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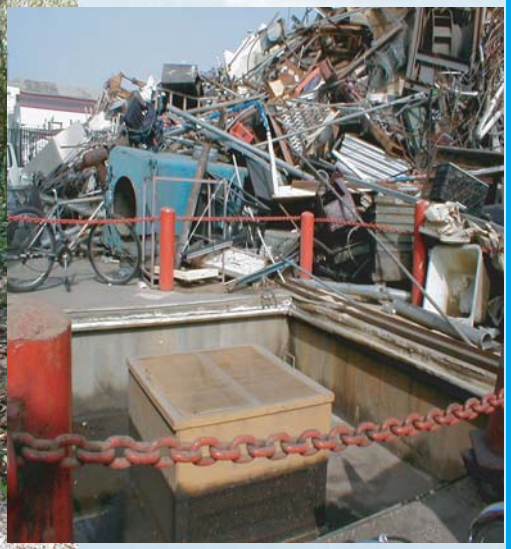
Evaluation of Best Management Practice (BMP) Effectiveness



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Assessment of Best Management Practice (BMP) Effectiveness

Final Report

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Executive Summary

Best Management Practices (BMPs) are often relied upon to reduce or eliminate water quality impairments caused by trash, nutrients, or toxic constituents in urban runoff. The BMPs are extremely varied and may include public education, installation of treatment facilities/devices, the routing of runoff through grassy/wetland habitats, or diversion to sanitary sewers. Selection of the appropriate BMP for a given situation is a difficult decision that should consider factors such as cost, engineering parameters, and effectiveness in attaining the desired result. Previous studies have examined the effectiveness of BMPs in southern California, but they have limited utility for assessing effectiveness regarding toxicity due to a limited suite of constituents analyzed. Most studies of BMP effectiveness do not include measures of toxicity.

The goal of this project was to assess the effectiveness of BMPs in southern California for improving water quality impacts related to toxicity. Collaborative monitoring was established with local research and stormwater management agencies that implement BMPs in the southern California coastal area. Samples of stormwater or dry weather flow from upstream and downstream of the BMP were analyzed for toxicity to aquatic life and the concentration of contaminants associated with runoff toxicity.

Five BMP technologies were assessed for their effectiveness to reduce contaminant concentrations and toxicity at field sites in southern California. The sites included an enhanced stream wetland in Laguna Niguel (Wet CAT), constructed sub-surface flow wetland cells at the Orange County Water Department field station in Anaheim (OCWD SSF), a screening/settlement sump in Los Angeles (L.A. metal recycling yard), three sites with hydrodynamic devices using Continuous Deflection Separation (CDS) units (Pico-Kenter in Santa Monica, BC120 in Culver City, and a site in South Pasadena), and a site that used a combination of screening, microfiltration, and UV treatment [Santa Monica Urban Runoff Recycling Facility (SMURRF)].

Four to five sampling events were conducted at each site. Samples were collected both before and after the BMP treatment process in order to evaluate the effectiveness of each BMP system. The L.A. metal recycling yard and South Pasadena sites were sampled only during storm events, while the Wet CAT, Pico-Kenter, and SMURRF sites were sampled only during dry weather flow. The BC120 site was sampled during both wet and dry weather events. Finally, the OCWD SSF site was experimentally dosed with a mixture of Cu, Zn, and diazinon over a six-week period. Most of the data in this study were collected specifically for this investigation, however some of the data were obtained from existing monitoring programs. Each BMP site was evaluated for consistency at reducing contaminant levels by more than would be expected from analytical variability. If at least 75% of the samples had a meaningful reduction for a given constituent, the BMP was then evaluated for its ability to attain the appropriate chronic water quality criterion.

The effectiveness of the Wet CAT wetland site usually varied by constituent, and often appeared to be related to constituent concentration. There was a consistent reduction (at least 75% of the samples) in concentrations of total suspended solids (TSS), diazinon, total Al, Cd, Cu, Ni, Se, and Zn, and dissolved Al, Cd, Ni, and Zn between inflow and outflow samples at the Wet CAT site. Outflow concentrations of total Al, dissolved Cd and dissolved Ni were also reduced below the water quality criteria after treatment at this site. Concentrations of dissolved Cu were probably too low in the inflow samples to expect large reductions in the outflow. Other constituents (dissolved Zn, diazinon) were reduced in the outflow, but the inflow concentrations were below the chronic criteria, and therefore could not be evaluated for attainment of water quality criteria. Toxicity, when present, was reduced after treatment.

The sub-surface flow wetlands at the OCWD field station were very effective at reducing concentrations of total and dissolved Cu and Zn, but not as effective at reducing diazinon. Concentrations of dissolved Cu were consistently reduced below the chronic water quality criterion, when the inflow levels exceeded this threshold. Concentrations of dissolved Zn, while reduced between inflow and outflow, were consistently below the chronic criterion in the inflow. Therefore attainment of the criterion could not be evaluated. Concentrations of diazinon were consistently reduced between the inflow and outflow samples, but concentrations in the outflow were rarely reduced below the chronic criterion. Toxicity in the inflow samples was rare, and was reduced after treatment.

Most of the hydrodynamic devices using the CDS units were ineffective at reducing metal concentrations or toxicity, and had mixed results with TSS. The CDS units at Pico-Kenter, South Pasadena, and the wet weather samples at BC120 did not consistently reduce the concentrations of total or dissolved metals. However, the dry weather samples from BC120 had consistent reductions in total Al, Cu, Pb, and Zn. Total Al concentrations (the only one of these metals with a water quality criterion) were not reduced below the chronic criterion. TSS was reduced in both of the dry weather samples from BC120, but was not reduced in the wet weather samples from BC120, and was inconsistently reduced in the samples from Pico-Kenter and South Pasadena. Chlorpyrifos was the only pesticide found in at least two sampling events. This pesticide was only measured in two inflow and outflow samples from the South Pasadena site. Chlorpyrifos was not consistently reduced, and was never found below the chronic criterion. In general, the CDS units had no effect on toxicity. This is not surprising, since the CDS units were designed to remove solids from runoff, yet the fraction usually associated with toxicity is the dissolved phase, and the CDS units had little effect on the dissolved metals.

The treatment process at the SMURRF site was effective at reducing concentrations of most total metals and TSS. Concentrations of total Al, Cr, Cu, Ni, Pb and Zn were reduced in the effluent. The SMURRF treatment process also reduced the levels of dissolved Al and Zn, while most other dissolved metals were probably too low to expect large reductions. The dissolved metals could not be evaluated for attainment of water quality criteria because the inflow concentrations were always below these thresholds. The SMURRF site consistently reduced TSS levels by >94%. The toxicity data could not be used to evaluate toxicity removal effectiveness. There was no consistent toxicity to *Ceriodaphnia dubia* (one of the species tested), while the sea urchin test was influenced by the chlorinated water used to backflush the treatment screens at SMURRF.

The screening/settlement apparatus at the L.A. metal recycling yard was inconsistent in reducing most metals and TSS. This apparatus was effective at reducing concentrations of dissolved Cr, Cu, and Pb, although dissolved Cu was never reduced below the chronic criterion and dissolved Pb levels were reduced to below the chronic criterion only half of the time. This site had either no effect or an inconsistent reduction at best with other metals. TSS was reduced half of the time. The toxicity of the samples was often reduced after treatment, although the outflow samples were still highly toxic.

This study has produced new information regarding the effectiveness of various BMP types. Although this study was limited in scope and duration, several conclusions are evident:

- BMPs based on wetland systems (e.g., Wet CAT, SSF wetlands) were most effective in reducing the concentrations of toxic constituents to levels likely to protect aquatic life.
- Hydrodynamic devices (e.g., CDS units) are not effective for reducing concentrations of dissolved contaminants, which are the forms most likely to cause water column toxicity.

- The use of chemicals to maintain the BMP (e.g., filter cleaning) can increase toxicity to aquatic life; such procedures should be used with caution when the downstream environment contains aquatic life habitat.
- The effectiveness of many BMPs is variable, and changes in contaminant concentrations among sampling events complicate the assessment process. Comparison of both relative changes in concentration and ability to attain water quality objectives is needed to evaluate BMP effectiveness.

This study examined several BMP technologies that are in use in southern California, but it was not an exhaustive comparison. Most of the BMPs investigated were installed for purposes other than reducing toxicity and this study provides information regarding the effectiveness of these approaches for reducing toxic constituents. Further study is needed to evaluate BMP technologies that are more specific for toxics and have had limited use in southern California. In addition, an evaluation of the effectiveness of BMPs to reduce toxic impacts due to contaminants associated with particles is needed. Some of the BMPs examined in this study that were not effective in reducing water column toxicity are intended to remove particles, and they may have greater effectiveness in reducing particle-associated toxicity.

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Introduction

Urban and agricultural discharges have contributed to degraded water quality throughout southern California. For example, more than 150 sites are on the state's list of impaired waterbodies in southern California. As a result, runoff management agencies are implementing various Best Management Practices (BMPs) to reduce or eliminate these water quality impairments. The BMPs are extremely varied and may include public education, installation of treatment facilities/devices, the routing of runoff through grassy/wetland habitats, or diversion to sanitary sewers to reduce or remove constituents of concern such as trash, nutrients, or toxic constituents.

There are several issues that make evaluating BMP effectiveness challenging. One challenge is that BMP effectiveness must be differentiated from variability. This includes variability in discharge characteristics, sample collection, and analysis. Second, because BMPs tend to perform better with higher concentrations of contaminants in the inflow, the removal effectiveness can be under-estimated if the inflow concentrations are very low. Third, large reductions in contaminant levels do not necessarily imply effectiveness, if concentrations in the effluent are still above the levels of protection. Fourth, the approaches used to evaluate effectiveness are not consistent among studies. Common approaches have included calculating the percent reduction either between the study mean inflow and outflow concentrations, or the mean of individual event percent reductions, or between inflow and outflow mass. More recently, effectiveness has been estimated using hypothesis testing (e.g., ANOVA), probability plots, linear regression, and threshold approaches (e.g., compare effluent concentrations with water quality criteria). Each method can give a different measure of effectiveness.

Previous studies have examined the effectiveness of BMPs in southern California. The study conducted by Caltrans is one of the most comprehensive BMP evaluations (Caltrans 2004). Using the linear regression approach for evaluation, the Caltrans study determined that BMPs which use infiltration or sand filtration technologies were some of the most effective for reducing levels of TSS, total nutrients and total metals. Data from this and other studies from southern California have been included in the International Stormwater BMP Database (Strecker et al. 2004). This database contains inflow and outflow contaminant concentrations for a variety of BMPs in order for users to assess removal effectiveness, determine the achievable water quality values for effluents, and predict changes in mass loadings for the different BMP types. The data in the International Stormwater Database and the Caltrans study, however, do not include direct measures of BMP effectiveness regarding toxicity.

While information on chemical constituents is usually included in BMP effectiveness studies, information on changes in toxicity is comparatively lacking. Toxicity to aquatic life from urban runoff discharges is frequently detected. Aquatic toxicity has been measured in waterbodies such as Ballona Creek, Santa Monica Bay, Los Angeles River, Santa Ana River, San Diego Creek, Newport Bay, Chollas Creek, and San Diego Bay. Because of the many chemical constituents found in runoff, measuring a routine suite of chemicals alone does not give a complete assessment of changes made by the BMP. Including measures of toxicity can improve the evaluation of BMP effectiveness because toxicity tests help account for unmeasured contaminants, they incorporate the additive and antagonistic interactions of chemicals, and they are direct measures of effect.

The goal of this project was to assess the effectiveness of BMPs in southern California for improving water quality impacts related to toxicity. Collaborative monitoring programs were established with local research and stormwater management agencies that implement BMPs in

the southern California coastal area. Samples of stormwater or dry weather flow from upstream and downstream of the BMPs were analyzed for toxicity to aquatic life and the concentration of contaminants associated with runoff toxicity.

Methods

Study Design

Seven BMP sites representing five BMP technologies were assessed for their effectiveness to reduce contaminant concentrations and toxicity (Figure 1). The five BMP technologies included wetlands, hydrodynamic devices [e.g., continuous deflection separation (CDS) units], microfiltration, UV treatment, and screening/settlement. Four to five sampling events were conducted at each site (Table 1). Samples were collected both before and after the BMP treatment process in order to evaluate the effectiveness of each BMP system. Paired inflow/outflow samples of dry weather or stormwater runoff were collected between 2/2/04 and 3/10/05. Two sites were sampled only during storm events, and three sites were sampled only during dry weather flow. One other site was sampled during both storm and dry weather events. Finally, one site was experimentally dosed with a mixture of Cu, Zn, and diazinon over a six week period. Time-weighted composite samples were collected at most BMP sites, with multiple grabs collected and composited at two of the sites.

Most of the data in this study were collected specifically for this investigation, however some of the data were obtained from other monitoring programs. Differences in the constituents analyzed among the various sites reflected differences in study design among the monitoring programs (Table 2). Samples from most sites were analyzed for metals, organophosphorus pesticides, pyrethroid pesticides, glyphosate (active ingredient in Roundup and Rodeo), and toxicity (echinoderm fertilization test, and *Ceriodaphnia dubia* survival and reproduction test).

Wetlands

Wet CAT (wetland)

The Wetland Capture and Treatment network (Wet CAT) was designed to treat low-flow urban runoff from a residential neighborhood in the Aliso Creek watershed. It was constructed as a mitigation wetland in 1991. Within one growing season after construction, the created and enhanced wetland was fully vegetated and colonized by native wetland plant species. In 2002 the wetland was enhanced with the addition of four shallow berms to spread and store water within a natural marsh habitat. While there are three distinct wetlands in the Wet CAT network, this study focused on the largest one, known as the West wetland.

The West wetland is a 1.4 acre, ½ mile long parcel of land on the west side of Alicia Parkway in Laguna Niguel. It is located on privately-owned common-area property, and maintained by the City of Laguna Niguel. The West wetland treats 317 acres of exclusively urban runoff. It is designed to treat flows of approximately 0.2 cfs, with measured flows at 0.15 cfs in the summer and 0.12 cfs in the fall of 2003. The hydraulic residence time is 3 days. Effluent from the West wetland leads to Sulphur Creek, then to Aliso Creek. Only dry weather runoff samples from the Wet CAT site were collected for this study. Samples were collected at the head of the wetland, and as the water left the wetland (Figure 2).

OCWD (sub-surface flow constructed wetland)

The other wetland BMP in this study was the Orange County Water Department's sub-surface flow (SSF) constructed wetlands, located next to OCWD's Field Research Laboratory near Anaheim Lake. These wetlands measure approximately 1 m tall x 2 m wide x 8 m long, and are constructed from concrete panels (Figure 3). Each wetland cell is filled with ¾" pea gravel. A

monoculture of wetland plants (bulrushes, genus *Scirpus*) are planted in the gravel. The gravel provides an approximate thousand-fold increase in surface area for the growth of bacterial biofilms that increase the rate of contaminant degradation or removal. Within the gravel matrix there are distinct oxygen rich (aerobic) and oxygen free (anaerobic) zones where specific microbial processes take place. Water flows beneath the surface of the gravel matrix. The source water for the wetlands comes from Conrock Basin, which receives wet and dry weather flow from the Santa Ana River. The advantages of sub-surface flow wetlands are less land area required for a system, the elimination of vector problems and viable operation in winter. The wetland cells were constructed in 2002.

This was the only BMP in this study that was experimentally dosed with contaminants. Two replicate wetland cells were used in this study. Each cell was continuously dosed with a mixture of Cu, Zn, and diazinon and monitored over a six week period. The nominal concentrations flowing into each cell were 30 µg/L Cu, 60 µg/L Zn, and 0.4 µg/L diazinon. Concentrations of each contaminant were measured in the influent and effluent from each replicate system over five sampling periods. The samples were also analyzed for toxicity using the sea urchin fertilization test.

The flow rate for the source water from Conrock Basin was maintained at 4 L/min. Two stock solutions (one for Cu and Zn, and one for diazinon) were made up, and diluted to working solutions on a daily basis (Figure 4). The working solutions were added to each wetland cell on a continuous basis using peristaltic pumps. The flow rates for the working solutions were maintained at 5 mL/min. Filters made from montmorillonite clay and granular activated carbon were used to recover any remaining amounts of contaminants from the effluent that were not removed by the wetlands.

Hydrodynamic devices (CDS units)

Three of the BMP sites used a CDS Technologies Continuous Deflective Separation (CDS) hydrodynamic device. These devices use a vortex and screening process to remove solids from dry and wet weather runoff. The components of a CDS unit consist of a sump, separation chamber (which contains a stationary screen cylinder), and diversion weir (Figure 5). Treatment flows are introduced tangentially along the stainless steel screen by the CDS unit's intake structure located above the cylindrical screen. A balanced set of hydraulics is produced in the separation chamber. These balanced hydraulics provide washing flows across the stainless steel screen surface, which prevent any clogging of the apertures as well as establish the hydraulic regimen necessary to separate solids through deflective separation/swirl concentration/vortex separation. Vortex separation produces a low energy, quiescent zone in the middle of the swirl that enables effective settlement of fines through a much wider range of flowrates than could otherwise be achieved using a simple settling tank in the same footprint. Particles within the diverted treatment flow are retained by the deflective screen and are maintained in a circular motion, forcing them to the center of the separation chamber, creating an enhanced swirl concentration of solids (vortex separation), until they settle into the sump.

Pico-Kenter (hydrodynamic device)

This CDS unit is located at the end of Pico Blvd. near the beach in Santa Monica, and is operated by the City of Santa Monica (Figure 6). It receives a mix of runoff from approximately 4,200 acres of western Los Angeles County which includes commercial, residential, and transportation areas. The effluent from this CDS unit feeds into the Santa Monica Urban Runoff Recycling Facility (SMURRF) (see below). This unit has been operating since February 2001.

BC120 (hydrodynamic device)

This CDS unit is located near Ballona Creek in Culver City (Figure 7). It receives runoff from approximately 4,077 acres of Culver City, and drains into Ballona Creek at Overland Ave. This BMP was installed in January 2005.

South Pasadena (hydrodynamic device)

This CDS unit is located near the intersection of Orange Grove and El Centro in the City of South Pasadena, and is operated by the Los Angeles County Department of Public Works (LACDPW) (Figure 8). It receives runoff from 6 acres comprised of approximately 70% residential, 20% industrial, and 10% other. It has been operating since 2003.

Screening/hydrodynamic device/microfiltration/UV treatment

SMURRF (screening/hydrodynamic device/microfiltration/UV treatment)

The Santa Monica Urban Runoff Recycling Facility (SMURRF) is located at 1601 Appian Way, adjacent to the Santa Monica Pier (Figure 9). It receives runoff from approximately 5,100 acres of commercial, residential and transportation activities, which includes mostly the runoff from the Pico-Kenter CDS unit (see above), and to a smaller degree the Pier storm drain. This BMP treats dry weather flow using a combination of technologies, including 2 mm^2 screening, a hydrodynamic device to remove sand and grit, microfiltration to remove turbidity (effluent turbidity <2 ntu), and ultraviolet radiation to kill pathogens (Boyle Engineering Corp. 1999). Water from the facility is used for City landscaping and government toilets. This system is designed to treat up to 500,000 gallons of runoff per day. The facility is operated by the City of Santa Monica, and has been in service since May 2001.

Screening/settlement

L.A. metal recycling yard (screening/settlement)

The L.A. metal recycling yard BMP is located at a metal scrap facility near downtown Los Angeles (Figure 10). This BMP treats runoff that is exclusive to this site, and is monitored only during wet weather events. Approximately 0.85 acres of the scrap yard is treated by the BMP. Water from the site flows into a sump, where settlement of the heavier particles occurs. The water then flows through a screen mesh into an infiltration trench. This BMP is being monitored by the Los Angeles and San Gabriel Rivers Watershed Council as part of a Watershed Augmentation Study. It is currently owned and maintained by the Watershed Council and Geomatrix, but will be turned over to the L.A. metal recycling yard after the 2004-2005 monitoring season. This BMP has been in operation since October 2003.

Sampling Methods

Wet CAT, Pico-Kenter, BC120, SMURRF

The samples from the Wet CAT, Pico-Kenter, BC120 and SMURRF sites were collected by MACTEC Engineering and Consulting Inc. (San Diego). Samples from each of these sites were

collected with American Sigma 900 Max Autosamplers, configured with 19 L borosilicate jars. Flow monitors (American Sigma 950 Area Velocity Bubbler Flowmeters) were used at each site, except for Pico-Kenter, where the flowmeters could not be installed due to the non-ideal configuration. The components of each monitoring system used were calibrated for time and sample aliquot volume prior to deployment. The autosamplers at these sites collected 200 mL aliquot inflow and outflow samples every 15 min for 24 h. Because the flow at the SMURRF site was intermittent (treatment occurred only when sufficient volume of runoff had accumulated), the autosamplers were triggered by the flowmeter only when the effluent was flowing. Most of these sites used paired autosamplers to collect the inflow and outflow samples simultaneously. At the Wet CAT wetland, however, sampling of the outflow was delayed by 24 h after starting the inflow collection, in order to account for the hydraulic residence time of the wetland. All sample containers were iced at the onset of sampling and refreshed with ice prior to transport to the chemical analysis laboratory. Hydrographs of each sampling event can be found in the Appendix.

The samples from the other sites in this study (OCWD SSF, South Pasadena, L.A. metal recycling yard) were each collected by different agencies, using different methods.

OCWD SSF

Five sampling events were sampled at the OCWD SSF wetlands. At approximately weekly intervals, OCWD personnel collected 2 L composite samples of the inflow and outflow samples from each wetland for chemical and toxicity analysis. Three manual grab samples were collected over 24 h and composited. The flow rate was monitored and adjusted by visual inspection of a sight glass flow meter.

South Pasadena

Five stormwater sampling events were captured at the South Pasadena site. Composite samples were collected by LADPW personnel. The samples for toxicity testing were collected every 20 min usually for 3 h during the initial part of each storm. The samples for chemical analysis were also collected every 20 min, but the sample duration was usually longer, lasting from 3 h up to 4 d. The hydrographs of each sampling event can be found in the Appendix.

L.A. metal recycling yard

Four stormwater sampling events were captured at the L.A. metal recycling yard. Multiple grab samples were collected and composited for the first two events (2/2/04, 2/18/04), while single grab samples were collected for the other two events (10/26/04, 2/11/05). The samples were collected by GeoMatrix.

Chemical Analysis

Because the samples in this study were analyzed by multiple agencies, more than one testing procedure was sometimes used (Table 3). The samples from the SMURRF, Pico-Kenter, WetCAT, and BC120 sites were analyzed for metals, organophosphate (OP) pesticides and pyrethroid pesticides by CRG Marine Laboratories (Torrance). The samples from the South Pasadena site were analyzed for metals and OP pesticides by the LADPW Environmental Toxicology Laboratory (South Gate), and the samples from the L.A. metal recycling yard were

analyzed for metals by CalScience (Garden Grove). The OCWD SSF samples were analyzed for metals by CRG Marine Laboratories, and for diazinon by SCCWRP. All glyphosate analyses were made by MHW Laboratories (Monrovia).

All metals analyses at CRG were made using Inductively Coupled Plasma Mass Spectrometry (ICPMS), following EPA 200.8 (EPA 1996). The samples for trace metals were filtered in the laboratory immediately upon receipt using 0.45 µm Nalgene disposable cellulose nitrate filters. The dissolved fraction was then acidified to a pH <2 using Optima nitric acid and allowed to sit for a minimum of 16 hours. The samples were then analyzed using ICPMS by direct aspiration into the nebulizer.

All organics analyses at CRG were made using Gas Chromatography Mass Spectrometry (GCMS), following EPA 625 (EPA 1996). Samples for trace organics were first spiked with recovery surrogates, then extracted 3 times with methylene chloride using a separatory funnel. The combined solvent extract was dried using anhydrous sodium sulfate, concentrated by roto-evaporation, and cleaned up using alumina/silica gel chromatography. Internal standards were added to the cleaned extracts, which were then analyzed using GCMS.

The diazinon analyses at SCCWRP used Enzyme-Linked Immuno Sorbent Assay (ELISA). ELISA is an analytical method that uses antibodies to target specific pesticides, and a color changing reaction to quantify the amount of pesticide present in a sample. Pesticide analyses by ELISA were made using Strategic Diagnostics Inc. (Newark, DE) EnviroGard plate kits.

Toxicity Testing

Dry-weather and wet-weather samples were tested for toxicity using the 7-d *Ceriodaphnia dubia* survival and reproduction test (USEPA 1994). The samples were usually tested at three concentrations (100%, 50%, and 25% runoff concentrations). All toxicity tests were started within 2 d of sample collection. Ten replicates were included in each test. The test endpoints were percent of survival and the number of offspring. A concurrent copper reference toxicant test was conducted with each testing event. Each test included a laboratory control. Test solutions were changed on a daily basis, and the organisms were fed each day. Dissolved oxygen, conductivity, pH, and temperature were measured each day. Alkalinity, hardness, and total ammonia were measured at the beginning of each experiment. Water quality measurements during the test met the test recommended ranges.

The echinoderm fertilization test was also used (USEPA 1995). This test measures toxic effects on sea urchin or sand dollar sperm, as a reduction in their ability to fertilize eggs. Purple sea urchins (*Strongylocentrotus purpuratus*) were used in the majority of tests, while sand dollars (*Dendraster excentricus*) were used for the tests from November 2004. The tests consisted of a 20 minute exposure of sperm to samples of 25, 50, or 100% runoff sample diluted with hypersaline brine. Eggs were then added and given 20 minutes for fertilization to occur. The eggs were then preserved and examined later with a microscope to assess the percentage of successful fertilization. Toxic effects were expressed as a reduction in fertilization percentage. The tests were conducted in glass shell vials containing 10 mL of solution at a temperature of 15°C. Four replicates were tested for each sample. A seawater blank was included as negative control. A concurrent reference toxicity test with copper was conducted with each testing event.

Data Analysis

Chemistry

Tiered Approach to Evaluating Effectiveness

In many cases there was a difference between the inflow and outflow concentrations. Determining what constitutes a meaningful difference, however, is important when evaluating BMP effectiveness. With the limited number of sampling events in this study, the effectiveness could not be evaluated using a statistical approach. Therefore a tiered approach was used, which first examined the magnitude of the difference in concentrations between the inflow and outflow samples. If the difference was consistently greater than what would be expected from variability alone, then the data were compared to the appropriate chronic water quality criterion (Table 4). In this approach, the BMP had to have a meaningful difference between the inflow and outflow concentrations, even if the outflow concentration was meeting the water quality criterion. Two designations of effectiveness were assigned for each constituent at a BMP site; one designation for whether the BMP reduced the constituent, and a second designation (if the magnitude was great enough) for whether the water quality criteria was met due to reductions by the BMP.

One potential source of the differences between inflow and outflow concentrations that could confound the interpretation of BMP efficiency is analytical variability. This type of variability can be caused by such things as differences in sample preparation and instrument conditions. Fortunately, analytical variability can be estimated from the sample duplicates that were measured as part of the quality assurance objectives in this study. The relative percent difference (RPD) is a measure of variability between a pair of samples, with higher RPD values indicating greater variability between the data pairs. The RPD was calculated as:

$$\frac{|Influent - Effluent|}{Average} x(100)$$

In this study, there were 120 pairs of laboratory duplicate analyses for metals using field samples that were measured by CRG Marine Laboratories. Most of the pairs had RPD values <10% (Figure 11, Table 5), indicating that analytical variability was usually less than 10% for both dissolved and total metals. Therefore, differences of $\geq$10% for the inflow and outflow metals data are greater than what would be expected from analytical variability, and are probably meaningful. This was the first tier of the evaluation approach. While the duplicate measurements were only available for the analyses made by CRG Marine Laboratories, the concept that differences between the inflow and outflow concentrations had to be at least 10% to be meaningful was applied to the metals data from all three analytical laboratories. The 10% difference rule was also applied to TSS and pesticides, because these constituents did not have enough duplicate measurements made to determine a meaningful level of analytical variability.

The percent reduction between inflow and outflow contaminant concentrations was calculated for each BMP site as:

$$\frac{Influent - Effluent}{Influent} x(100)$$

Values calculated as the RPD are similar to values calculated using the percent reduction equation, when the percent reduction is low (<30%).

The second tier in evaluating BMP effectiveness was to compare the outflow concentrations to chronic water quality criteria. While the water quality criteria are not currently used to assess regulatory compliance of the runoff in this study, these criteria are useful for determining if concentrations in the inflow and outflow are at protective levels. For those samples that had a ≥10% reduction between inflow and outflow concentrations for at least 75% of the sampling events, the data were compared with the appropriate freshwater chronic water quality criterion. California Toxics Rule values were used for total Se, as well as for dissolved As, Cd, Cu, Ni, Pb, and Zn (Table 4). There are no chronic criteria for dissolved Ag, Al, Cr(3+6), Se or Sn. For total Al, chlorpyrifos and malathion, the national freshwater chronic water quality criteria were used, while for diazinon, the California Department of Fish and Game freshwater chronic criterion was used. In cases where at least two of the inflow samples exceeded the water quality criterion, the relationship of the outflow concentration to the water quality criterion was examined. If the outflow concentration was consistently below the criterion, the site was designated "yes/+" for that contaminant, where the first part of the designation refers to the BMP's ability to reduce concentrations by at least 10%, and the second part of the designation refers to the ability to attain a specific water quality criterion. If the outflow concentrations never met the criterion, the designation would be "yes/–". For cases where the outflow met the criterion inconsistently, the site was designated "yes/?". If the inflow concentrations were consistently below a criterion, then the ability to attain the criteria could not be determined, and the site was designated "yes/U" for that contaminant (U for undetermined). For those contaminants that did not have a ≥10% reduction between the inflow and outflow samples, the site was designated "no/U", for no meaningful reduction by the BMP.

Toxicity

Data from the echinoderm and *C. dubia* tests were evaluated for significant reductions in fertilization, survival or reproduction using analysis of variance (ANOVA) with Dunnett's test, or with Steel's Many-One rank test when assumptions of normality or homoscedasticity were not met. Comparisons were made against the seawater control for the echinoderm fertilization test, and against the laboratory dilution water control for the *C. dubia* test. Using this approach, the highest concentration of runoff that did not cause significant toxicity (the no effect concentration, NOEC) was estimated for each of the inflow and outflow samples.

The median-effect concentrations (LC50 or EC50) were also calculated. These are the concentrations of runoff that caused a 50% reduction in survival (LC50), or reproduction or fertilization (EC50). Toxicity units were then calculated to compare the magnitude of response. Toxic units (TU) were derived as 100/LC50 or 100/EC50. A TU > 1 indicates a strong toxic response. Because the highest concentration of runoff sample tested with the echinoderm fertilization test was 50%, the lowest TU that could be calculated was 2. Therefore, having no toxicity in the 50% sample would be associated with TU <2. The lowest concentration of runoff in the fertilization test was 12.5%. Therefore in cases with extreme toxicity where the EC50<12.5%, the associated TU would be >8.

Data Quality Evaluation

The data were evaluated for deviations in sampling strategies, sediment holding time, and chemistry and toxicity testing methods. The chemistry data were assessed for accuracy, precision, and negative control response. The toxicity test results were assessed for negative control response, and positive control response. Exceedance of a data quality objective did not automatically invalidate the data.

Sampling

There were a few deviations from the original sampling strategy. The planned number of sampling events described in the QAPP (up to eight events) was not feasible from both a cost- and time-basis. Instead of reducing the number of constituents analyzed to fit within the budget, it was decided to reduce the number of sampling events to four. This allowed us to maintain the diverse group of constituents that were likely to be found in urban runoff. Delays in installation at the BC120 site was another reason for the reduced sampling. Only two dry weather and two wet weather sampling events were captured from the BC120 site, instead of the planned four dry and wet weather sampling events each. Installation of the CDS unit at this site was not completed until mid-January. The QAPP also called for a minimum dry weather antecedent period of 10 days before collecting the dry weather samples. However, with the frequency and unpredictability of the storm events during the 2004-2005 storm season, this desired antecedent period was rarely met (Table 1). Finally, because of the non-ideal conditions of the upstream pipe configuration, flowmeters were not installed at the Pico-Kenter site, and therefore no flow data were obtained from this site.

There were differences in sampling methods both among and within sites. Stormwater samples were collected as flow-weighted composites at BC120, and time-weighted composites at South Pasadena because the South Pasadena samples were collected as part of another study. At the L.A. metal recycling yard, automated composite samples were collected during the February 2004 sampling events, while grab samples were collected during the October 2004 and February 2005 sampling events.

There were some problems with the dosing rates of the OCWD sub-surface wetland cells during the first two weeks. The flow rate for the diazinon stock solution to replicate cell #1 was about one-tenth the desired flow rate. The diazinon stock flow rate to replicate cell #2 was about one-quarter the desired flow rate only during the second week of the study. The flow rate for the metals stock solution to replicate cell #2 was about half the desired rate during the first two weeks. While the flow rates were low, useful data on the removal efficiencies of Cu, Zn and diazinon were obtained.

Finally, the inflow and outflow samples from the Wet CAT site were not matched exactly. The sampling of the outflow was delayed for 24 h from the start of the inflow sampling in order to account for the hydraulic residence time of the wetland. However, after further investigation it was found that the hydraulic residence time for this site is three days, not one. Therefore while we saw a consistent reduction in the concentrations of certain contaminants over the four sampling events, the outflow sample did not exactly match the inflow sample.

Chemistry

The majority of the data quality objectives specified in the QAPP were met. Most analyses were completed within the specified sampling holding times. The matrix spike/matrix spike duplicate and lab spikes were within acceptable ranges, indicating the data had good accuracy and precision. The method detection limits were met or exceeded for chemistry measurements.

Sample holding times were exceeded for analysis of general constituents (e.g., pH, conductivity) for the BC120 samples from 1/19, 1/26, and 2/11/05, and from the Wet CAT, Pico-Kenter and SMURRF samples from 12/16/04 and 1/20/05. However, the pH and conductivity measurements of the Wet CAT and SMURRF samples reported by the chemistry analytical lab were consistent with those made by the toxicity testing lab, which measured pH and conductivity upon sample arrival. The pH and conductivity for the Pico-Kenter samples from December are also consistent between the two labs, however the comparability of the January samples from the BC120 and Pico-Kenter samples could not be assessed because these samples had been temporarily lost during shipment, and therefore were not analyzed by the toxicology lab. Both pH (inflow pH=6.5 CRG, inflow pH=7.4 Nautilus) and conductivity measurements (inflow = 59,500 µS CRG, 63 µS Nautilus) varied among the labs for the BC120 samples from 2/11/05.

The variability quality assurance objective was exceeded for As and Se in the December dry weather samples from Pico-Kenter, Wet CAT and SMURRF. The variability objective was also exceeded for Cd in the March sample from Wet CAT. For the overall study, however, the average relative percent difference (RPD) was met for the dissolved and total fraction of each metal (Table 5).

There were no metal or pesticide MS/MSD data for the dry weather samples from November, December, or March. There also are no metals MS/MSD data for the February wet weather samples from BC120. For the data that were available, the highest RPD for metals was 9%, indicating excellent precision.

The method detection limit (MDL) for total and dissolved As, Cd, Cr, Cu, Pb, Ni, Zn (0.1 µg/L) was lower than the value specified in the QAPP (0.5 µg/L). The MDL was also lower for chlorpyrifos, diazinon, malathion, dimethoate (0.005 µg/L) than the value in the QAPP (0.01 µg/L).

There were some differences in the list of pesticides measured, compared to the list in the QAPP. The organophosphorus pesticides cuomaphos and guthion were not analyzed in this study, however the remaining 19 OP pesticides listed in the QAPP were measured. The pyrethroid pesticides fenpropathrin and pyrethrin were not analyzed, but demitol (not listed in the QAPP) was included.

The chemistry data from the L.A. metal recycling yard, South Pasadena and NASSCO sites were obtained from on-going studies, and therefore the chemistry quality assurance objectives in this study were not applied to these data.

Toxicity

The BC120 and Pico-Kenter subsamples for the *C. dubia* toxicity testing from January were temporarily lost by the overnight delivery company. These samples were eventually found, but were not tested for toxicity because the holding time had expired. The samples for chemistry analysis and echinoderm toxicity testing from this sampling event were not compromised.

While the majority of samples tested for toxicity with *C. dubia* (14 inflow/outflow pairs) used the 7 d chronic method (which assess both survival and reproduction), there were eight inflow/outflow pairs that were tested with the 4 d acute method (which assesses only survival). The reasons for using the shorter test varied. The Pico-Kenter, SMURRF, and Wet CAT samples collected in November and December used the shorter test because of conflicts with the Thanksgiving and Christmas holidays, respectively. The SMURRF and Wet CAT samples from January were assessed only for survival because the controls had poor reproduction. While survival was reported after 4 d with the SMURRF and Wet CAT samples from January, the tests were initiated as 7 d tests, which used 10 replicates with one animal each, instead of four replicates with 10 animals each in the 4 d test.

No useful data were obtained from the *C. dubia* test with the BC120 stormwater samples from January 26. Survival and reproduction in the controls were poor, and the test was not repeated because the sample holding time had expired. Useful data were obtained, however, from the concurrent sea urchin fertilization test.

Results

Wet CAT (wetland)

Chemistry

There was a consistent reduction in the concentrations of TSS, total Cd, Ni, and Zn, and dissolved Al, Cd, Ni, Zn between inflow and outflow samples from the Wet CAT site (Figure 12 and13, Table 6). The reduction in dissolved Cd varied from a 65% reduction in November (from 2.6 µg/L in the inflow to 0.9 µg/L in the outflow), up to a 99% reduction in March (from 37.1 µg/L in the inflow to 0.2 µg/L in the outflow). Reductions in dissolved Zn ranged from 43% - 82%. The concentrations of dissolved Cu were relatively low in both the inflow and outflow samples during all four sampling events.

Diazinon and malathion were the only pesticides detected in any of the Wet CAT samples (Figure 14). Diazinon was detected in the inflow sample from November, and in both the inflow and outflow samples from December. Concentrations of diazinon were reduced between the inflow and outflow samples by a factor of >3 in November and by a factor of 2 in December. Malathion was reduced by a factor of >7 in November, the only sampling event with detectable malathion.

Outflow concentrations of dissolved As, Cd, Cu, Ni, Zn, and diazinon were consistently below their respective criteria. Concentrations of dissolved As, Cu, Zn and diazinon were also consistently below the criteria in the inflow samples, however the inflow concentrations of dissolved Cd were above the criterion during three out of the four sampling events, and half of the inflow samples exceeded the Ni criterion (Figure 13). Wet CAT outflow sample concentrations were consistently above the water quality criterion for total Se by at least a factor of six (Figure 12).

Toxicity

The Wet CAT samples were inconsistently toxic to sea urchin fertilization (Figure 15). When toxicity was present, however, it was greater in the inflow samples. Toxicity to sea urchin fertilization was reduced from 3.1 toxic units in the January inflow sample to <2 TU in the outflow sample, and from >8 TU in the March inflow sample to 2.2 TU in the outflow sample. There was no measurable toxicity in the November or December samples.

All four sampling events had low *C. dubia* survival in the 100% sample. However, comparing the survival in the field samples to the survival in the accompanying salt control indicated that the toxicity could have been caused by the high salt content of the samples. The conductivity values (a measure of the dissolved salt content) of the Wet CAT samples ranged from 5.8 – 7.2 mS, which were greater than the values for any other site in this study (Table 6). For example, the conductivity values ranged from 0.8 – 1.9 mS at Pico-Kenter, and from 0.2 – 0.9 mS at BC120. A salt blank that matched the conductivity of the sample was analyzed for toxicity concurrently with the field samples. Toxicity in the salt blank was also consistently high, ranging from 0% survival in March to 30% survival in November. The November Wet CAT inflow sample was the only sample where the toxicity could be resolved from interferences from dissolved salts (Figure 15, Table 7). While the salt content was relatively high in the inflow

sample, the toxicity was significantly greater than that found in the salt control. This sample had a TU value = 2.4.

The only sample evaluated for impairment to *C. dubia* reproduction was the March sample. While this sample had low reproduction, it was not significantly different from the salt control. Therefore toxicity from other contaminants could not be resolved from the effect of the high salt content.

OCWD (sub-surface flow wetlands)

Chemistry

Concentrations of total and dissolved Cu and Zn were consistently reduced by at least a factor of two between the inflow and outflow samples (Figure 16 and 17, Table 6). Reductions of dissolved Cu ranged from a 53% reduction in the 2/3/05 sample from replicate cell #2, up to a 93% reduction in the 2/3/05 sample from replicate cell #1. Reductions of dissolved Zn ranged from a 75% reduction in the 3/10/05 sample in replicate cell #1, up to a 100% reduction in the 3/3/05 sample from replicate cell #2. Because the wetlands were dosed with a stock solution of metals, the total and dissolved metals concentrations were similar, and only the results of the dissolved fraction are reported here.

There was some indication that the metal binding capacity of the sub-surface flow gravel matrix in replicate cell #1 had been diminished after six weeks of continuous dosing. The removal efficiencies for both Cu and Zn were lowest during the fifth sampling event (week 6), from an average of 87% removal of dissolved Cu and 97% removal of dissolved Zn during the first five weeks to 64% removal of dissolved Cu and 75% removal of dissolved Zn at week 6. In contrast, there did not appear to be a “breakthrough” in metal binding capacity with replicate cell #2. The average % removal of dissolved Cu and Zn during the first five weeks (70% and 92%, respectively), were similar to the removal in week 6 (75% removal for dissolved Cu, and 98% removal for dissolved Zn).

Overall, diazinon removal by the OCWD wetlands was less effective than metal removal (Figure 18). Diazinon was removed from the wetlands by less than a factor of two during the last four sampling events. In the first sampling event, however, diazinon was reduced by a factor of >12 in replicate cell #2, going from 0.36 µg/L in the inflow to <0.03 µg/L in the outflow sample. Diazinon was also reduced in replicate cell #1, however due to dosing technical difficulties, the concentration in the inflow (0.04 µg/L) was close to the reporting level (0.03 µg/L).

The wetlands reduced the concentration of dissolved Cu to levels below the chronic criterion during all five sampling events in replicate cell #1 (Figure 17). For replicate cell #2, the concentration of dissolved Cu in the inflow was above the criterion during two of the five sampling events. In both cases, dissolved Cu concentrations were reduced to levels below the criterion. Concentrations of dissolved Zn in the inflow and outflow samples were consistently below the criterion during all sampling events in both replicate wetland cells. Concentrations of diazinon were reduced to levels below the chronic criterion in the first sampling event, but were above the chronic criterion for each of the last four sampling events in both replicate cells.

