.2	418	555	DH48	>26.7	13.3	8.480	39.571	48.051	12-Feb-04	
23-Feb-04	9:55	0.2	0.674	12.5	8.2	431	456	DH48	>49.7	3.05	0	20.101	20.101	25-Mar-04	
25-Feb-04	16:41	0.3	0.831	13.5	8.2	431	495	DH48	20.8	46.8	16.94	89.548	106.490	25-Mar-04	
26-Feb-04	13:30	1.6	18.716	11	8.2	213	444	DH76	9	121	0	69.263	69.263	25-Mar-04	high water mark @ approx 3m
27-Feb-04	12:23	1.1	16.282	13	8.3	213	671	DH76	16.8	51.5	5.579	33.474	39.053	25-Mar-04	
1-Mar-04	11:26	0.5	1.694	12	8.3	397	643	DH48	25.9	7.79	0	15.097	15.097	25-Mar-04	
UVA-LUC															
28-Dec-03	15:27	0.9	0.574	10.5	7.24	793.9	401	DH48	>60	3.82	6.543	0	6.543	6-Jan-04	
29-Dec-03	16:57	1.4	1.984	9.5	8.5	178	447	DH48	6.8	197	12.07	111.04	123.108	6-Jan-04	
30-Dec-03	7:41	1.6	NA	10	8.3	146	474	DH48	14.6	72.8	27.85	58.230	86.079	6-Jan-04	too fast & deep to measure Q safely
30-Dec-03	16:51	1.4	2.342	11.5	8.7	306	672	DH48	>19.2	40.5	23.91	51.226	75.132	6-Jan-04	
31-Dec-03	9:50	1.4	NA	10.5	8.2	256	690	DH48	9	124	10.55	44.828	55.376	6-Jan-04	too fast & deep to measure safely
1-Jan-04	13:55	2.1	NA	10	8.3	175	586	DH48	4.3	307	0	968.67	968.670	6-Jan-04	too fast & deep to measure safely
2-Jan-04	15:35	1.5	NA	13	8.1	290	619	DH48	21.9	36.3	2.499	24.987	27.486	6-Jan-04	too fast & deep to measure safely
5-Jan-04	11:25	1.4	4.801	10.5	8.3	273	572	DH48	21.9	39	2.566	7.697	10.262	6-Jan-04	high water mark @ 5.14 ft
1-Feb-04	17:11	1.0	1.051	11.5	8.1	332	584	DH48	>26.8	3.22	2.834	19.836	22.670	12-Feb-04	
2-Feb-04	11:15	1.1	0.691	11	7.5	342	647	grab	>23.5	4.02	9.825	0.000	9.825	12-Feb-04	
3-Feb-04	8:22	1.3	1.726	10	7	350	572	DH48	22	37.3	3.596	46.751	50.348	12-Feb-04	
4-Feb-04	11:57	1.3	1.716	13	8.3	341	401	grab	>27.8	19.3	2.722	19.052	21.773	12-Feb-04	
5-Feb-04	15:32	1.2	1.160	13	8.3	334	551	DH48	>28.9	13.5	7.765	23.294	31.058	12-Feb-04	
23-Feb-04	10:52	1.4	3.283	12	8.3	322	462	DH48	>23.3	9.13	8.379	19.551	27.930	25-Mar-04	
25-Feb-04	19:50	2.6	NA	11.5	8.4	175	575	grab	2.1226	608	16.778	458.6	475.378	25-Mar-04	too fast & deep to measure safely
26-Feb-04	16:05	1.9	NA	12	8.3	259	539	DH48	13.7	65.6	3.807	68.535	72.342	25-Mar-04	too fast & deep to measure safely
27-Feb-04	14:57	1.8	NA	14	8.3	271	661	DH48	>23.8	26.5	2.734	43.750	46.485	25-Mar-04	too fast & deep to measure safely
1-Mar-04	13:00	1.5	4.816	14	8.2	351	673	DH48	>19.8	17.2	16.472	16.472	32.945	25-Mar-04	