Toxicity

The toxicity to sea urchin fertilization, when present, was reduced after treatment by the SSF wetland (Table 8). The replicate cell #1 samples from 2/3/05 went from 60% fertilization success in the inflow to 92% in the outflow, and the samples from 3/10/05 went from 86% fertilization success in the inflow to 95% in the outflow. None of the samples reduced fertilization by 50%, and therefore the TU was <2 for all samples (Figure 19). There was no toxicity in the inflow or outflow samples from either replicate cell from 2/10, 2/24, or 3/3.

Pico-Kenter (hydrodynamic device)

Chemistry

The Pico-Kenter CDS unit did not appear to be effective at removing total or dissolved metal concentrations, or TSS (Figure 20 and 21, Table 6). Concentrations were usually similar between inflow and outflow. In the March samples, however, there was an increase in the concentrations of four total metals between the inflow and outflow samples, and a reduction in one other. Specifically, total Al decreased by 62% between the inflow and outflow samples in March, but the concentration of total Cu increased by 84%, total Zn increased by 375%, total Ni increased by 344%, total Pb increased by 1161%. The dissolved fraction of Al, Cu, Ni, Pb and Zn in March, however, was more consistent between inflow and outflow samples, with differences ranging from 2% for dissolved Cu to 17% for dissolved Zn. There was also a large reduction (95%) in total As during the December sampling event, while dissolved As concentrations were consistent between the inflow and outflow samples. The removal effectiveness for total and dissolved Ag, Cd and Sn could not be determined, because these constituents were usually below the reporting level.

Chlorpyrifos was the only pesticide detected in any of the samples (Figure 22). This pesticide was found only in the outflow sample from March, at a concentration of 0.12 µg/L.

Concentrations of total Al were consistently above the chronic criterion, while total Se was below the chronic criterion for three of the four sampling events. All of the dissolved metals with chronic criteria (As, Cd, Cu, Ni, Pb and Zn) had inflow and outflow concentrations at or below their respective criteria. The single measured chlorpyrifos concentration at Pico-Kenter was 3 times the chronic criterion.

Toxicity

Over half of the samples were toxic to sea urchin fertilization (Figure 23, Table 9). The only samples that were not toxic to sea urchin fertilization were the inflow and outflow samples from November. For the December and January inflow and outflow samples, the highest concentration tested (50% dilution) was toxic. For the March samples, the inflow sample had greater toxicity than the outflow sample; the inflow sample was toxic at the lowest dilution tested (12.5% inflow), while the outflow sample was toxic at the 25% sample concentration. The toxicity of the January inflow samples, and the November and March inflow and outflow samples was not great enough to produce a median-effect response (i.e., none of these samples reduced fertilization by 50%), hence an EC50 and TU value could not be calculated.

Samples from three collection events were tested for *C. dubia* survival (11/18/04, 12/16/04, 3/10/05), while one event was tested for reproduction impairment (3/10/05). None of the Pico-Kenter samples tested were toxic to survival or reproduction (Figure 23).

BC120 Dry weather (hydrodynamic device)

Chemistry

There was a difference in removal efficiencies between the total and dissolved metal fractions for certain metals (i.e., Al, Cu, Pb, Zn) for at least one of the two dry weather sampling events at BC120 (Figures 24 and 25, Table 6). For example, total Al was reduced by 34% between the inflow and outflow samples in January, and by 52% in March, while the dissolved fraction of Al increased by 25% and 55%, respectively, between the inflow and outflow in these same samples. The concentration of total Cu was reduced by 26% in the January outflow, but dissolved Cu concentrations were similar between the inflow and outflow samples. Both total Pb and total Zn were reduced 32% and 24%, respectively, between the inflow and outflow samples from January, but virtually unchanged in the dissolved fraction. This difference was not apparent between total and dissolved Pb or Zn from March; both metals showed a reduction between inflow and outflow in both the total and dissolved fractions.

There was a 73% reduction in TSS in the January sample, and a 50% reduction in the March sample.

Diazinon and bifenthrin were the only pesticides found in the dry weather samples from BC120 (Figure 26). Diazinon was detected in both the inflow and outflow samples from March, while bifenthrin was detected in both the inflow and outflow samples from January. The concentration of each pesticide in the outflow samples were similar to the inflow concentration.

A reduction in contaminant concentration did not necessarily lead to values being below the water quality criteria, and vice versa. While concentrations of total Al were reduced between the inflow and outflow samples from January and March, the outflow concentrations were above the chronic criterion for both sampling events. And, while concentrations of total Se, dissolved As, and dissolved Ni were virtually unchanged between the inflow and outflow samples, the outflow concentrations of these metals were consistently below their respective chronic criteria. Dissolved Cu concentrations, similarly unchanged between inflow and outflow samples, were consistently above the chronic criterion. Both dissolved Pb and dissolved Zn were above the criteria in January (when inflow and outflow concentrations were similar), and below the criteria in March (when there was a slight reduction in concentration between the inflow and outflow samples). Both the inflow and outflow concentrations of diazinon were below the chronic criterion.

Toxicity

Both the inflow and outflow samples from January were toxic to sea urchin fertilization (Figure 27, Table 10). The inflow sample was toxic at the 50% dilution, and the outflow sample (with greater toxicity) was toxic at the 25% sample concentration. The toxicity increased between the inflow and outflow samples from March. While the inflow sample from March showed no toxicity at the highest dilution tested (50% dilution), the outflow sample was toxic even at the lowest dilution tested (12.5% sample)

Only the samples from March were tested for impairment to *C. dubia* survival or reproduction. Neither the inflow nor outflow samples were toxic to *C. dubia* (Figure 27).

BC120 Wet weather (hydrodynamic device)

Chemistry

The concentrations of most total and dissolved metals increased between the inflow and outflow samples from January (Figure 28 and 29, Table 6). Concentrations of total Al, As, Cd, Cr, Cu, Pb, Ni and Zn increased by at least 26% in the January samples, while dissolved concentrations of Al, As, Cr, Cu, Pb, Ni and Zn increased by at least 35% in January. The concentrations of most total metals also increased in the February samples, although not by as much.

Concentrations of TSS were similar between the inflow (TSS = 204 mg/L) and outflow (TSS = 217 mg/L) samples from January. However for the February samples, the level of TSS increased by 67% between inflow (84 mg/L) and outflow (140 mg/L) (Figure 28).

Diazinon was the only pesticide found in either of the wet weather sampling events at BC120 (Figure 30). This pesticide was detected in the February samples, where there was a 50% reduction between the inflow and outflow samples, from 0.08 µg/L to 0.04 µg/L.

Concentrations of total Al, dissolved Cu, and dissolved Zn exceeded the chronic criteria during both wet weather sampling events at BC120. Concentration of dissolved Pb were exceeded in the February sample. The diazinon concentration in the outflow sample was below the chronic criterion.

Toxicity

Samples from both the January and February wet weather sampling events were toxic to sea urchin fertilization (Table 11). In the January samples, the lowest concentration of inflow and outflow sample tested (12.5% sample) was toxic. Because the level of toxicity was so strong in these samples, it was not possible to detect differences between the inflow and outflow samples. The samples from February had lower toxicity. Both the inflow and outflow samples were only toxic at the 50% dilution. These samples had comparable TU values (inflow sample TU=2.6, outflow TU = 2.9) (Figure 31).

Only the samples from February were tested for impairment to *C. dubia* survival or reproduction. Neither the inflow nor outflow samples were toxic to *C. dubia* (Figure 31).

South Pasadena (hydrodynamic device)

Chemistry

There was greater variability in total and dissolved metals among sampling events than there was between inflow and outflow concentrations from a single sampling event (Figure 32 and 33, Table 6). For example, total Cu concentrations in the inflow samples from the South Pasadena site varied by up to a factor of 5.1 and the outflow samples varied by a factor of 3.8, while the largest difference between inflow and outflow concentrations for a single event was by a factor

of 1.4. For dissolved Cu, the inflow concentrations varied by a factor of 3.8 and the outflow concentrations varied by a factor of 3.2, while the largest difference between inflow and outflow samples from a single event was by a factor of 1.6. This pattern was consistent for each metal that was detected.

Differences in TSS concentrations between inflow and outflow samples were variable among the five sampling events. Concentrations increased by over 50% in the samples from 12/5/04 and 1/26/05, but decreased by 97% in the samples from 1/2/05 (Figure 32).

The OP pesticides chlorpyrifos and diazinon were the only pesticides detected in any of the South Pasadena samples. Chlorpyrifos was detected in the inflow and outflow samples from 1/7 and 1/26/05, while diazinon was detected in the inflow and outflow samples from 12/5/04 (Figure 34). Concentrations of chlorpyrifos were similar between the inflow and outflow samples from 1/7/05, but there was a 67% increase in chlorpyrifos between the inflow and outflow samples from 1/26/05. The diazinon inflow and outflow concentrations from 12/5/04 were similar.

While there were some metal concentrations in the outflow samples below their respective chronic water quality criteria, none of the metals were below the criteria because of a reduction from the inflow concentration. Total Se, and dissolved Cd were consistently below the criteria and also consistently below the reporting limit. Dissolved Cu was consistently above the chronic criterion, while dissolved Pb and Zn had some values above and some below their criteria. The chronic water quality criterion for total Al is only valid for sample pH 6.5 – 9.0. Only one outflow sample was within this pH range (the sample from 1/26/05), and the concentration of total Al in this sample exceeded the criterion. The two detectable concentrations of chlorpyrifos in the outflow samples were both above the chronic water quality criteria. The detected concentration of diazinon was equal to the criterion.

Toxicity

Samples from all five sampling events were highly toxic to sea urchin fertilization, and this toxicity was not reduced by the CDS unit (Figure 35, Table 12). The toxic units were comparable between the inflow and outflow samples for most sampling events. For the samples collected from the 1/7 and 1/26/05 storm events, the toxicity was too great to tell if there was a difference between the inflow and outflow samples. Among sites, TUs ranged from 3.3 and 3.6 in the inflow and outflow samples, respectively, from 12/5/04, to TU >8 in the inflow and outflow samples from 1/7 and 1/26/05.

None of the samples were toxic to *C. dubia* survival or reproduction (Figure 35).

SMURRF (screening/hydrodynamic device/microfiltration/UV treatment)

Chemistry

For TSS and most of the total metals constituents (Al, Cr, Cu, Pb, Ni, Zn), there was a consistent reduction in concentrations between the inflow and outflow samples (Figure 36, Table 6). Concentrations of TSS were reduced below the reporting level for three of the four sampling events, reducing TSS by $\geq$93%. The one sampling event that had measurable TSS in the outflow had a 99% removal rate. The reduction in total Cu varied from 47% to 59%, while the reduction in total Zn varied from 52% to 68%.

A strong and consistent reduction between the inflow and outflow concentrations was less apparent for the dissolved metals (Figure 37). Only dissolved Al and Zn showed a consistent removal, with efficiencies ranging from 11-65% for dissolved Al and from 10-34% for dissolved Zn.

The concentration of residual chlorine increased between the inflow and outflow samples during each of the four sampling events. The smallest increase was from 0.05 mg/L to 0.08 mg/L in March, while the largest increase was from 0.05 mg/L to 0.66 mg/L in the November sample (Table 6). The most likely source of the chlorine is from the use of this chemical to backflush the screens at SMURRF (Louis Hernandez, personal communication).

Malathion was the only pesticide detected in any of the samples from SMURRF (Figure 38). This pesticide was detected in the March samples, where the concentrations were 0.05 µg/L in the inflow and 0.03 µg/L in the outflow sample.

The reduction in total Al consistently brought the concentrations down below the chronic criterion. Total Se concentrations, which were not reduced by the treatment at SMURRF, were above the chronic criterion only in the March outflow sample. The concentrations of dissolved metals (As, Cd, Cu, Pb, Ni, Zn) were consistently below the respective criteria prior to treatment at SMURRF, and remained below the criteria after treatment. The concentrations of malathion were likewise below the chronic criterion both before and after treatment.

Toxicity

Toxicity to sea urchin fertilization increased in three of the four outflow samples from SMURRF (Figure 39, Table 13). This increase in toxicity corresponded with an increase in residual chlorine concentrations between the inflow and outflow samples. For example, the November sample went from TU <2 in the inflow sample (0.05 mg/L chlorine) to TU = 8.7 in the outflow sample (0.66 mg/L chlorine). Similarly, the December samples went from TU = 2.5 (0.07 mg/L chlorine) to TU >8 (0.23 mg/L chlorine), and the January samples went from TU = 1.2 (0.17 mg/L chlorine) to TU >8 (0.35 mg/L chlorine). The inflow and outflow samples from March were toxic at the 50% dilution, but the toxicity was not great enough to calculate a median effect concentration, therefore TU values could not be estimated. Chlorine concentrations in these samples were relatively low, with residual chlorine in the outflow sample (0.08 mg/L) being similar to the inflow sample (0.05 mg/L).

The only sample that was toxic to *C. dubia* survival was the outflow sample from November. This sample had 0% survival in the 100% sample, and a TU value = 1.4. This was also the sample with the highest residual chlorine concentration (0.66 mg/L). All other samples, including the November inflow sample had TU values <1. The only samples tested for impairment to *C. dubia* reproduction (the March inflow and outflow samples) were not toxic.

L.A. metal recycling yard (screening/settlement)

Chemistry

There were no consistent differences between inflow and outflow samples for total metals, but there were patterns among certain dissolved metals (Figure 40 and 41, Table 6). For example, dissolved Cr concentrations were reduced for each of the four sampling events, ranging from a

36% – 79% reduction between the inflow and outflow samples. Concentrations of dissolved Pb were reduced during three of the events, ranging from a 48% – 87% reduction between inflow and outflow concentrations. For the fourth sampling event, however, dissolved Pb increased by 54% in the outflow. There was a consistent increase in dissolved Zn, ranging from a 57% – 2009% increase between inflow and outflow concentrations. Most of the sampling events also showed a strong increase in dissolved Cd concentrations, ranging from a 262% – 601% increase. The fourth sampling event, however, had a 55% reduction in dissolved Cd in the outflow sample.

The chronic criteria for both total Al and Se were exceeded (Figure 40). Only two of the outflow samples were within the appropriate pH range (6.5 – 9.0) to compare against the total Al criterion, but both of these samples exceeded the criterion. All four of the outflow samples exceeded the criterion for total Se. The reductions in dissolved Pb resulted in outflow concentrations that were below the criterion for two of the sampling events, but not for a third event (Figure 41). The increases in dissolved Zn concentrations resulted in exceedances of the chronic criterion for three of the four sampling events. Dissolved Ni, which had inconsistent differences between inflow and outflow concentrations, exceeded the chronic criterion once, during the sampling event with the largest reduction in dissolved Ni.

Pesticides were not analyzed in the samples from the L.A. metal recycling yard.

Toxicity

The toxicity of the samples to sea urchin fertilization decreased between inflow and outflow for two of the events, but the toxicity was too high to detect any changes between inflow and outflow during the other two events (Figure 42, Table 14). In the samples from 2/18/04, the toxicity was reduced from TU >8 to TU = 5.4, while in for the samples from 10/26/04, the toxicity went from TU = 2.5 to TU <2. The inflow and outflow samples from 2/2/04 and 2/11/05 each had TU values >8, and therefore differences could not be determined.

The toxicity to *C. dubia* survival was also inconsistent among the four sampling events (Figure 42). During the event on 2/2/04, the toxicity was too great to differentiate the inflow and outflow samples (TU > 4; the lowest concentration tested was 25% sample). However, toxicity increased in the samples from 2/18/04, from TU <1 in the inflow to TU = 2.1 in the outflow. Toxicity was reduced between the inflow and outflow samples during the last two events, from TU = 16 in the inflow (6.25% sample was the lowest concentration tested) to TU = 8.3 in the outflow from 10/26/04, and from TU = 2.2 to TU 1.4 in the samples from 2/11/05.

Reproductive impairment was reduced between the inflow and outflow samples during three of the sampling events. The largest reduction in toxicity was in the samples from 2/18/04, where toxicity dropped from TU = 9.4 to 5.2. There were slight reductions in toxicity in the samples from 10/26/04 (inflow TU = 7, outflow TU = 5.7), and 2/11/05 (inflow TU = 6.7, outflow TU = 5.9). The samples from 2/2/04 had toxicity that was too great to differentiate the inflow and outflow samples (TU >4 for both samples).

Discussion

This study expands our understanding of BMP effectiveness under field conditions in southern California, adding new information for sites that have not been examined previously, and assessing additional constituents of concern for aquatic life protection (e.g., toxicity, OP pesticides) at sites that have been studied before. The assessment of treatment effectiveness described in this study is intended to provide information regarding the technologies examined and to aid in the selection of BMPs for future installations, not to evaluate the suitability of a specific BMP at the study sites. The BMPs included in this study were installed for purposes other than removal of aquatic life toxicity and the results are therefore not intended to assess the overall effectiveness of the specific BMP for its intended purpose. For example, the effluents from the SMURRF and L.A. metal recycling yard treatment systems do not enter urban creeks or channels, but are used as reclaimed water (SMURRF) or for ground water infiltration. The Wet CAT and CDS systems were installed for the treatment of constituents other than toxicity, such as bacteria (Wet CAT) and trash.

Effectiveness of Metals Removal

The wetland BMP systems (Wet CAT and OCWD sub-surface flow) both showed great potential to effectively reduce concentrations of dissolved Zn. Concentrations of dissolved Zn were consistently reduced by more than 10% in the outflow samples from both sites, however the concentrations in the inflow samples did not exceed the chronic criterion (Table 15-17). Therefore the ability to attain the water quality criterion for dissolved Zn could not be evaluated for these sites. For dissolved Cu, the wetlands showed different responses. The SSF wetlands consistently reduced concentrations of dissolved Cu by more than 10% and reduced outflow concentrations to levels below the chronic criterion, but the Wet CAT wetland was unable to produce a meaningful reduction. Concentrations at the Wet CAT site, however, were quite low in the inflow samples ($\leq$11 µg/L), and therefore it may not be realistic to expect large reductions in the outflow. Other metal constituents with water quality criteria were only analyzed in the samples from the Wet CAT site. The Wet CAT wetland was very effective at reducing concentrations of dissolved Cd and Ni to levels below the chronic criteria. This wetland was also effective at reducing concentrations of total Al and Se by >10%, although total Al was not always reduced to levels below the chronic criterion, and total Se was never reduced below the criterion. There were several metals without chronic criteria that were consistently reduced by >10% between the inflow and outflow at the Wet CAT site (Table 15). This included total Cd, Cr, Cu, Ni, and Zn. Total Cu and Zn were also reduced by >10% in the OCWD SSF samples.

The BMPs using hydrodynamic devices (CDS units) were generally ineffective at reducing metal concentrations by $\geq$10%, for metals with chronic water quality criteria (Table 15). There was one exception; concentrations of total Al were reduced by >10% in both of the dry weather outflow samples at the BC120 site. This reduction was only partially effective, however, since the outflow concentrations were never reduced below the chronic criterion (Table 16). One constituent, dissolved Cd, was below the reporting level for most sampling events at each of the CDS BMP sites, and could not be evaluated for consistent reductions. Most of the metals that were consistently reduced by $\geq$10% in the dry weather samples from BC120 do not have chronic criteria. Total Cu, Pb and Zn were reduced by >10% between inflow and outflow during both dry weather sampling events at this site (Table 15). In general, CDS units are designed to remove particulate material, which would be a substantial benefit for reducing the total load of metals. However, the majority of metals chronic criteria are for the dissolved phase.

The SMURRF site was effective at reducing two of the metals with chronic criteria by ≥10%. The treatment process at SMURRF consistently reduced concentrations of total Al and dissolved Zn by ≥10%, with total Al reduced to levels below the chronic criterion (Table 17). Dissolved Zn concentrations, however, were consistently below the chronic criterion in the inflow, and therefore the ability to attain this water quality criterion could not be assessed. The majority of metal constituents that were consistently reduced by ≥10% do not have chronic criteria (Table 15); concentrations of total Cr, Cu, Ni, Pb, and Zn, and dissolved Al were consistently reduced between the inflow and outflow samples at SMURRF. Similar to the CDS units, the microfiltration process at SMURRF works better on particulate metals, rather than dissolved metals.

The screening/settlement apparatus at the L.A. metal recycling yard was usually effective at reducing concentrations of dissolved Cu and Pb by ≥10% (Table 15). Dissolved Pb was reduced to levels below the chronic criterion half of the time, while dissolved Cu was never reduced below the criterion. This BMP was not effective for reducing any of the other metals with chronic criteria (Table 16). Only one metal constituent without a chronic criterion (dissolved Cr) was consistently reduced by ≥10% (Table 15).

Effectiveness of Pesticides Removal

Only three BMP sites had at least two sampling events with detected amounts of pesticide, and could be evaluated for removal effectiveness (Table 15). Diazinon was measured in the inflow from the Wet CAT and OCWD SSF wetlands, while chlorpyrifos was detected in the inflow from the South Pasadena CDS site. Both wetland BMPs were able to reduce diazinon by ≥10%. However, the OCWD SSF wetlands were inconsistent over time in their ability to reduce concentrations below the chronic criterion, and the inflow concentrations at the Wet CAT site were not high enough to evaluate attainment of the water quality criterion (Table 16). The OCWD sub-surface flow wetlands appeared to completely remove diazinon during the first week, but were less effective during the other four sampling events. It is unclear why the effectiveness of diazinon removal was reduced after the first event, however the most likely explanation is that because there were inconsistencies with the dosing of the wetlands during the first week, the lack of diazinon in the outflow sample was because the diazinon had not mixed throughout the system. The dosing of the metals solution at OCWD, which used a different delivery system, was not affected. At the South Pasadena site, the concentrations of chlorpyrifos were not consistently reduced by ≥10%, hence this BMP was not effective at removing this OP pesticide.

Effectiveness of TSS Removal

Numerical water quality criteria do not exist for TSS, so the BMPs were only evaluated for their ability to reduce the concentrations of TSS by at least 10% (Table 15). The Wet CAT wetland was able to reduce TSS during all sampling events captured, presumably because of the long residence time which allowed for sedimentation processes to occur. A previous study found an average TSS reduction of 23% at the Wet CAT site (CH2MHill 2004), which is less than the 74% average reduction found in this study.

There were mixed results for the CDS units. TSS was reduced in both of the dry weather samples from BC120, but was not reduced in the wet weather samples from BC120, and was inconsistently reduced in the samples from Pico-Kenter and South Pasadena.

The microfiltration process used at SMURRF consistently reduced the levels of TSS by more than 10%. The screening/settlement process used at the L.A. metal recycling yard, however, was not able to consistently reduce TSS levels.

Reduction in TSS is not a parameter of direct relevance to water column toxicity, as contaminants usually need to be in the dissolved form to produce effects on organisms under laboratory exposure conditions. However, TSS removal does correspond to reductions in particle-associated contaminants, which could have a beneficial impact on sediment toxicity or bioaccumulation from feeding. The study design and analytical methods used in this study were not sufficient to assess potential impacts on sediment toxicity. Different procedures for sample collection and testing are needed to the toxicity associated with runoff particles.

Changes in Toxicity

Toxicity, when present, was reduced by the two wetland BMPs. Both the Wet CAT wetland, and the OCWD SSF wetland reduced the toxicity in two of the sampling events, while the other sampling events at these sites did not have sufficient toxicity to evaluate removal. While there was a consistent reduction for many of the metal contaminants in the events with the non-toxic samples, the inflow concentrations were not great enough to have caused toxicity.

The toxicity to *C. dubia* survival and reproduction in the samples from the Wet CAT site was influenced by dissolved salts. While survival and reproduction were consistently low in these samples, the toxicity was usually equivalent to the salt blank that was tested concurrently with the Wet CAT samples. In a previously study, concentrations of dissolved salts associated with conductivity values greater than 1.8-2.8 mS caused impairment to *C. dubia* reproduction (Brown and Bay 2003). In the present study, the conductivity values in all of the Wet CAT samples exceeded this threshold range by at least a factor of two. Toxicity due to other contaminants could only be resolved in the November inflow sample. While the conductivity value was relatively high in this sample, the survival was significantly lower than that found in the salt control. The high salt content did not cause interference with the echinoderm fertilization test, since hypersaline brine was added to the samples to bring the conductivity level up to approximately 54 mS.

In general, the CDS units had no effect on the toxicity. This is not surprising, since the CDS units were designed to remove solids from runoff, yet the fraction usually associated with toxicity is the dissolved phase, and the CDS units had little effect on the dissolved metals in this study (Table 15).

The toxicity data for the samples from the SMURRF site could not be used to evaluate toxicity removal effectiveness. While the inflow samples from two of the events were toxic to echinoderm fertilization, reductions in toxicity could not be assessed because of the influence of added chlorine. As part of the treatment process at SMURRF, chlorinated water is used to backflush the screens. This chlorination step results in increased residual chlorine in the outflow samples. Previous studies have shown that the echinoderm test is sensitive to chlorine, with an approximate median effect threshold of 0.02 mg/L (Dinnel et al. 1981). In the present study, the residual chlorine concentrations in the outflow samples from SMURRF were 12-33 times this value in the samples from November, December and January. The increased toxicity was not due to other contaminants, since the other dissolved contaminants analyzed at SMURRF either remained fairly constant, or were reduced between the inflow and outflow samples. There was no consistent toxicity to *C. dubia.*

Toxicity at the L.A. metal recycling yard was usually reduced after treatment, according to the *C. dubia* reproduction test. While the toxicity was usually reduced in the outflow samples, the toxicity was still quite high after treatment. The toxicity was often too high in both the inflow and outflow samples in the sea urchin fertilization test to determine if a consistent reduction had occurred. The pattern of reduced toxicity in the *C. dubia* reproductive test was similar to the pattern found for dissolved Cr and Cu, but strikingly different from the patterns for dissolved Zn and Cd, where concentrations tended to increase substantially. While dissolved Cu tended to decrease after treatment, the concentrations were still consistently above the chronic criterion.

Comparison to the International Stormwater Database

The data were compared with the International Stormwater BMP Database in order to determine if the removal effectiveness was comparable with other technologies and studies. The stormwater database contains inflow and outflow data for metals and TSS that has been collected over the past decade from several types of BMPs (Strecker et al. 2004). The database is sponsored by several agencies, including the US EPA and the American Society of Civil Engineers. For analysis of the data, the upper and lower 95% prediction limits from log transformed paired inflow and outflow data from biofiltration BMPs in the stormwater database were calculated and compared with the data for each of the BMPs in the present study. Biofiltration BMPs (which include grass strips and swales) are believed to be one of the most effective types of BMPs currently in use (E. Strecker, personal communication). Analyses were made for dissolved Cu, Zn and TSS. For dissolved Cu, most of the data from the present study fell within the prediction limits from the international stormwater database (Figure 43). The data were also compared to the one-to-one reference line (which represents no change between inflow and outflow). This comparison showed that while most of the data for the biofiltration BMPs were below this line (indicating a general net reduction in dissolved Cu between inflow and outflow), there were only two BMP sites in the present study that were consistently below this line. The OCWD SSF wetland and L.A. metal recycling yard were the only sites that had consistent reductions in dissolved Cu, with median reductions of 85% for OCWD replicate cell #1, 75% for replicate cell #2, and 28% for the metal recycling yard, compared to a 22% median reduction by the biofilter BMPs.

The reductions in the present study were usually within the biofilter prediction levels for dissolved Zn, except for the OCWD SSF wetland and the L.A. metal recycling yard (Figure 44). For the OCWD SSF wetland, the data were below the lower prediction limit of the biofiltration BMPs for dissolved Zn, indicating a greater reduction by the SSF wetland than the biofilter BMPs. The dissolved Zn data from the L.A. metal recycling yard, however, were usually above the biofiltration upper prediction limit. The data at the L.A. recycling yard were also above the one-to-one reference line, indicating a net gain in dissolved Zn. Other than the OCWD SSF wetland, the only other sites that were consistently below the one-to-one line were the Wet CAT wetland, and SMURRF. The median reductions in dissolved Zn at the OCWD (95% for replicate cell#1, 98% for replicate #2), and Wet CAT sites (72%) were greater than the median reduction from the biofiltration BMPs (45%), while the median reduction at SMURRF (20%) was lower.

For TSS, only the data from SMURRF and Wet CAT were below the lower biofilter prediction limit. (Figure 45). The median reductions in TSS at SMURRF (>98%) and the Wet CAT wetland (88%), and the reductions in the two dry weather samples from BC120 (73%, 50%) were all greater than the median reduction for the biofiltration BMPs in the stormwater database (18%). Data from the other sites in this study were usually within the prediction limits for TSS, except for the wet weather flow from BC120, which consistently exceeded the upper prediction limit.

The data from the CDS units in this study were also compared with the data from the hydrodynamic devices in the stormwater database. All of the data from the CDS units fell within the 95% prediction limits of the hydrodynamic devices for dissolved Cu (Figure 46) The reductions in dissolved Cu were more variable with the database. However, the median reduction from the database (2%) was similar to the median reduction from Pico-Kenter (3%), the two dry weather events from BC120 (-1%, 0%), and the January wet weather event from BC120 (-5%). The median reduction in dissolved Cu in the database was lower than the median reduction from South Pasadena (9%). The reduction in the February wet weather event from BC120 was negative (-82%).

For dissolved Zn, the reductions from the current study fell within the prediction limits of the hydrodynamic devices in the stormwater database (Figure 47). The results of the current study appear to coincide to the one-to-one reference line better than the data from the stormwater database for dissolved Zn. However, the median reduction in dissolved Zn from the database (0%) was lower than the median reduction from Pico-Kenter (8%), and South Pasadena (12%), and the March dry weather event from BC120 (29%), and the January wet weather event from BC120 (18%). The median reduction of the January dry weather event and February wet weather event from BC120 were negative (-10% and -42%, respectively).

There was also a greater range in reduction of TSS for data from the stormwater database than the current study (Figure 48). Overall, the median reduction in TSS from the database (48%) was greater than the median reduction for Pico-Kenter (5%), and South Pasadena (15%), or the two wet weather samples from BC120 (-6%, -67%). The TSS reduction in the database was not as great, however, as for the two dry weather samples from BC120 (73%, 50% removal).

Research Needs

While this study adds to the knowledge base, there were some limitations to this study. First, this study had a limited number of sampling events from each site and was conducted over a relatively short time frame. This study was restricted to a maximum of five sampling events due to the resources available and the short time-line of the project. Because of this, the among-event variability measured at each site may not be representative of other times of the year (for the dry weather samples), or additional years (particularly for wet weather, since the 2004-2005 rain season had double the normal amount of rainfall).

Second, while analytical variability was incorporated into the two-tiered approach, there are other potential sources of variability that were not. This includes sampling variability (inconsistencies in the composition of the flow), and variability from sample handling (conditions that change the concentrations between the time of sample collection and analysis). Inconsistencies in the composition of the flow can lead to erroneous conclusions about differences between the inflow and outflow sample if there were spikes in contaminant concentrations that were picked up by one of the autosamplers and not the other. For example, the large increases in several of the total metals (Cd, Cr, Cu, Ni, Pb, Zn) and chlorpyrifos in the March 2005 samples from Pico-Kenter probably did not originate from the CDS unit itself, but were more likely due to inconsistencies in the flow composition. Differences in how samples are handled (e.g. temperature, time until analysis) can also lead to variability between samples.

Third, there were instances where the apparent removal effectiveness was low, because the inflow concentrations were too low to expect large reductions. For example, only one of the four sampling events at the Wet CAT site had concentrations of dissolved Cu that were reduced by $\geq$10%. However, the concentration of dissolved Cu in the inflow for these events was probably too low to expect large reductions in the outflow. The overall evaluation in the two-tiered

approach did not distinguish between situations where the inflow was probably too low to evaluate removal by the BMP, and situations where the BMP failed to reduce high concentrations of contaminants.

Finally, there are other types of BMPs in use in southern California that were not represented in this study, including detention basins and media filters. A previous study by Caltrans (2004) indicated these BMPs are among the most effective technologies for improving water quality, but did not examine reductions in toxicity or pesticides. Media filtration has been shown to substantially reduce toxicity in runoff from the National Steel and Shipbuilding Company (NASSCO) (H. Bermudez, personal communication).

Future investigations would benefit by increasing the number of sampling events and the duration of the study. Increasing the number of sampling events would allow additional statistical approaches to be used to evaluate the data. Future studies would also benefit by including additional BMP types, in order to characterize the wide variety of the BMPs being used in southern California.

The assessment of BMP effectiveness regarding sediment toxicity is another issue in need of investigation. Sediment toxicity is frequently encountered in receiving waters near the mouths of urban rivers and creeks, and runoff discharge is a likely contributor to this situation. Just as the effectiveness of a particular BMP for a constituent such as trash may have little relevance to reducing water column toxicity, the characteristics of BMPs that are important for reducing water column toxicity may differ from those needed to be effective in reducing sediment toxicity.

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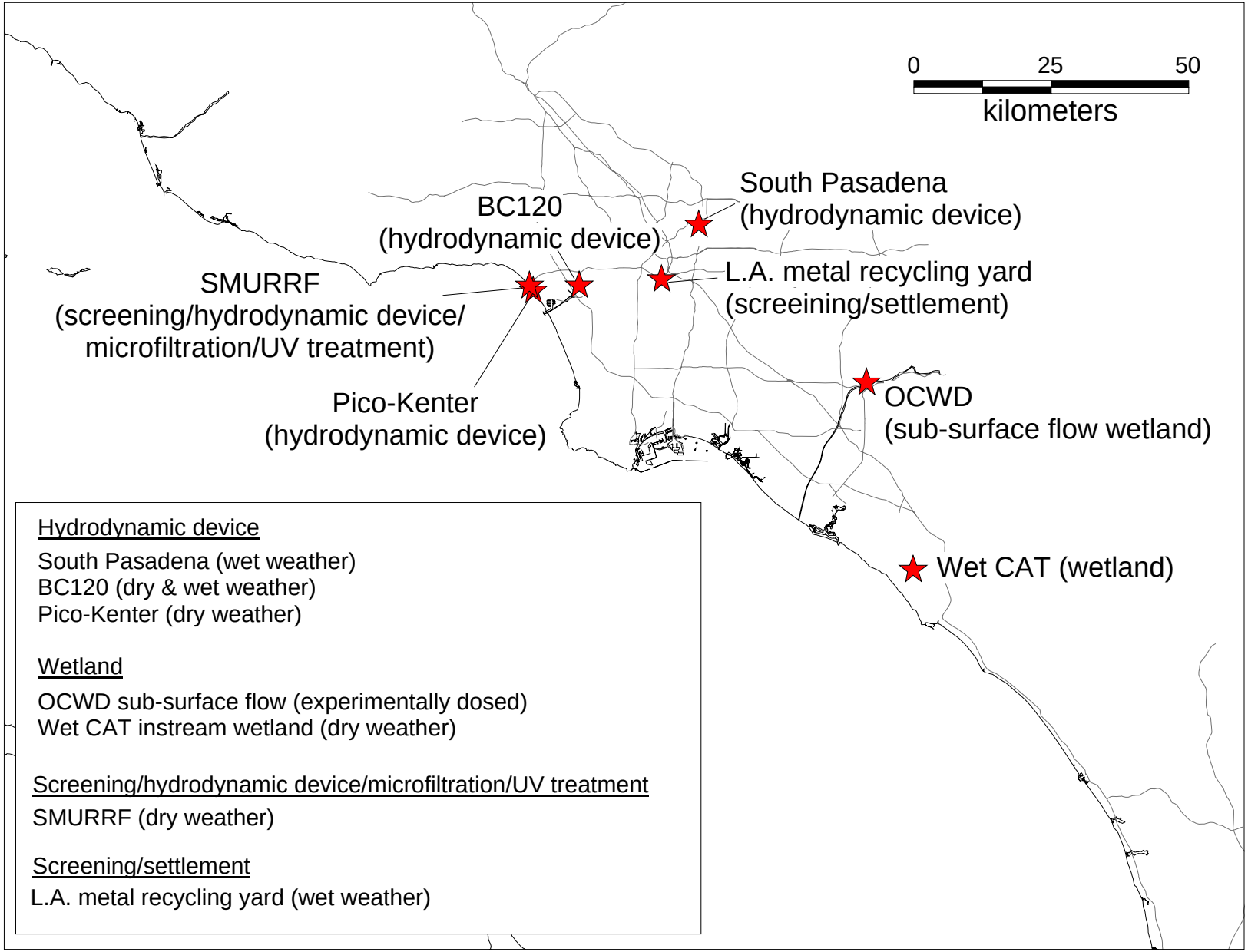


Figure 1. BMP sampling locations. The type of sample collected for this study (dry or wet weather) is indicated in the text box. The freeways in Los Angeles and Orange Counties have been added for reference.

Figure 2. Wet CAT upstream (top photo) and downstream (bottom photo) locations. The sites are separated by about half a mile of wetland. Water from the wetland flows down a slope as it leaves the wetland. The arrow in the bottom photo indicates the slope where the outflow was taken. The concrete structure on the left part of the photo contains ground water flow.

Figure 3. Orange County Water District's sub-surface flow wetlands. These wetlands are constructed from concrete panels, and measure approximately 1 m tall x 2 m wide x 8 m long. Each wetland cell is filled with a gravel matrix composed of pea gravel. A monoculture of wetland plants (bulrushes, genus *Scirpus*) are planted in the gravel. The gravel provides an approximate thousand-fold increase in surface area for the growth of bacterial biofilms that increase the rate of contaminant degradation or removal. Within the gravel matrix there are distinct oxygen rich (aerobic) and oxygen free (anaerobic) zones where specific microbial processes take place. Water flows beneath the surface of the gravel matrix.

A.

B.

Figure 4. A. Dosing setup for the sub-surface flow wetlands at OCWD. Diazinon, Cu and Zn were added to the wetlands by peristaltic pumps. The metals stock solution is separate from the diazinon stock solution. B. Outflow from the two replicate cells.

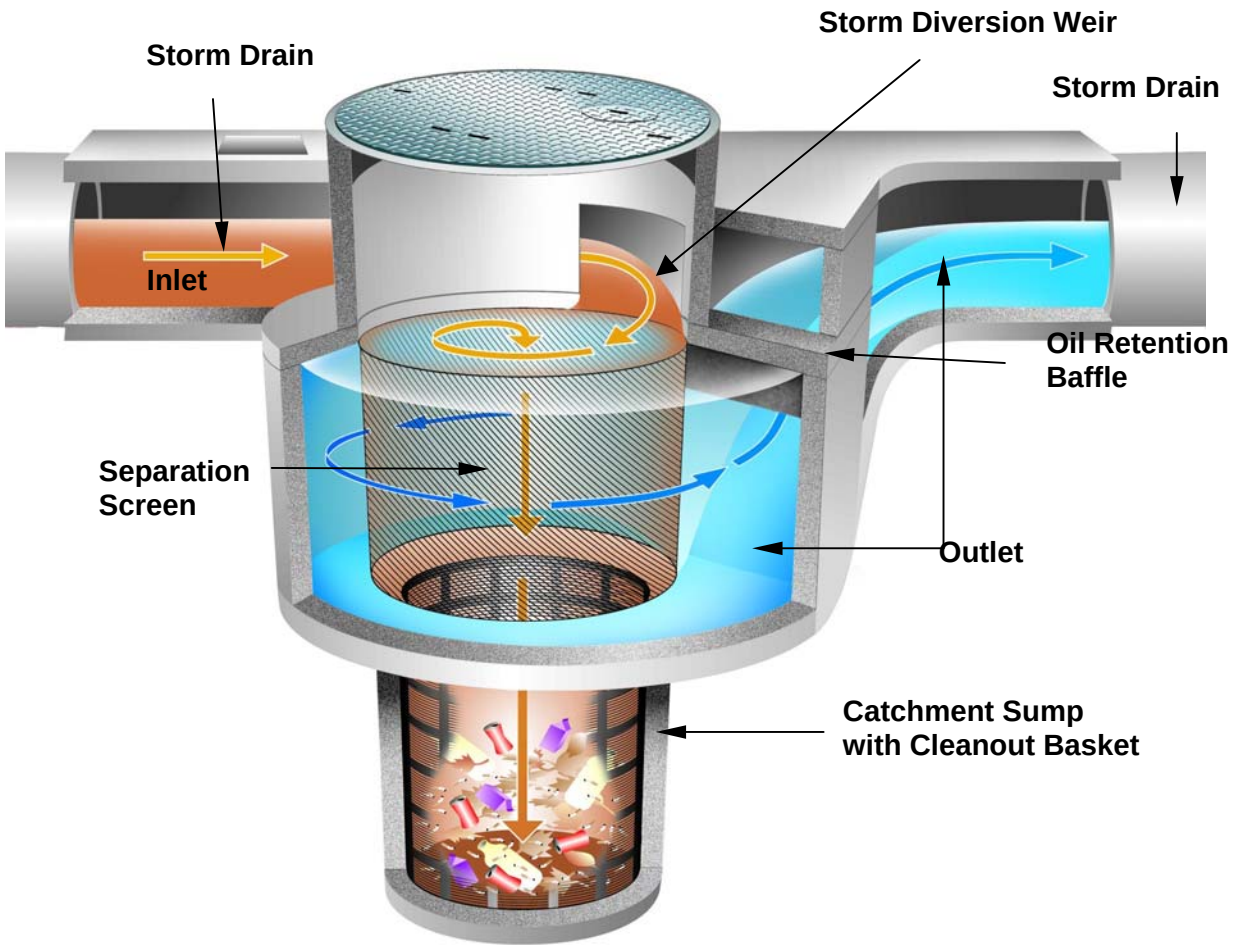


Figure 5. Schematic of a hydrodynamic device (CDS unit from CDS Technologies). The manhole cover on top is the only part of the unit visible from street level.

A.

B.

Figure 6. A. CDS unit at the Pico-Kenter site. B. Influent and effluent autosamplers in a pit adjacent to the Pico-Kenter CDS unit.

A.

B.

Figure 7. The CDS unit housing at the BC120 site, near Ballona Creek and Overland Ave. in Culver City.

A.

B.

Figure 8. A. Autosampler contained within green housing box at the South Pasadena site. B. Housing containing the autosampler located next to the manhole cover of the CDS unit.