date	time	stage (m)	discharge (m3/s)	temp C	pH	TDS (uS)	SSC bottle #	sample method	Transp (cm)	Turb (NTU)	SSC >63um	SSC <63um	Suspended Solids Concentration (mg/L)	lab analysis date	field notes
CND-BLO															
28-Dec-03	14:45	0.16	0.483	8.09	7.15	793	680	DH48	>60	2.17	0	0	0.000	6-Jan-04	
29-Dec-03	15:48	0.6	3.470	10	8.3	247	463	DH48	2.2	1126	8.274	582.0	590.237	6-Jan-04	
30-Dec-03	7:16	0.6	NA	10.5	8.1	222	535	DH48	7.9	135	7.286	98.364	105.650	6-Jan-04	too fast & deep to measure safely
30-Dec-03	15:51	0.2	4.077	12.5	8.2	275	477	DH48	18.6	46.6	0	24.584	24.584	6-Jan-04	
31-Dec-03	9:20	0.2	4.394	10	8.3	264	444	DH48	8.8	122	0	52.661	52.661	6-Jan-04	
1-Jan-04	13:35	0.8	NA	10	8.25	194	445	DH48	3.6	542	21.25	307.05	328.296	6-Jan-04	too fast & deep to measure safely
2-Jan-04	14:40	0.3	5.147	12	8.3	280	485	DH48	14.9	62.9	2092	73.082	2164.623	6-Jan-04	
5-Jan-04	10:41	0.2	4.308	9	8.3	270	581	DH48	21.2	39.5	14.64	29.273	43.909	6-Jan-04	high water mark @ 1ft (0.0348 m)
1-Feb-04	16:03	-0.3	0.796	10.5	10.1	338	690	DH48	>24.2	9.96	12.7	28.584	41.289	12-Feb-04	
2-Feb-04	10:53	-0.2	0.555	11	8.1	350	673	grab	>23.3	3.39	0	30.014	30.014	12-Feb-04	
3-Feb-04	7:37	0.0	1.725	9.5	9.2	332	467	DH48	8.7563	114	25.6	108.78	134.375	12-Feb-04	
4-Feb-04	11:40	0.0	1.805	11.5	8.4	332	433	DH48	>24.7	23.4	12.42	24.846	37.270	12-Feb-04	high water mark at 0.26 ft (0.08 m)
5-Feb-04	15:05	-0.1	1.166	12.5	8.4	331	699	DH48	>26.6	13.7	8.613	25.840	34.453	12-Feb-04	
23-Feb-04	10:30	0.1	3.519	11	8.4	302	558	DH48	>24.7	13.8	2.638	15.830	18.469	25-Mar-04	
25-Feb-04	18:10	2.8	54.662	11	8.4	156	569	DH76	1.0147	1032	304.1	1216.6	1520.747	25-Mar-04	
26-Feb-04	14:45	0.6	12.601	12	8.4	248	606	DH76	10.9	87.2	32.73	81.813	114.538	25-Mar-04	
27-Feb-04	13:33	0.6	10.905	12.5	8.4	265	476	DH76	19.3	40.6	2.462	41.848	44.310	25-Mar-04	
1-Mar-04	12:13	0.2	0.579	13	8.3	341	551	DH48	>29.7	19	4.368	24.025	28.393	25-Mar-04	
WAT-ERR															
28-Dec-03	16:43	0.4	nmf	9.6	6.82	646	453	grab	>60	4.65	0	0.000	0.000	6-Jan-04	
30-Dec-03	8:46	0.9	0.675	9	7.4	221	559	DH48	11.6	83.2	19.5	109.21	128.712	6-Jan-04	
30-Dec-03	17:56	0.8	0.279	10	7.5	205	606	DH48	>19.6	33.2	16.77	33.533	50.299	6-Jan-04	
31-Dec-03	10:35	0.8	0.372	11	7.8	209	462	DH48	6	271	23.03	348.68	371.702	6-Jan-04	
1-Jan-04	14:49	0.8	0.074	10.5	8.1	176	584	DH48	3.7	481	0	254.64	254.643	6-Jan-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
2-Jan-04	16:15	0.7	0.443	10	7.8	190	576	DH48	>28.3	18.3	16.03	25.195	41.228	6-Jan-04	wind moving surface flow upstream
5-Jan-04	12:27	0.4	0.088	10	7.6	217	560	DH48	7	153	6.220	136.84	143.064	6-Jan-04	high water mark @ 0.41m
1-Feb-04	18:04	0.1	nmf	11	8.1	325	408	grab	>25.8	11.4	8.755	20.427	29.182	12-Feb-04	wind moving surface flow upstream

nmf = no measurable flow

date	time	stage (m)	discharge (m3/s)	temp C	pH	TDS (uS)	SSC bottle #	sample method	Transp (cm)	Turb (NTU)	SSC >63um	SSC <63um	Suspended Solids Concentration (mg/L)	lab analysis date	field notes
WAT-ERR															
2-Feb-04	12:26	0.3	nmf	10.5	7	335	474	grab	4.5685	291	20.08	200.76	220.833	12-Feb-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
3-Feb-04	9:30	0.3	nmf	11	7	302	606	grab	19.9	40.2	0	36.240	36.240	12-Feb-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
4-Feb-04	12:37	0.2	nmf	12.5	7.6	302	609	grab	>25.9	10.7	0	11.622	11.622	12-Feb-04	wind moving surface flow upstream, high water mark at 0.32 m
5-Feb-04	16:24	0.2	nmf	13.5	7.6	311	672	grab	>27.6	4.71	0	5.447	5.447	12-Feb-04	wind moving surface flow upstream, high water mark at 0.28 m
23-Feb-04	11:50	0.3	nmf	14	7.6	284	469	DH48	>28.9	5.55	4.483	11.208	15.691	25-Mar-04	wind moving surface flow upstream. Road work being done on upstream side of bridge.
25-Feb-04	20:23	0.7	nmf	12	7.6	252	619	grab	4.1137	24.3	23.347	331.52	354.868	25-Mar-04	wind moving surface flow upstream. high water mark @ 0.71m
26-Feb-04	16:55	0.6	nmf	12.5	7.4	253	441	grab	>11.3	17.8	0	19.395	19.395	25-Mar-04	wind moving surface flow upstream
27-Feb-04	15:49	0.5	nmf	14	8.1	228	549	grab	>28.7	10.5	2.264	11.322	13.587	25-Mar-04	wind moving surface flow upstream
1-Mar-04	13:46	0.4	nmf	13	7.6	284	486	grab	16.7	41.7	0	33.630	33.630	25-Mar-04	wind moving surface flow upstream
WAT-SHE															
28-Dec-03	16:58	NA		11.3	6.81	430	461	grab	24.2	26.6	4.268	136.59	140.856	6-Jan-04	
30-Dec-03	9:14	0.8		9.5	7.8	857	673	grab	19.1	36.9	0	17.484	17.484	6-Jan-04	pump is on
30-Dec-03	18:27	0.8		11	7.6	1004	467	grab	15.8	33.5	0	16.466	16.466	6-Jan-04	
31-Dec-03	11:05	0.7		10.5	7.6	1016	450	grab	19.1	36.7	0	64.525	64.525	6-Jan-04	pump is on
1-Jan-04	15:24	0.8		11	7.8	1036	557	grab	9.8	84	0	29.660	29.660	6-Jan-04	pump is on
2-Jan-04	16:40	0.6		9.5	7.7	880	723	grab	17.2	35.9	0	39.457	39.457	6-Jan-04	pump is on, oil slick in water coming from pump house
5-Jan-04	12:56	1.1		9.5	7.8	675	646	grab	>22.2	29	0	20.656	20.656	6-Jan-04	pump is on
1-Feb-04	18:20	1.5		11	7	893	484	grab	>27.9	19.8	16.01	40.030	56.042	12-Feb-04	pump is on
2-Feb-04	12:37	1.4		10.5	7	930	557	grab	>24.5	13.1	0	37.500	37.500	12-Feb-04	pump is on
3-Feb-04	9:40	1.2		10.5	7	1284	654	grab	14.2	65.1	0	58.914	58.914	12-Feb-04	pump is on
4-Feb-04	12:55	1.1		12.5	7.9	930	565	grab	18.9	34.6	0	86.691	86.691	12-Feb-04	pump is on
5-Feb-04	16:40	1.3		13.5	7.8	935	718	grab	26.6	20.7	0	40.387	40.387	12-Feb-04	pump is on
23-Feb-04	12:00	1.2		14	7.8	1005	728	grab	25.5	23.4	0	29.962	29.962	25-Mar-04	
25-Feb-04	21:15	0.8		12.5	7.9	623	535	grab	9.9	99.7	2.248	49.465	51.714	25-Mar-04	pump is on