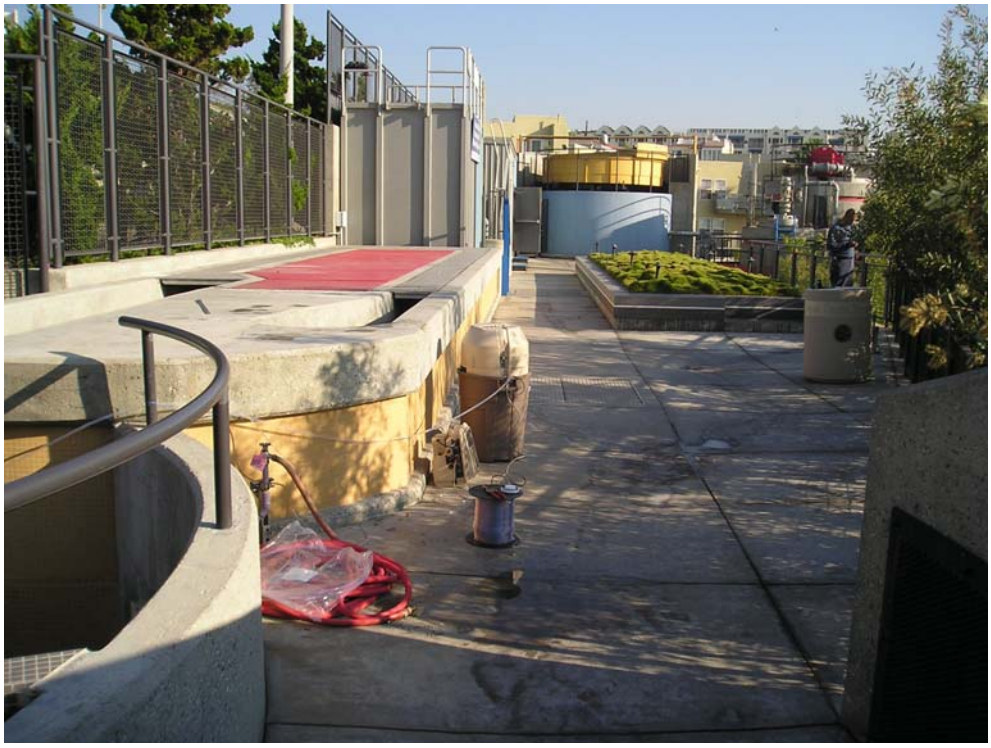


Figure 9. Santa Monica Urban Runoff Recycling Facility (SMURRF). The autosampler in the center of this picture is collecting the post-treatment effluent water.

Figure 10. L.A. metal recycling yard BMP. Water flows through the grating of the metal top hat, into an infiltration trench.

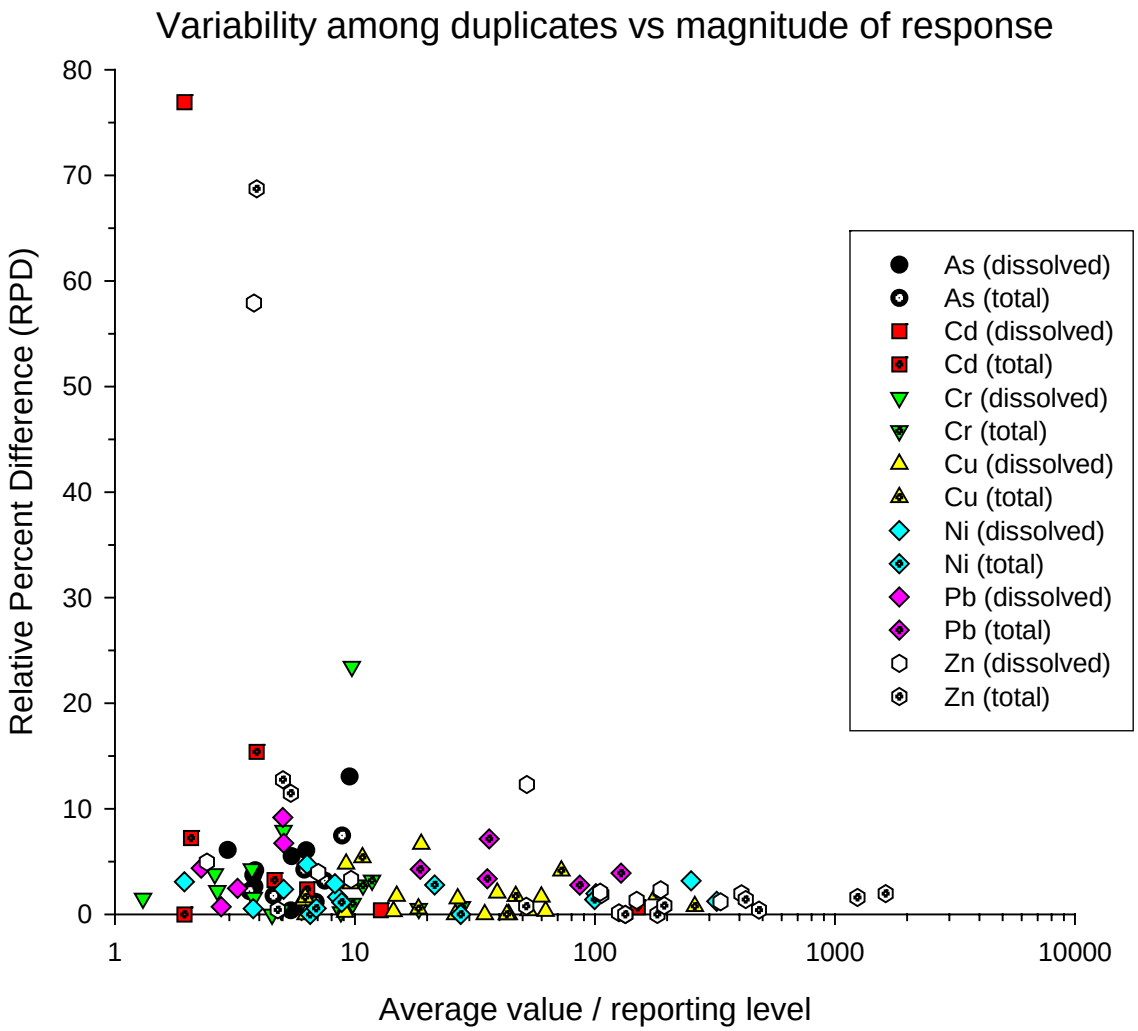


Figure 11. Variability among lab duplicates of field samples vs magnitude of response. Most duplicates had relative percent difference (RPD) values <10%, and were more than twice the reporting level. These data represent analyses only from CRG Marine Laboratories.

Table 1. Sampling event descriptions for each of the BMPs in this study.

Site	Sampling event	Sample Date	Type of sample	Antecedent dry weather period (days)	Flow volume sampled (gallons)
Wet CAT wetland (dry)	1 Inflow	11/17/04	Composite (time weighted)	8	203,773
	1 Outflow	11/18/04	Composite (time weighted)	9	208,167
	2 Inflow	12/15/04	Composite (time weighted)	6	163,815
	2 Outflow	12/16/04	Composite (time weighted)	7	169,486
	3 Inflow	1/19/05	Composite (time weighted)	7	51,534
	3 Outflow	1/20/05	Composite (time weighted)	8	50,673
	4 Inflow	3/9/05	Composite (time weighted)	5	65,559
	4 Outflow	3/10/05	Composite (time weighted)	6	64,347
OCWD sub-surface wetland (Experimental dosing)	1	2/3/05	Composite (multiple grabs)	5	Approx. 1,440
	2	2/10/05	Composite (multiple grabs)	12	Approx. 1,440
	3	2/24/05	Composite (multiple grabs)	0	Approx. 1,440
	4	3/3/05	Composite (multiple grabs)	7	Approx. 1,440
	5	3/10/05	Composite (multiple grabs)	6	Approx. 1,440
Pico-Kenter hydrodynamic device (dry)	1	11/18/04	Composite (time weighted)	9	Not measured
	2	12/16/04	Composite (time weighted)	7	Not measured
	3	1/20/05	Composite (time weighted)	8	Not measured
	4	3/10/05	Composite (time weighted)	6	Not measured
BC120 hydrodynamic device (dry)	1	1/19/05	Composite (time weighted)	7	11,176
	2	3/10/05	Composite (time weighted)	6	3,217
BC120 hydrodynamic device (storm)	1	1/26/05	Composite (flow weighted)	14	284,257
	2	2/11/05	Composite (flow weighted)	13	4,911,939
South Pasadena hydrodynamic device (storm)	1	12/5/04	Composite (time weighted)	5	55,475
	2	1/2/05	Composite (time weighted)	1	30,954 (toxicity); 163,113 (chemistry)
	3	1/7/05	Composite (time weighted)	1	20,332 (toxicity); 1,307,639 (chemistry)
	4	1/26/05	Composite (time weighted)	14	12,066 (toxicity); 13,884 (chemistry)
	5	2/11/05	Composite (time weighted)	12	39,677 (toxicity); 304,322 (chemistry)
SMURRF UV/filtration/ hydrodynamic device (dry)	1	11/18/04	Composite (time weighted)	9	201,907
	2	12/16/04	Composite (time weighted)	7	25,900
	3	1/20/05	Composite (time weighted)	8	333,043
	4	3/10/05	Composite (time weighted)	6	234,788
L.A. metal recycling yard screening/settlement (storm)	1	2/2/04	Composite (multiple grabs)	14	4,309
	2	2/18/04	Composite (multiple grabs)	15	27,460
	3	10/26/04	Grab	5	Not measured
	4	2/11/05	Grab	13	Not measured

Table 2. Constituents analyzed for each BMP site. Differences in the constituents among sites reflect differences in study design among the monitoring programs contributing data. OP pesticides = organophosphorus pesticides.

			Chemistry				Toxicity	
Site	Sampling event	Sample Date	Metals (dissolved & total)	OP pesticides	Pyrethroid pesticides	Glyphosate	*Ceriodaphnia dubia* chronic test	Sea urchin fertilization test
Wet CAT wetland (dry)	1 Inflow	11/17/04	✓	✓	✓	✓	Acute test	✓
	1 Outflow	11/18/04	✓	✓	✓	✓	Acute test	✓
	2 Inflow	12/15/04	✓	✓	✓	✓	Acute test	✓
	2 Outflow	12/16/04	✓	✓	✓	✓	Acute test	✓
	3 Inflow	1/19/05	✓	✓	✓	✓	Acute test	✓
	3 Outflow	1/20/05	✓	✓	✓	✓	Acute test	✓
	4 Inflow	3/9/05	✓	✓	✓	✓	✓	✓
	4 Outflow	3/10/05	✓	✓	✓	✓	✓	✓
OCWD sub-surface wetland (dry)	1	2/3/05	✓	✓				✓
	2	2/10/05	✓	✓				✓
	3	2/24/05	✓	✓				✓
	4	3/3/05	✓	✓				✓
	5	3/10/05	✓	✓				✓
Pico-Kenter hydrodynamic device (dry)	1	11/18/04	✓	✓	✓	✓	Acute test	✓
	2	12/16/04	✓	✓	✓	✓	Acute test	✓
	3	1/20/05	✓	✓	✓	✓		✓
	4	3/10/05	✓	✓	✓	✓	✓	✓
BC120 hydrodynamic device (dry)	1	1/19/05	✓	✓	✓	✓		✓
	2	3/10/05	✓	✓	✓	✓	✓	✓
BC120 hydrodynamic device (storm)	1	1/26/05	✓	✓	✓	✓		✓
	2	2/11/05	✓	✓	✓	✓	✓	✓
South Pasadena hydrodynamic device (storm)	1	12/5/04	✓	✓			✓	✓
	2	1/2/05	✓	✓			✓	✓
	3	1/7/05	✓	✓			✓	✓
	4	1/26/05	✓	✓			✓	✓
	5	2/11/05	✓	✓			✓	✓
SMURRF UV/filtration/ hydrodynamic device (dry)	1	11/18/04	✓	✓	✓	✓	Acute test	✓
	2	12/16/04	✓	✓	✓	✓	Acute test	✓
	3	1/20/05	✓	✓	✓	✓	Acute test	✓
	4	3/10/05	✓	✓	✓	✓	✓	✓
L.A. metal recycling yard screening/settlement (storm)	1	2/2/04	✓				✓	✓
	2	2/18/04	✓				✓	✓
	3	10/26/04	✓				✓	✓
	4	2/11/05	✓				✓	✓

Table 3. Constituent methods and reporting levels used to analyze the runoff samples. Differences reflect the multiple agencies involved, and the analytical laboratories that conducted the chemical analyses.

	SMURRF, Pico-Kenter, Wet CAT, BC120		L.A. metal recycling yard		South Pasadena	
Analyte	**Reporting Level**	**Method**	**Reporting Level**	**Method**	**Reporting Level**	**Method**
General						
Hardness (mg/L)	5	SM 2340 B	2	EPA 130.2	2	EPA 130.2
Dissolved Organic Carbon (mg/L)	0.5	EPA 415.1	0.5	EPA 415.1	Not analyzed	
Ammonia (mg/L)	0.05	SM 4500 NH3	0.10	EPA 350.2	0.1	EPA 350.3
pH	Not applicable	EPA 150.1	Not applicable	EPA 150.1	Not applicable	EPA 150.1
Conductivity (µmhos/cm)	0.2	SM 2510	1.0	EPA 120.1	Not analyzed	
Total dissolved solids (mg/L)	0.2	SM 2540 C	1.0	EPA 160.1	Not analyzed	
Total suspended solids (mg/L)	0.5	SM 2540 D	2.0	EPA 160.2	2	160.2
Metals (total and dissolved, µg/L)						
As	0.5	EPA 200.8	0.5	EPA 200.8	1.0	EPA 200.8
Cd	0.2	EPA 200.8	0.2	EPA 200.8	0.25	EPA 200.8
Cr	0.5	EPA 200.8	1.0	EPA 200.8	0.5	EPA 200.8
Cu	0.5	EPA 200.8	1.0	EPA 200.8	0.5	EPA 200.8
Fe	5.0	EPA 200.8	100	EPA 200.7	100	EPA 236.1
Pb	0.5	EPA 200.8	0.5	EPA 200.8	0.5	EPA 200.8
Hg	0.1	EPA 200.8	0.1	EPA 7470A	0.2	EPA 245.1
Ni	0.5	EPA 200.8	1.0	EPA 200.8	1.0	EPA 200.8
Se	0.5	EPA 200.8	1.0	EPA 200.8	1.0	EPA 200.8
Zn	0.5	EPA 200.8	5	EPA 200.8	1.0	EPA 200.8
Organics (µg/L)						
Organophosphate Pesticides[1]	0.01-0.02	EPA 625	Not analyzed		0.01-2.00	EPA 507
Pyrethroids[2]	0.01-0.025	EPA 625	Not analyzed		Not analyzed	
Glyphosate	6	EPA 547	Not analyzed		Not analyzed	

[1] OP pesticides include: Bolstar (Sulprofos), Chlorpyrifos, Coumaphos, Demeton, Diazinon, Dichlorvos, Dimethoate, Disulfoton, Ethoprop (Ethoprofos), Fenchlorophos (Ronnel), Fensulfothion, Fenthion, Guthion, Malathion, Merphos, Mevinphos (Phosdrin), Parathion-methyl, Phorate, Tetrachlorovinphos (Stirophos), Tokuthion, and Trichloronate.

[2] Pyrethroid pesticides include: Allethrin, Permethrin, Bifenthrin, Cyfluthrin, Cypermethrin, Deltamethrin, Fenpropathrin, Lamda Cyhalothrin, Prallethrin, and Pyrethrins.

Table 4. Freshwater chronic criteria used to compare the effluent data. For samples with a hardness >400 mg/L $CaCO_3$, a hardness of 400 mg/L is used in the calculations.

Constituent	Freshwater Chronic Criteria (µg/L)	Criterion Source
Metals (total)		
Al	87 for pH 6.5-9.0	Nat'l Criteria, EPA 2002
Se	5.0	Cal Toxics Rule, EPA 2000
Metals (dissolved)		
As	150	Cal Toxics Rule, EPA 2000
Cd	[1.101672 – ln(*hardness*) x 0.041838] x exp[0.7852 x ln(*hardness*) – 2.715]	Cal Toxics Rule, EPA 2000
Cu	0.96 x exp[0.8545 x ln(*hardness*) – 1.702]	Cal Toxics Rule, EPA 2000
Ni	0.997 x exp[0.846 x ln(*hardness*) + 0.0584]	Cal Toxics Rule, EPA 2000
Pb	[1.46203 – ln(*hardness*) x 0.145712] x exp[1.273 x ln(*hardness*) – 4.705]	Cal Toxics Rule, EPA 2000
Zn	0.986 x exp[0.8473 x ln(*hardness*) + 0.884]	Cal Toxics Rule, EPA 2000
OP pesticides		
Chlorpyrifos	0.041	Nat'l Criteria, EPA 2002
Diazinon	0.05	Cal Fish & Game, Siepmann and Finlayson 2000
Malathion	0.1	Nat'l Criteria, EPA 2002

Table 5. Average relative percent differences for duplicate lab measurements of field samples analyzed by CRG.

Constituent	Pairs of data (n)	Average RPD	Median RPD
Total metals			
As	7	2.9	2.2
Cd	6	4.8	2.8
Cr	7	0.5	0.5
Cu	12	1.6	1.2
Ni	7	1.0	1.1
Pb	7	5.8	4.3
Zn	12	8.4	1.1
Dissolved metals			
As	8	5.2	4.8
Cd	6	17.5	3.4
Cr	8	5.6	3.0
Cu	13	1.7	1.5
Ni	8	2.6	2.6
Pb	6	6.9	5.5
Zn	13	7.2	2.1

Table 6. Chemistry and toxicity measurements in pre- and post-BMP samples. The dates indicate when sampling was terminated. Non-detects were replaced with < reporting level. NA = not analyzed.

	11/18/04		12/16/04		1/20/05		3/9/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Wet CAT (instream wetland)								
General Constituents								
Ammonia (mg/L)	0.41	<0.05	0.43	<0.05	0.14	<0.05	0.06	<0.05
Conductivity (mS)	5.8	6.12	6.1	6.1	7.24	7.022	7.25	6.88
pH	7.67	8.14	7.7	8.2	7.5	8.0	7.6	8.1
Residual Chlorine (mg/L)	0.06	0.04	0.1	0.04	0.15	0.05	0.04	0.04
Total Dissolved Solids (mg/L)	463	488	5,060	5,170	6,300	6,240	5560	5610
Dissolved Organic Carbon (mg/L)	8.6	8.2	12	12	15	14	6.6	6.3
Total Hardness as CaCO3 (mg/L)	1,690	2,050	2,290	2,440	2,950	3,230	2440	2550
Total Suspended Solids (mg/L)	14.8	2.0	14.6	1.6	23.8	2.4	15.2	10.5
Metals (µg/L)								
Ag (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Al (dissolved)	65.4	3.21	78.9	3.42	106	3.61	113	2.42
As (dissolved)	2.8	2.88	3.11	2.95	3.05	3.05	3.84	5.06
Cd (dissolved)	2.56	0.89	9.58	0.76	8.55	1.32	37.1	0.24
Cr (dissolved)	2.62	3.77	3.71	3.07	4.62	3.71	5.05	5.43
Cu (dissolved)	7.26	9.24	8.95	9.54	10.7	10	10.2	9.13
Hg (dissolved)	<0.1	<0.1	<0.1	<0.1	0.07	<0.1	<0.1	<0.1
Ni (dissolved)	128	30.9	146	31.5	387	57.5	308	51
Pb (dissolved)	<0.5	0.25	<0.5	<0.5	<0.5	<0.5	0.05	0.05
Se (dissolved)	29.5	28.4	36.6	31.3	44	40.3	47.3	47.06
Sn (dissolved)	<0.5	<0.5	0.7	0.69	<0.5	<0.5	<0.5	<0.5
Zn (dissolved)	53.1	30.5	66.3	22.4	136	30.9	135	24.4
Ag (total)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Al (total)	1,150	1,170	617	3.6	3,470	12.6	2110	84.3
As (total)	3.45	3.02	3.95	4.41	4.1	4.13	4.28	4.26
Cd (total)	30.1	0.88	33.4	0.75	77.5	0.98	69.9	0.72
Cr (total)	5.33	4.51	5.14	4.93	5.51	4.12	5.9	4.92
Cu (total)	13.1	10	11	8.84	14	10	13	9.18
Hg (total)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (total)	162	33.5	146	36.4	323	53.2	281	50.2
Pb (total)	0.43	0.66	<0.5	<0.5	0.23	<0.5	0.1	0.13
Se (total)	36.6	29.9	43.9	39.4	52	44.6	52.4	42.7
Sn (total)	<0.5	<0.5	0.69	0.69	<0.5	<0.5	<0.5	<0.5
Zn (total)	97	34.8	84.1	21	208	19.6	170	25.8
Organophosphorus pesticides (µg/L)[1]								
Diazinon	0.03	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01
Malathion	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Other OP pesticides	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pyrethroid pesticides (µg/L)[2]	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Glyphosate (µg/L)	<6	<6	<6	<6	<6	<6	<6	<6
Toxicity								
C. dubia % survival (100% sample)	0	35	5	55	0	20	0	0
C. dubia reproduction, % control (100% sample)	NA	NA	NA	NA	NA	NA	0	0
Echinoderm fertilization (50% sample)	69	85	91	98	27	74	11	39

[1] OP pesticides include: Bolstar (Sulprofos), Chlorpyrifos, Coumaphos, Demeton, Diazinon, Dichlorvos, Dimethoate, Disulfoton, Ethoprop (Ethoprofos), Fenchlorophos (Ronnel), Fensulfothion, Fenthion, Guthion, Malathion, Merphos, Mevinphos (Phosdrin), Parathion-methyl, Phorate, Tetrachlorovinphos (Stirophos), Tokuthion, and Trichloronate.

[2] Pyrethroid pesticides include: Allethrin, Permethrin, Bifenthrin, Cyfluthrin, Cypermethrin, Deltamethrin, Fenpropathrin, Lamda Cyhalothrin, Prallethrin, and Pyrethrins.

Table 6 continued

	2/3/05		2/10/05		2/24/05		3/3/05		3/10/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
OCWD Replicate #1 (sub-surface flow wetland)										
Metals (µg/L)										
Cu (dissolved)	43.3	3.11	26.6	3.16	25.7	3.97	25.3	4.35	21.4	7.6
Zn (dissolved)	120	5.99	69.4	3.32	63.6	0.63	54.2	0.41	58.7	14.8
Cu (total)	52.4	3.15	29.7	3.34	36.6	2.25	31.2	5.54	24.77	8.86
Zn (total)	128	3.02	66.4	2.47	67.3	4.26	61.3	2.41	64.67	16.3
Organophosphorus pesticides (µg/L)										
Diazinon	0.04	<0.03	0.07	0.08	0.23	0.19	0.33	0.29	0.43	0.31
Toxicity										
Echinoderm fertilization (50% sample)	60	92	93	98	99	100	90	96	86	95
OCWD Replicate #2 (subsurface flow wetland)										
Metals (µg/L)										
Cu (dissolved)	6.61	3.11	9.24	3.07	22.5	4.49	21.9	4.28	18.5	4.56
Zn (dissolved)	27.8	4.74	30.6	3.59	64.2	1.18	63.1	0.12	54.8	1.35
Cu (total)	10.7	3.08	12.9	3.12	23.2	4.88	23.2	4.75	20.8	5.52
Zn (total)	36.6	2.35	33.8	2.39	67.3	2.86	66.9	1.99	61.9	2.62
Organophosphorus pesticides (µg/L)										
Diazinon	0.36	<0.03	0.11	0.08	0.28	0.23	0.32	0.22	0.46	0.29
Toxicity										
Echinoderm fertilization (50% sample)	99	99	98	98	99	99	81	96	90	98

Table 6 continued

	11/18/04		12/16/04		1/20/05		3/10/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Pico-Kenter (CDS)								
General Constituents								
Ammonia (mg/L)	<0.05	<0.05	0.05	0.03	0.05	0.04	<0.05	0.08
Conductivity (mS)	0.931	0.923	1	1	0.824	0.825	1.86	1.76
pH	8.05	7.97	8.3	8.3	8.1	8.1	8.4	8.3
Residual Chlorine (mg/L)	0.07	0.07	0.08	0.07	0.19	0.16	0.05	0.36
Total Dissolved Solids (mg/L)	35	41	750	630	1,120	1,100	940	790
Dissolved Organic Carbon (mg/L)	11	11	12	11	6	5	5	5
Total Hardness as CaCO3 (mg/L)	173	169	223	224	207	210	417	389
Total Suspended Solids (mg/L)	11.4	9.2	0.9	3.6	19.8	17.0	26.5	27.5
Metals (µg/L)								
Ag (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.02
Al (dissolved)	10.2	14.5	14.4	11.2	7.63	5.67	4.84	5.51
As (dissolved)	2.82	2.83	3.23	3.06	1.48	1.5	2.59	2.71
Cd (dissolved)	0.11	<0.2	0.14	0.14	0.18	<0.2	<0.2	<0.2
Cr (dissolved)	1.06	1.14	1.9	1.95	0.94	0.82	2.09	1.87
Cu (dissolved)	11.5	11.8	19.8	17.7	4.37	4.16	7.95	7.83
Hg (dissolved)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (dissolved)	2.22	2.27	2.49	2.4	1.51	1.39	2.75	2.68
Pb (dissolved)	0.26	0.26	<0.5	<0.5	<0.5	<0.5	0.16	0.14
Se (dissolved)	1.29	1.46	2.05	1.62	2.25	2.61	5.97	5.3
Sn (dissolved)	<0.5	<0.5	0.82	0.83	<0.5	<0.5	<0.5	<0.5
Zn (dissolved)	28.9	30.5	52.7	48.4	7.52	6.89	17.6	14.6
Ag (total)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Al (total)	167	168	84.5	102	256	284	2240	840
As (total)	2.96	2.90	62.10	3.36	1.87	1.87	2.58	4.23
Cd (total)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	3.01
Cr (total)	1.62	1.65	2.48	2.56	1.65	1.68	5.59	10.7
Cu (total)	20.7	21.6	19	19.9	8.28	8.01	27.9	51.4
Hg (total)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (total)	2.84	2.77	3.76	3.71	2.29	2.24	7.9	35.1
Pb (total)	3.35	3.21	2.87	3.6	2.32	1.92	4.71	45.4
Se (total)	1.35	1.24	2.56	2.66	2.95	3.036	5.4	5.97
Sn (total)	<0.5	<0.5	0.82	0.83	<0.5	<0.5	<0.5	<0.5
Zn (total)	55.7	58.2	56.2	59.3	18.2	17.1	97.9	465
Organophosphorus pesticides (µg/L)[1]								
Chlorpyrifos	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12
Other OP pesticides	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pyrethroid pesticides (µg/L)[2]	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Glyphosate (µg/L)	<6	<6	<6	<6	<6	<6	<6	<6
Toxicity								
C. dubia % survival (100% sample)	90	95	100	100	NA[3]	NA[3]	100	100
C. dubia reproduction, % control (100% sample)	NA	NA	NA	NA	NA	NA	124	117
Echinoderm fertilization (50% sample)	83	70	59	43	84	5	68	59

[3] FedEx temporarily lost this sample. The holding time had expired before the sample was found.

Table 6 continued

	1/19/05 (dry)		1/26/05 (wet)		2/11/05 (wet)		3/10/05 (dry)	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
BC120 (CDS)								
General Constituents								
Ammonia (mg/L)	0.02	0.03	0.45	0.45	0.33	0.55	0.01	0.01
Conductivity (mS)	0.709	0.707	0.176	0.186	0.063	0.090	0.65	0.67
pH	7.4	7.1	7.4	7.4	6.5	6.5	7.7	7.8
Residual Chlorine (mg/L)	0.18	0.19	0.04	0.04	0.2	0.27	0.11	0.09
Total Dissolved Solids (mg/L)	1,040	1,110	810	770	<0.2	<0.2	1,050	290
Dissolved Organic Carbon (mg/L)	14	14	28	29	7	13	10	9
Total Hardness as $CaCO_3$ (mg/L)	144	140	29.8	29.5	10	16.4	103	106
Total Suspended Solids (mg/L)	51	14	204	217	84	140	17	8
Metals (µg/L)								
Ag (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.12	<0.2
Al (dissolved)	7.91	9.9	47.7	51.9	51.8	73.4	18.8	29.1
As (dissolved)	2.7	2.7	1.85	1.88	1.43	1.93	4.05	4.09
Cd (dissolved)	0.24	0.17	0.16	0.12	<0.2	<0.2	<0.2	<0.2
Cr (dissolved)	2.04	1.91	1.33	1.32	0.65	2.26	1.35	1.32
Cu (dissolved)	17.3	17.4	29.7	31.2	7.4	13.5	23.3	23.2
Hg (dissolved)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (dissolved)	3.07	3.24	4.07	4.2	0.96	1.89	2.44	2.42
Pb (dissolved)	1.34	1.38	2.61	2.62	1.17	1.64	2.37	2.01
Se (dissolved)	1.27	1.26	1.04	0.85	<0.5	<0.5	2.36	2.52
Sn (dissolved)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zn (dissolved)	67.5	74.2	202	166	66.9	95	88.1	62.8
Ag (total)	<0.2	<0.2	<0.2	0.16	<0.2	<0.2	0.16	0.16
Al (total)	461	305	3,140	4,880	885	948	370	176
As (total)	3.02	3.14	3.15	3.81	1.84	2.31	4.31	4.29
Cd (total)	<0.2	<0.2	0.91	1.28	0.39	0.4	<0.2	<0.2
Cr (total)	2.71	2.47	9.25	13.9	4.38	5.8	1.85	1.59
Cu (total)	29.2	21.5	89.5	131	26.4	35.5	35.2	30.6
Hg (total)	0.07	0.08	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (total)	4.09	3.44	10.6	13.8	3.26	4.43	2.97	2.69
Pb (total)	14	9.57	42.7	65.5	17.5	18.8	14.5	9.67
Se (total)	2.04	2.16	1.59	1.66	<0.5	<0.5	2.11	2.21
Sn (total)	<0.5	<0.5	0.35	0.38	0.2	0.18	0.1	0.1
Zn (total)	120	91.1	616	806	211	241	111	74.7
Organophosphorus pesticides (µg/L)[1]								
Diazinon	<0.01	<0.01	<0.01	<0.01	0.08	0.04	0.04	0.04
Other OP pesticides	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pyrethroid pesticides (µg/L)[2]								
Bifenthrin	0.13	0.14	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Other pyrethroid pesticides	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Glyphosate (µg/L)	<6	<6	<6	<6	<6	<6	<6	<6
Toxicity								
C. dubia % survival (100% sample)	NA[3]	NA[3]	NA[4]	NA[4]	100	100	100	100
C. dubia reproduction, % control (100% sample)	NA	NA	NA	NA	92	108	122	119
Echinoderm fertilization (50% sample)	1	20	27	1	10	10	76	67

[3] FedEx temporarily lost this sample. The holding time had expired before the sample was found.

[4] This test had poor control survival, and no usable data were obtained.

Table 6 continued

	12/5/04		1/2/05		1/7/05		1/26/05		2/11/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
South Pasadena (CDS)										
General Constituents										
Ammonia (mg/L)	0.512	0.56	0.354	0.464	0.236	0.304	0.566	0.603	0.11	<0.1
Conductivity (mS)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
pH	6.07	6.05	6.1	5.95	6.06	5.89	6.48	6.08	6.23	6.27
Residual Chlorine (mg/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Dissolved Solids (mg/L)	4	6	36	188	22	22	46	32	6	2
Dissolved Organic Carbon (mg/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness as CaCO3 (mg/L)	18.0	20.0	20.0	60.0	12.0	20.0	34	36	12	14
Total Suspended Solids (mg/L)	9.0	14.0	868.1	26.0	33.0	26.0	75	118	126	107
Metals (µg/L)										
Ag (dissolved)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Al (dissolved)	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
As (dissolved)	<1	<1	<1	<1	<1	<1	1.80	1.53	<1	<1
Cd (dissolved)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<.25
Cr (dissolved)	<0.5	0.51	0.49	0.61	0.65	1	1.37	1.7	0.83	0.79
Cu (dissolved)	10.1	11.5	6.23	9.99	5.85	6.62	21.3	17.2	5.63	5.44
Hg (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ni (dissolved)	1.24	1.19	1.17	1.4	<1	<1	3.11	2.93	<1	<1
Pb (dissolved)	0.67	1.01	1.25	1.14	0.59	ND	0.65	0.90	<0.5	<0.5
Se (dissolved)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zn (dissolved)	61.5	81.9	39.5	44.8	17.4	21.7	135	141	47.6	52.3
Ag (total)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	0.26	<0.25
Al (total)	590	294	383	<100	<100	<100	245	448	3,610	11,000
As (total)	<1	<1	<1	<1	1.42	1.3	2.56	1.87	1.32	<1
Cd (total)	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	0.29	0.25	0.48	0.32
Cr (total)	1.97	2.15	2.06	0.92	1.04	1.11	1.56	2.19	6.71	5.59
Cu (total)	31.7	28.7	20.6	15.2	7.43	7.79	23.8	25.2	37.7	29.5
Hg (total)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ni (total)	4.28	4.64	2.27	1.89	1.02	1.37	3.81	3.49	6.4	4.47
Pb (total)	8.37	7.94	10.4	2.12	4.59	1.96	3.71	5.53	25.2	21.3
Se (total)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zn (total)	116	102	74.2	59.8	78.4	78.4	117	147	173	125
Organophosphorus pesticides (µg/L)[1]										
Chlorpyrifos	<0.05	<0.05	<0.05	<0.05	0.16	0.13	0.62	1.04	<0.05	<0.05
Diazinon	0.06	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Pyrethroid pesticides (µg/L)[2]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Glyphosate (µg/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toxicity										
C. dubia % survival (100% sample)	100	100	100	100	100	100	80	80	100	100
C. dubia reproduction, % control (100% sample)	135	139	133	152	100	96	91	83	96	121
Echinoderm fertilization (50% sample)	7	6	22	11	3	3	2	1	1	1

Table 6 continued

	11/18/04		12/16/04		1/20/05		3/10/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
SMURRF (UV with pretreatment)								
General Constituents								
Ammonia (mg/L)	0.14	0.05	0.05	0.1	0.06	<0.05	<0.05	0.02
Conductivity (mS)	0.98	0.981	1	1	0.799	0.804	1.52	1.49
pH	7.98	8.27	8.1	8.4	8	8.2	8.3	8.4
Residual Chlorine (mg/L)	0.05	0.66	0.07	0.23	0.17	0.35	0.05	0.08
Total Dissolved Solids (mg/L)	40	40	750	740	1,190	1,040	720	760
Dissolved Organic Carbon (mg/L)	12	11	10	9	6	6	5.3	4.9
Total Hardness as CaCO3 (mg/L)	173	167	217	219	194	197	355	346
Total Suspended Solids (mg/L)	8	<0.5	21.2	0.2	21.6	<0.5	44	<0.5
Metals (µg/L)								
Ag (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Al (dissolved)	11.2	9.96	15.3	8.65	6.88	3.65	4.57	1.6
As (dissolved)	2.91	2.82	3.39	3.44	1.59	1.59	2.79	2.67
Cd (dissolved)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cr (dissolved)	1.17	1.09	1.54	1.78	0.85	0.82	1.23	1.4
Cu (dissolved)	11.5	10.8	9.45	12.4	4.59	4.36	4.9	6.74
Hg (dissolved)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni (dissolved)	2.54	2.25	2.98	3.01	1.4	1.29	3.41	3.28
Pb (dissolved)	0.24	0.22	<0.5	<0.5	<0.5	<0.5	0.17	0.12
Se (dissolved)	1.33	1.48	2.63	2.95	2.42	2.7	6.1	6.01
Sn (dissolved)	<0.5	<0.5	0.78	0.8	<0.5	<0.5	<0.5	<0.5
Zn (dissolved)	28.8	23.7	35.7	32.1	11	8.52	21.3	14
Ag (total)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Al (total)	148	11.4	217	9.58	267	<5	308	<5
As (total)	3.01	2.83	3.35	3.59	1.98	1.92	3	2.64
Cd (total)	<0.2	<0.2	0.21	0.14	<0.2	<0.2	<0.2	<0.2
Cr (total)	1.95	1.15	2.56	2.11	1.63	0.97	2.41	1.67
Cu (total)	22	11	31.2	13.9	7.98	4.26	16.2	6.7
Hg (total)	<0.1	<0.1	<0.1	<0.1	<0.1	0.07	<0.1	<0.1
Ni (total)	3.04	2.15	3.5	1.2	2.18	1.46	4.14	3.16
Pb (total)	2.47	0.52	5.88	0.32	2.06	0.11	3.4	0.09
Se (total)	1.39	1.5	1.2	2.5	3.11	3.79	6.12	6.26
Sn (total)	<0.5	<0.5	0.77	0.82	<0.5	<0.5	<0.5	<0.5
Zn (total)	50.4	24.1	85.8	38.5	18	8.59	39.8	12.8
Organophosphorus pesticides (µg/L)[1]								
Malathion	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.03
Other OP pesticides	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pyrethroid pesticides (µg/L)[2]	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Glyphosate (µg/L)	<6	<6	<6	<6	<6	<6	<6	<6
Toxicity								
C. dubia % survival (100% sample)	95	0	100	100	80	80	100	100
C. dubia reproduction, % control (100% sample)	NA	NA	NA	NA	NA	NA	114	100
Echinoderm fertilization (50% sample)	82	0	20	0	56	0	76	75

Table 6 continued

	2/2/04		2/18/04		10/26/04		2/11/05	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
L.A. metal recycling yard (grit removal)								
General Constituents								
Ammonia (mg/L)	0.84	0.91	1.3	1.1	1.2	1.1	NA	NA
Conductivity (mS)	0.76	0.95	0.93	1.50	1.30	1.50	1.37	1.17
pH	8.01	5.63	8.80	7.14	8.93	7.14	11.15	11.6
Residual Chlorine (mg/L)	NA	NA	NA	NA	NA	NA	NA	NA
Total Dissolved Solids (mg/L)	520	670	700	1,200	1,100	1,200	1,400	1,400
Dissolved Organic Carbon (mg/L)	110	97	110	200	130	200	130	440
Total Hardness as CaCO3 (mg/L)	200	320	330	520	620	520	540	640
Total Suspended Solids (mg/L)	61	170	440	240	320	240	1,200	1,200
Metals (µg/L)								
Ag (dissolved)	<1	<1	<1	<1	<1	<1	1	1
Al (dissolved)	<50	<50	<50	<50	76.5	<50	248	379
As (dissolved)	<0.5	<0.5	1.22	<0.5	2.96	<0.5	2.03	2.94
Cd (dissolved)	2.48	14.1	0.737	5.17	3.26	5.17	0.627	0.285
Cr (dissolved)	16.7	3.53	12.7	2.99	8.95	2.99	75.5	48.3
Cu (dissolved)	116	58.4	87.2	47	59.7	47	97.3	87.4
Hg (dissolved)	0.219	0.180	0.235	0.279	0.175	0.279	0.1	0.1
Ni (dissolved)	425	226	46.5	68.4	38	68.4	32	21
Pb (dissolved)	11.8	6.16	27.9	3.69	47.1	3.69	120	185
Se (dissolved)	<1	2.76	10.8	15.7	5.14	15.7	7.36	7.02
Sn (dissolved)	<1	<1	<1	<1	1.42	<1	3.54	2.29
Zn (dissolved)	244	1550	33	696	230	696	16.9	26.6
Ag (total)	<1	<1	1.7	1.2	<1	1.2	5.43	6.14
Al (total)	434	868	8,360	3,410	2,380	3,410	5,930	5,620
As (total)	1.72	5.4	11.9	6.18	6.9	6.18	9.35	10.3
Cd (total)	9.1	19.1	17.5	12.5	15.1	12.5	24.1	46.4
Cr (total)	56.9	59.8	76.1	36.7	22.7	36.7	144	111
Cu (total)	192	223	792	330	148	330	293	303
Hg (total)	1.48	3.48	8.19	3.92	1.97	3.92	4.3	3.9
Ni (total)	496	273	120	89.5	61	89.5	94	85
Pb (total)	292	486	3,020	1,560	834	1,560	1,430	1,500
Se (total)	<1	6.95	13.7	14.2	6.52	14.2	7.12	7.31
Sn (total)	4.44	4.9	30	23.5	16.2	23.5	20.5	21
Zn (total)	1,090	2,790	2,110	1,410	2,110	1,410	3,220	2,690
Organophosphorus pesticides (µg/L)[1]	NA	NA	NA	NA	NA	NA	NA	NA
Pyrethroid pesticides (µg/L)[2]	NA	NA	NA	NA	NA	NA	NA	NA
Glyphosate (µg/L)	NA	NA	NA	NA	NA	NA	NA	NA
Toxicity								
C. dubia % survival (100% sample)	0	0	60	0	0	0	0	0
C. dubia reproduction, % control (100% sample)	0	0	0	0	0	0	0	0
Echinoderm fertilization (50% sample)	0	0	0	1	34	86	0	0

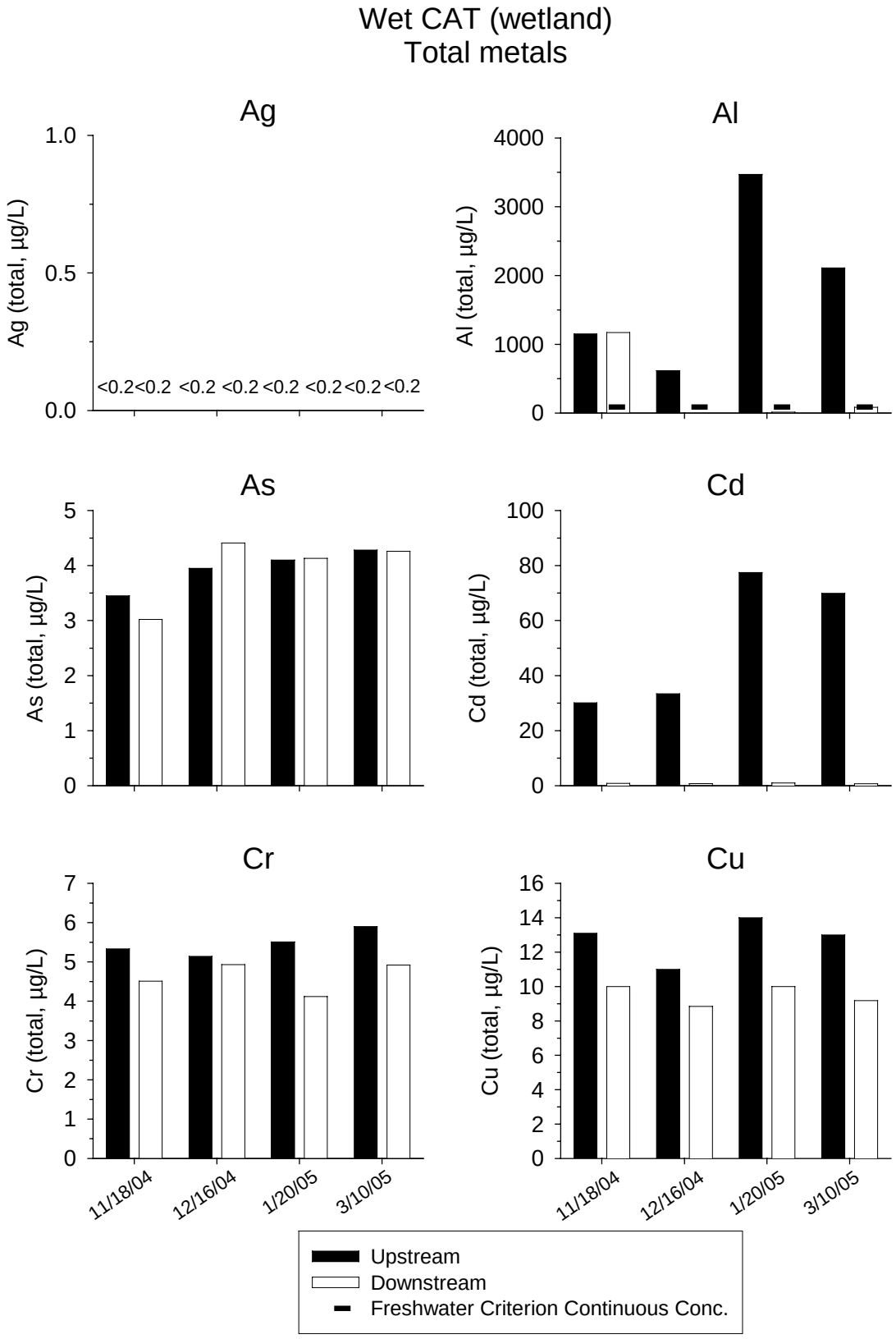


Figure 12. Concentrations of total metals and total suspended solids (TSS) at the Wet CAT site over four sampling events.