nmf = no measurable flow

stage at WAT-SHE is inverse (is distance from platform to water surface)

date	time	stage (m)	discharge (m3/s)	temp C	pH	TDS (uS)	SSC bottle #	sample method	Transp (cm)	Turb (NTU)	SSC >63um	SSC <63um	Suspended Solids Concentration (mg/L)	lab analysis date	field notes
WAT-SHE															
26-Feb-04	17:13	0.5		12	7.7	8830	555	grab	16.4	38.5	8.885	55.533	64.419	25-Mar-04	water flowing upstream (tidal influence)
27-Feb-04	16:10	0.6		14.5	7.9	4880	642	grab	22.4	26	4.594	34.457	39.051	25-Mar-04	
1-Mar-04	14:05	1.0		13.5	7.8	717	464	grab	10.7	68.8	0	64.511	64.511	25-Mar-04	

nmf = no measurable flow

stage at WAT-SHE is inverse (is distance from platform to water surface)

date	time	stage (m)	discharge (m3/s)	Nutrient bottle #	10020 NO3-N (mg/L)	10023 NH3-N (mg/L)	8048 PO4-P (mg/L)	lab analysis date	field notes
PAC-WAL									
28-Dec-03	12:44	0.0	0	N2891	0.2	0.035	0.115	20-Jan-04	no flow, stagnant pools
29-Dec-03	14:44	0.1	0	N2394	0.65	0.065	1.46	22-Jan-04	
30-Dec-03	5:30	0.2	0.169	N2313	0.7	0.02	0.25	22-Jan-04	high water mark at 0.26 - 0.27 m
30-Dec-03	14:31	0.6	1.445	N2117	1.5	0	0.17	21-Jan-04	high water mark at 0.69 m
31-Dec-03	8:30	0.4	0.602	N2443	1.05	0.01	0.05	22-Jan-04	
1-Jan-04	12:16	0.4	0.414	N2143	0.7	0.02	0.15	22-Jan-04	
2-Jan-04	12:54	0.8	4.951	N2161	1.3	0.01	0.21	16-Jan-04	high water mark at 0.92 - 0.93 m
5-Jan-04	9:44	0.4	0.868	N2451	1.1	0.01	0.1	16-Jan-04	
1-Feb-04	14:53	0.2	0.588	N2173	0.0, 0.0	0.0, nd	0.11, 0.14	12-Mar-04	
2-Feb-04	9:18	0.2	0.703	N2149	0.0, 0.0	0.0, 0.0	0.09, 0.06	12-Mar-04	high water mark at 0.21m
3-Feb-04	5:56	0.3	0.318	N2493	0.4	0.0, nd	0.09	12-Mar-04	
4-Feb-04	10:20	0.4	0.850	N2387	0.3	0.02	0.08	16-Mar-04	high water mark at 0.5 m
5-Feb-04	13:45	0.4	0.618	N2339	0.1	nd	0.16	16-Mar-04	
23-Feb-04	9:02	0.4	0.855	N2597	0.0, 0.1	0	0.09	26-Mar-04	
25-Feb-04	14:45	1.0	7.386	N2219	0.3	0.02, 0.03	0.41	26-Mar-04	
26-Feb-04	12:22	1.5	21.374	N2591	0.8	0.02	0.31	23-Mar-04	
27-Feb-04	11:03	1.1	12.311	N2475	2.3	0.03	0.42, 0.51	23-Mar-04	
1-Mar-04	10:50	0.6	1.842	N2182	0.09	0.01	0.20, 0.18	23-Mar-04	
PAC-LOV									
28-Dec-03	14:01	0.1	0.105	N2225	1.4	0.01	0.16	21-Jan-04	braided channel, small channel flowing to the right of Q measurements not measured.
29-Dec-03	15:13	0.1	0.153	N2391	0.8	0	0.8	22-Jan-04	braided channel, small channel flowing to the right of Q measurements not measured.
30-Dec-03	6:09	0.2	0.143	N2393	1.1	0.01	0.61	21-Jan-04	high water mark at 0.92 m
30-Dec-03	15:11	0.2	0.131	N2400	2.7	0.03	1.32	21-Jan-04	
31-Dec-03	8:50	0.3	0.584	N2888	1.3	0.05	0.2	22-Jan-04	
1-Jan-04	13:00	0.2	0.336	N2478	1.1	0.12	0.12	16-Jan-04	
2-Jan-04	13:45	0.9	6.430	N2447	1.3	0.04	0.345	16-Jan-04	
5-Jan-04	10:11	0.3	0.587	N2583	0.9	0.01	0.11	16-Jan-04	high water mark at 0.34 m

nmf = no measurable flow

date	time	stage (m)	discharge (m3/s)	Nutrient bottle #	10020 NO3-N (mg/L)	10023 NH3-N (mg/L)	8048 PO4-P (mg/L)	lab analysis date	field notes
PAC-LOV									
1-Feb-04	15:24	0.1	0.162	N2249	0.7	0	0.1	12-Mar-04	
2-Feb-04	9:50	0.1	0.161	N2448	0.9	0.02	0.06	12-Mar-04	high water mark at 0.13 m
3-Feb-04	6:50	0.1	0.152	N2599	0.7	0.04	0.06, 0.09	12-Mar-04	high water mark at 0.27 m
4-Feb-04	11:00	0.3	0.647	N2395	0.2	0.00, 0.00	0.15	16-Mar-04	high water mark at 0.34 m
5-Feb-04	14:30	0.2	0.514	N2370	0.5	0.00, 0.01	0.18, 0.14	16-Mar-04	
23-Feb-04	9:55	0.2	0.674	N2577	0	0	0.08	23-Mar-04	
25-Feb-04	16:41	0.3	0.831	N2462	0.2	0.01	0.09	26-Mar-04	
26-Feb-04	13:30	1.6	18.716	N2896	0.3	0.01	0.38	26-Mar-04	high water mark @ approx 3m
27-Feb-04	12:23	1.1	16.282	N2456	0.8	0.02	0.2	23-Mar-04	
1-Mar-04	11:26	0.5	1.694	N2582	0.5	0	0.25	23-Mar-04	
UVA-LUC									
28-Dec-03	15:27	0.9	0.574	N2575	1	0.01	0.13	21-Jan-04	
29-Dec-03	16:57	1.4	1.984	N2324	0.4	0.05	0.7	22-Jan-04	
30-Dec-03	7:41	1.6	NA	N2352	1.2	0.01	0.32	21-Jan-04	too fast & deep to measure Q safely
30-Dec-03	16:51	1.4	2.342	N2341	1.3, 1.5	0.03, 0.04	0.22, 0.21	20-Jan-04	
31-Dec-03	9:50	1.4	NA	N2594	0.9	0.01	0.03	22-Jan-04	too fast & deep to measure safely
1-Jan-04	13:55	2.1	NA	N2180	0.7	0.03	0.6	16-Jan-04	too fast & deep to measure safely
2-Jan-04	15:35	1.5	NA	N2222	1.4	0	0.19	16-Jan-04	too fast & deep to measure safely
5-Jan-04	11:25	1.4	4.801	N2233	0.4	0.01	0.14	16-Jan-04	high water mark @ 5.14 ft
1-Feb-04	17:11	1.0	1.051	N2144	1.4, 1.5	nd	0.12	12-Mar-04	
2-Feb-04	11:15	1.1	0.691	N2292	1.1	nd	0.14	12-Mar-04	
3-Feb-04	8:22	1.3	1.726	N2454	1.1	nd	0.31	12-Mar-04	
4-Feb-04	11:57	1.3	1.716	N2085	1.3, 1.3	0.02, 0.0	0.15	16-Mar-04	
5-Feb-04	15:32	1.2	1.160	N2398	1.1	0.1	0.13, 0.16	16-Mar-04	
23-Feb-04	10:52	1.4	3.283	N2401	0.4	0.02	0.1	26-Mar-04	
25-Feb-04	19:50	2.6	NA	N2895	0.6	0.02, 0.03	0.35	26-Mar-04	too fast & deep to measure safely
26-Feb-04	16:05	1.9	NA	N2477	1	0.01	0.24	23-Mar-04	too fast & deep to measure safely
27-Feb-04	14:57	1.8	NA	N2211	1	0.01	0.27	23-Mar-04	too fast & deep to measure safely
1-Mar-04	13:00	1.5	4.816	N2473	1.0, 1.1	0.02, 0.20	0.06	23-Mar-04	

date	time	stage (m)	discharge (m3/s)	Nutrient bottle #	10020 NO3-N (mg/L)	10023 NH3-N (mg/L)	8048 PO4-P (mg/L)	lab analysis date	field notes
CND-BLO									
28-Dec-03	14:45	0.2	0.483	N2399	1	nd	0.41	21-Jan-04	
29-Dec-03	15:48	0.6	3.470	N2423	0.1	0.05	0.38	22-Jan-04	
30-Dec-03	7:16	0.6	NA	N2128	1.1	0.04	0.24	22-Jan-04	too fast & deep to measure safely
30-Dec-03	15:51	0.2	4.077	N2317	1.4	0.09	0.2	21-Jan-04	
31-Dec-03	9:20	0.2	4.394	N2467	0.8	0.03	0.07	22-Jan-04	
1-Jan-04	13:35	0.8	NA	N2761	0.2	0.04	0.38	22-Jan-04	too fast & deep to measure safely
2-Jan-04	14:40	0.3	5.147	N2492	1.25	0.02	0.18	16-Jan-04	
5-Jan-04	10:41	0.2	4.308	N2179	1.2	0	0.06	16-Jan-04	high water mark @ 1ft (0.0348 m)
1-Feb-04	16:03	-0.3	0.796	N2402	1.4	0.03, 0.0	0.12, 0.12	12-Mar-04	
2-Feb-04	10:53	-0.2	0.555	N2404	1.2	nd	0.16, 0.11	12-Mar-04	
3-Feb-04	7:37	0.0	1.725	N2165	0.8	0.02	0.27	12-Mar-04	
4-Feb-04	11:40	0.0	1.805	N2389	1	0	0.22	16-Mar-04	high water mark at 0.26 ft (0.08 m)
5-Feb-04	15:05	-0.1	1.166	N2343	1.3	0.11	0.14, 0.16	16-Mar-04	
23-Feb-04	10:30	0.1	3.519	N2263	0.6	0.01	0.11	26-Mar-04	
25-Feb-04	18:10	2.8	54.662	N2170	0.3, 0.4	0.06	0.39	26-Mar-04	
26-Feb-04	14:45	0.6	12.601	N2373	0.7	0.01	0.28	26-Mar-04	
27-Feb-04	13:33	0.6	10.905	N2866	0.6	0.01	0.12	23-Mar-04	
1-Mar-04	12:13	0.2	0.579	N2472	1.2	0.04	0.14	23-Mar-04	
WAT-ERR									
28-Dec-03	16:43	0.4	0	N2279	0.6	0.14	1.83	21-Jan-04	
30-Dec-03	8:46	0.9	0.675	N2349	0.1	0.17	1.48	22-Jan-04	
30-Dec-03	17:56	0.8	0.279	N2378	0.4	0.12	1.3	21-Jan-04	
31-Dec-03	10:35	0.8	0.372	N2041	0	0.12	1.12	22-Jan-04	
1-Jan-04	14:49	0.8	0.074	N2471	0.1	0.09	0.78	16-Jan-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
2-Jan-04	16:15	0.7	0.443	N2778	0.2	0.05	1.27	16-Jan-04	wind moving surface flow upstream
5-Jan-04	12:27	0.4	0.088	N2767	0.5	0.19	1.26	16-Jan-04	high water mark @ 0.41m
1-Feb-04	18:04	0.1	nmf	N2192	0	0.06	1.14	16-Mar-04	wind moving surface flow upstream