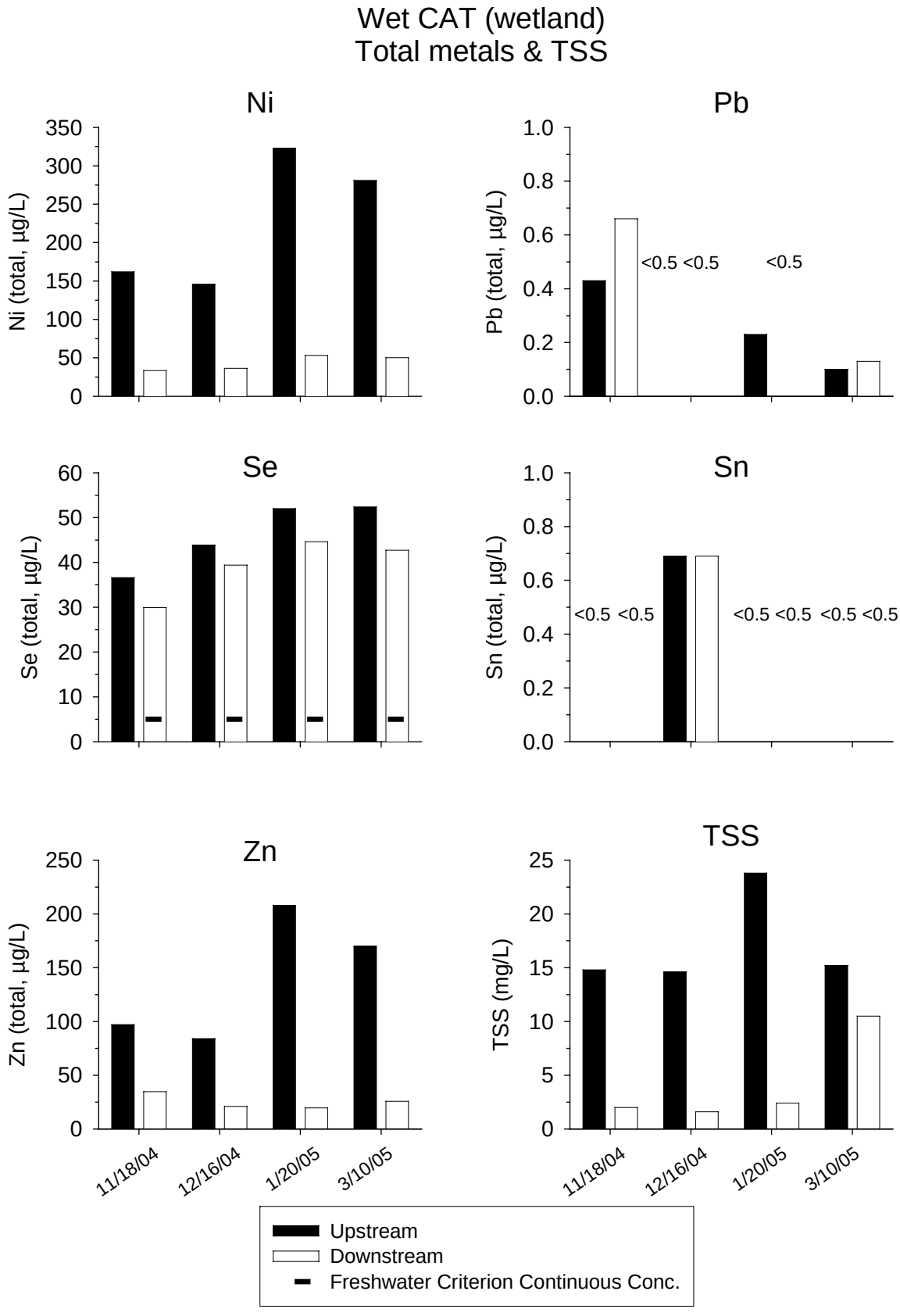


Figure 12 continued.

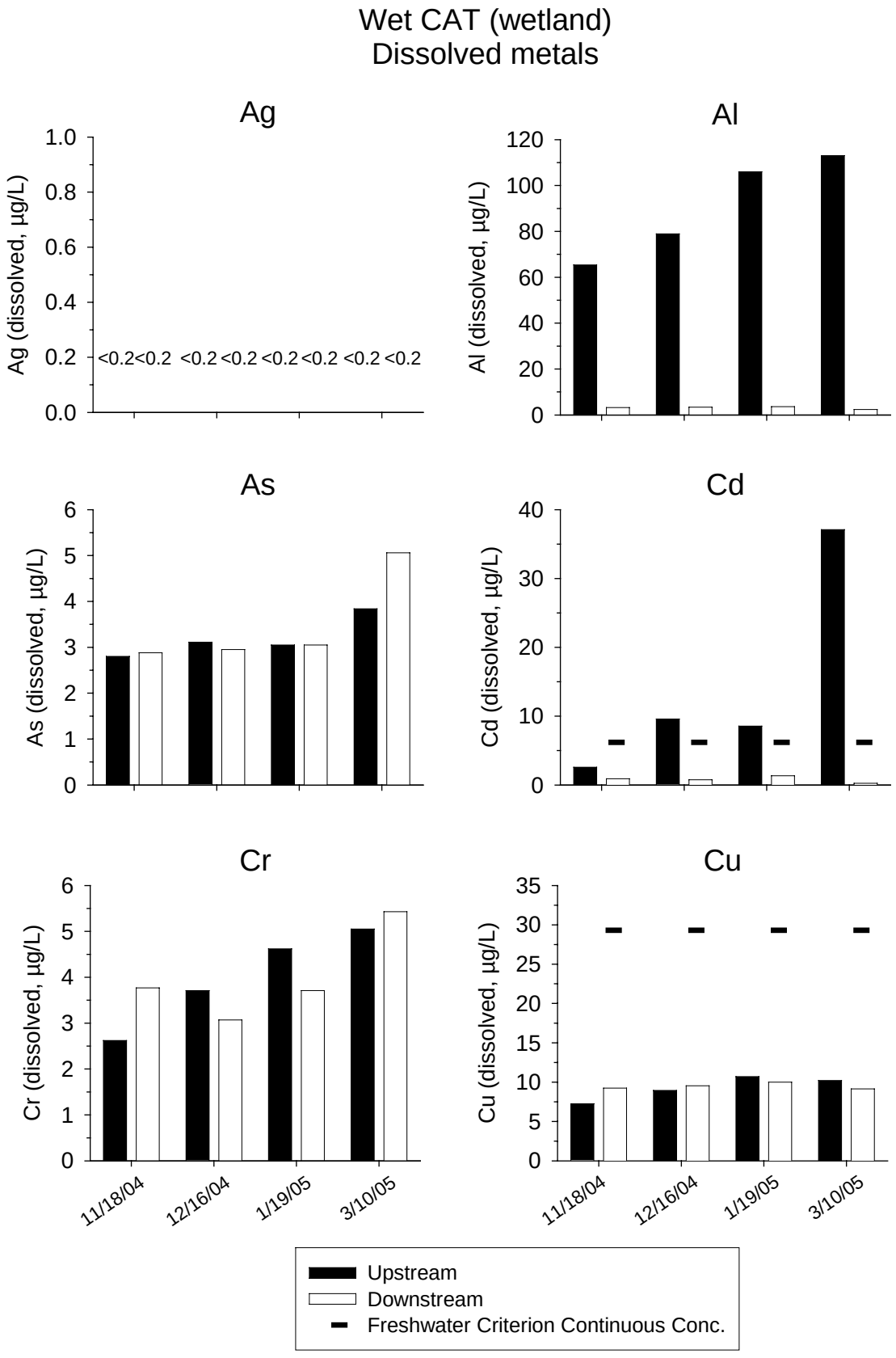


Figure 13. Concentrations of dissolved metals at the Wet CAT site over four sampling events. The chronic criteria for dissolved As (150 µg/L) and Pb (10.9 µg/L) are not shown.

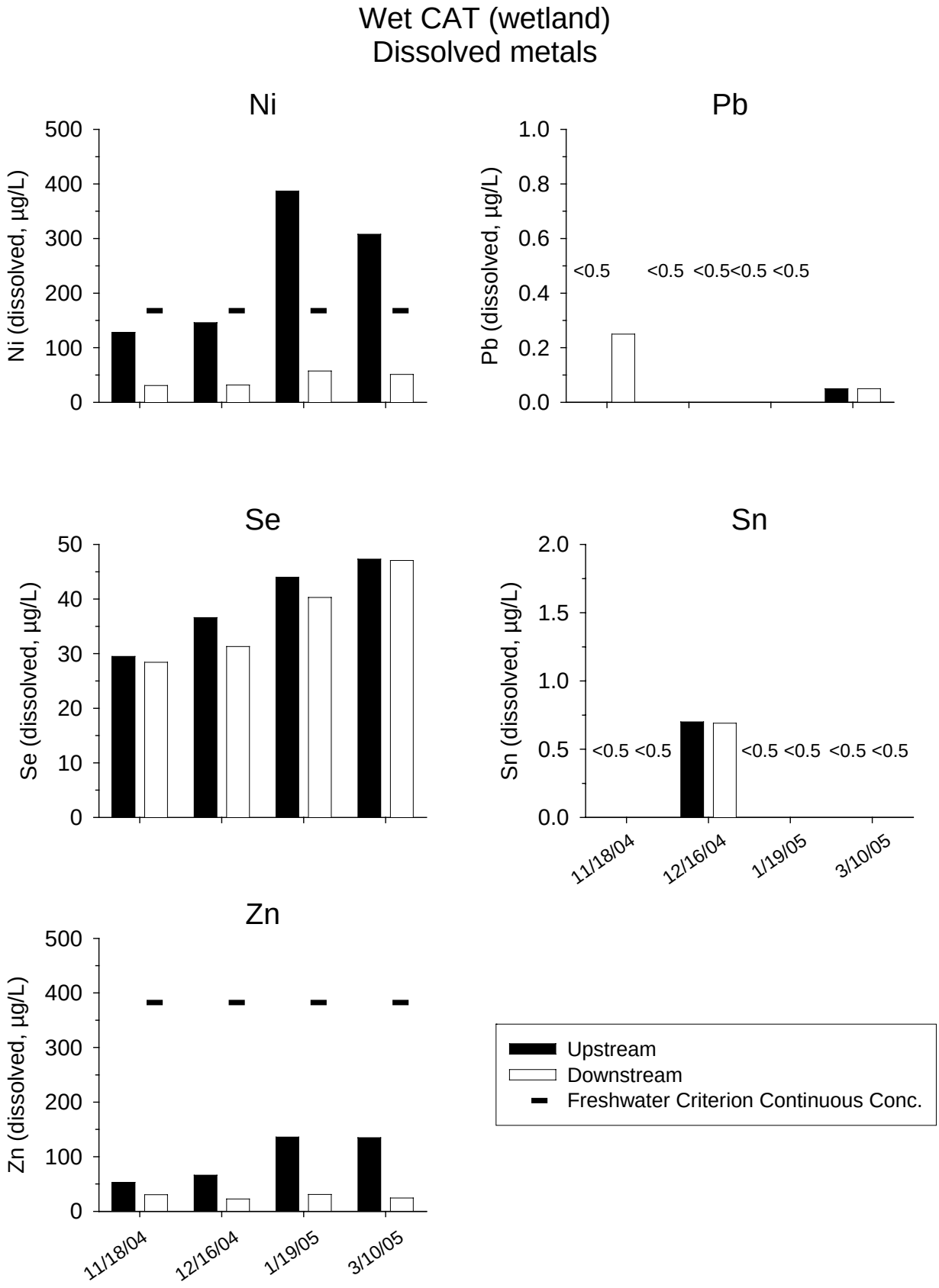


Figure 13 continued.

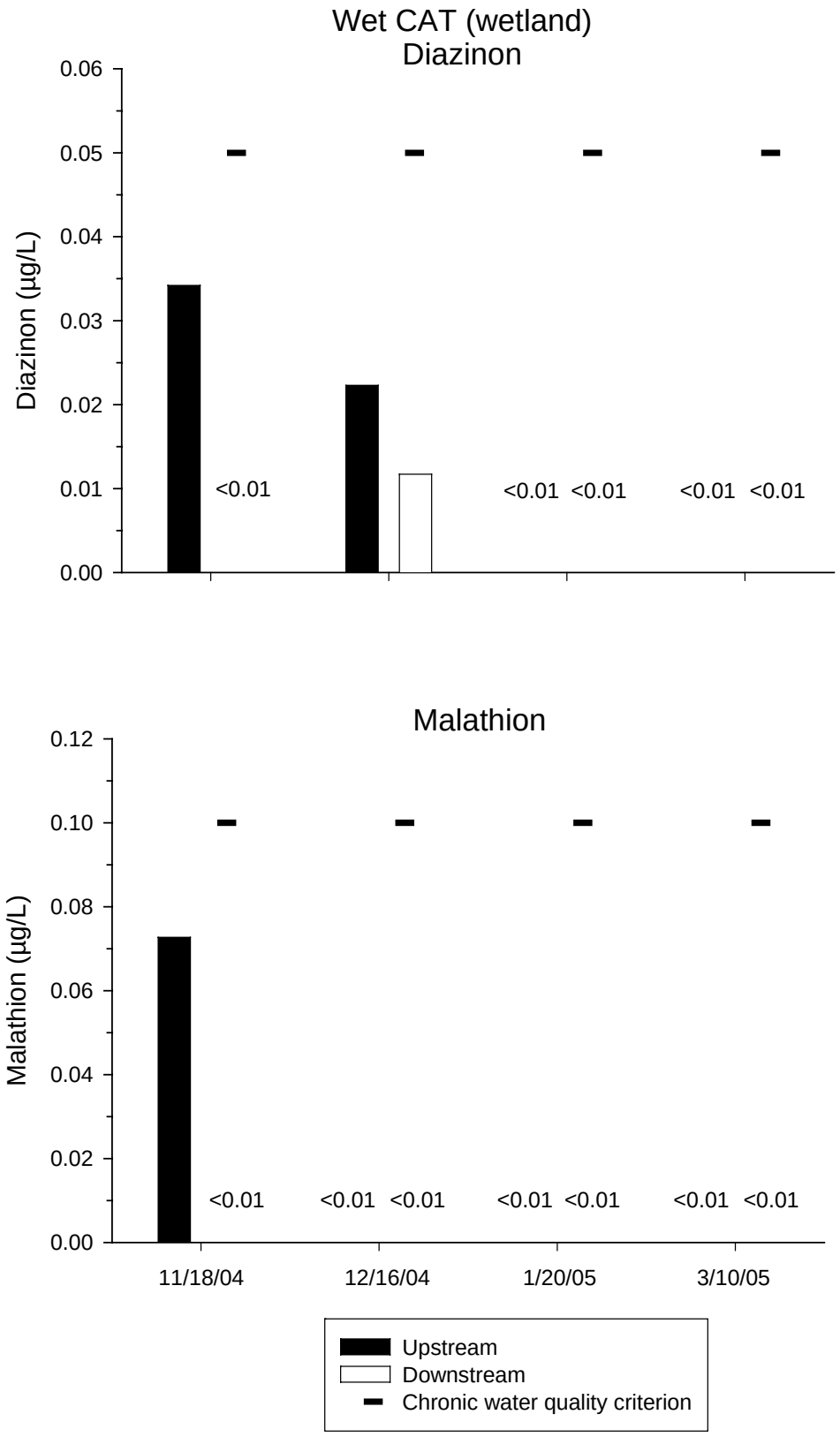


Figure 14. Concentrations of diazinon and malathion at the Wet CAT site.

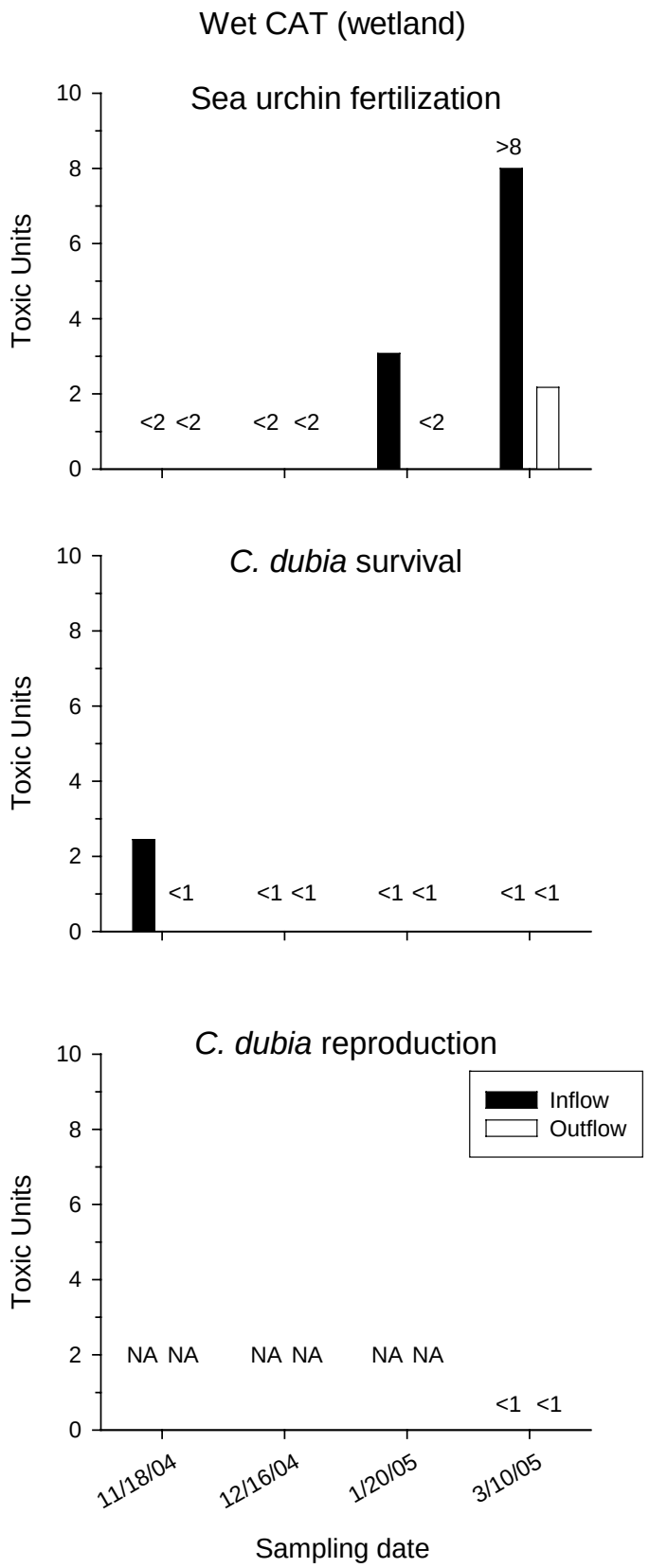


Figure 15. Toxicity in the Wet CAT samples. NA = not analyzed.

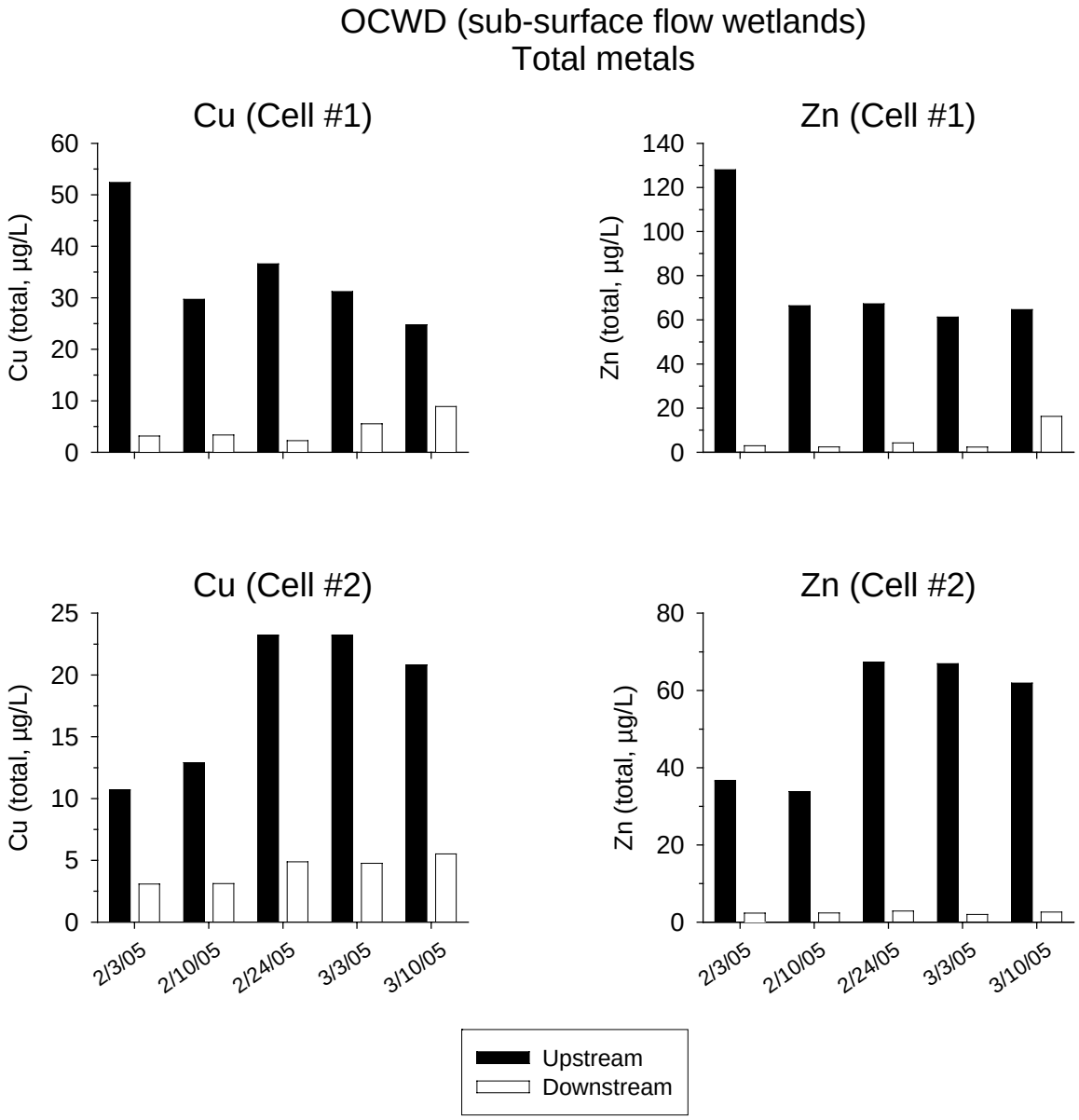


Figure 16. Concentrations of total metals at the OCWD sub-surface flow wetland site over five sampling events.

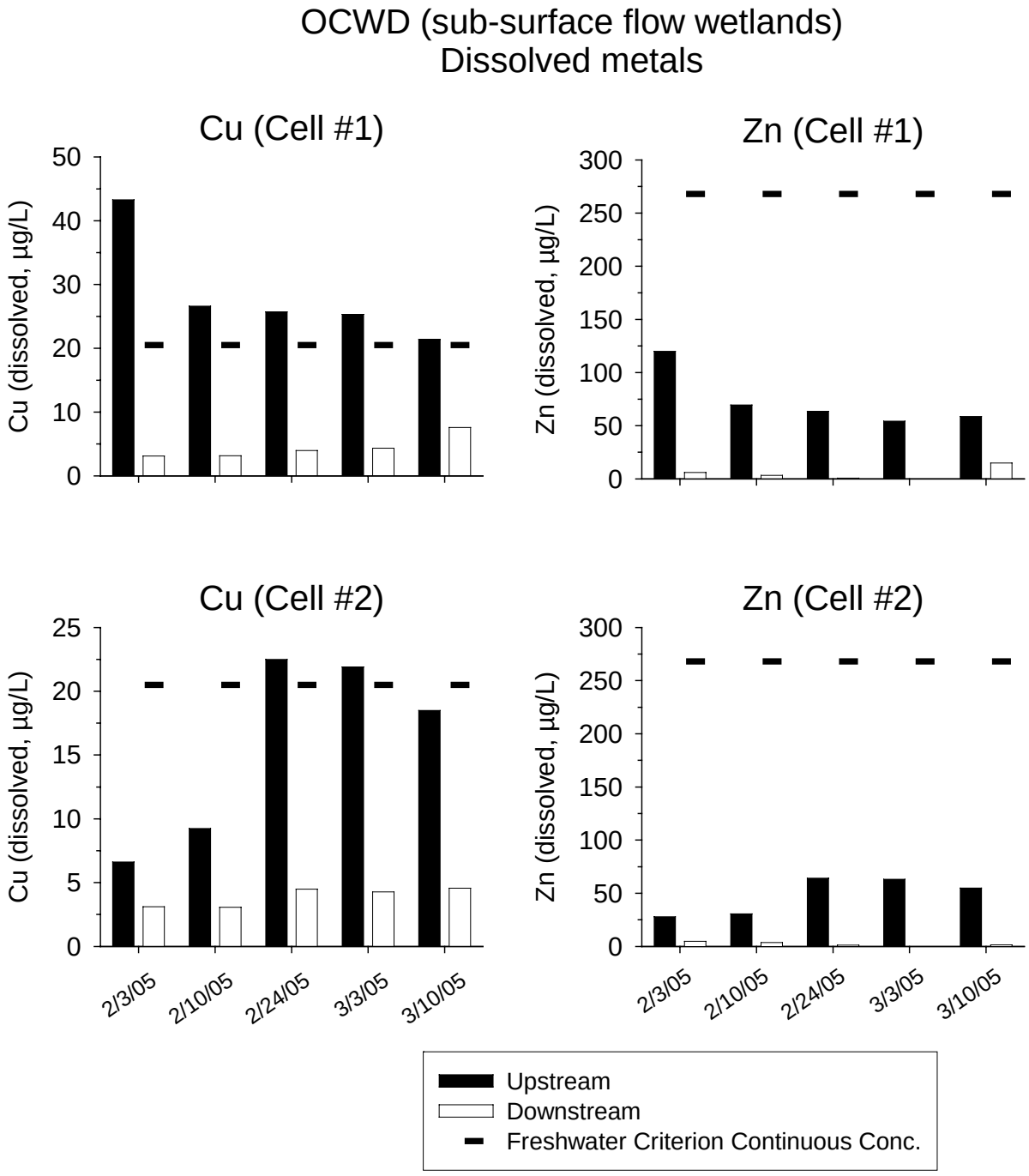


Figure 17. Concentrations of dissolved metals at the OCWD sub-surface flow wetland site over five sampling events.

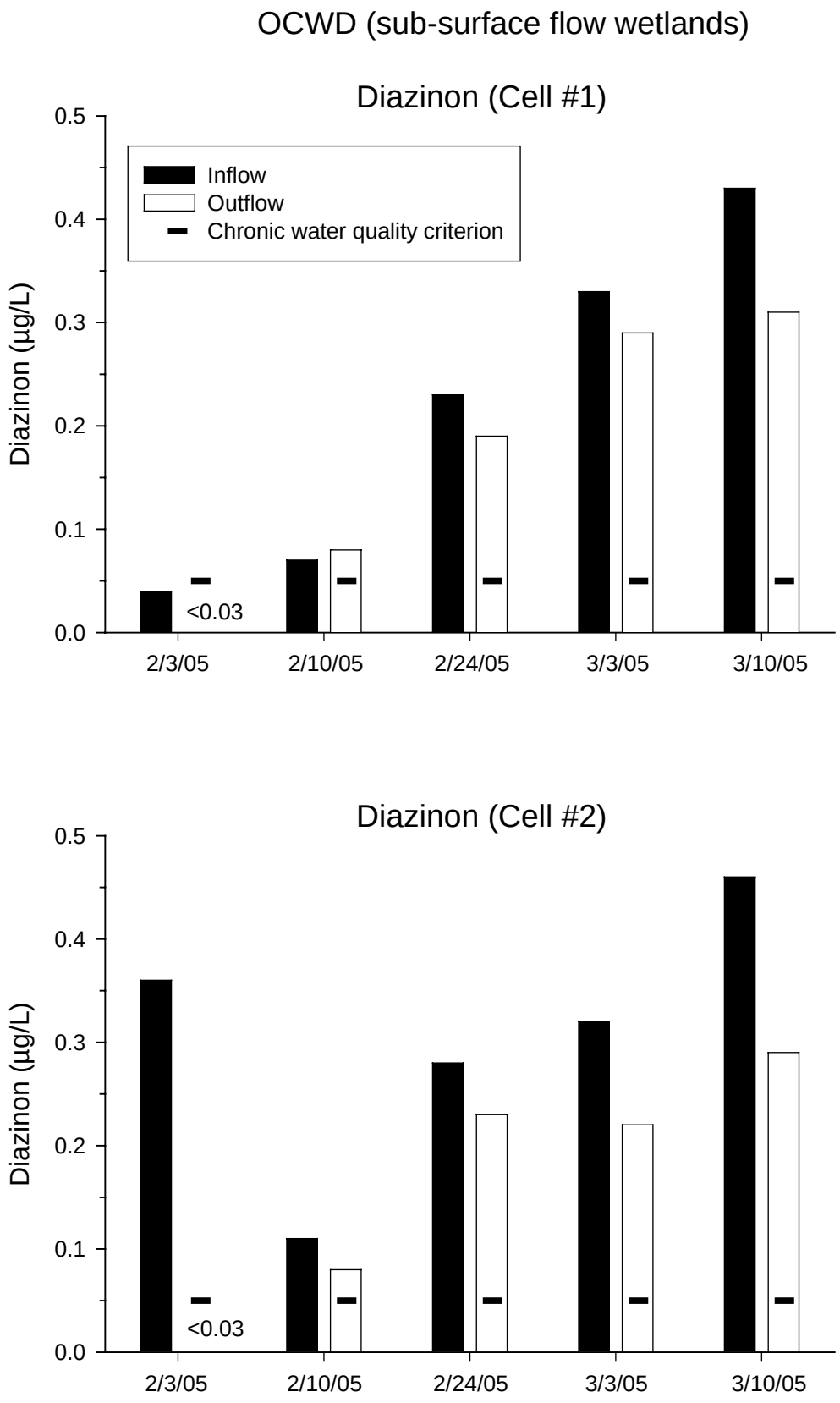


Figure 18. Concentrations of diazinon at the OCWD sub-surface flow wetland site over five sampling events.

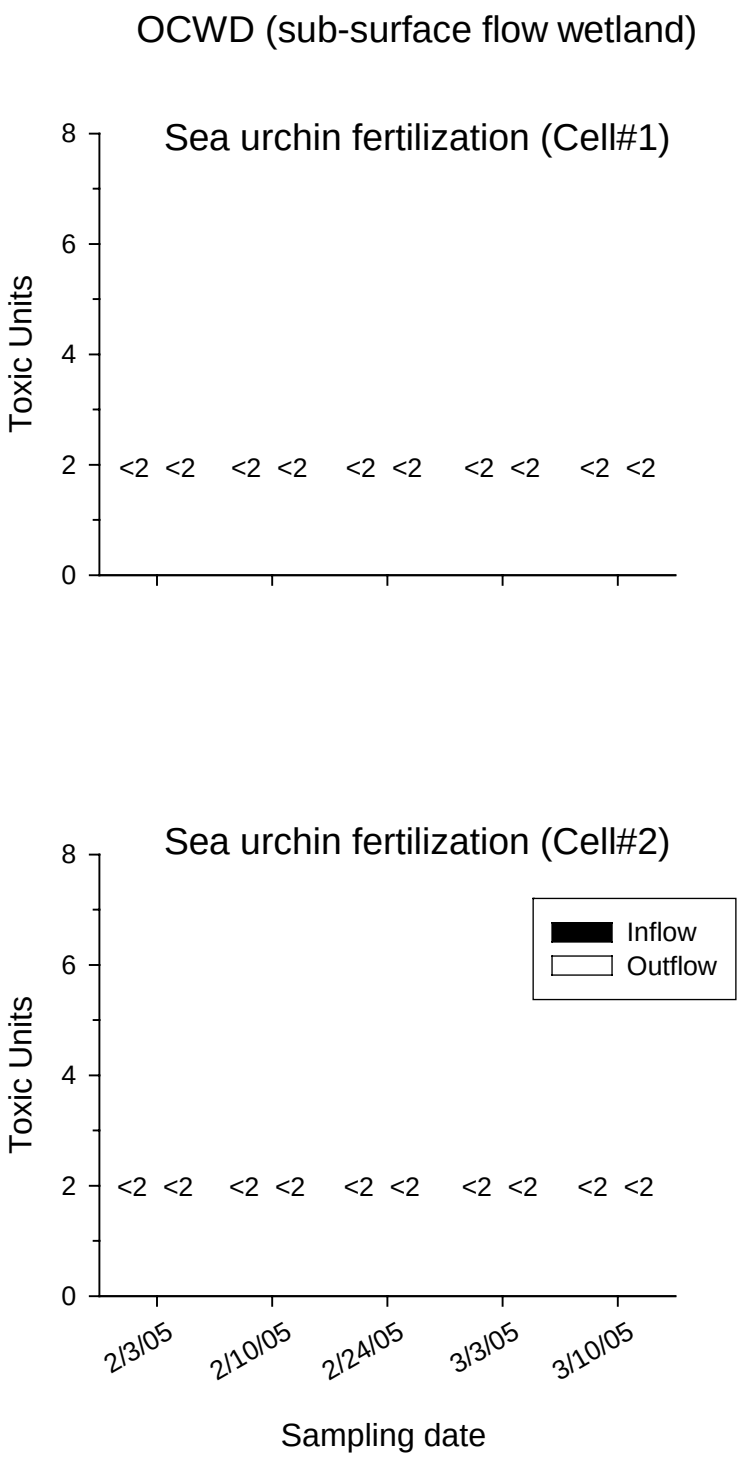


Figure 19. Toxicity in the OCWD samples. None of the samples tested reduced sea urchin fertilization by half.

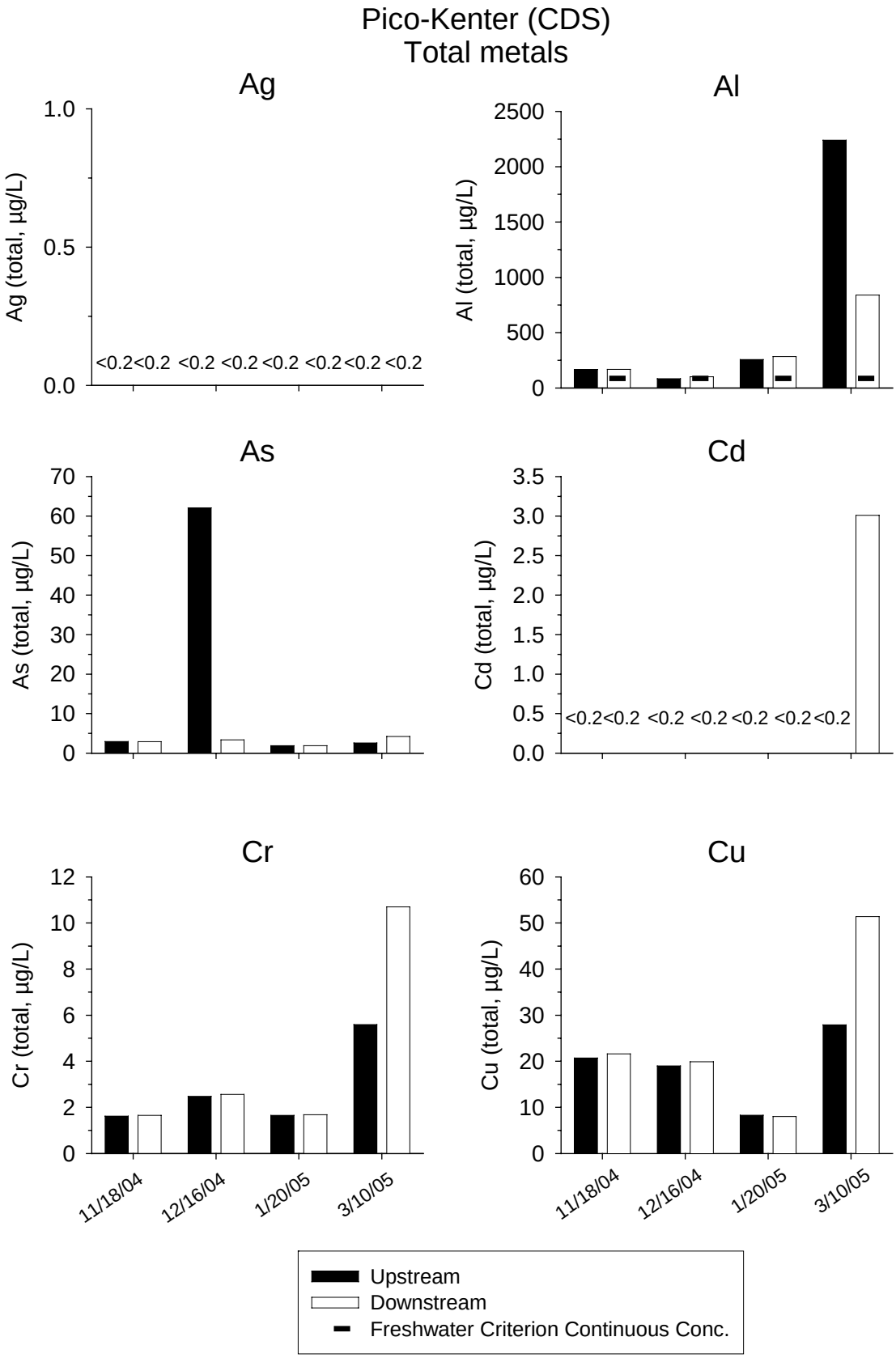


Figure 20. Concentrations of total metals and total suspended solids (TSS) at the Pico-Kenter CDS site over four sampling events.

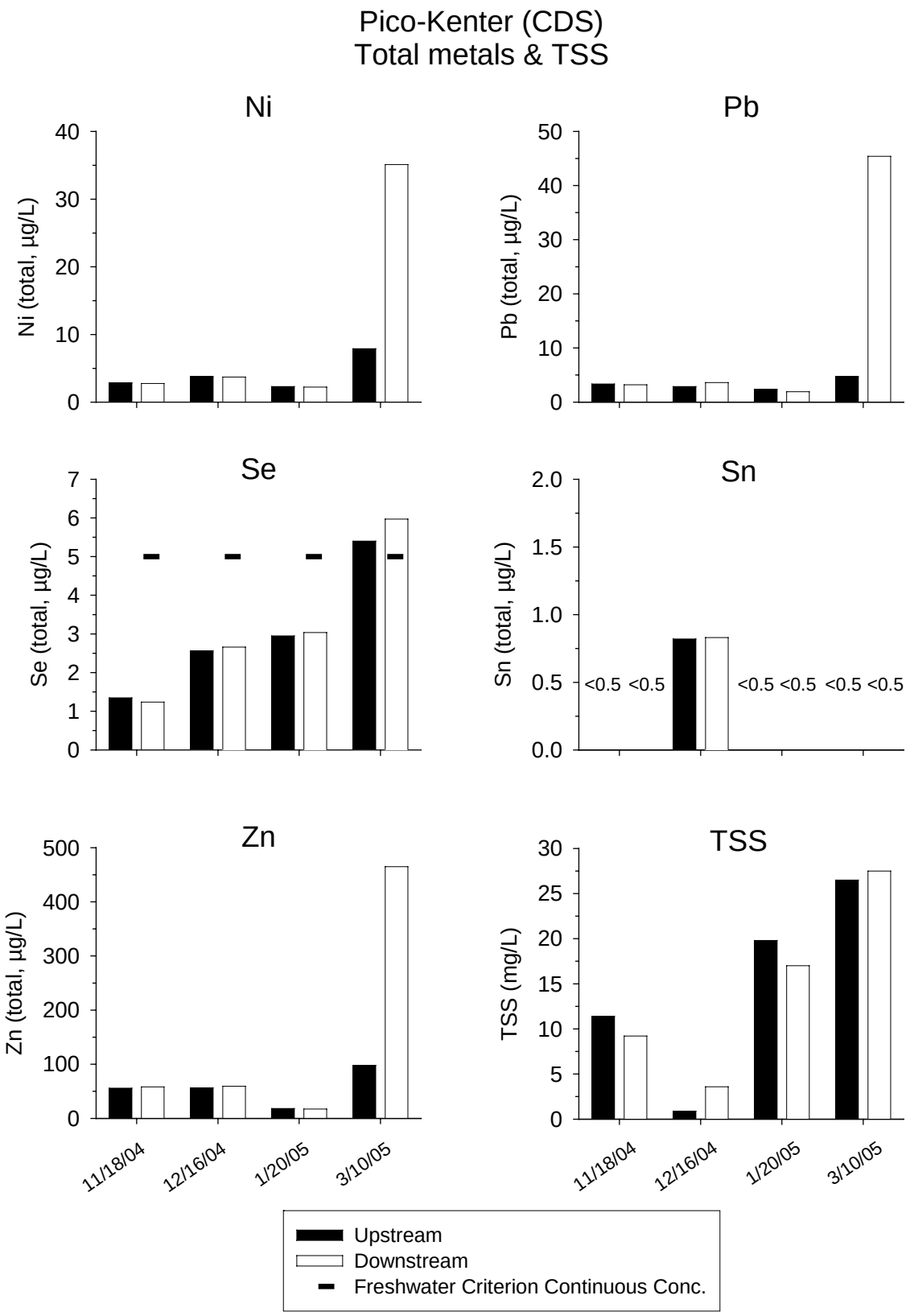


Figure 20 continued.