nmf = no measurable flow

date	time	stage (m)	discharge (m3/s)	Nutrient bottle #	10020 NO3-N (mg/L)	10023 NH3-N (mg/L)	8048 PO4-P (mg/L)	lab analysis date	field notes
WAT-ERR									
2-Feb-04	12:26	0.3	nmf	N2344	0.3	0.09	0.9	12-Mar-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
3-Feb-04	9:30	0.3	nmf	N2586	0.4	0.08, 0.08	0.75, 0.77	16-Mar-04	wind moving surface flow upstream, gutter is overflowing from street into ditch; contributing ss
4-Feb-04	12:37	0.2	nmf	N2870	0.1, 0.0	0.08	0.91	16-Mar-04	wind moving surface flow upstream, high water mark at 0.32 m
5-Feb-04	16:24	0.2	nmf	N2338	0	0.06	0.92	16-Mar-04	wind moving surface flow upstream, high water mark at 0.28 m
23-Feb-04	11:50	0.3	nmf	N2202	0.1	0.08	0.95	26-Mar-04	wind moving surface flow upstream. Road work being done on upstream side of bridge.
25-Feb-04	20:23	0.7	nmf	N2592	0.2	0.1	0.98, 0.97	26-Mar-04	wind moving surface flow upstream. high water mark @ 0.71m
26-Feb-04	16:55	0.6	nmf	N2411	0.6	0.1	1.15	23-Mar-04	wind moving surface flow upstream
27-Feb-04	15:49	0.5	nmf	N2286	0.4, 0.5	0.12	0.87	23-Mar-04	wind moving surface flow upstream
1-Mar-04	13:46	0.4	nmf	N2496	0.6	0.12	0.61	23-Mar-04	wind moving surface flow upstream
WAT-SHE									
28-Dec-03	16:58	NA		N2396	49.2	0.02	1.51	21-Jan-04	
30-Dec-03	9:14	0.8		N2113	18.7	0.06	2.83	21-Jan-04	pump is on
30-Dec-03	18:27	0.8		N2009	22.2	0.06	2.93	21-Jan-04	
31-Dec-03	11:05	0.7		N2364	23.8	0.03	2.36	22-Jan-04	pump is on
1-Jan-04	15:24	0.8		N2603	17.7	0.15	2.28	16-Jan-04	pump is on
2-Jan-04	16:40	0.6		N2187	17.7, 17.5	0.34, 0.27	2.49, 2.51	16-Jan-04	pump is on, oil slick in water coming from pump house
5-Jan-04	12:56	1.1		N2481	9.7	0.15	1.58	16-Jan-04	pump is on
1-Feb-04	18:20	1.5		N2771	3.6	0.06	1.27	12-Mar-04	pump is on
2-Feb-04	12:37	1.4		N2457	3.9	0.18, 0.18	1.48	12-Mar-04	pump is on
3-Feb-04	9:40	1.2		N2406	5.8	0.18	1.52	16-Mar-04	pump is on
4-Feb-04	12:55	1.1		N2455	6.1	0.13	1.55	16-Mar-04	pump is on
5-Feb-04	16:40	1.3		N2218	5.8	0.14	1.59	16-Mar-04	pump is on
23-Feb-04	12:00	1.2		N2476	6.5	0.08	1.64	26-Mar-04	
25-Feb-04	21:15	0.8		N2420	7.3	0.06	2.11, 2.14	26-Mar-04	pump is on