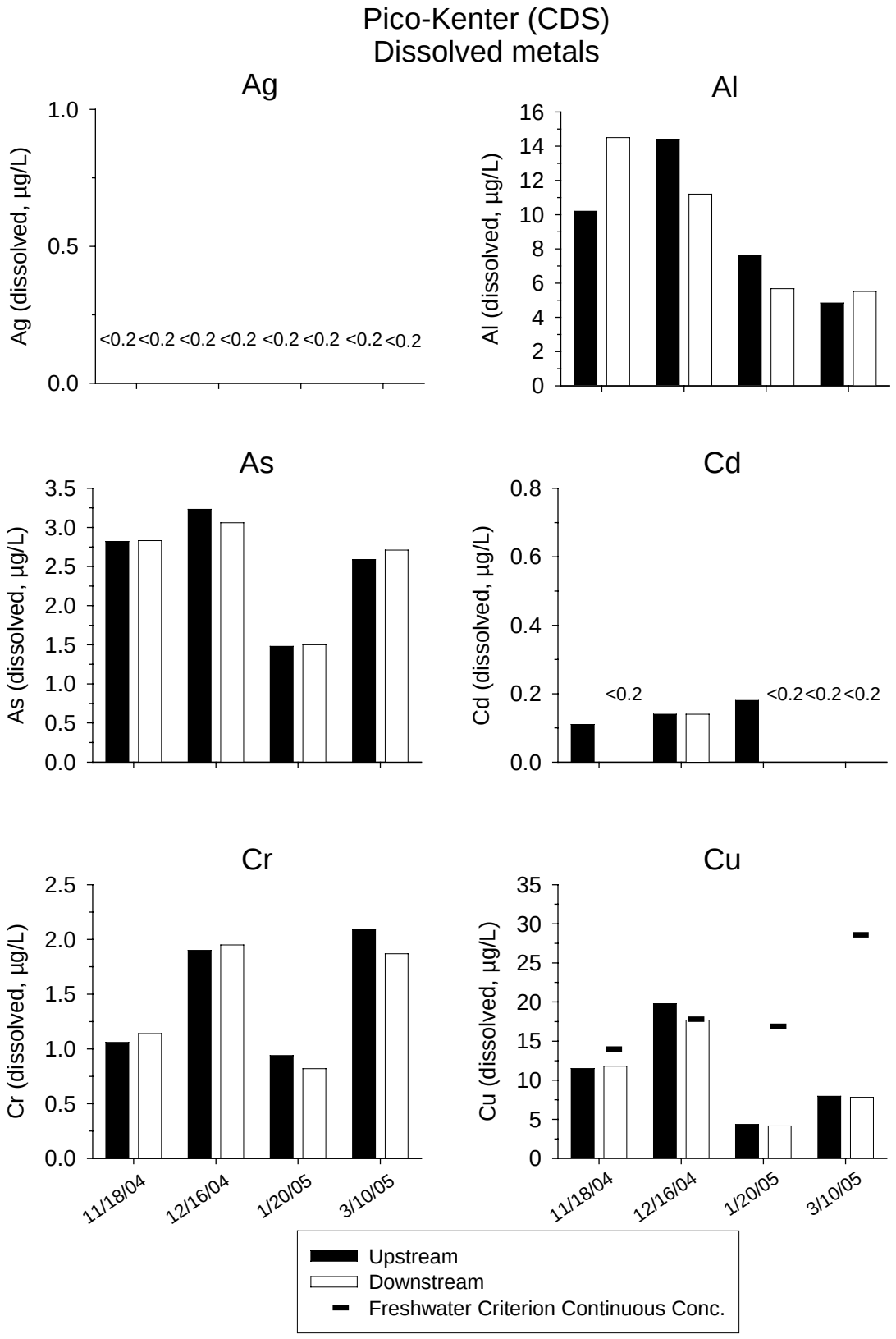


Figure 21. Concentrations of dissolved metals at the Pico-Kenter CDS site over four sampling events. The chronic criteria for dissolved As, Cd, Ni, Pb and Zn (not shown) are greater than the measured concentrations.

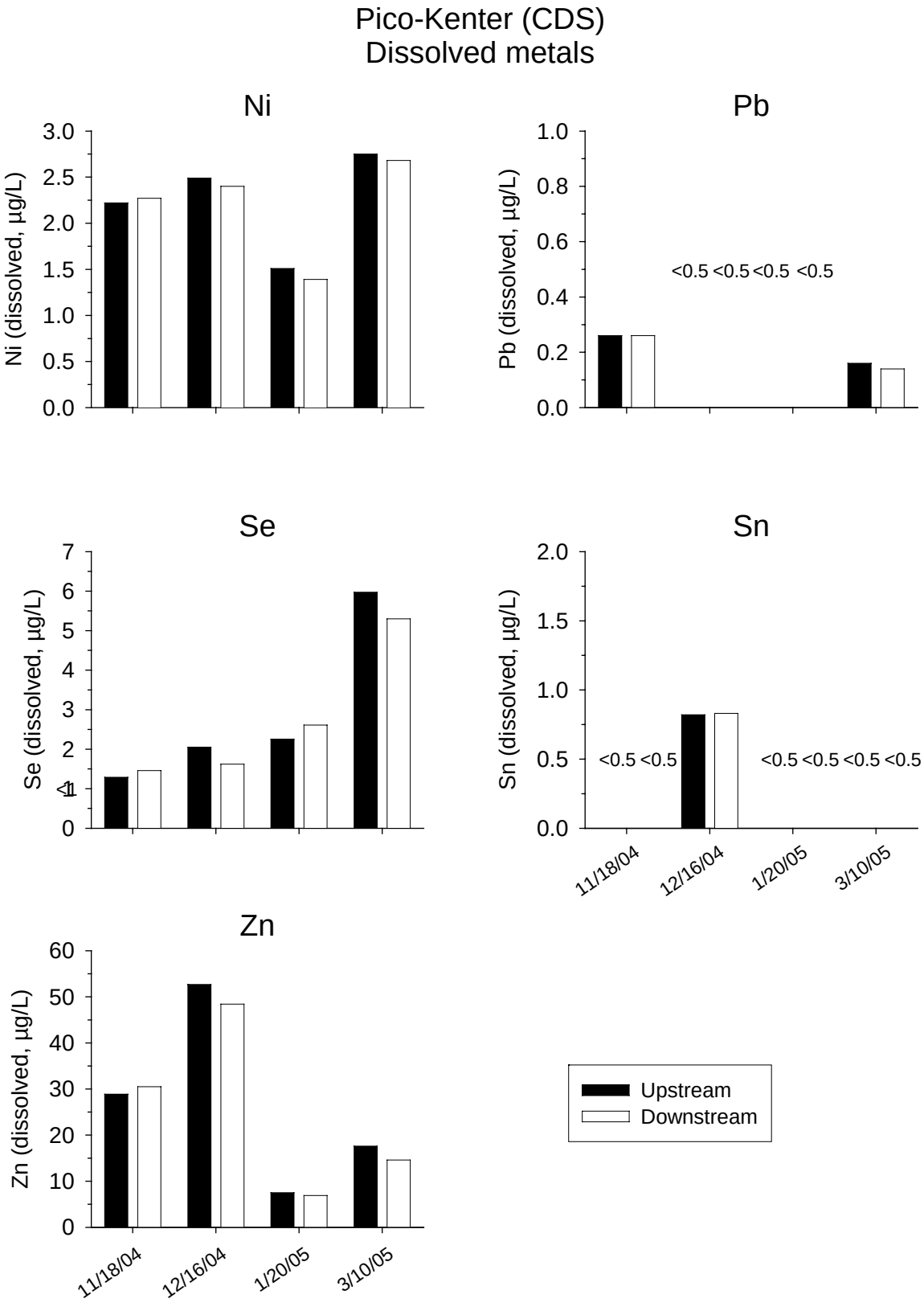


Figure 21 continued.

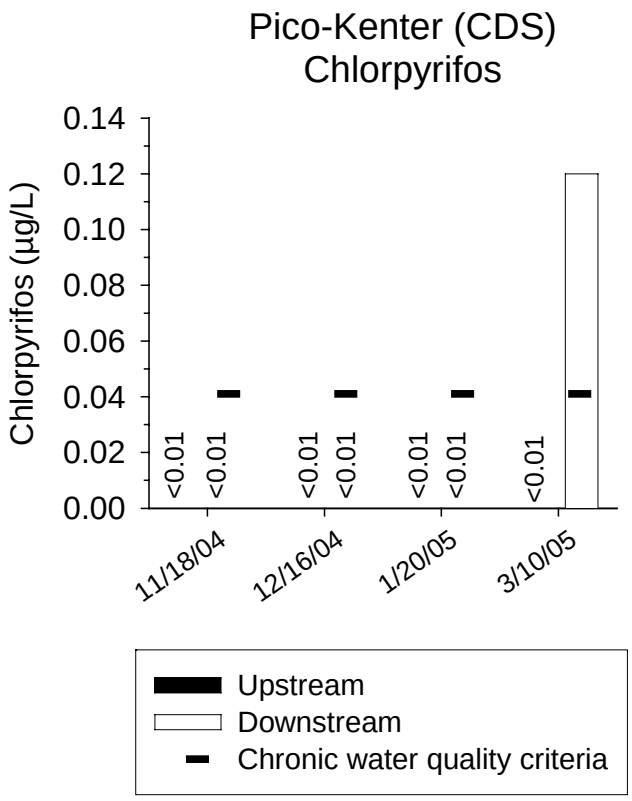


Figure 22. Concentrations of chlorpyrifos at the Pico-Kenter CDS site over four sampling events.

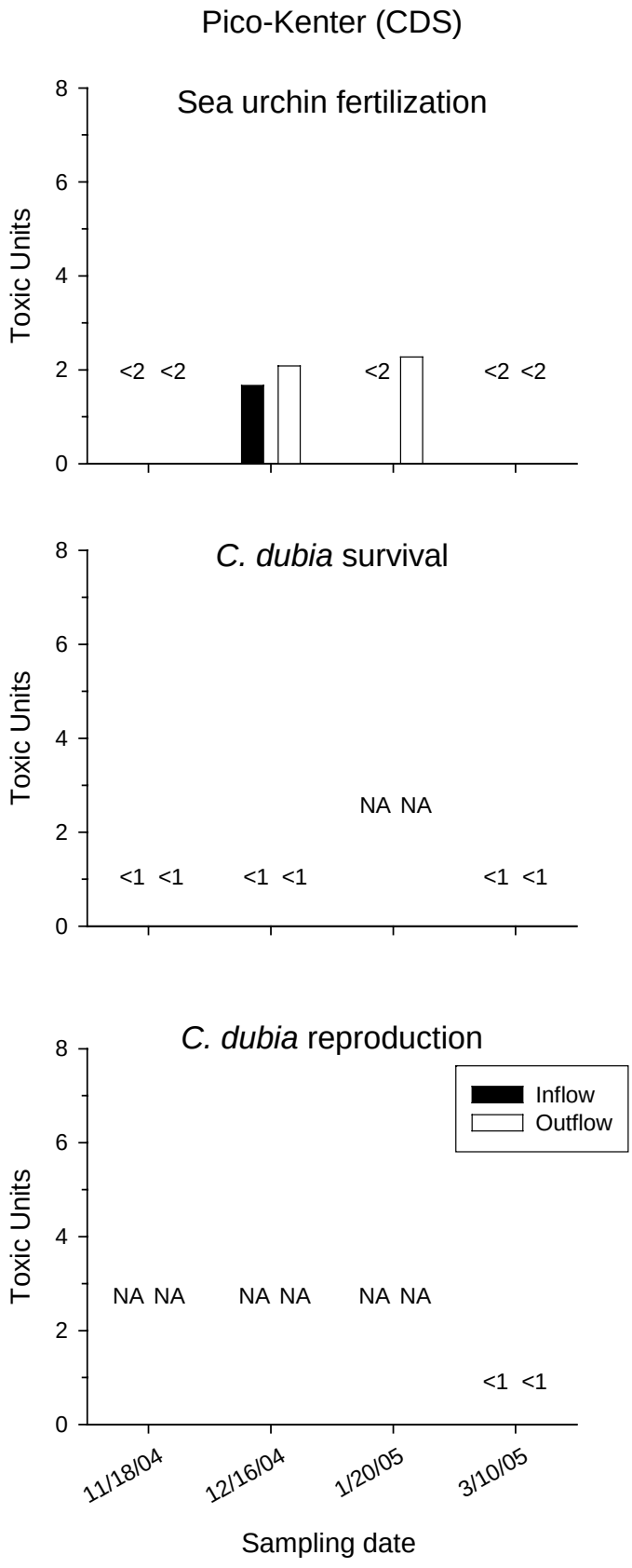


Figure 23. Toxicity in the Pico-Kenter samples. NA = not analyzed.

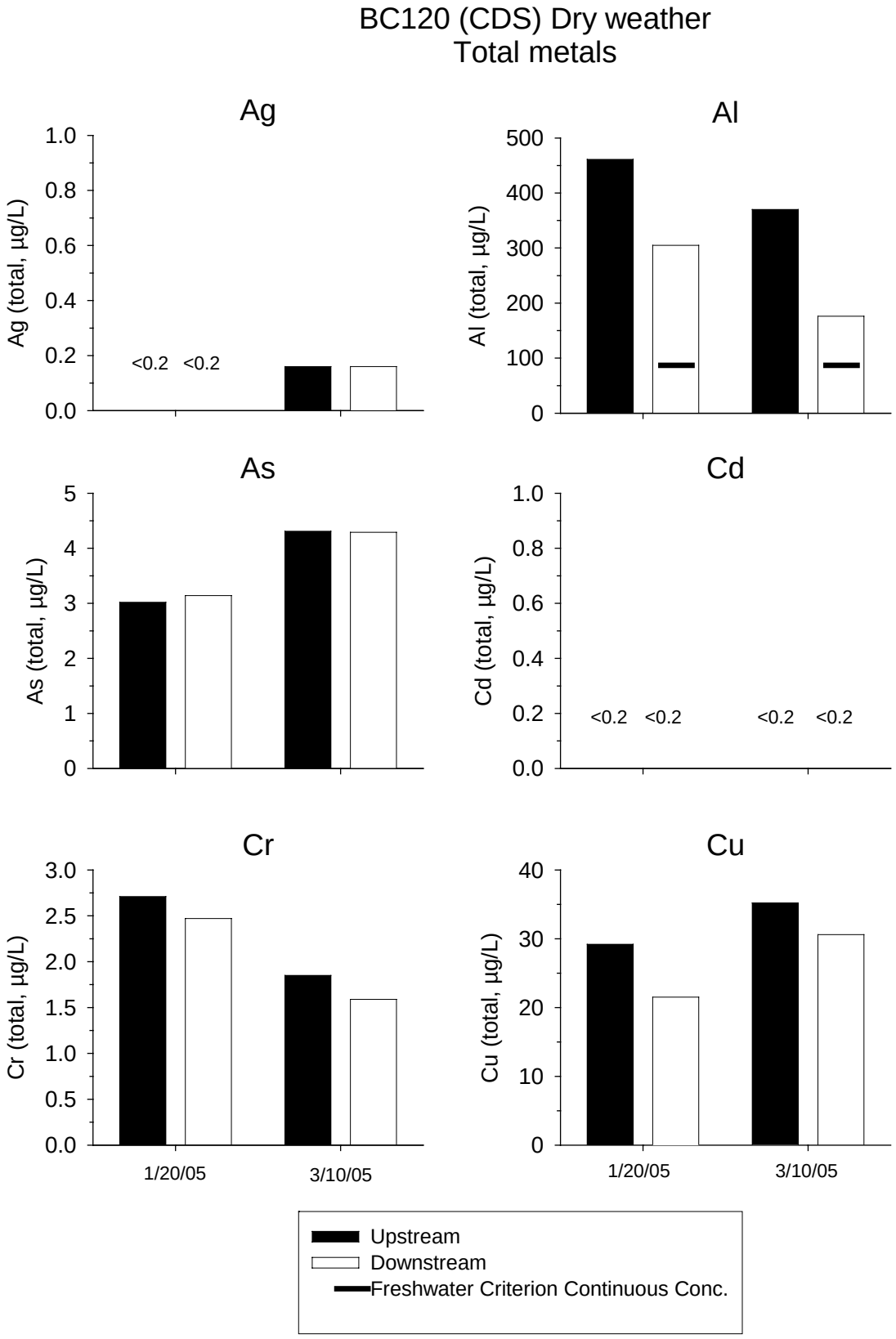


Figure 24. Concentrations of total metals and total suspended solids (TSS) at the BC120 CDS site over two dry weather sampling events.

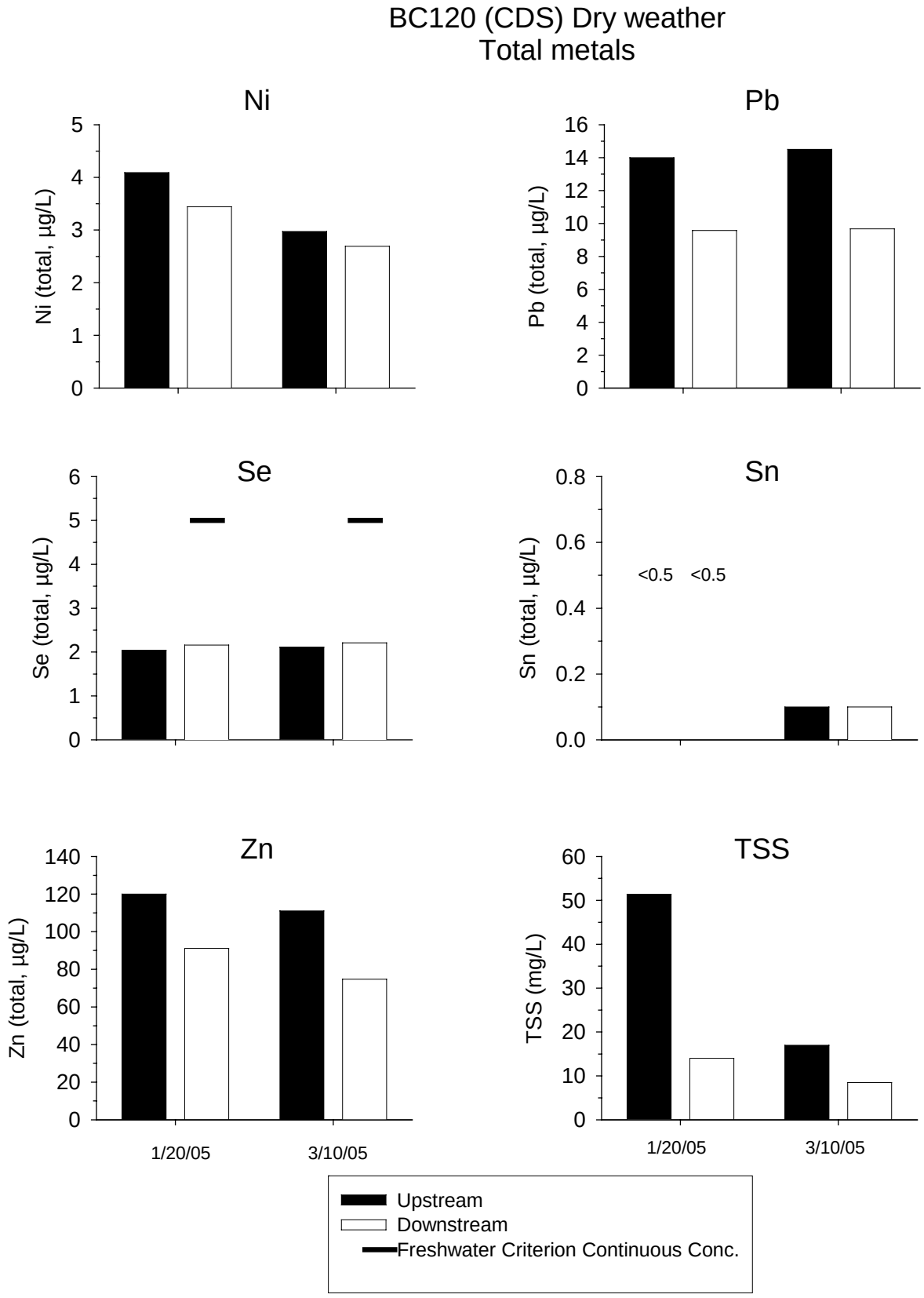


Figure 24 continued.

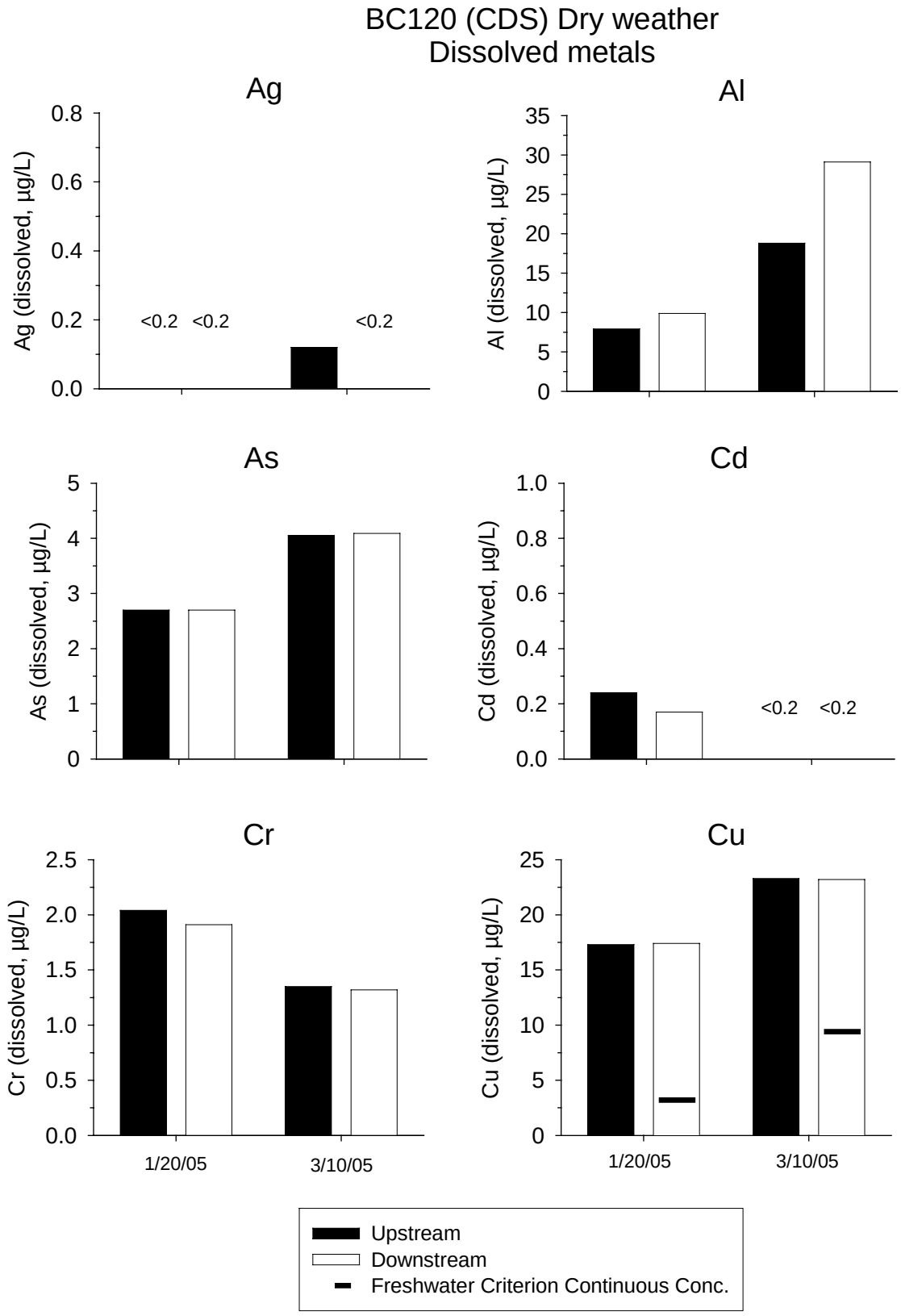


Figure 25. Concentrations of dissolved metals at the BC120 CDS site over two dry weather sampling events. The chronic criteria for dissolved As, Cd and Ni (not shown) are greater than the measured concentrations.

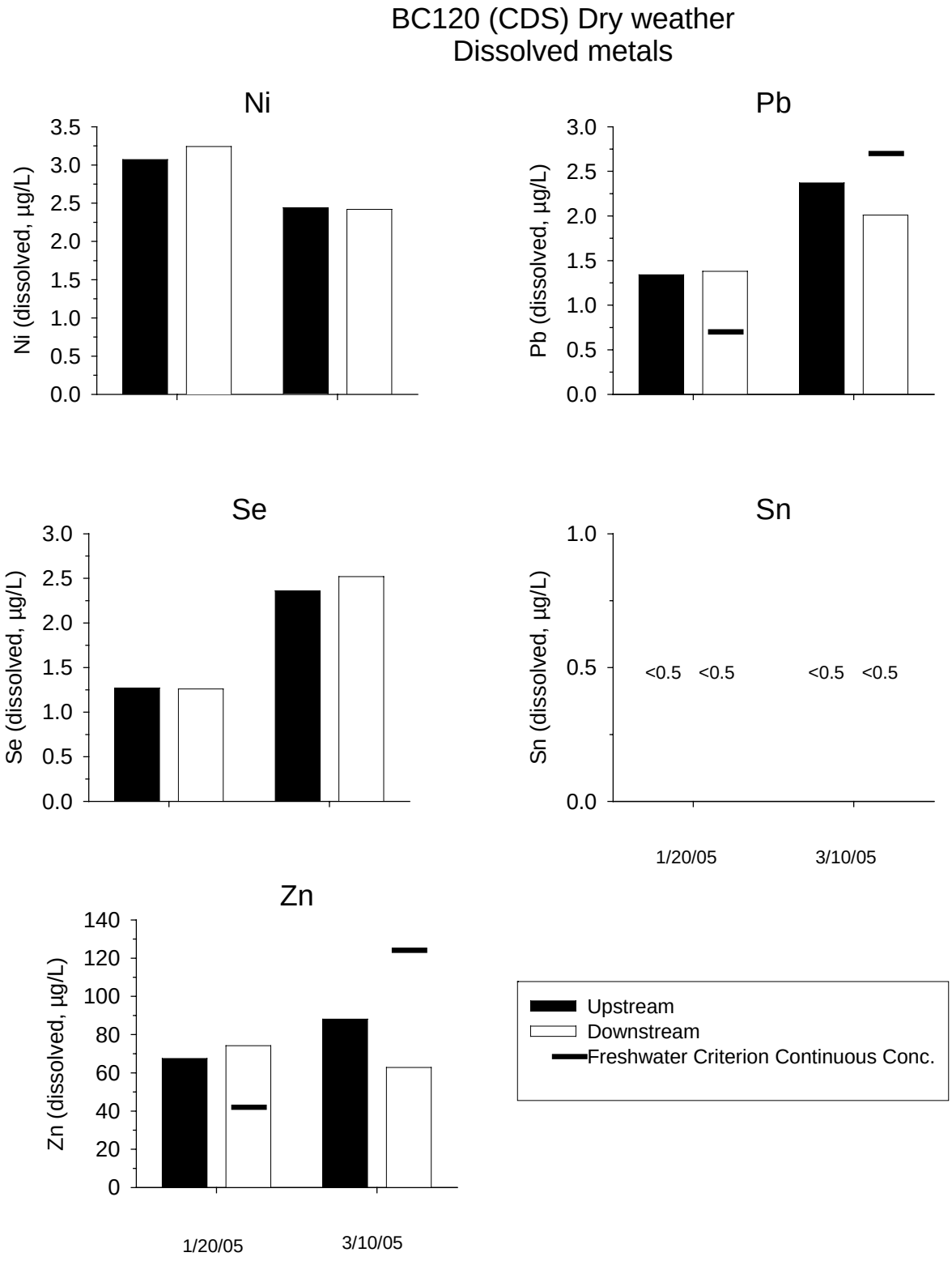


Figure 25 continued.

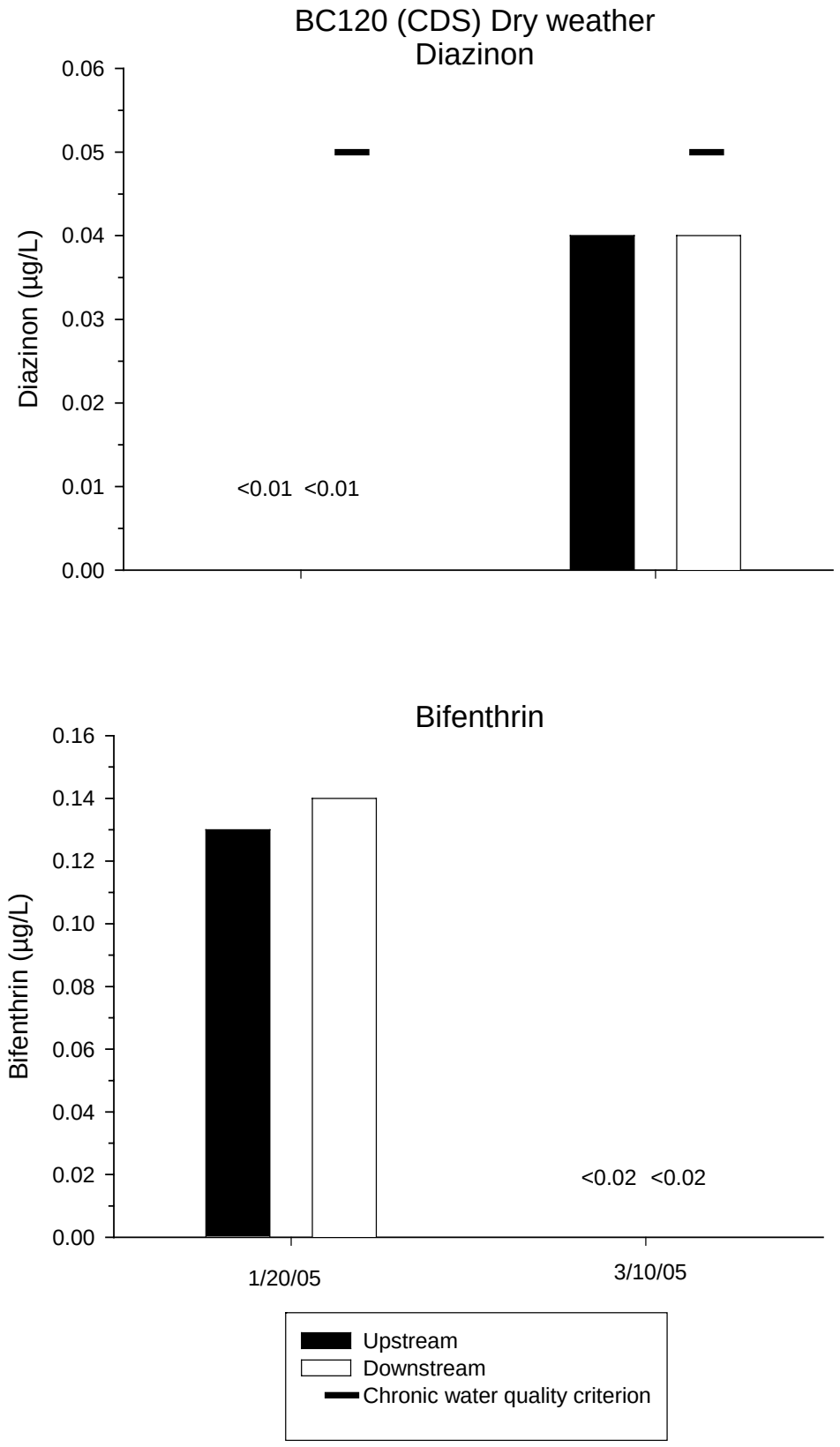


Figure 26. Concentrations of the diazinon (organophosphorus pesticide) and bifenthrin (pyrethroid pesticide) at the BC120 CDS site during the two dry weather sampling events. There is no chronic criterion for bifenthrin.

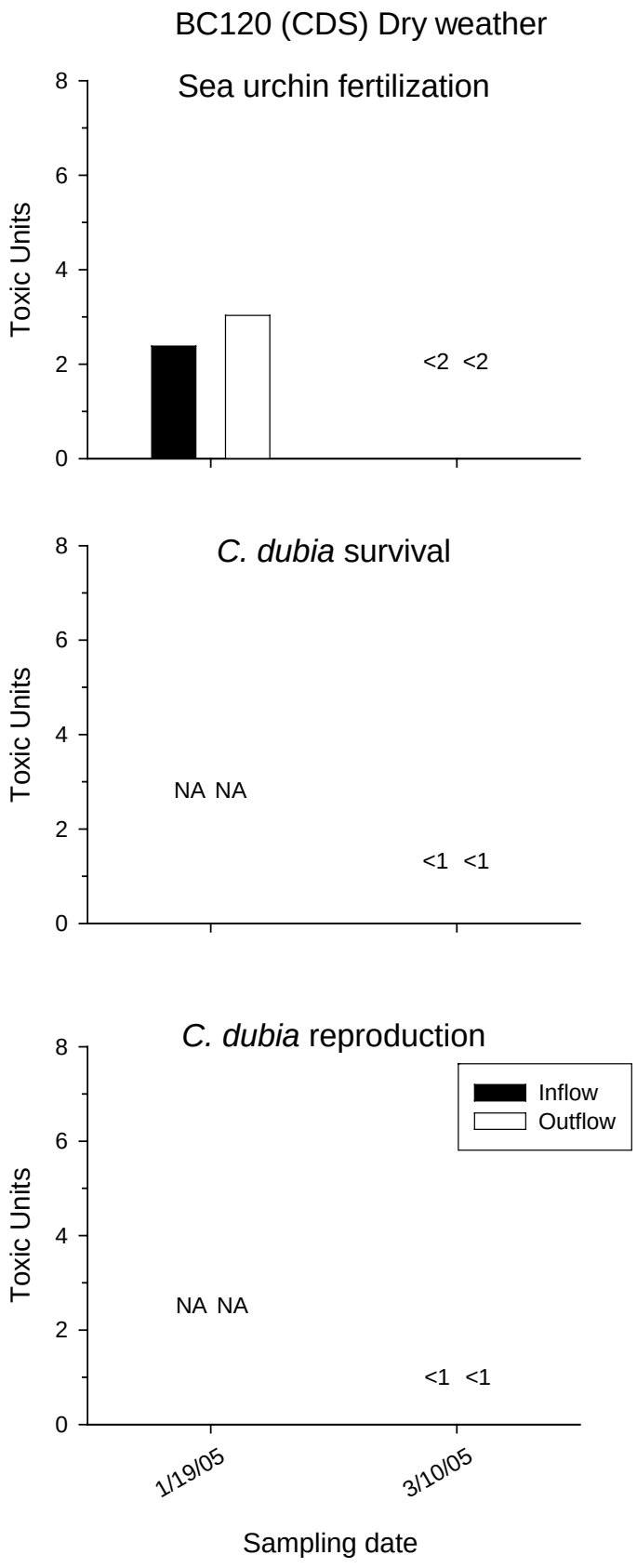


Figure 27. Toxicity in the BC120 dry weather samples. NA = not analyzed.

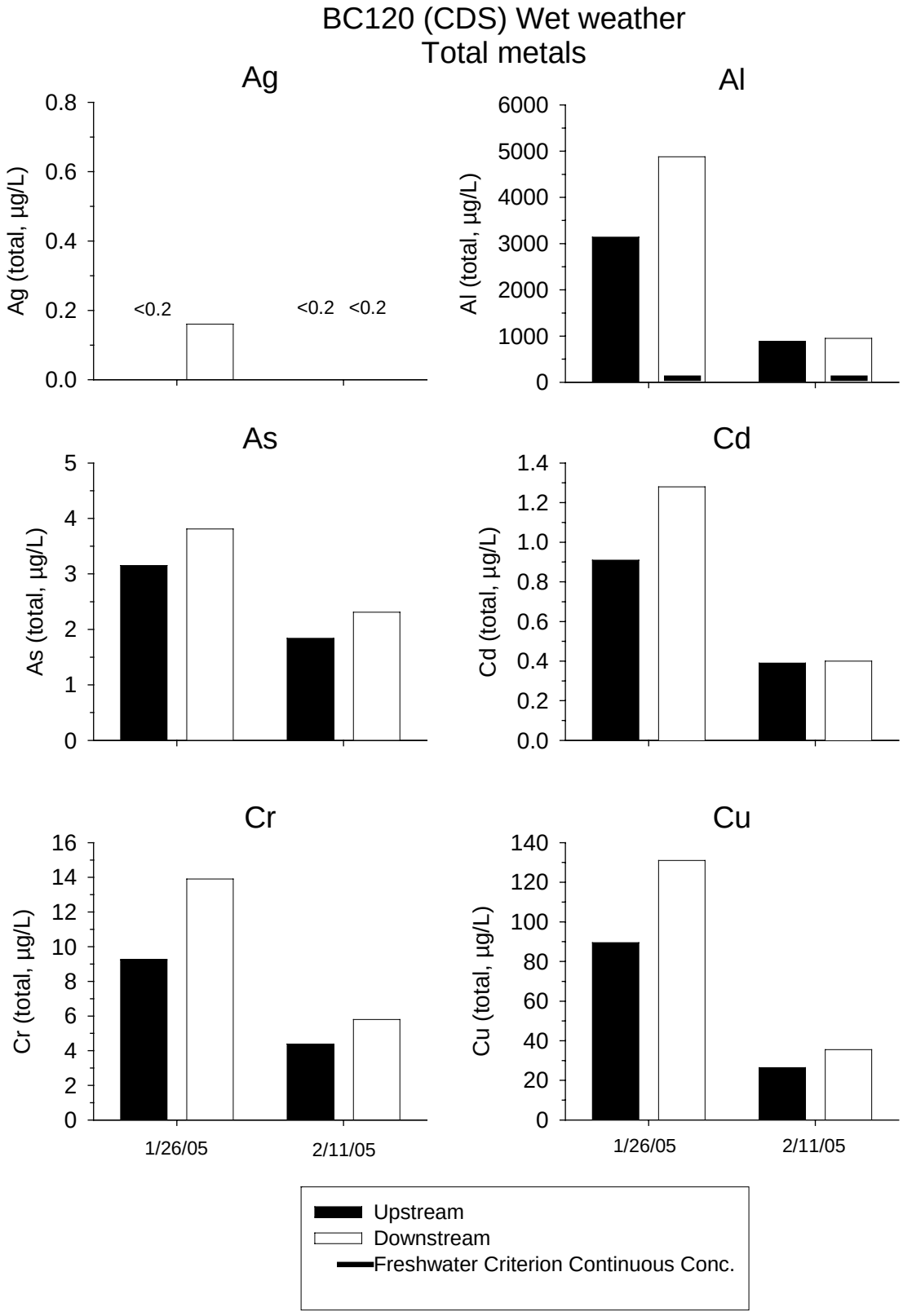


Figure 28. Concentrations of total metals at the BC120 CDS site over two wet weather sampling events.