nmf = no measurable flow

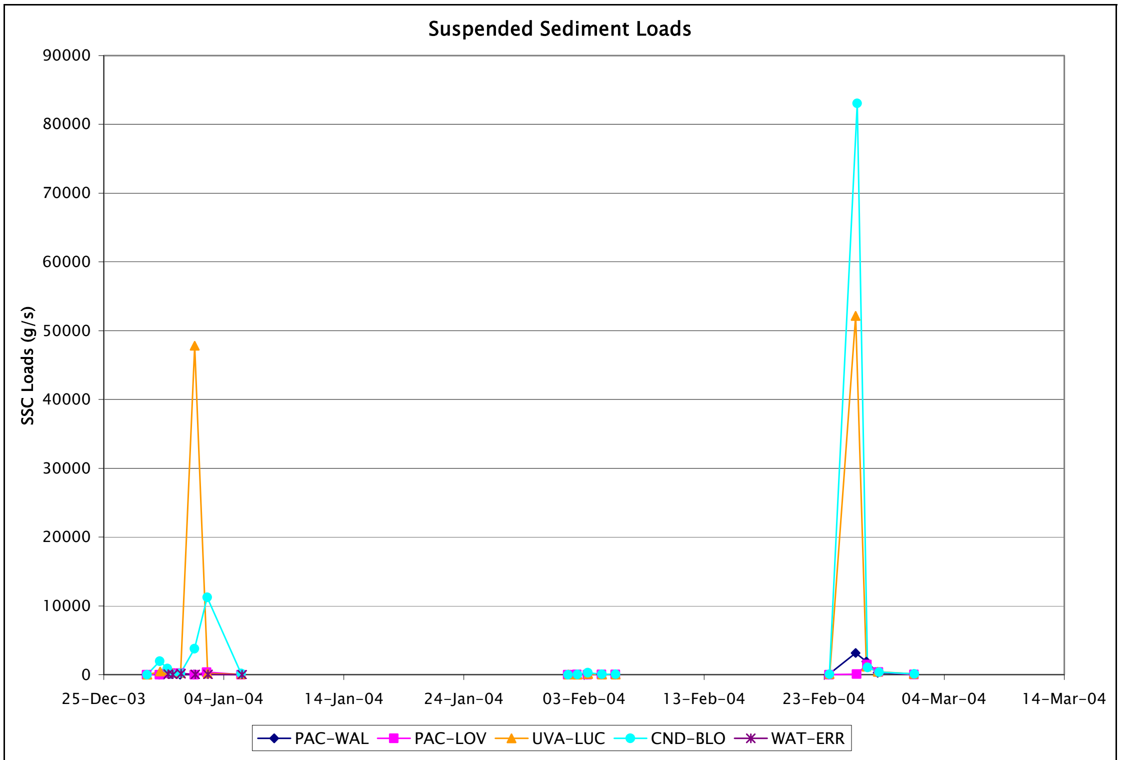
stage at WAT-SHE is inverse (is distance from platform to water surface)

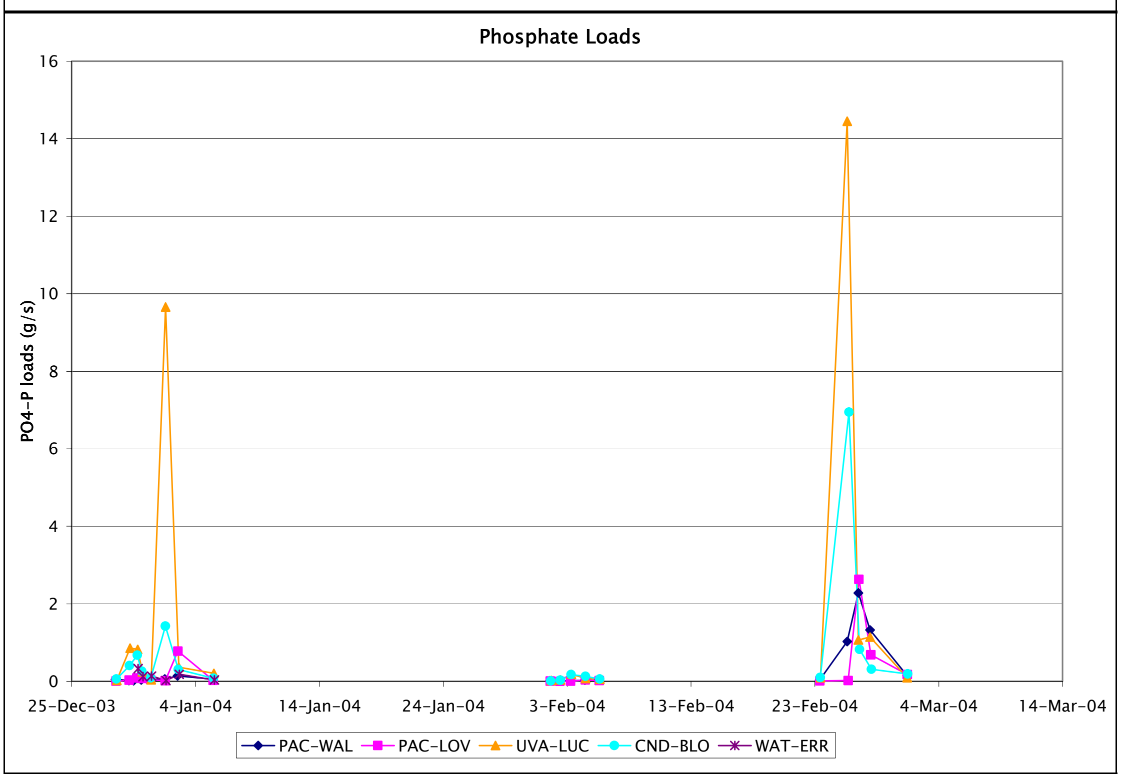
date	time	stage (m)	discharge (m3/s)	Nutrient bottle #	10020 NO3-N (mg/L)	10023 NH3-N (mg/L)	8048 PO4-P (mg/L)	lab analysis date	field notes
WAT-SHE									
26-Feb-04	17:13	0.5		N2867	8.9	0.05	1.2	26-Mar-04	water flowing upstream (tidal influence)
27-Feb-04	16:10	0.6		N2189	7.9	0.04, 0.05	1.65	23-Mar-04	
1-Mar-04	14:05	1.0		N2084	5.1	0.1	1.62	23-Mar-04	