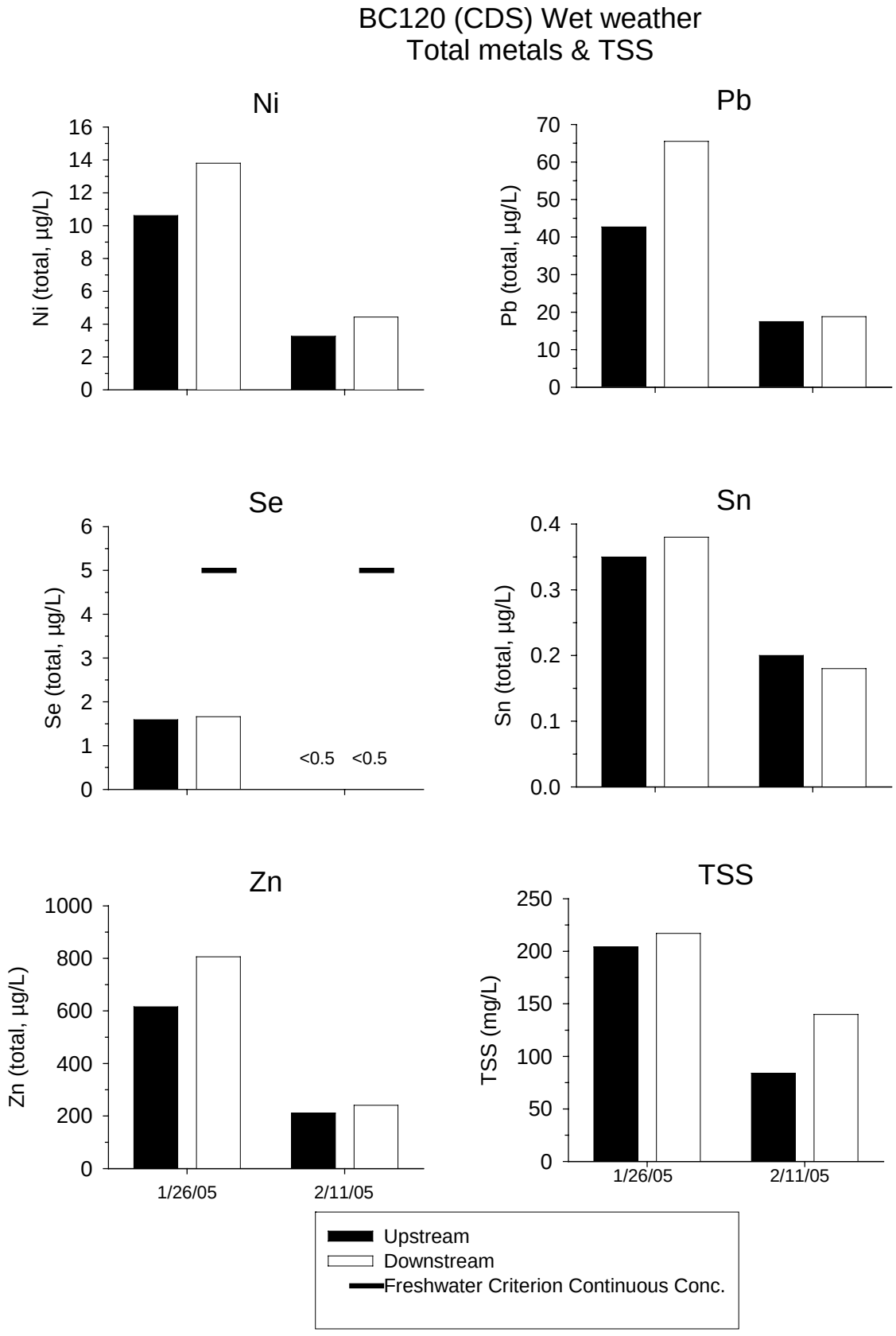


Figure 28 continued.

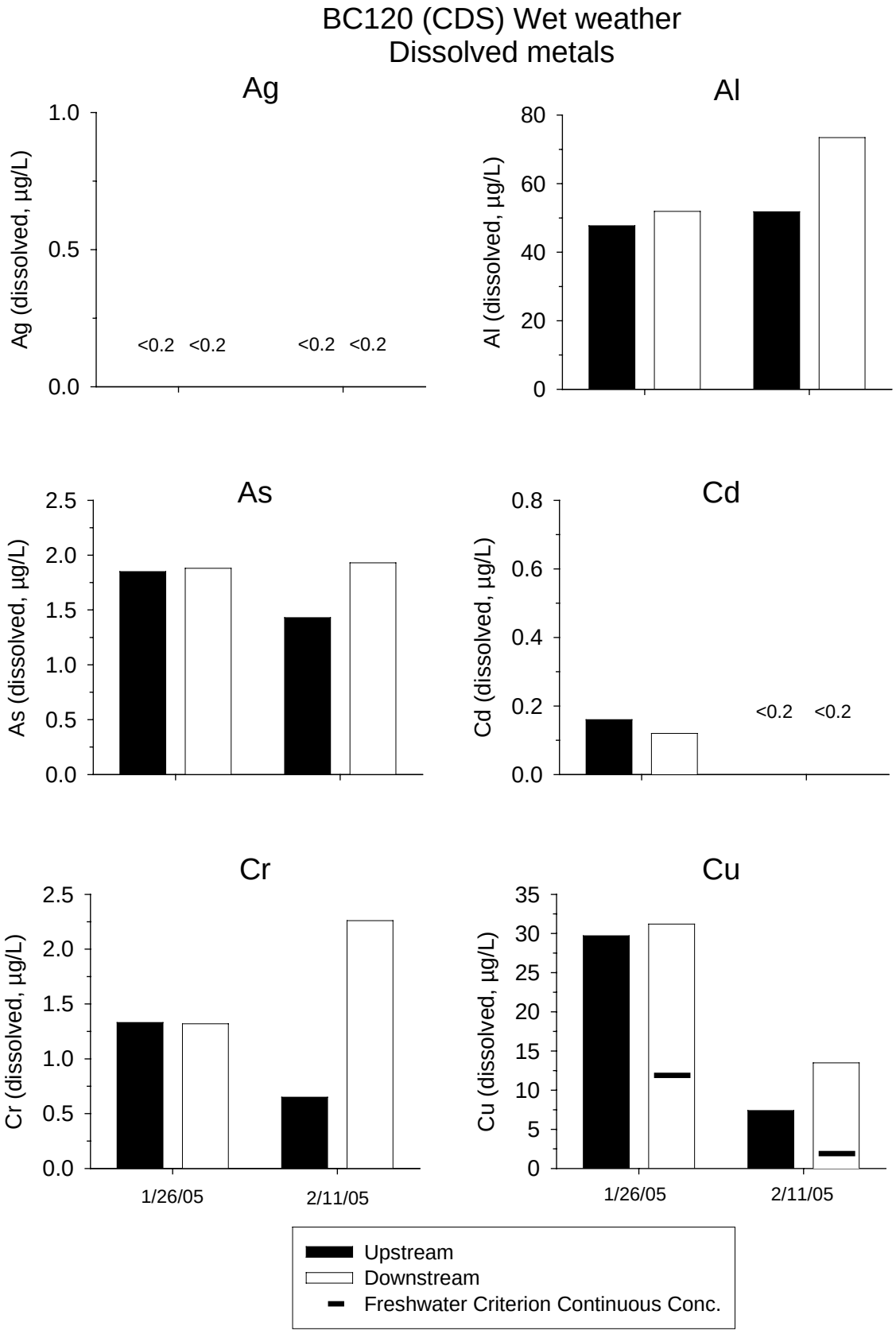


Figure 29. Concentrations of dissolved metals at the BC120 CDS site over two wet weather sampling events. The chronic criteria for dissolved As, Cd and Ni (not shown) are greater than the measured concentrations.

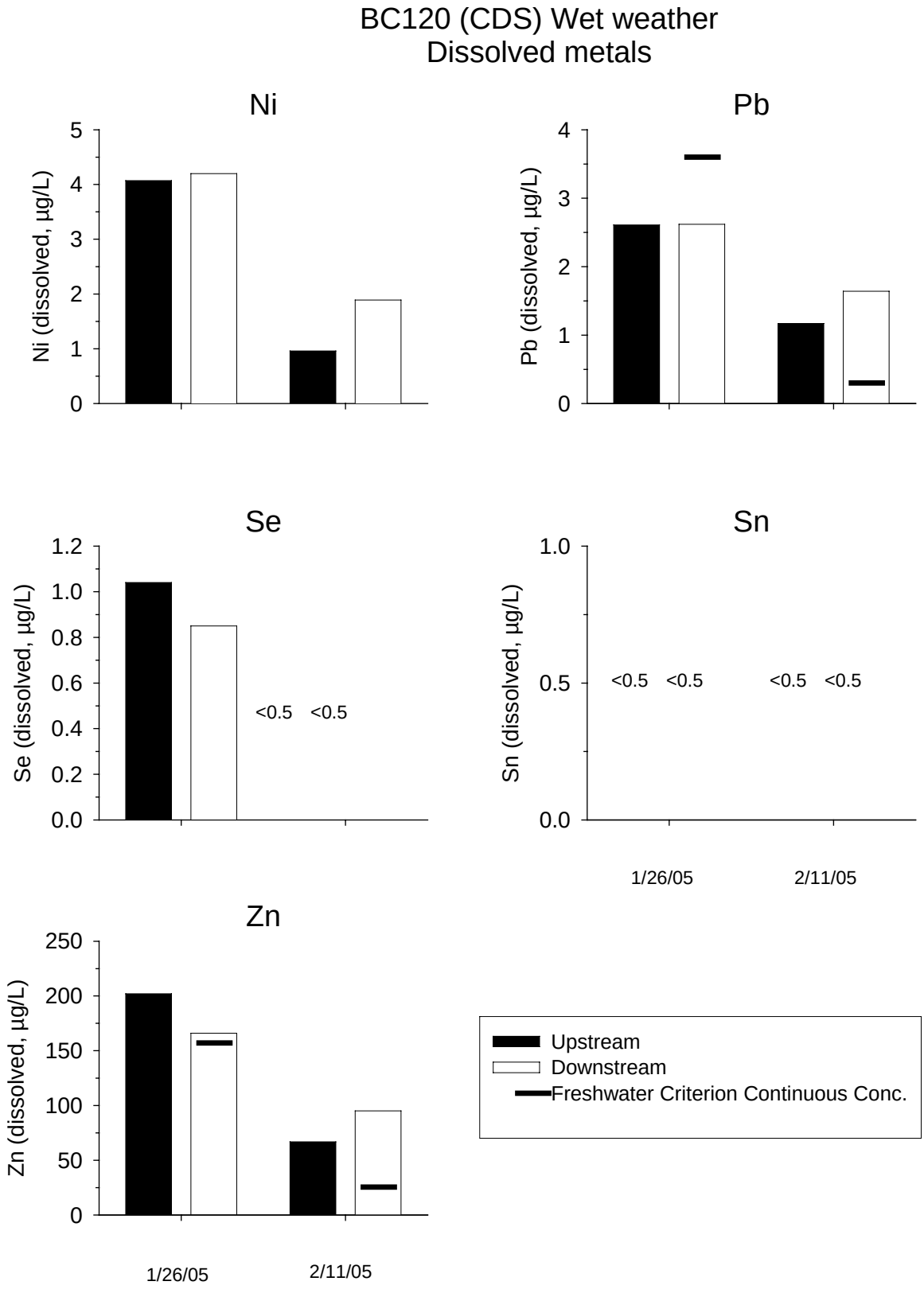


Figure 29. continued.

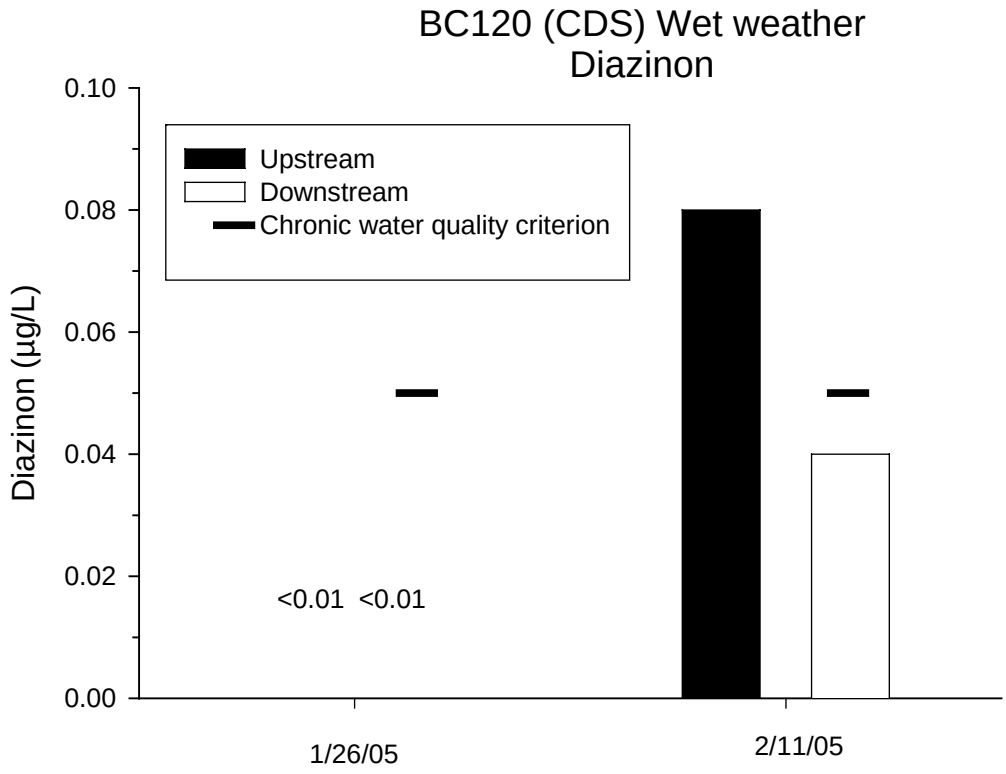


Figure 30. Concentrations of the diazinon (organophosphorus pesticide) at the BC120 CDS site during the two wet weather sampling events.

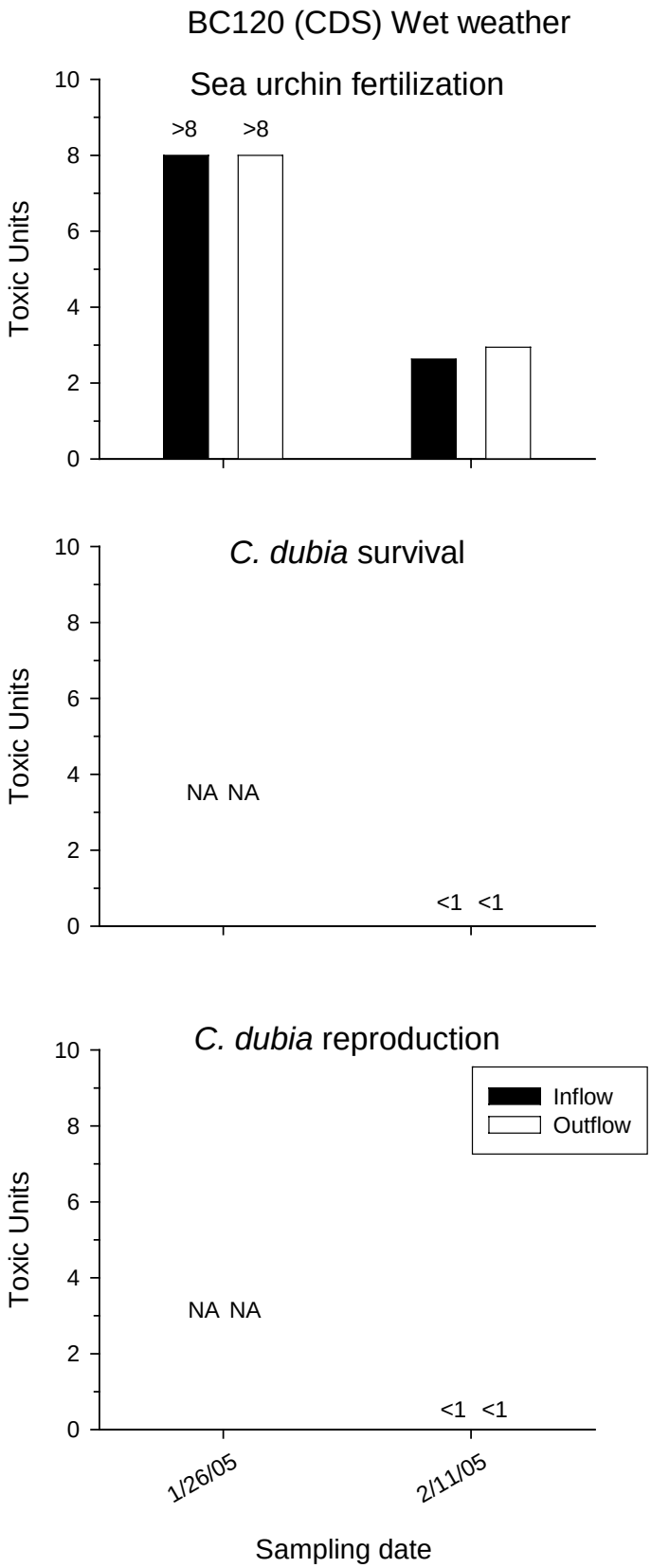


Figure 31. Toxicity in the wet weather samples from the BC120 CDS unit. NA = not analyzed.

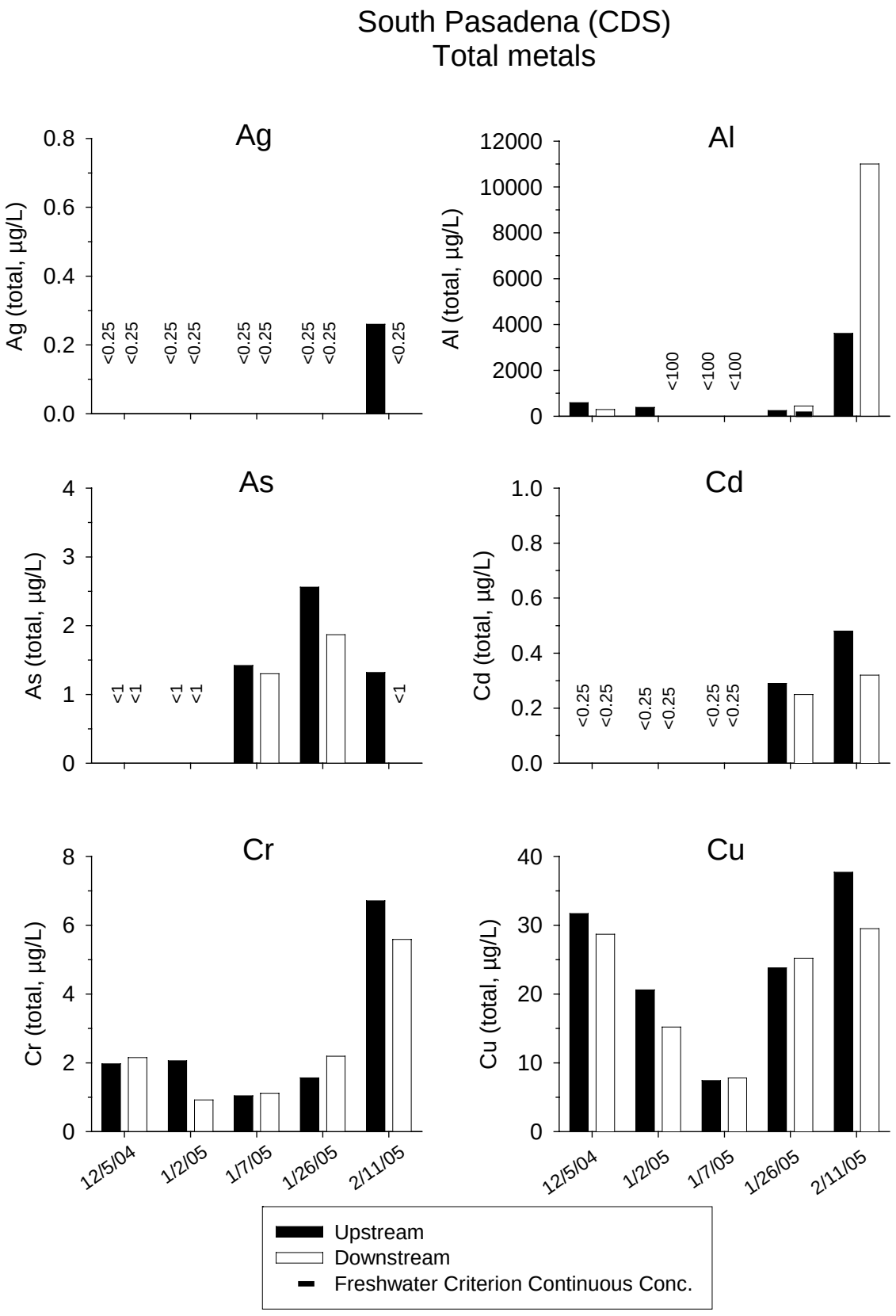


Figure 32. Concentrations of total metals and total suspended solids (TSS) at the South Pasadena CDS site over five sampling events. Tin was not analyzed in the South Pasadena samples.

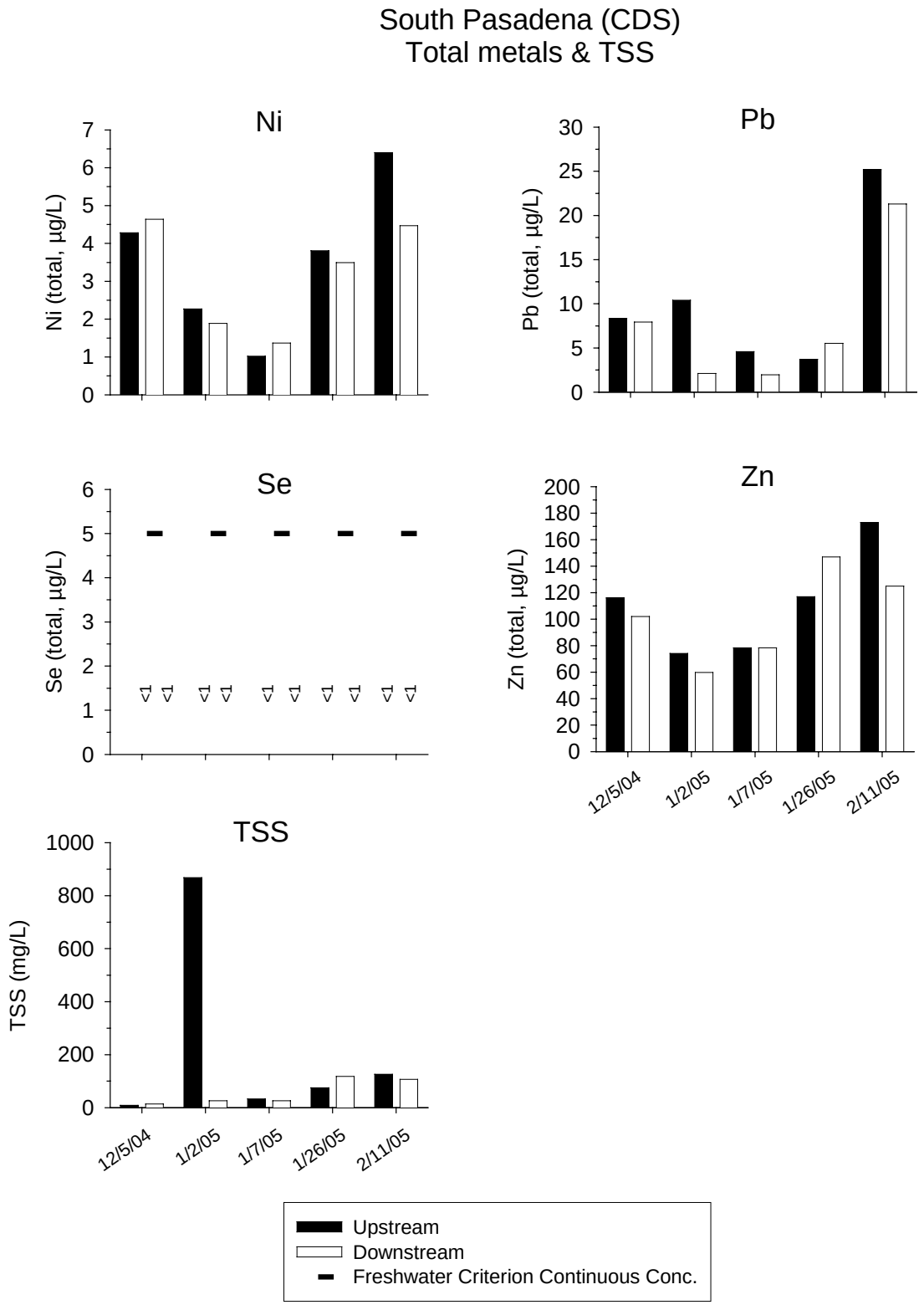


Figure 32 continued.

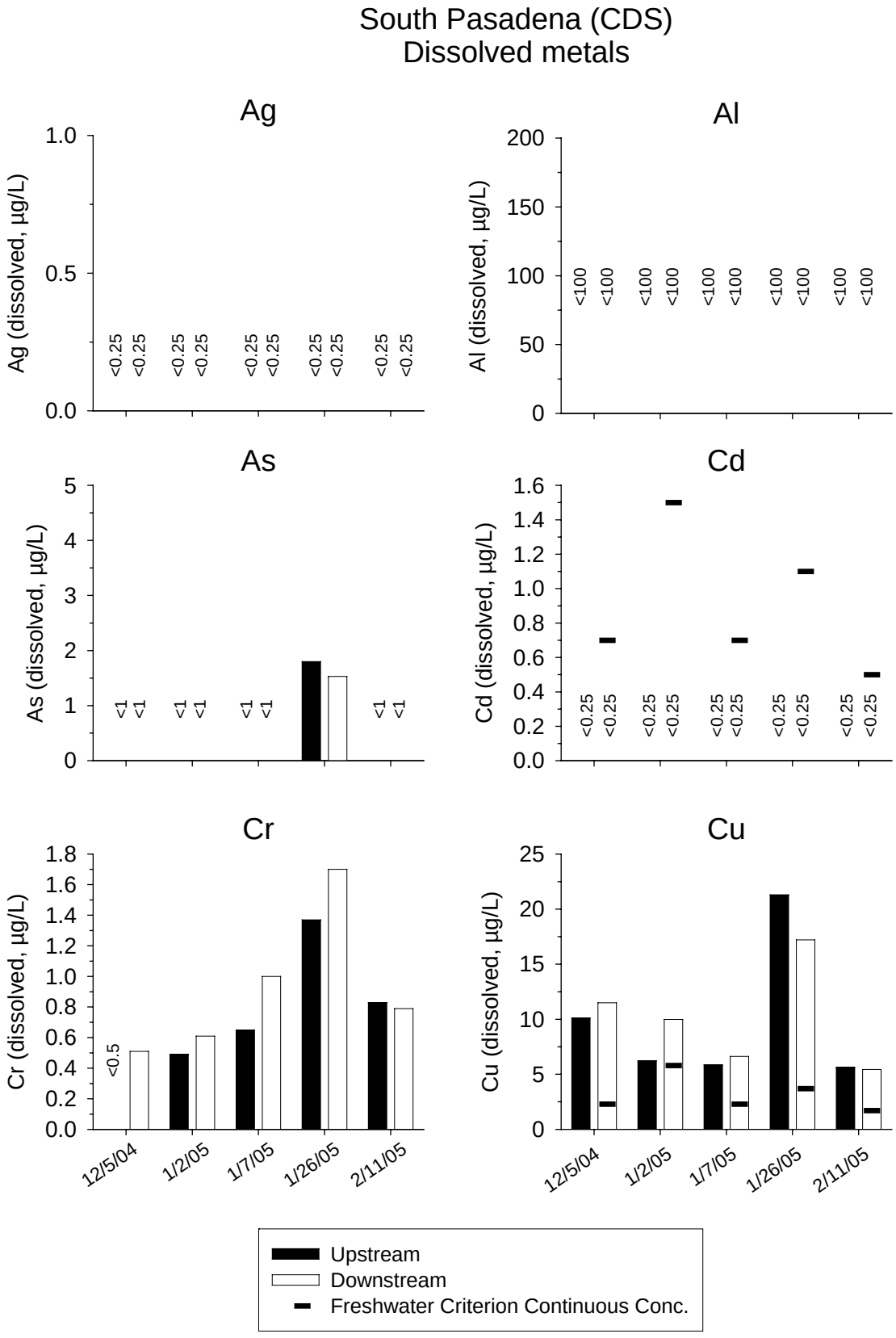


Figure 33. Concentrations of dissolved metals at the South Pasadena CDS site over five sampling events. The chronic criterion for dissolved As (150 µg/L) is not shown. Tin was not analyzed in the South Pasadena samples.

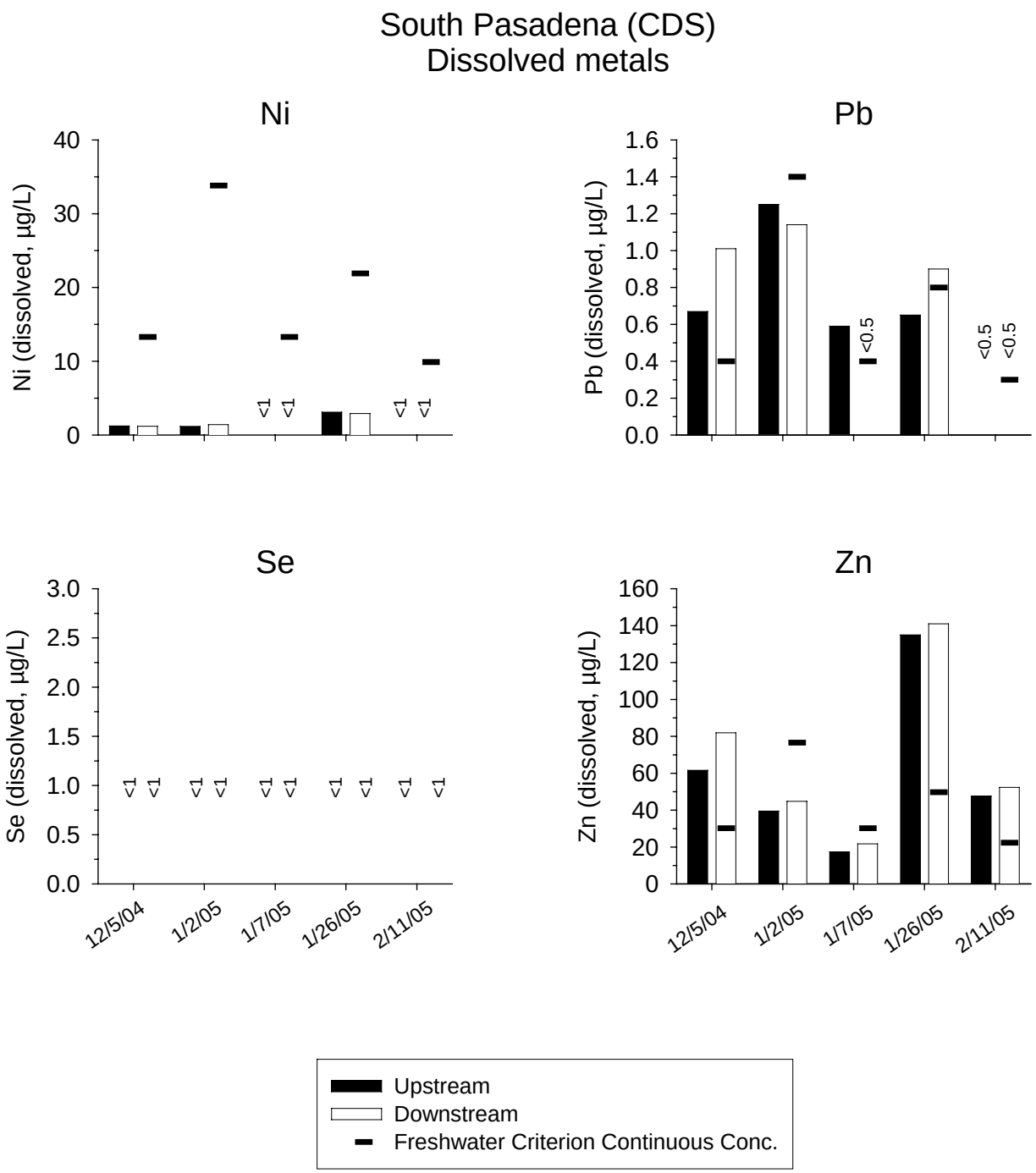


Figure 33 continued.

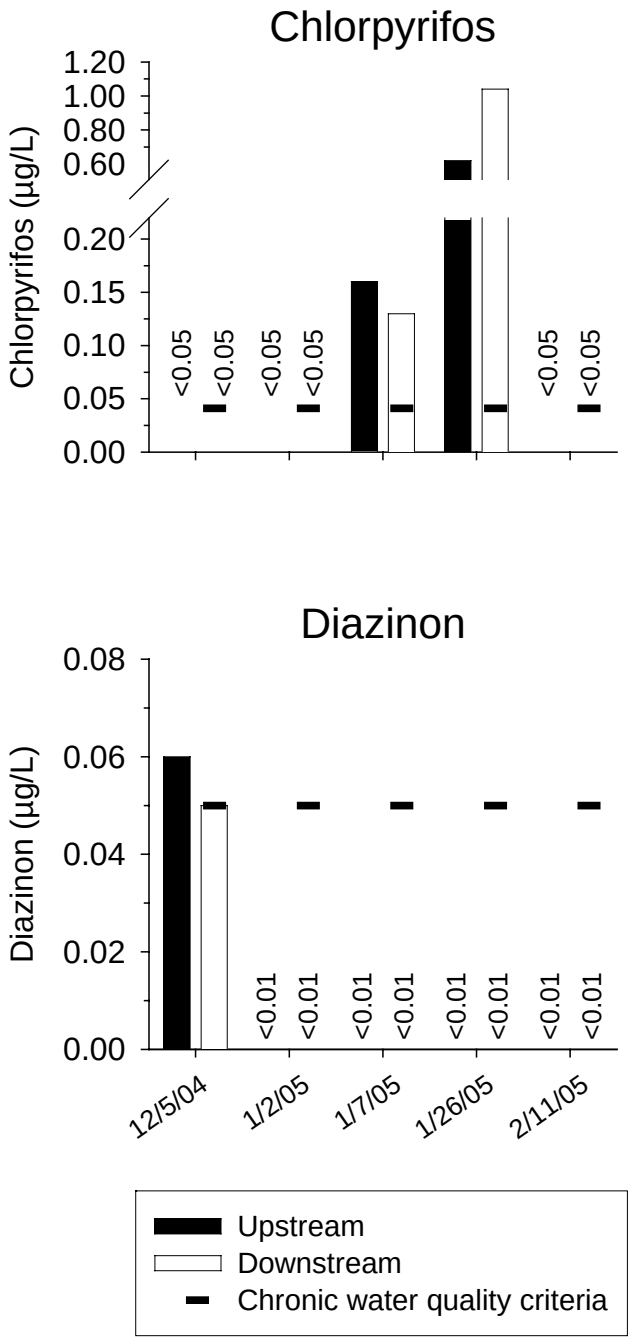


Figure 34. Concentrations of chlorpyrifos and diazinon from the South Pasadena CDS site over five stormwater sampling events.

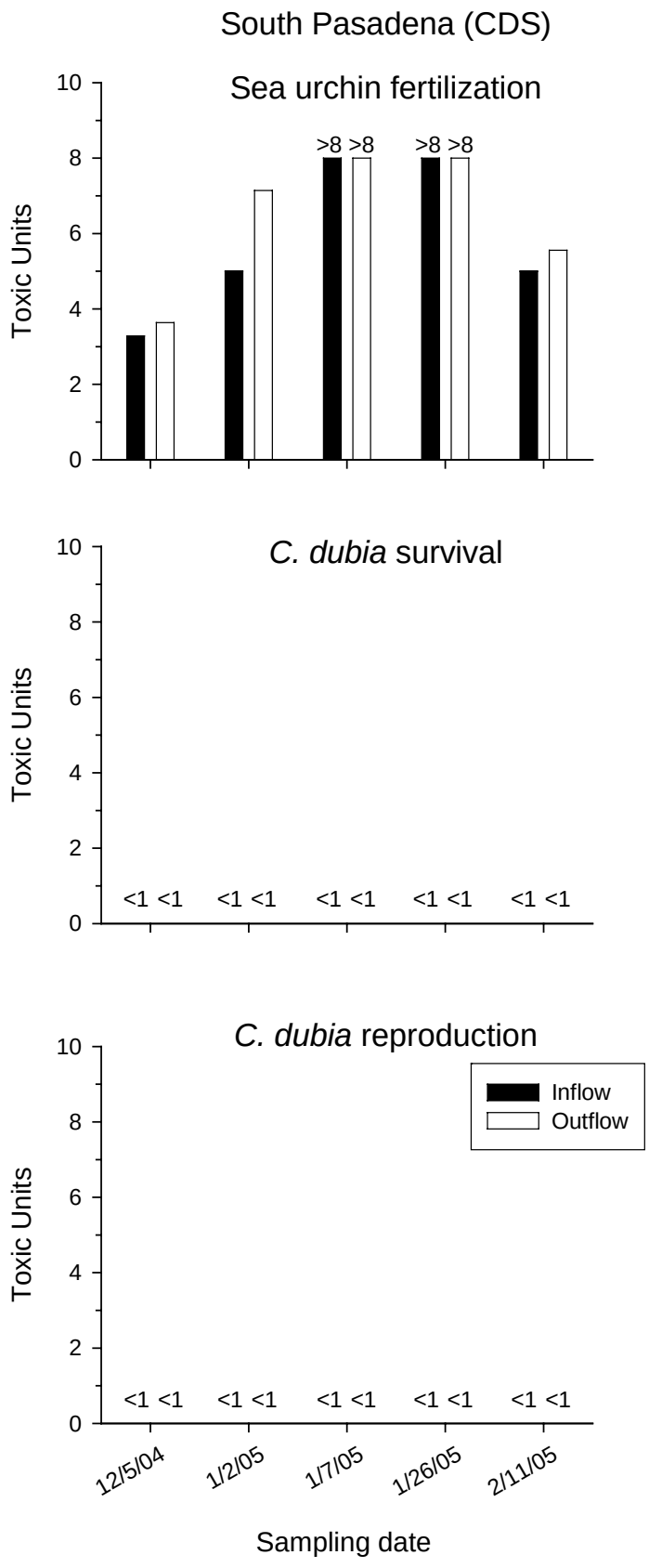


Figure 35. Toxicity of the South Pasadena CDS unit storm samples. None of the samples reduced the survival or reproduction of *Ceriodaphnia dubia* (*C. dubia*) by 50%.

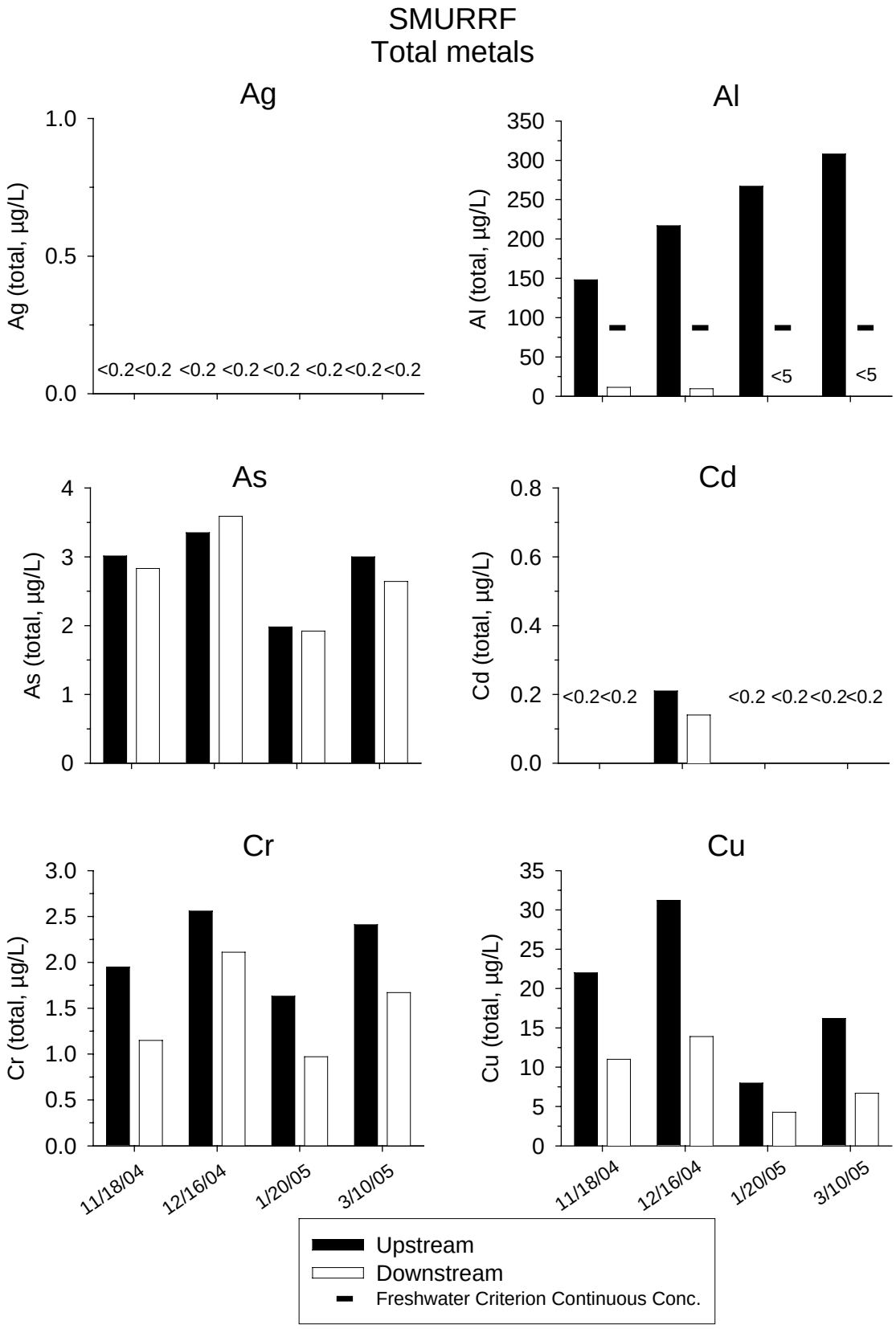


Figure 36. Concentrations of total metals and total suspended solids (TSS) at the SMURRF site over four sampling events.