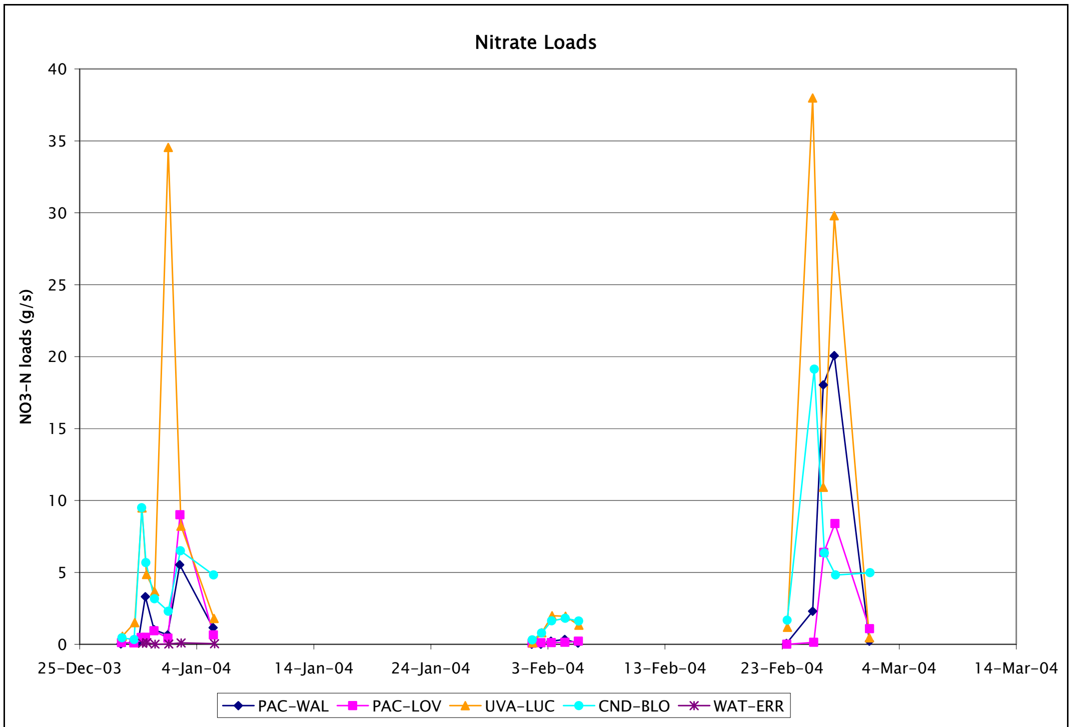
nmf = no measurable flow

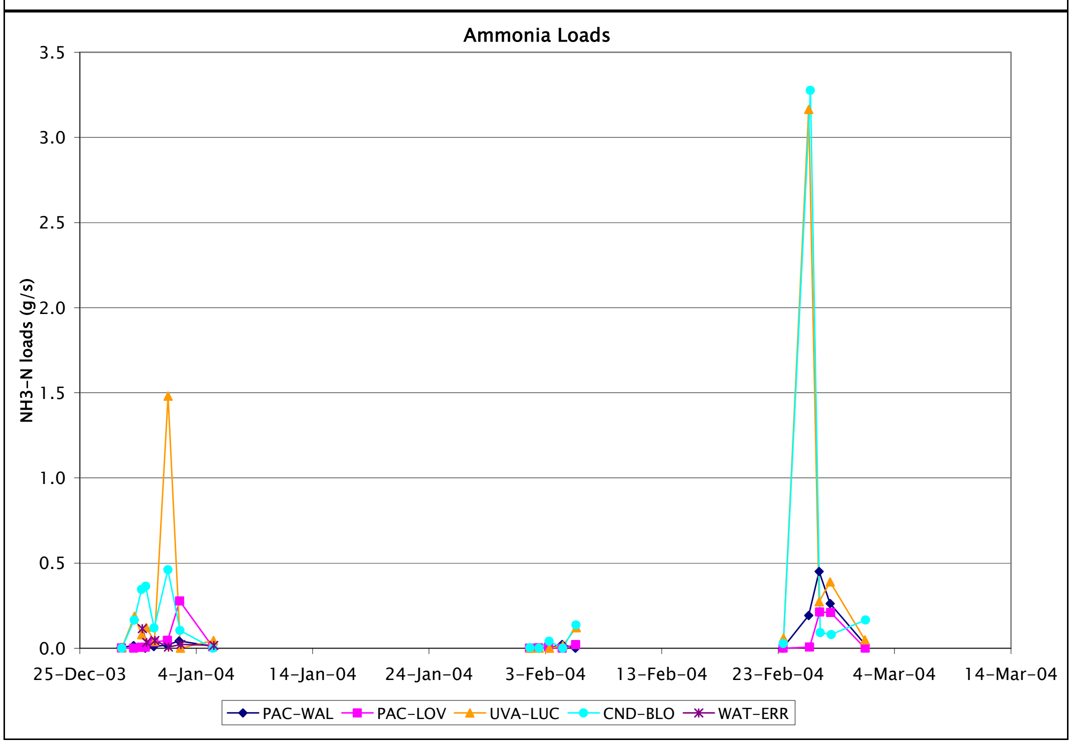
stage at WAT-SHE is inverse (is distance from platform to water surface)

7.5 **Appendix E** Time series of measured loads






Nitrate Loads
NO3-N loads (g/s)
40
35
30
25
20
15
10
5
0
25-Dec-03
4-Jan-04
14-Jan-04
24-Jan-04
3-Feb-04
13-Feb-04
23-Feb-04
4-Mar-04
14-Mar-04
PAC-WAL
PAC-LOV
UVA-LUC
CND-BLO
WAT-ERR