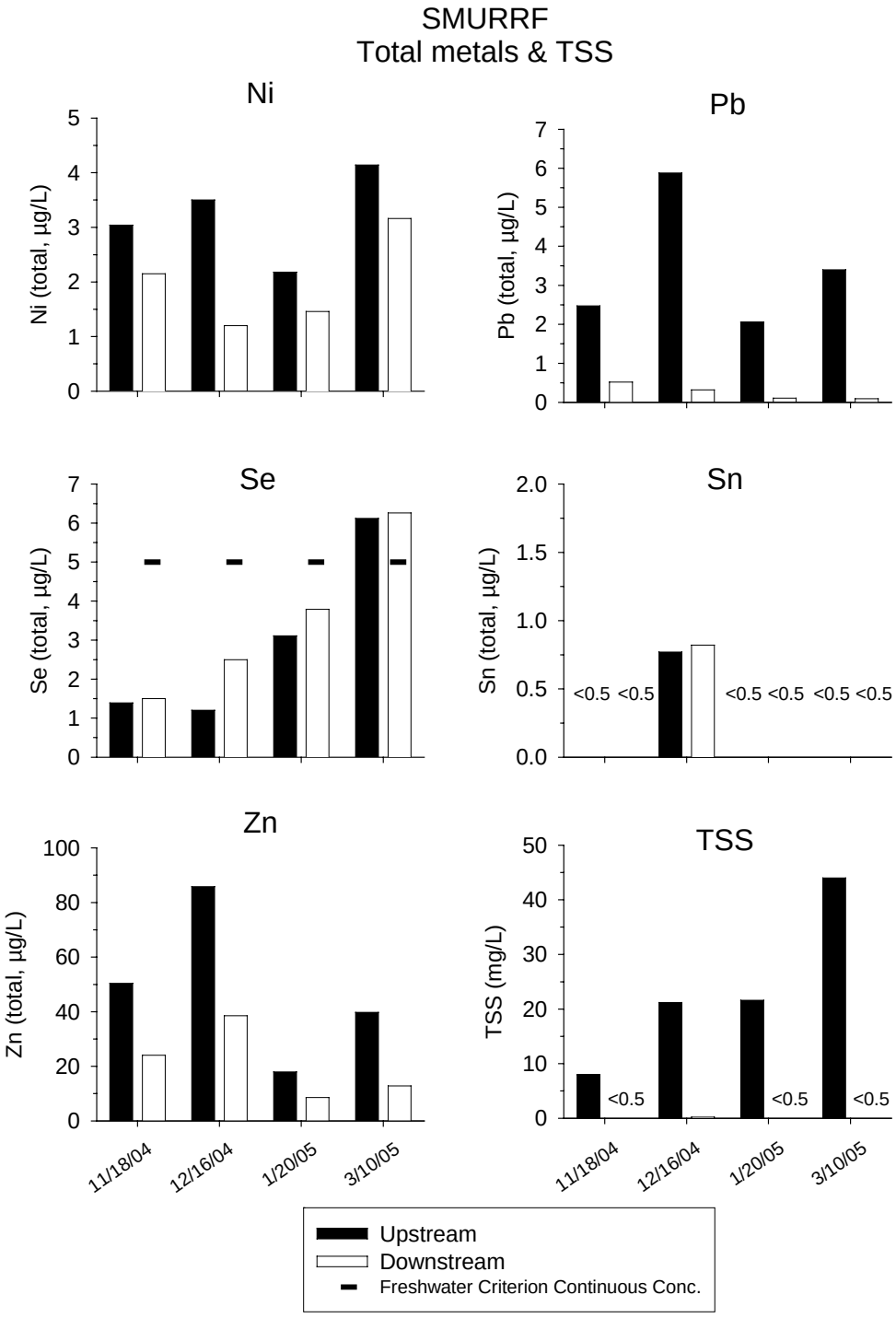


Figure 36 continued.

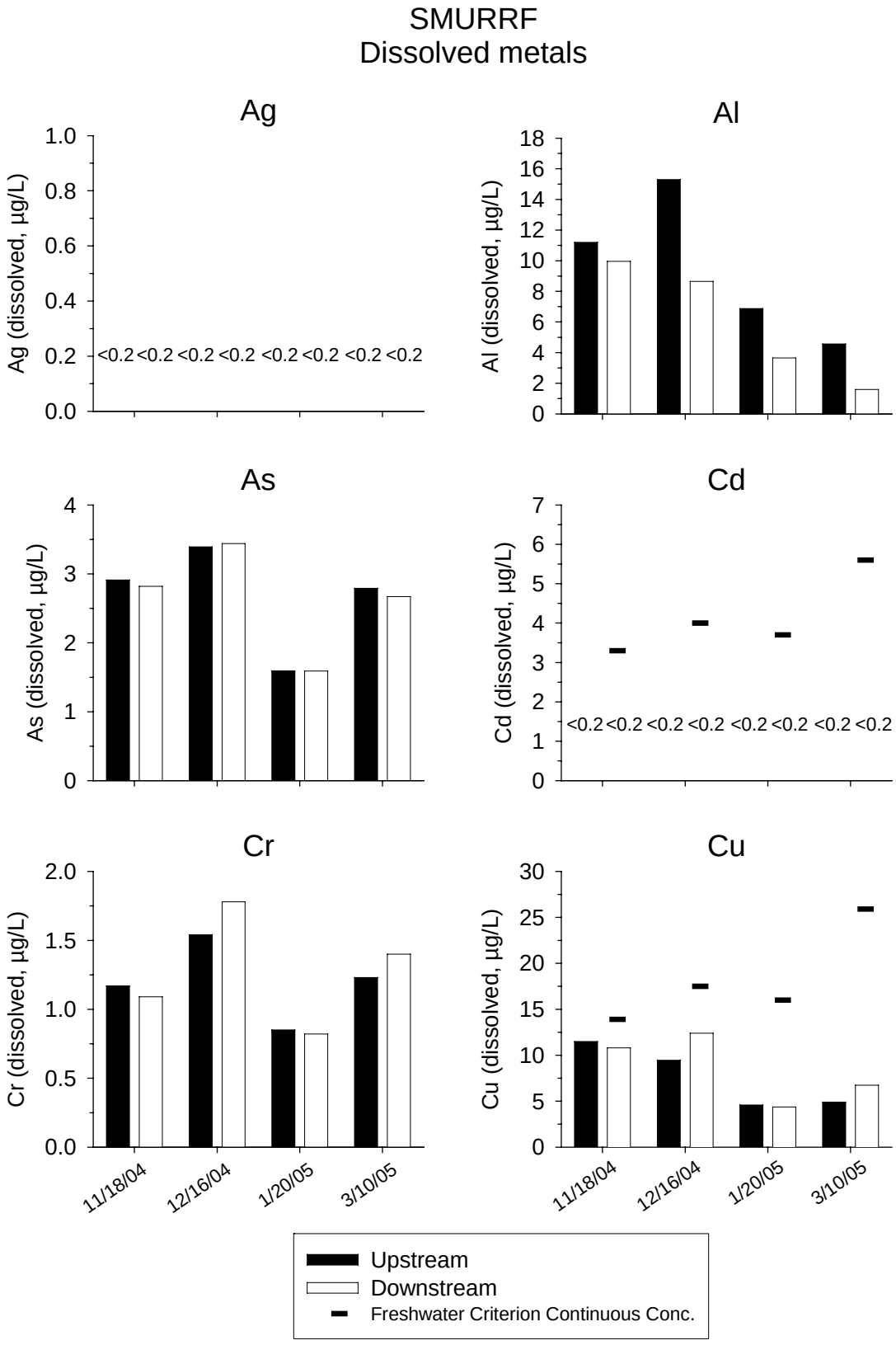


Figure 37. Concentrations of dissolved metals at the SMURRF site over four sampling events. The chronic criteria for dissolved As, Ni and Pb (not shown) are greater than the measured concentrations.

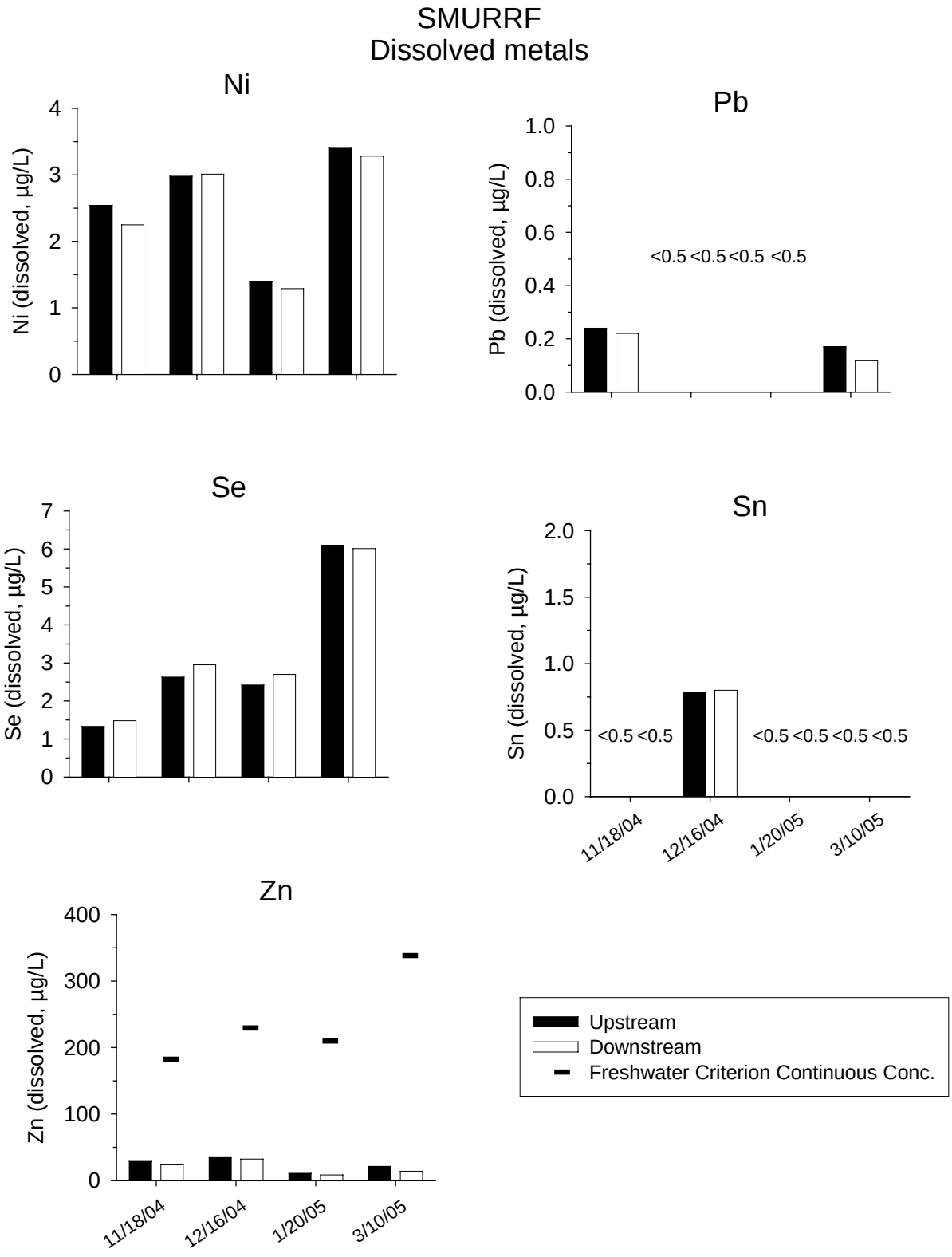


Figure 37 continued.

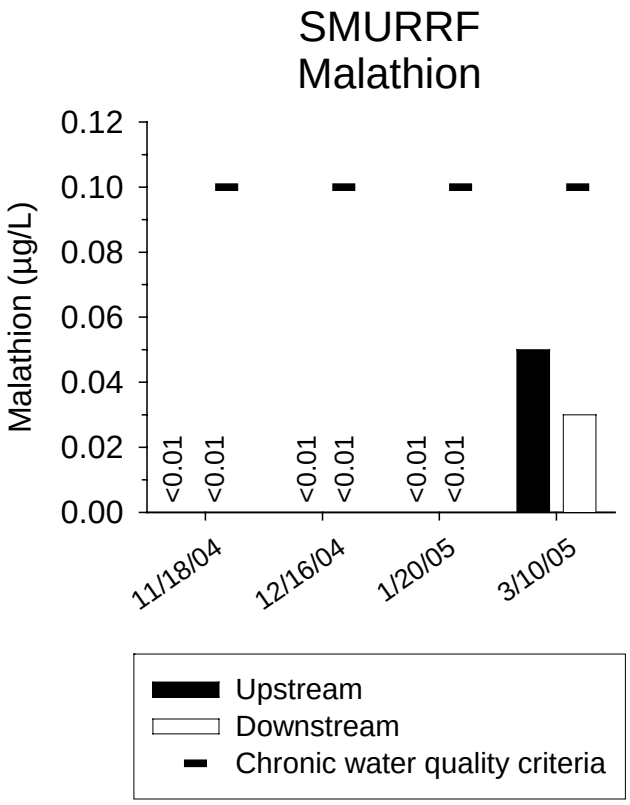


Figure 38. Concentrations of malathion at the SMURRF site over four sampling events.

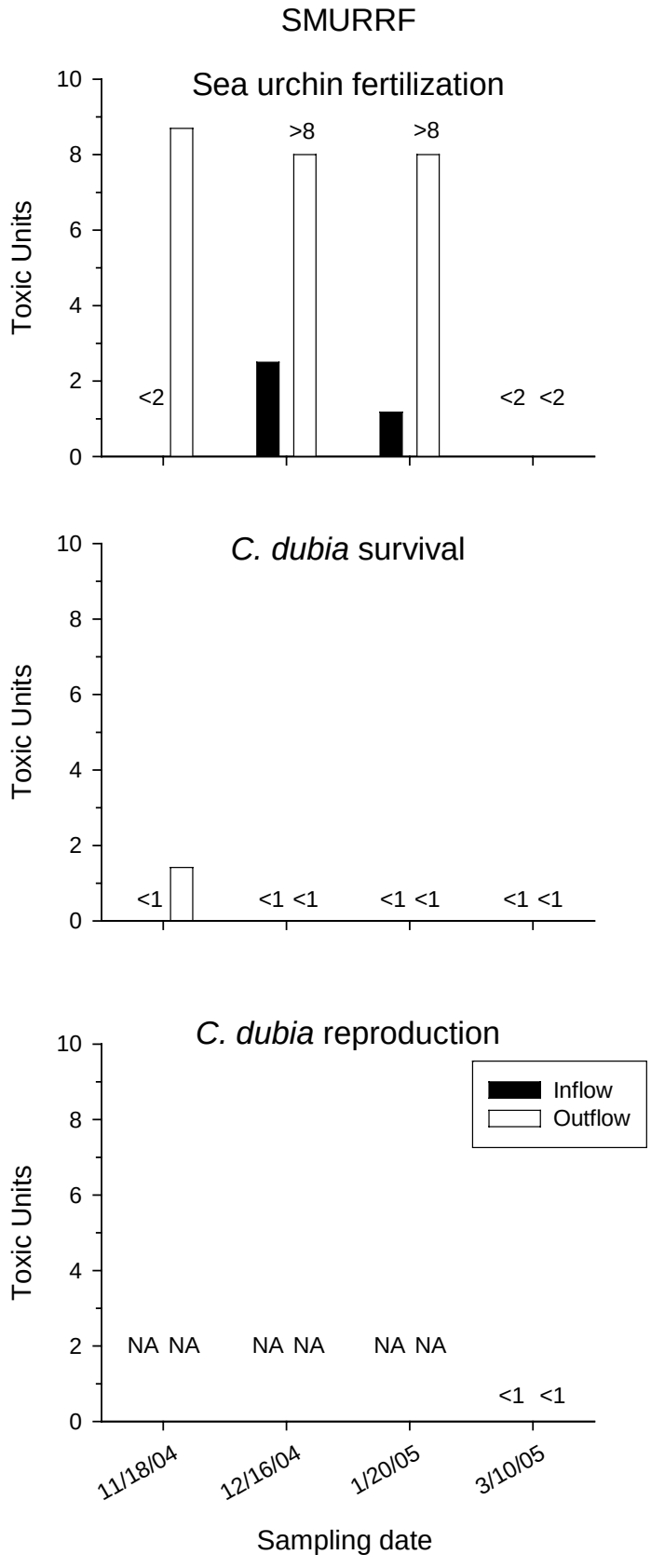


Figure 39. Toxicity in the SMURRF samples. NA = not analyzed.

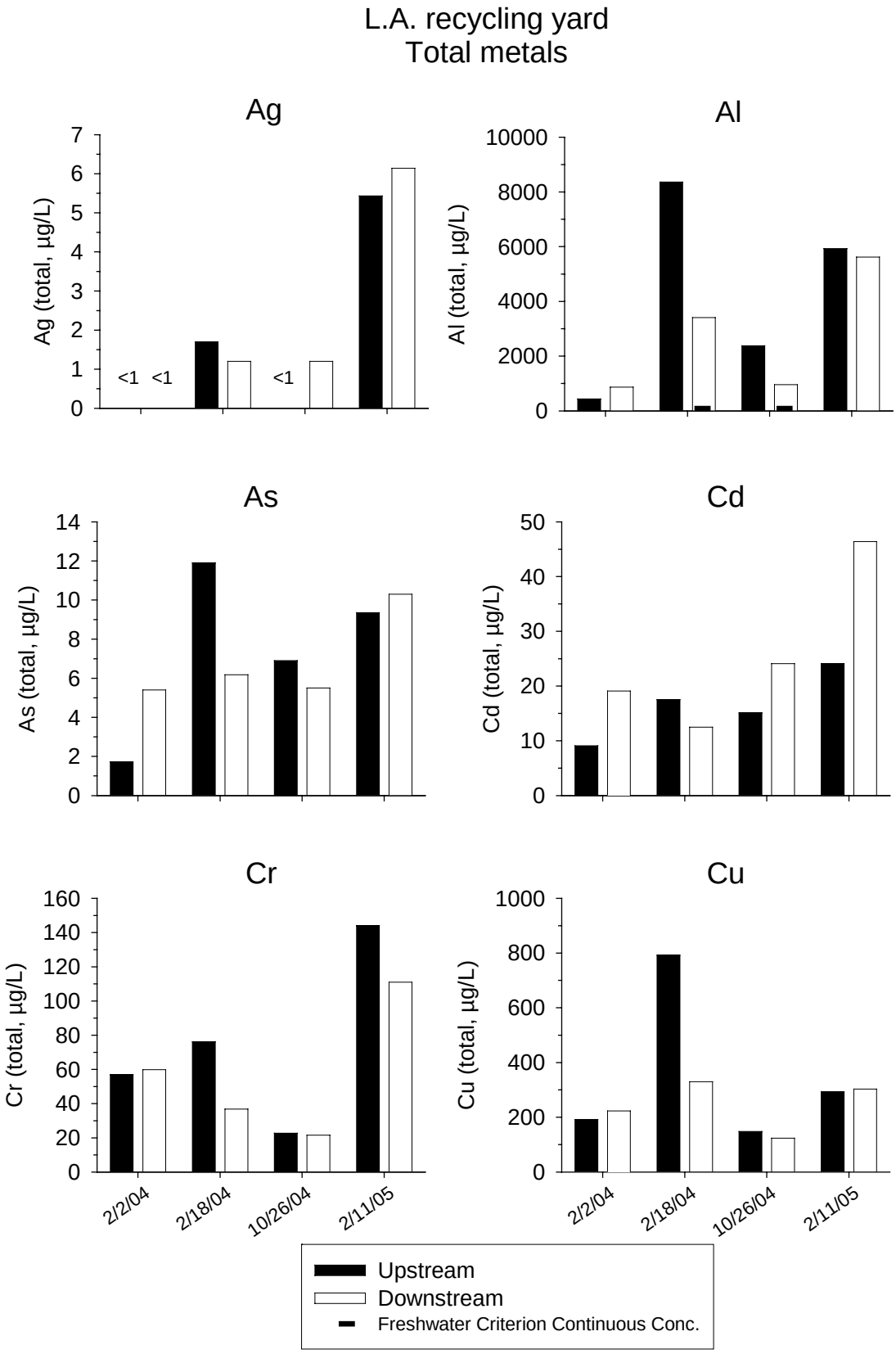


Figure 40. Concentrations of total metals and total suspended solids (TSS) at the L.A. metal recycling site over four sampling events.

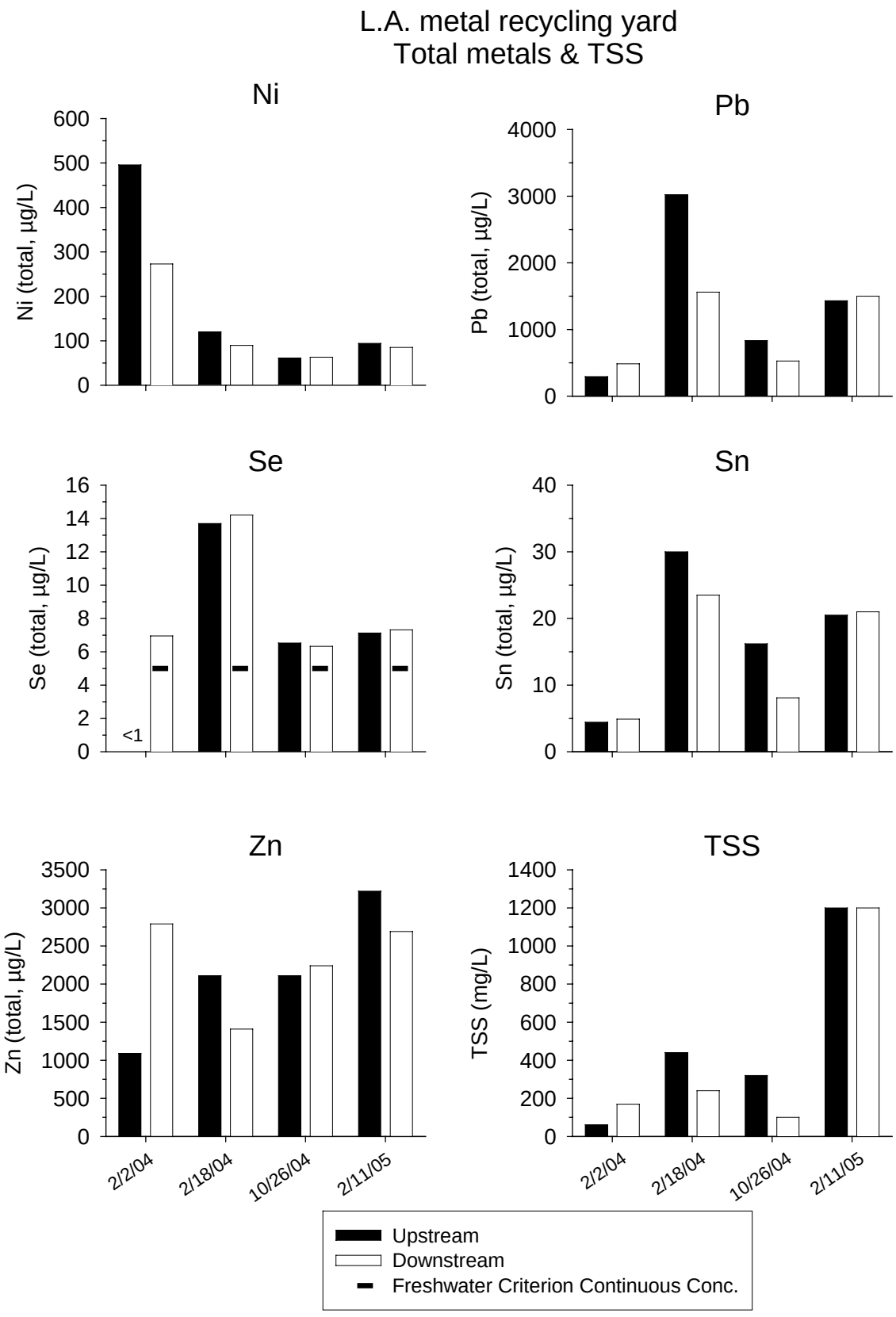


Figure 40 continued.

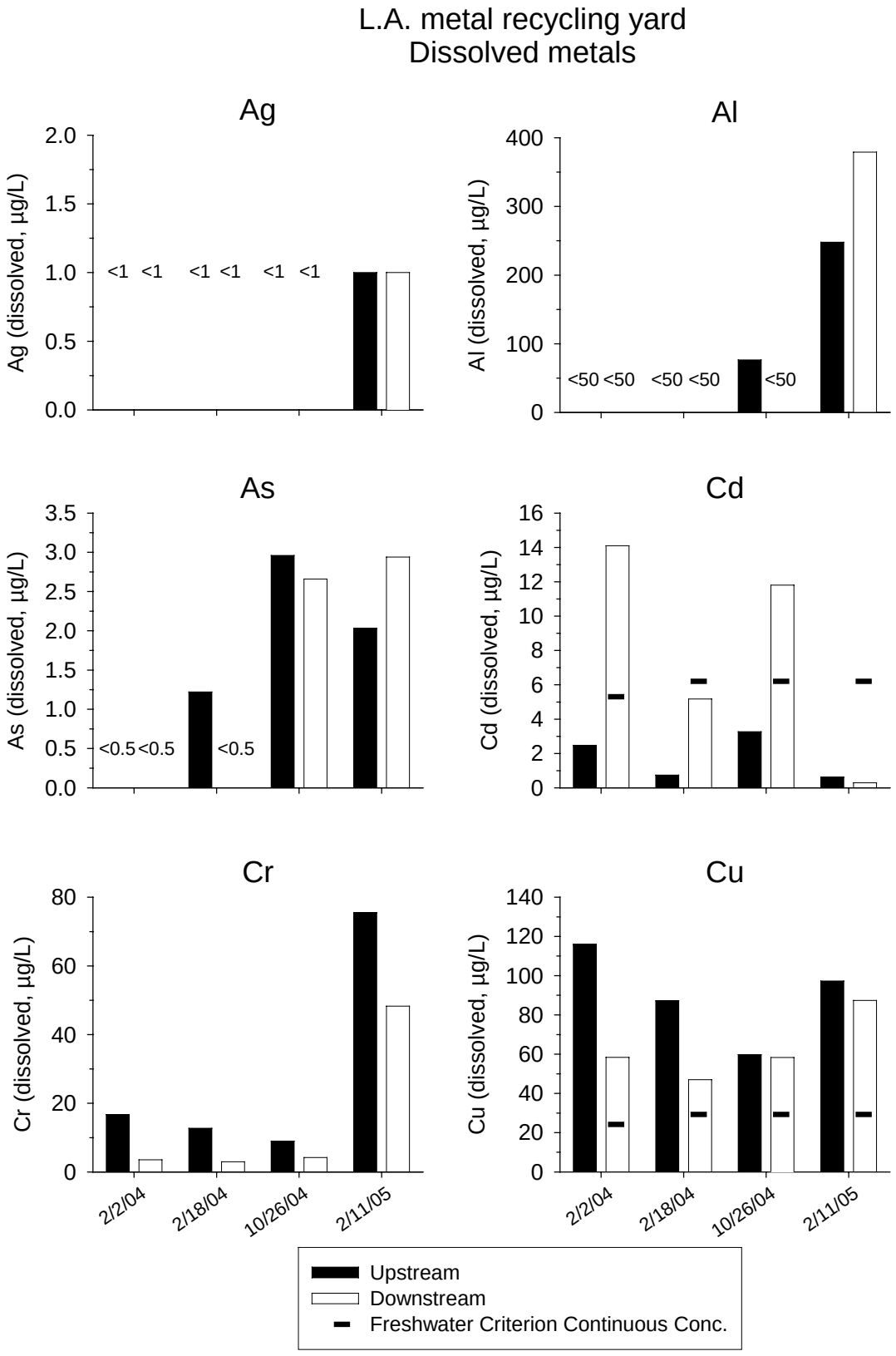


Figure 41. Concentrations of dissolved metals at the L.A. metal recycling site over four sampling events. The chronic criterion for dissolved As (150 µg/L) is not shown.

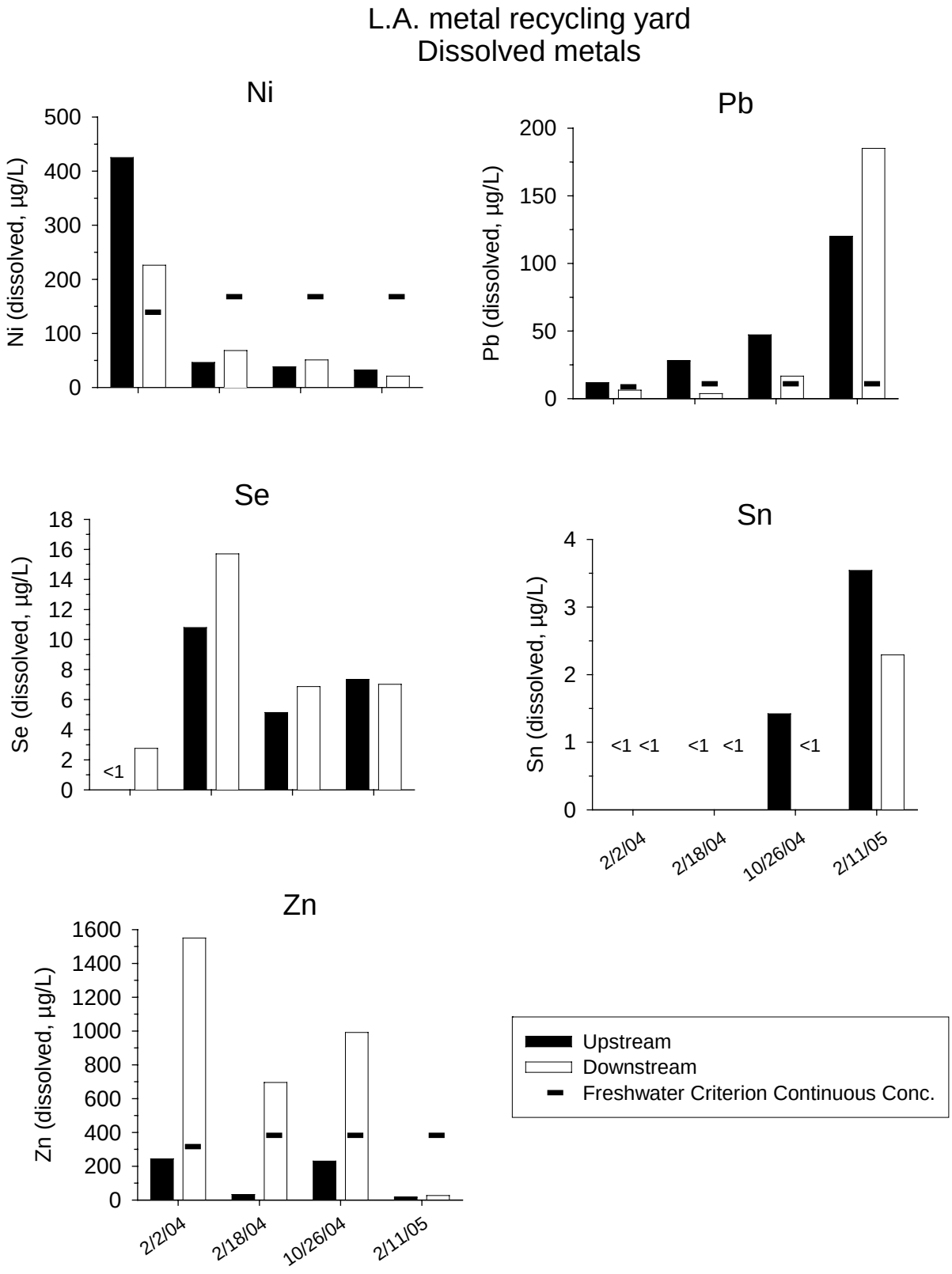


Figure 41 continued.

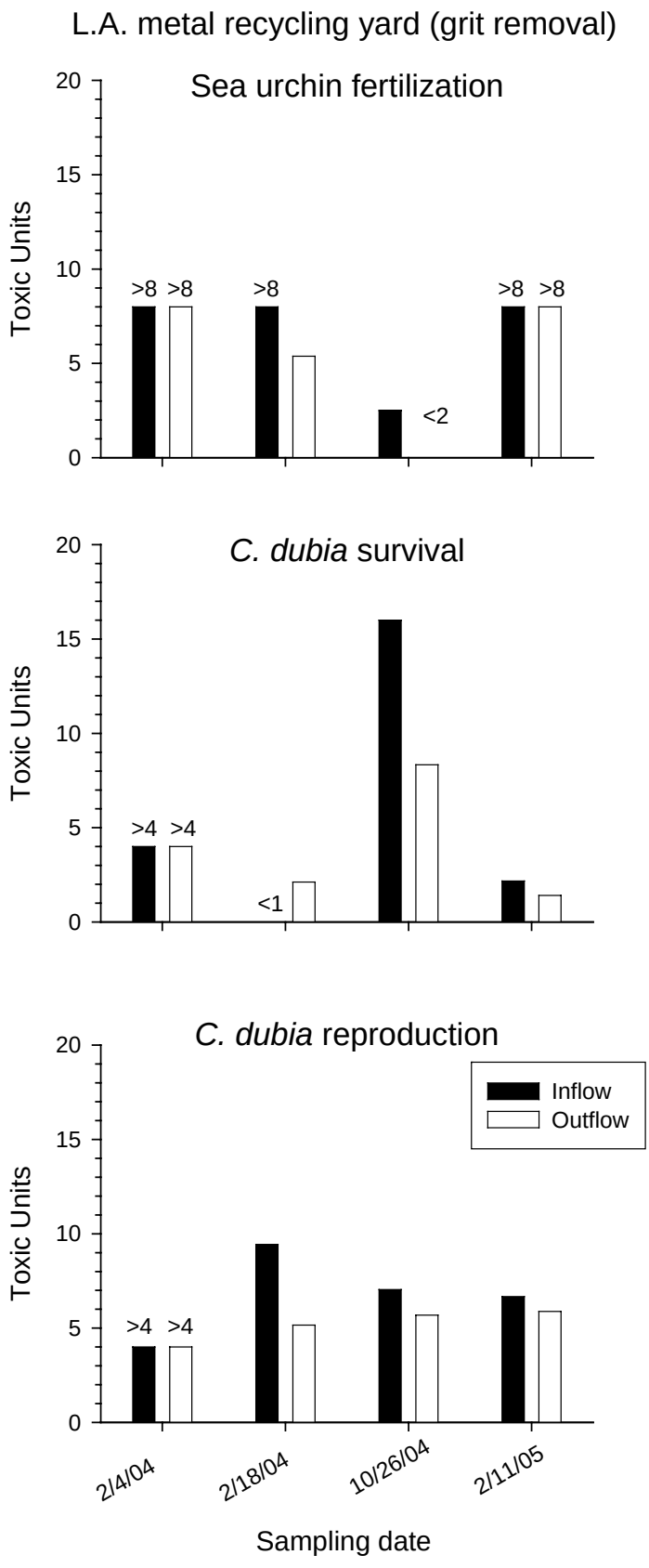


Figure 42. Toxicity in the stormwater samples from the L.A. metal recycling site.

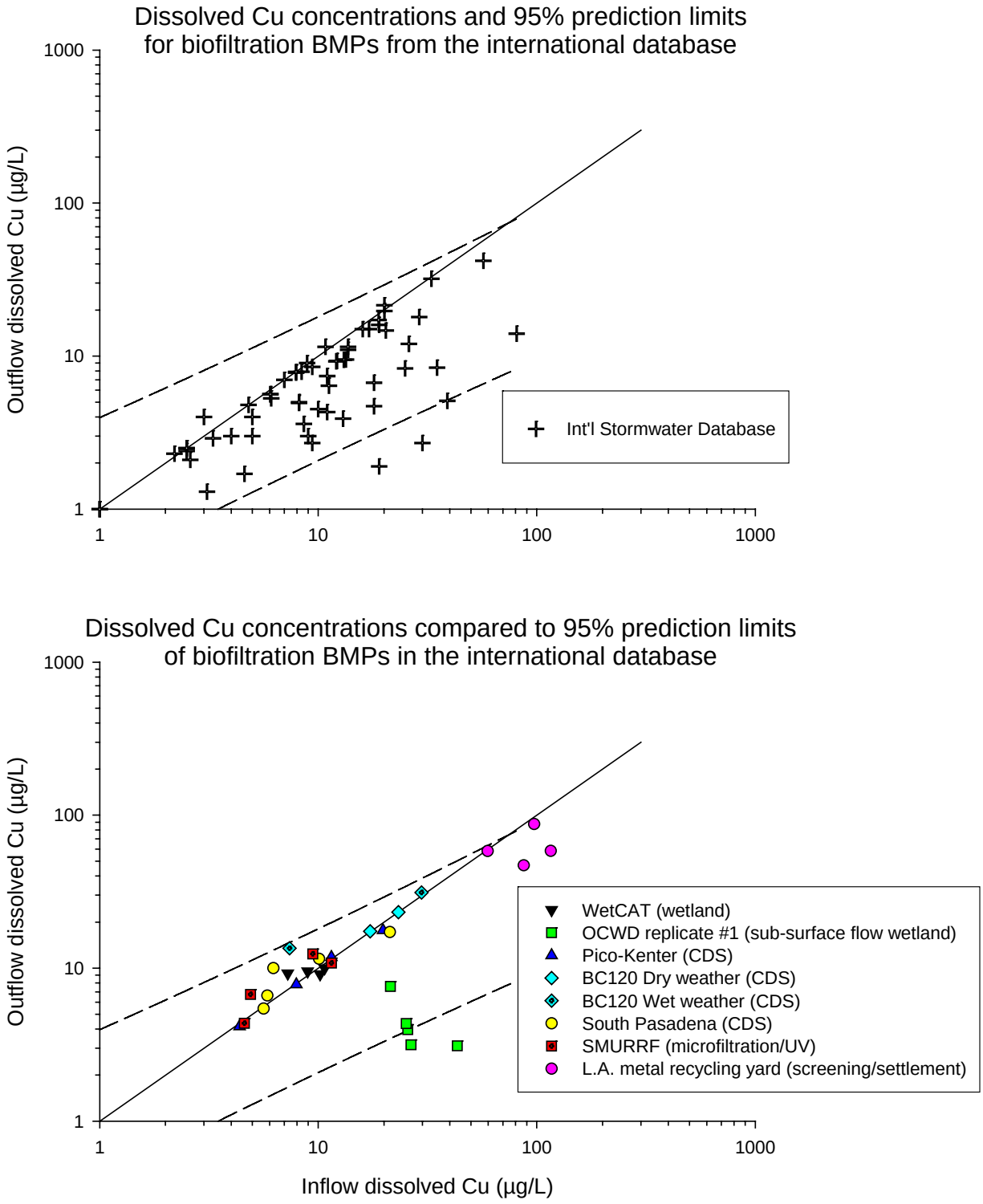


Figure 43. Dissolved Cu concentrations and 95% prediction limits (dashed lines) of biofiltration BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the biofiltration prediction limits from the database. The solid line is the one-to-one relationship. There were 60 pairs of inflow/outflow dissolved Cu data for biofiltration BMPs in the international database.

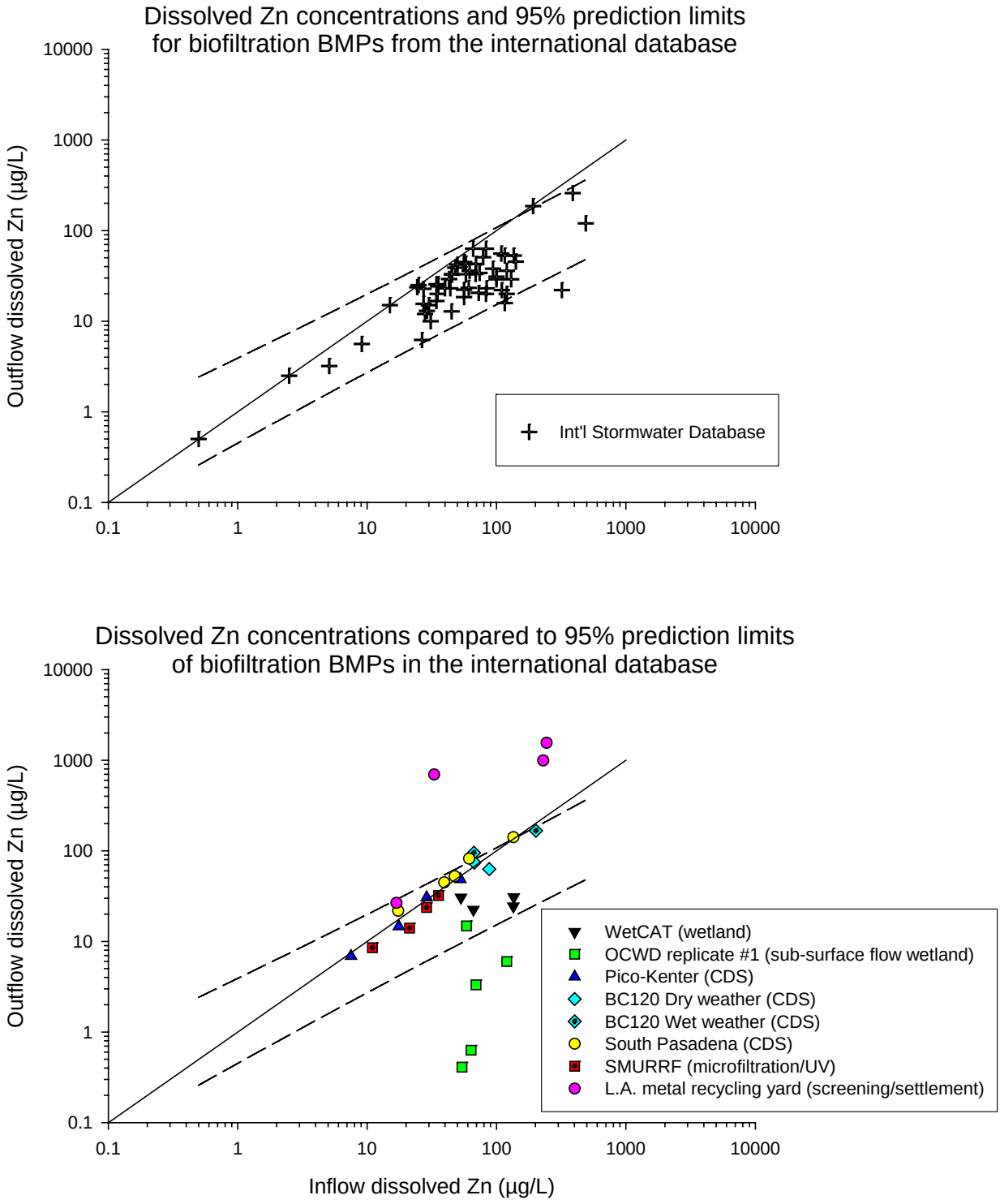


Figure 44. Dissolved Zn concentrations and 95% prediction limits (dashed lines) of biofiltration BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the biofiltration prediction limits from the database. The solid line is the one-to-one relationship. There were 60 pairs of inflow/outflow dissolved Zn data for biofiltration BMPs in the international database.