Ammonia Loads
NH3-N loads (g/s)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
25-Dec-03
4-Jan-04
14-Jan-04
24-Jan-04
3-Feb-04
13-Feb-04
23-Feb-04
4-Mar-04
14-Mar-04
PAC-WAL
PAC-LOV
UVA-LUC
CND-BLO
WAT-ERR

7.6 **Appendix** F Nutrient lab QA/QC

NO3-N

Lab analyasis date:	16-Jan-04			21-Jan-04			22-Jan-04			11-Mar-04			15-Mar-04			23-Mar-04			25-Mar-04		
STANDARDS																					
Standard value:	0.5	10	25	0.5	10	25	0.5	10	25	0.5	10	25	0.5	10	25	0.1	10	25	0.5	10	25
Measured value:	0	10.1	26.2	0.7	10.3	26.6	0.5	10.3	25.4	0.3	10.1	26.2	0.6	10.9	25.6	0.2	10.3	25.9	0.4	10.3	25.9
% Error:	100%	1%	5%	40%	3%	6%	0%	3%	2%	40%	1%	5%	20%	9%	2%	100%	3%	4%	20%	3%	4%
REPLICATES																					
Bottle #:	N2187			N2341			N2443			N2144			N2085			N2286			N2170		
Rep 1:	17.7			1.3			1.2			1.5			1.3			0.4			0.3		
Rep 2:	17.5			1.5			0.9			1.4			1.3			0.5			0.4		
% Difference:	1%			14%			29%			0%			0%			22%			29%		
Bottle #:	N2492			N2891			N2349						N2870			N2473			N2597		
Rep 1:	1.2			0.1			0.5						0.1			1			0.1		
Rep 2:	1.3			0.3			0.8						0			1.1			0		
% Difference:	8%			1%			46%						2%			0%			200%		
SPIKE RECOVERY																					
Sample value:	17.6			1.4			1.05			0			0.05			0.45			0.4		
Expected spike value:	13.8			5.7			5.525			5			5.025			5.225			5.2		
Measured spike value:	14.4			6.2			5.6			5.3			5.3			5.7			5.6		
% Recovery:	104%			109%			101%			106%			105%			109%			108%		

NH3-N

Lab analyasis date:	16-Jan-04			21-Jan-04			22-Jan-04			11-Mar-04			15-Mar-04			23-Mar-04			25-Mar-04		
STANDARDS																					
Standard value:	0.5	1	2.5	0.5	1	2.5	0.5	1	2.5	0.5	10	25	0.5	10	25	0.1	1	2.5	0.1	1	2.5
Measured value:	0.55	1.09	2.52	0.67	1.09	or	0.59	1.06	2.55	0.3	10.1	26.2	0.6	10.9	25.6	0.13	1.04	2.54	0.11	1.01	2.56
% Error:	10%	9%	1%	34%	9%	na	18%	6%	2%	40%	1%	5%	20%	9%	2%	30%	4%	2%	10%	1%	2%
REPLICATES																					
Bottle #:	N2187			N2341			N2443			N2149			N2085			N2189			N2219		
Rep 1:	0.34			0.03			0.01			0			0.02			0.04			0.02		
Rep 2:	0.27			0.04			0.01			0			0			0.05			0.03		
% Difference:	23%			29%			0%			0%			0%			22%			40%		
Bottle #:	N2492			N2891			N2394			N2457			N2586			N2473			N2895		
Rep 1:	0.02			0.04			0.05			0.18			0.08			0.02			0.03		
Rep 2:	0.02			0.03			0.08			0.18			0.08			0.02			0.02		
% Difference:	0%			29%			46%			0%			0%			0%			40%		
SPIKE RECOVERY																					
Sample value:	0.305			0.035			0.01			0.015			0.02			0.045			0.025		
Expected spike value:	0.6525			0.5175			0.505			0.5075			0.51			0.5225			0.5125		
Measured spike value:	0.55			0.53			0.51			0.53			0.48			0.52			0.48		
% Recovery:	84%			102%			101%			104%			94%			100%			94%		

PO4-P

Lab analyasis date:	16-Jan-04			21-Jan-04			22-Jan-04			11-Mar-04			15-Mar-04			23-Mar-04			25-Mar-04		
STANDARDS																					
Standard value:	0.5	1	5	0.5	1	5	0.5	1	5	0.1	1	5	0.1	1	5	0.1	1	5	0.1	1	5
Measured value:	0.51	1.02	4.94	0.51	1.05	4.93	0.47	0.97	4.93	0.12	1.02	4.84	0.14	1.01	5.13	0.12	1.04	4.91	0.11	1.03	4.99
% Error:	2%	2%	1%	2%	5%	1%	6%	3%	1%	20%	2%	3%	40%	1%	3%	20%	4%	2%	10%	3%	0%
REPLICATES																					
Bottle #:	N2187			N2341			N2443			N2173			N2343			N2182			N2402		
Rep 1:	2.49			0.22			0.04			0.11			0.14			0.2			2.14		
Rep 2:	2.51			0.21			0.06			0.14			0.16			0.18			2.11		
% Difference:	1%			5%			40%			24%			13%			11%			1%		
Bottle #:	N2492			N2891			N2394			N2402			N2370			N2475			N2592		
Rep 1:	0.21			0.15			1.46			0.12			0.18			0.42			0.98		
Rep 2:	0.18			0.08			1.46			0.12			0.14			0.51			0.97		
% Difference:	15%			61%			0%			0%			25%			19%			1%		
SPIKE RECOVERY																					
Sample value:	2.5			0.215			0.05			0.31			0.16			1.15			0.28		
Expected spike value:	1.75			0.6075			0.525			0.655			0.58			1.075			0.64		
Measured spike value:	1.76			0.67			0.46			0.66			0.58			0.84			0.63		
% Recovery:	101%			110%			88%			101%			100%			78%			98%		