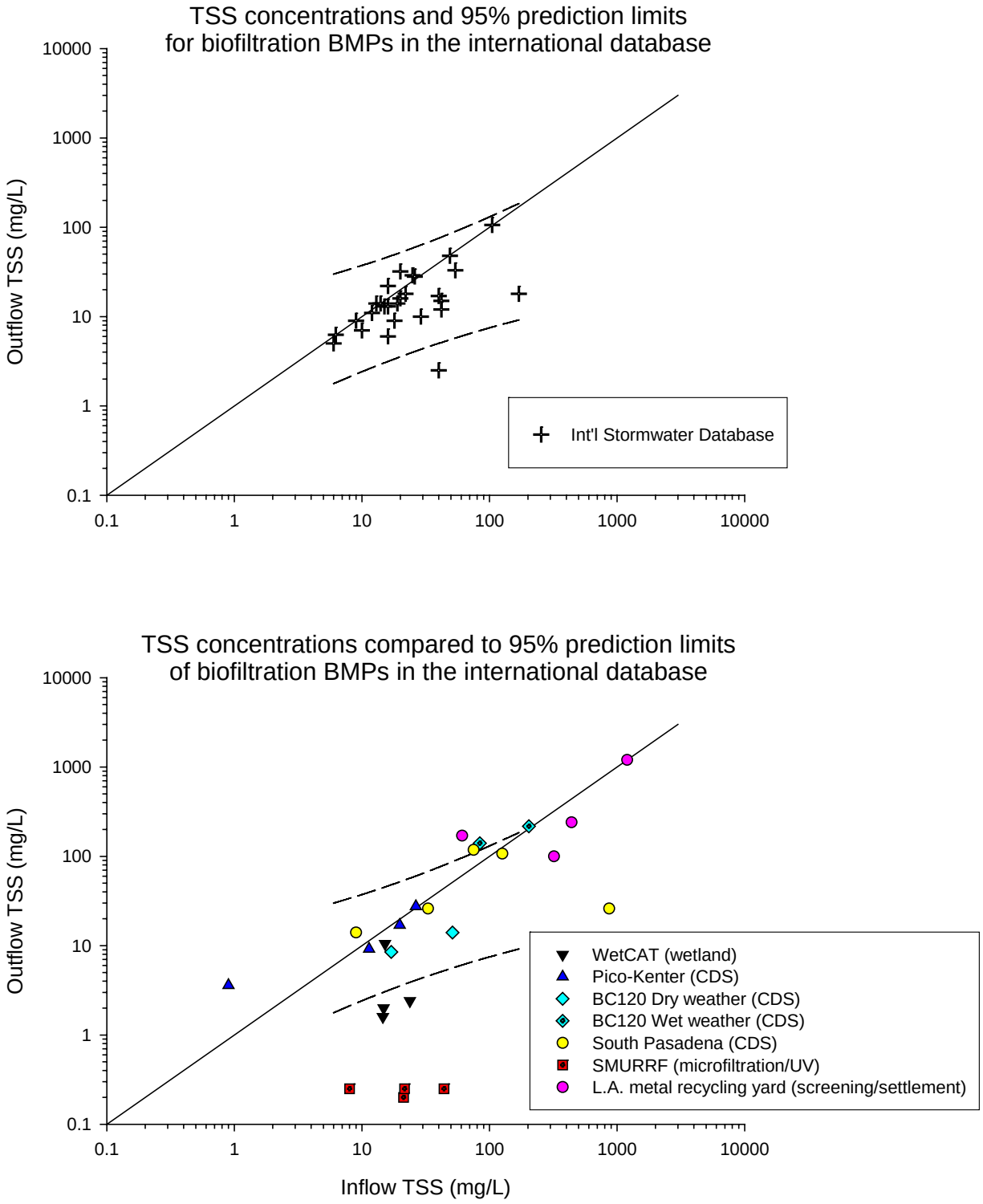


Figure 45. Concentrations of TSS and 95% prediction limits (dashed lines) of biofiltration BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the biofiltration prediction limits from the database. The solid line is the one-to-one relationship. There were 27 pairs of inflow/outflow TSS data from biofiltration BMPs in the international database.

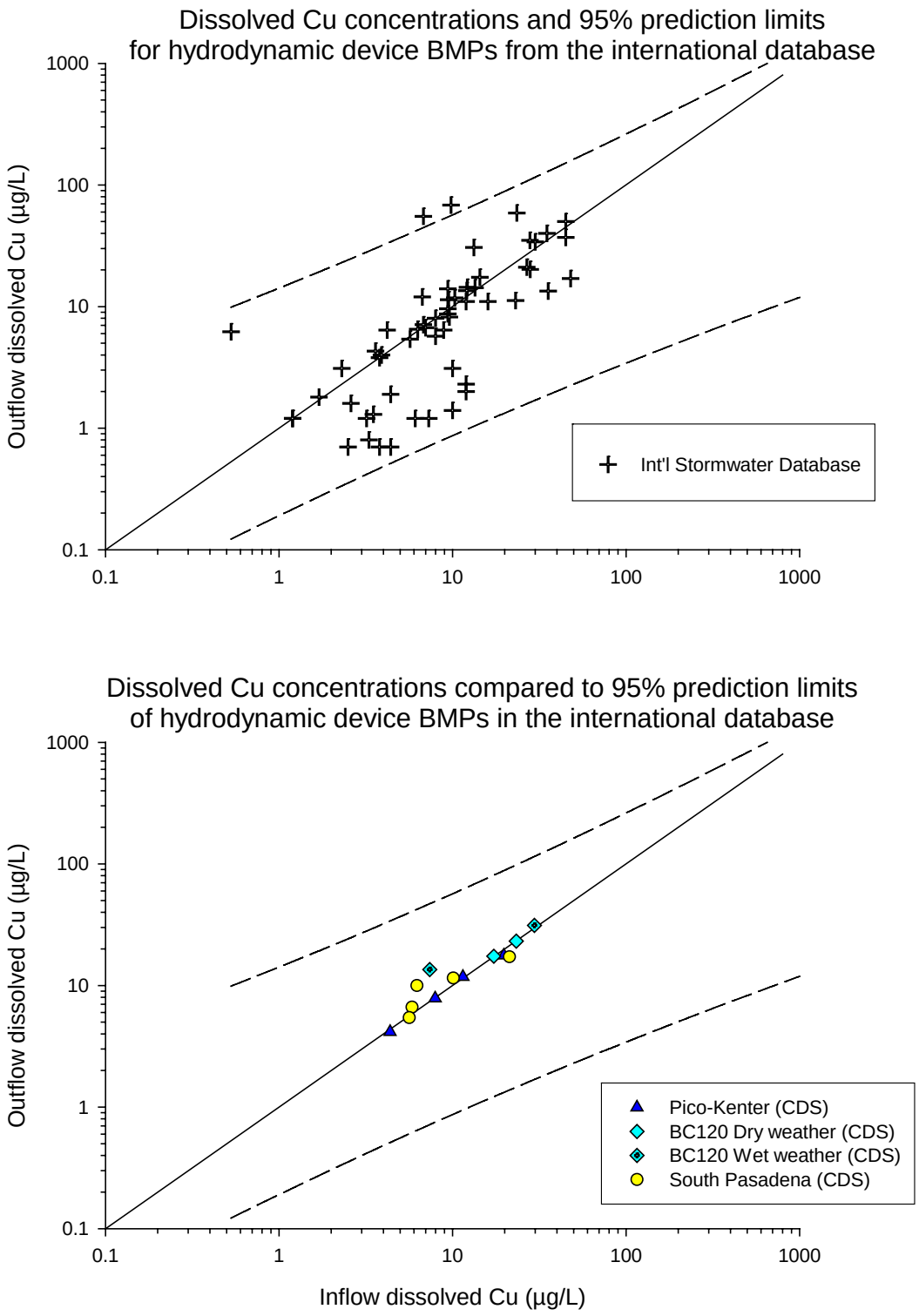


Figure 46. Concentrations of dissolved Cu and 95% prediction limits (dashed lines) of hydrodynamic device BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the hydrodynamic device prediction limits from the database. The solid line is the one-to-one relationship. There were 58 pairs of inflow/outflow dissolved Cu data from hydrodynamic device BMPs in the international database.

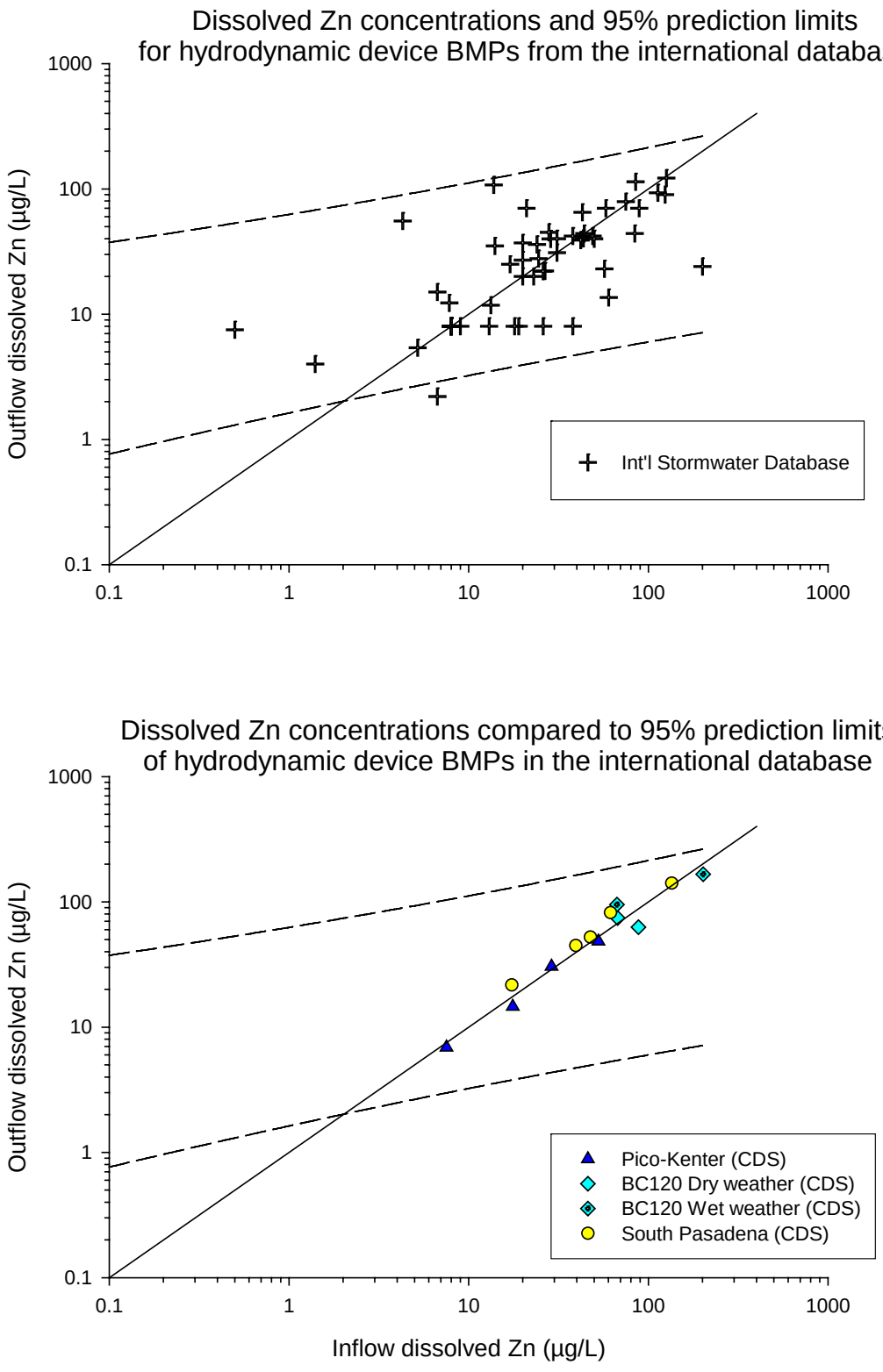


Figure 47. Concentrations of dissolved Zn and 95% prediction limits (dashed lines) of hydrodynamic device BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the hydrodynamic device prediction limits from the database. The solid line is the one-to-one relationship. There were 57 pairs of inflow/outflow dissolved Zn data from hydrodynamic device BMPs in the international database.

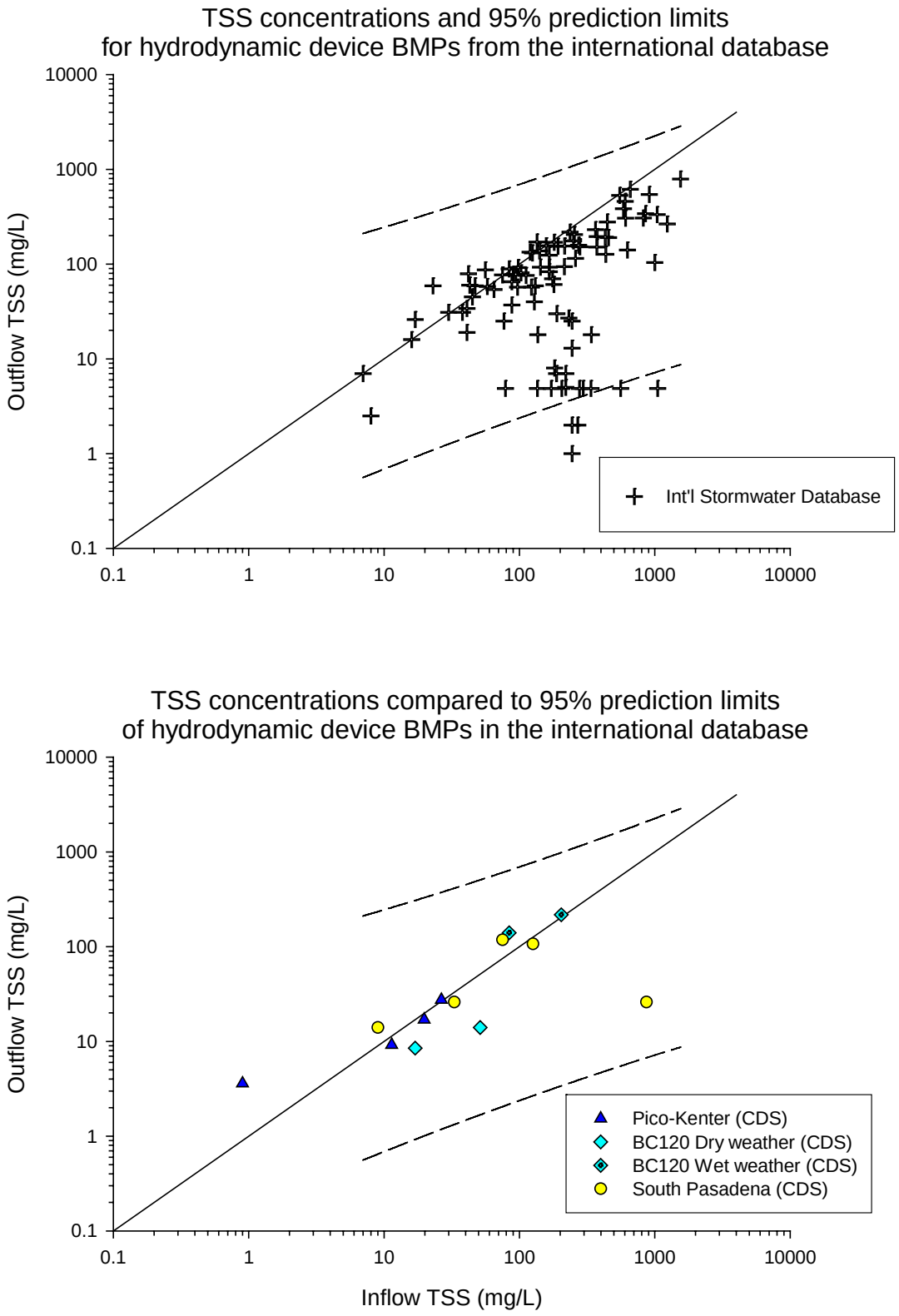


Figure 48. Concentrations of TSS and 95% prediction limits (dashed lines) of hydrodynamic device BMPs in the international stormwater database (top graph). The bottom graph shows data from the current study plotted against the hydrodynamic device prediction limits from the database. The solid line is the one-to-one relationship. There were 93 pairs of inflow/outflow TSS data from hydrodynamic device BMPs in the international database.

Table 7. Toxicity in the Wet CAT wetland samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50), or survival (LC50). TU = toxic units.

	11/18/04			12/16/04			1/20/05			3/10/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow												
Echinoderm fertilization	50	>50	<2	50	>50	<2	<12.5	33	3.1	<12.5	<12.5	>8
C. dubia survival	50	41	2.4	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1
Outflow												
Echinoderm fertilization	50	>50	<2	50	>50	<2	50	>50	<2	25	46	2.2
C. dubia survival	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1

Table 8. Toxicity in the OCWD sub-surface flow wetland cells. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 = concentration of sample that caused a 50% reduction in fertilization. TU = toxic units.

	2/3/05			2/10/05			2/24/05			3/3/05			3/10/05		
	NOEC (%)	EC50 (%)	TU	NOEC (%)	EC50 (%)	TU	NOEC (%)	EC50 (%)	TU	NOEC (%)	EC50 (%)	TU	NOEC (%)	EC50 (%)	TU
Wetland cell#1															
Inflow Echinoderm fertilization	25	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2	25	>50	<2
Outflow Echinoderm fertilization	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2
Wetland cell#2															
Inflow Echinoderm fertilization	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2
Outflow Echinoderm fertilization	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2	50	>50	<2

Table 9. Toxicity in the Pico-Kenter CDS samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50), or survival (LC50). TU = toxic units.

	11/18/04			12/16/04			1/20/05			3/10/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow												
Echinoderm fertilization	50	>50	<2	25	60	1.7	25	>50	<2	<12.5	>50	<2
C. dubia survival	100	>100	<1	100	>100	<1	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1
Outflow												
Echinoderm fertilization	50	>50	<2	25	48	2.1	25	44	2.3	12.5	>50	<2
C. dubia survival	100	>100	<1	100	>100	<1	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1

Table 10. Toxicity in the BC120 CDS dry weather samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50), or survival (LC50). TU = toxic units.

	1/19/05			3/10/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow						
Echinoderm fertilization	25	42	2.4	50	>50	<2
C. dubia survival	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	100	>100	<1
Outflow						
Echinoderm fertilization	12.5	33	3.0	<12.5	>50	<2
C. dubia survival	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	100	>100	<1

Table 11. Toxicity in the BC120 CDS wet weather samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50) or survival (LC50). TU = toxic units.

	1/26/05			2/11/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow						
Echinoderm fertilization	<12.5	<12.5	>8	25	38	2.6
C. dubia survival	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	100	>100	<1
Outflow						
Echinoderm fertilization	<12.5	<12.5	>8	25	34	2.9
C. dubia survival	NA	NA	NA	100	>100	<1
C. dubia reproduction	NA	NA	NA	100	>100	<1

Table 12. Toxicity in the South Pasadena CDS samples. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50) or survival (LC50). TU = toxic units.

	12/5/04			1/2/05			1/7/05			1/26/05			2/11/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow															
Echinoderm fertilization	12.5	30.5	3.3	<12.5	20	5.0	<12.5	<12.5	>8	<12.5	<12.5	>8	12.5	20	30.5
C. dubia survival	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1
Outflow															
Echinoderm fertilization	12.5	27.5	3.6	<12.5	14	7.1	<12.5	<12.5	>8	<12.5	<12.5	>8	<12.5	18	27.5
C. dubia survival	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1

Table 13. Toxicity in the SMURRF samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50), or survival (LC50). TU = toxic units

	11/18/04			12/16/04			1/20/05			3/10/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow												
Echinoderm fertilization	50	>50	<2	25	40	2.5	<12.5	85	1.2	25	>50	<2
C. dubia survival	100	>100	<1	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1
Outflow												
Echinoderm fertilization	6.25	11.5	8.7	<12.5	<12.5	>8	<12.5	<12.5	>8	25	>50	<2
C. dubia survival	50	70.7	1.4	100	>100	<1	100	>100	<1	100	>100	<1
C. dubia reproduction	NA	NA	NA	NA	NA	NA	NA	NA	NA	100	>100	<1

Table 14. Toxicity in the L.A. metal recycling yard BMP samples. NA = not analyzed. NOEC = No Effect Concentration, which is the highest concentration of sample tested that did not cause an effect. EC50 or LC50 = concentration of sample that caused a 50% reduction in fertilization or reproduction (EC50), or survival (LC50). TU = toxic units.

	2/2/04			2/18/04			10/26/04			2/11/05		
	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU	NOEC (%)	EC50 or LC50 (%)	TU
Inflow												
Echinoderm fertilization	<12.5	<12.5	>8	<12.5	<12.5	>8	12.5	40	2.5	<12.5	<12.5	>8
C. dubia survival	<25	<25	>4	100	>100	<1	6.25	6.25	16.0	25	46	2.2
C. dubia reproduction	<25	<25	>4	6.25	10.6	9.4	<6.25	14.2	7.0	<25	15	6.7
Outflow												
Echinoderm fertilization	<12.5	<12.5	>8	12.5	19	5.4	50	>50	<2	<12.5	<12.5	>8
C. dubia survival	<25	<25	>4	25	47	2.1	12.5	12	8.3	50	71	1.4
C. dubia reproduction	<25	<25	>4	12.5	19	5.2	12.5	18	5.7	<25	17	5.9

Table 15. Proportion of sampling events with ≥10% reduction between inflow and outflow samples. NA = not analyzed. ND = not detected.

	Wet CAT (wetland) Dry weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry weather	BC120 (CDS) Dry weather	BC120 (CDS) Wet weather	South Pasadena (CDS) Wet weather	SMURRF (filtration + UV) Dry weather	L.A. metal recycling yard (grit removal) Wet weather
Total metals								
Al	3/4	NA	1/4	2/2	0/2	2/4	4/4	2/4
As	1/4	NA	1/4	0/2	0/2	ND	1/4	2/4
Cd	4/4	NA	ND	ND	0/2	ND	1/1	1/4
Cr	3/4	NA	0/4	1/2	0/2	2/5	4/4	1/4
Cu	4/4	5/5 (cell#1 & #2)	0/4	2/2	0/2	2/5	4/4	1/4
Ni	4/4	NA	0/4	1/2	0/2	2/5	4/4	2/4
Pb	0/2	NA	2/4	2/2	0/2	3/5	4/4	2/4
Se	4/4	NA	0/4	0/2	0/2	ND	0/4	0/4
Zn	4/4	5/5 (cell#1 & #2)	0/4	2/2	0/2	3/5	4/4	2/4
Dissolved metals								
Al	4/4	NA	2/4	0/2	0/2	ND	4/4	1/2
As	0/4	NA	0/4	0/2	0/2	ND	0/4	2/3
Cd	4/4	NA	0/1	1/1	1/1	ND	ND	1/4
Cr	2/4	NA	2/4	0/2	0/2	0/4	0/4	4/4
Cu	1/4	5/5 (cell#1 & #2)	1/4	0/2	0/2	1/5	0/4	3/4
Ni	4/4	NA	0/4	0/2	0/2	0/3	1/4	2/4
Pb	0/1	NA	0/2	1/2	0/2	0/3	1/2	3/4
Se	1/4	NA	2/4	0/2	1/2	ND	0/4	0/4
Zn	4/4	5/5 (cell#1 & #2)	1/4	1/2	1/2	0/5	4/4	0/4
Total suspended solids	4/4	NA	2/4	2/2	0/2	3/5	4/4	2/4
Organophosphorus pesticides								
Chlorpyrifos	ND	NA	0/1	ND	ND	1/2	ND	NA
Diazinon	2/2	3/4 (cell#1) 5/5 (cell#2)	ND	0/1	1/1	1/1	ND	NA
Malathion	1/1	NA	ND	ND	ND	ND	1/1	NA
Pyrethroid pesticide	ND	NA	ND	ND	ND	NA	ND	NA
Bifenthrin	ND	NA	ND	0/1	ND	ND	ND	NA
Glyphosate	ND	NA	ND	ND	ND	NA	ND	NA

Table 16. BMP effectiveness with regard to chronic water quality criteria. The denominator indicates the number of inflow samples that exceeded the water quality criteria, while the numerator indicates the number of outflow samples that met the criteria only after treatment by the BMP. Instances where the inflow sample was already below the water quality criteria are not counted. NA = not analyzed.

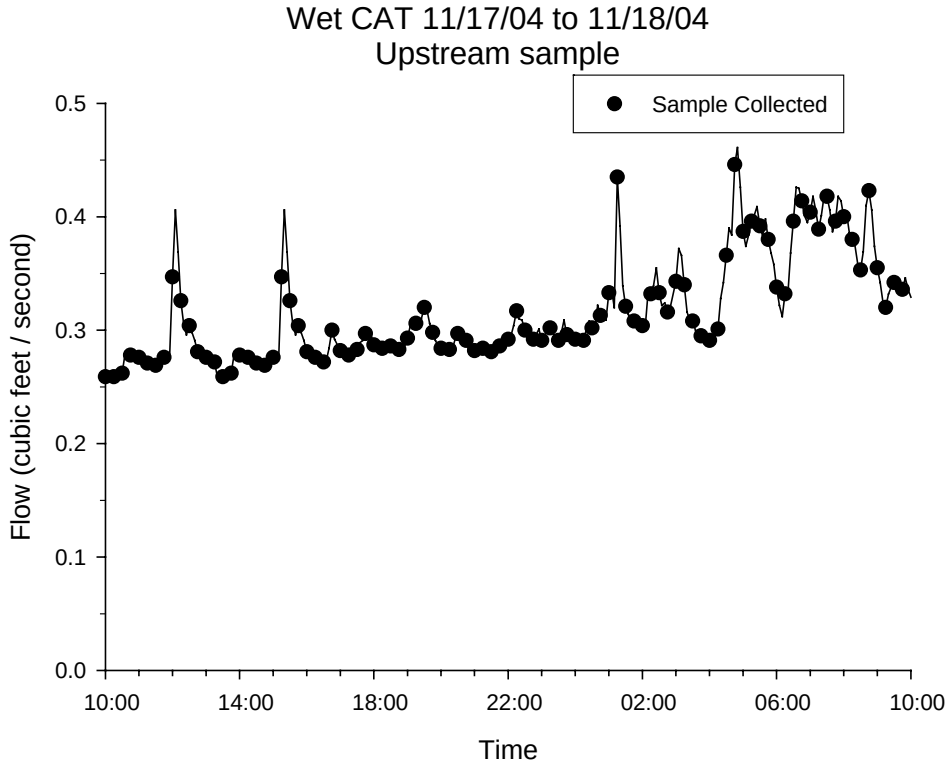
	Wet CAT (wetland) Dry weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry weather	BC120 (CDS) Dry weather	BC120 (CDS) Wet weather	South Pasadena (CDS) Wet weather	SMURRF (filtration + UV) Dry weather	L.A. metal recycling yard (grit removal) Wet weather
Total metals								
Al	3/4	NA	0/3	0/2	0/2	0/3	4/4	0/2
Se	0/4	NA	0/1	0/0	0/0	0/0	0/1	0/3
Dissolved metals								
As	0/0	NA	0/0	0/0	0/0	0/0	0/0	0/0
Cd	3/3	NA	0/0	0/0	0/0	0/0	0/0	0/0
Cu	0/0	5/5 (cell#1) 2/2 (cell#2)	1/1	0/2	0/2	0/5	0/0	0/4
Ni	2/2	NA	0/0	0/0	0/0	0/0	0/0	0/1
Pb	0/0	NA	0/0	0/1	0/1	1*/3	0/0	2/4
Zn	0/0	0/0 (cell#1) 0/0 (cell#2)	0/0	0/1	0/2	0*/4	0/0	0/1
OP pesticides								
Chlorpyrifos	0/0	NA	0/0	0/0	0/0	0/2	0/0	NA
Diazinon	0/0	0/4 (cell#1) 1/5 (cell#2)	0/0	0/0	1/1	1/1	0/0	NA

* = The outflow sample from 1/2/05 met the water quality criterion only because the hardness of the outflow sample increased substantially relative to the inflow sample, thereby increasing the criterion. These samples are not counted as meeting the chronic criteria after treatment in this table.

Table 17. Overall effectiveness of BMP treatment. The evaluation of the BMP efficiency used a two-tier approach, with a designation of effectiveness for each tier (tier 1/tier 2). The first part of the designation refers to the ability to reduce concentrations by ≥10%, while the second part of the designation refers to the ability to attain a water quality criterion. Reductions less than 10% were given a "No/U" designation for no meaningful reduction by the BMP. If the concentrations were reduced by ≥10% for at least 75% of the sampling events, the data were then compared to water quality criteria (second tier). If there was insufficient data to assess effectiveness (e.g., measurements were usually below the reporting level), the designation of "U/U" was used. If the outflow sample was reduced to below the chronic criterion a "Yes/+" designation was used. If the reduction did not result in outflow concentrations below the criterion, a "Yes/-" designation was used. If there was a consistent reduction, but the outflow inconsistently met the criterion, the designation of "Yes/?" was used. Instances where concentrations were reduced, but the inflow data was consistently below the criteria were given a "Yes/U" designation. NA = not analyzed.

	Wet CAT (wetland) Dry weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry weather	BC120 (CDS) Dry weather	BC120 (CDS) Wet weather	South Pasadena (CDS) Wet weather	SMURRF (filtration + UV) Dry weather	L.A. metal recycling yard (grit removal) Wet weather
Total metals								
Al	Yes/?	NA	No/U	Yes/–	No/U	No/U	Yes/+	No/U
Se	Yes/–	NA	No/U	No/U	U/U	U/U	No/U	No/U
Dissolved metals								
As	No/U	NA	No/U	No/U	No/U	U/U	No/U	No/U
Cd	Yes/+	NA	U/U	U/U	U/U	U/U	U/U	No/U
Cu	No/U	Yes/+	No/U	No/U	No/U	No/U	No/U	Yes/–
Ni	Yes/+	NA	No/U	No/U	No/U	U/U	No/U	No/U
Pb	U/U	NA	U/U	No/U	No/U	No/U	U/U	Yes/?
Zn	Yes/U	Yes/U	No/U	No/U	No/U	No/U	Yes/U	No/U
OP pesticides								
Chlorpyrifos	U/U	NA	U/U	U/U	U/U	No/U	U/U	NA
Diazinon	Yes/U	Yes/?	U/U	U/U	U/U	U/U	U/U	NA

Appendix: Hydrographs



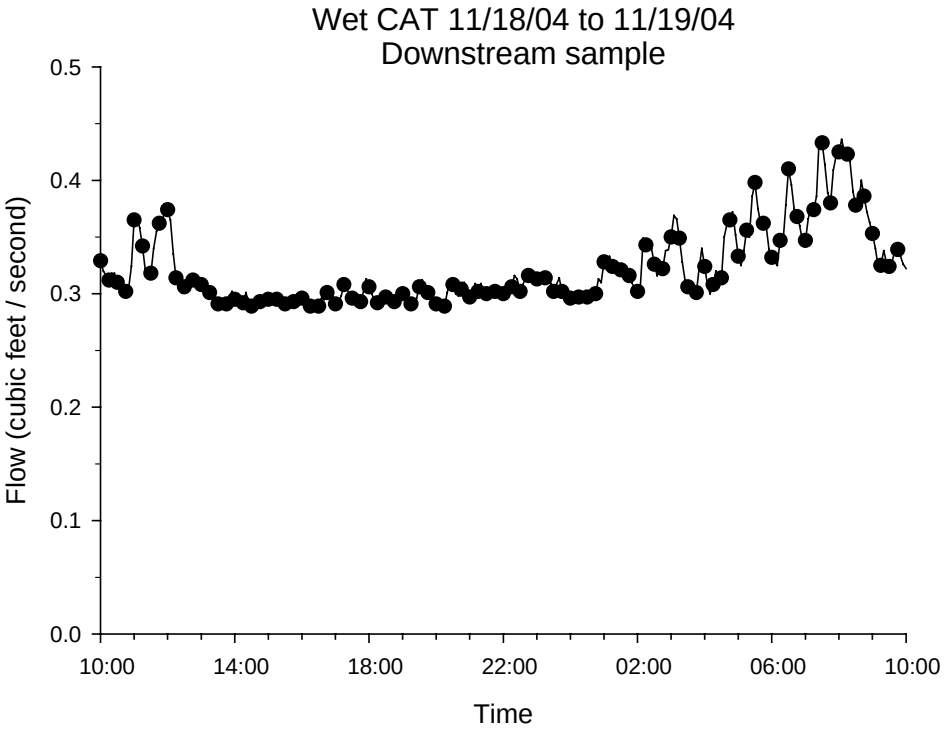
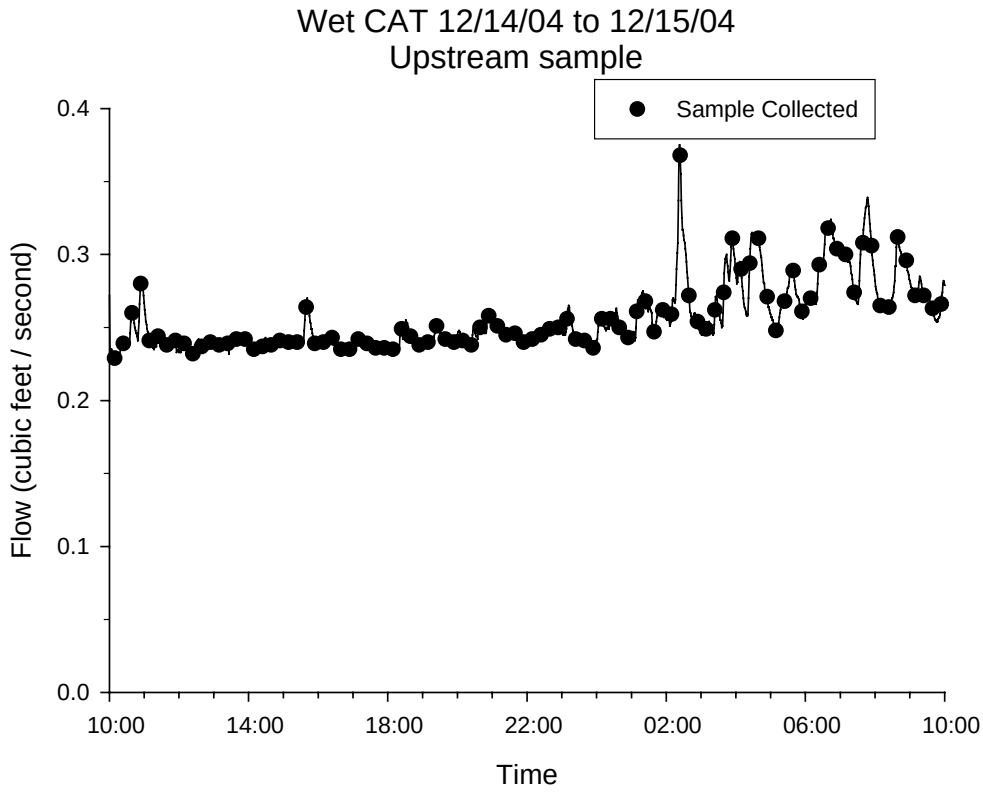


Figure A-1. Hydrograph at Wet CAT during the November 17-19, 2004 dry weather sampling event. Dots (●) indicate when the samples were collected for the chemistry and toxicity composite samples.



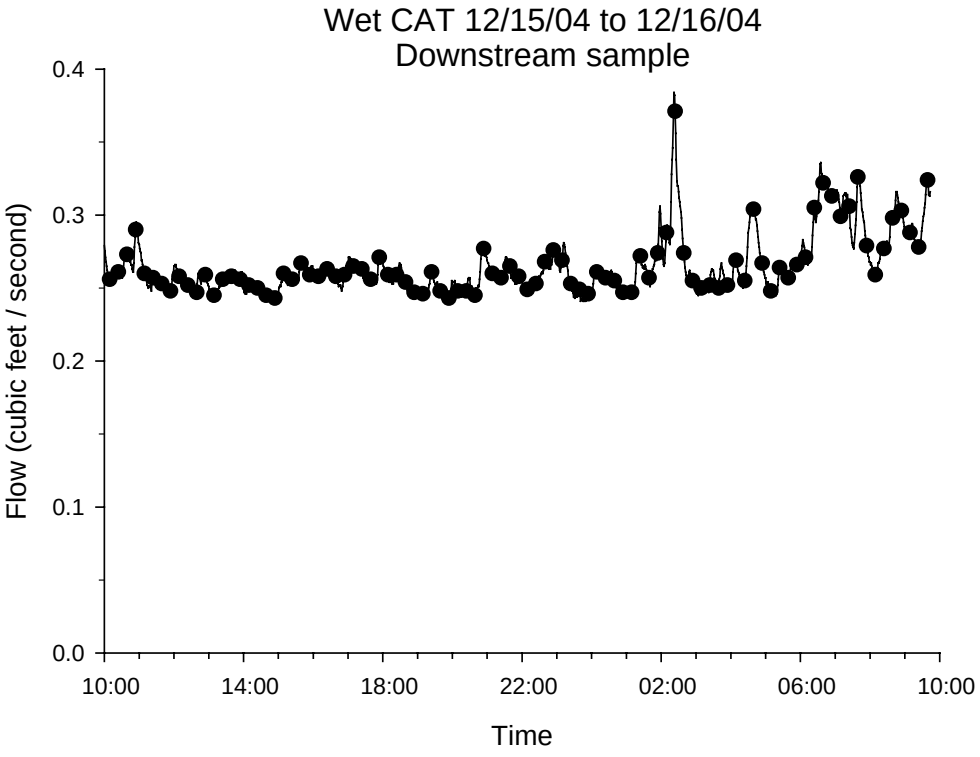
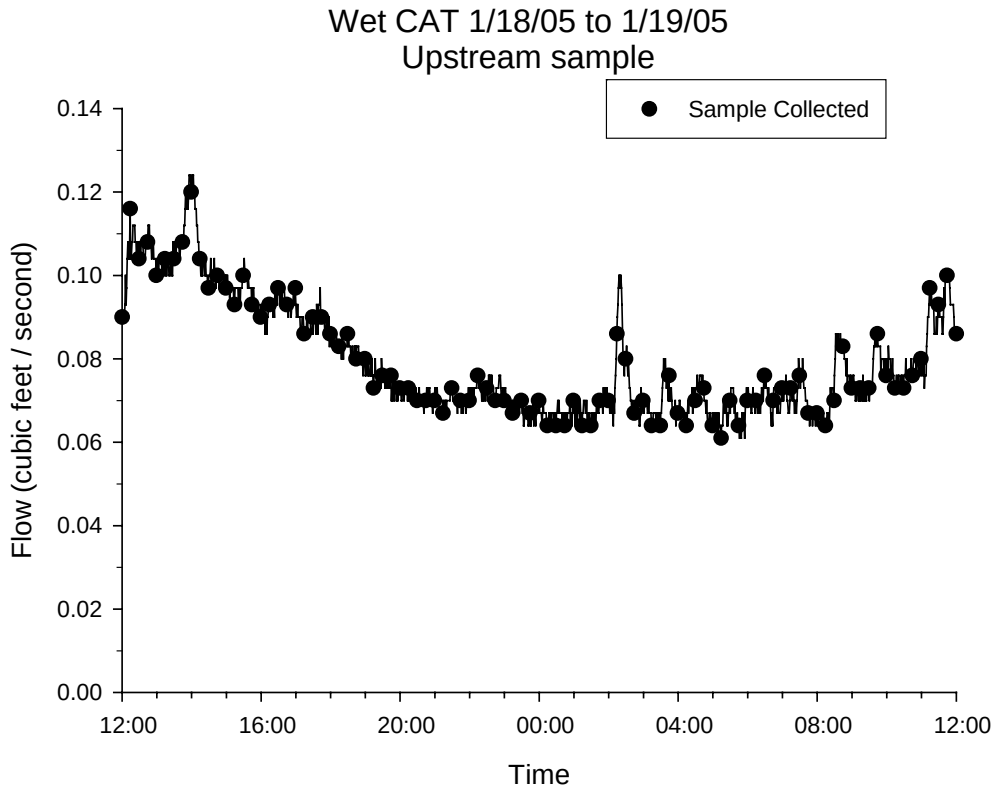


Figure A-2. Hydrograph at Wet CAT during the December 14-16, 2004 dry weather sampling event. Dots (●) indicate when the samples were collected for the chemistry and toxicity composite samples.



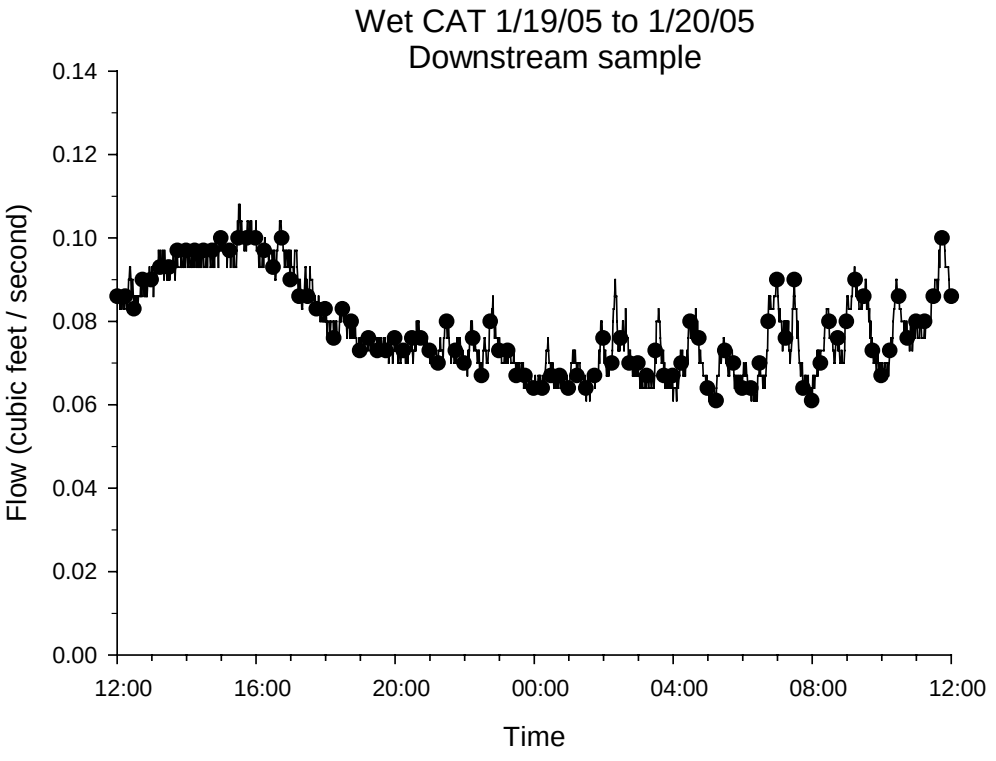
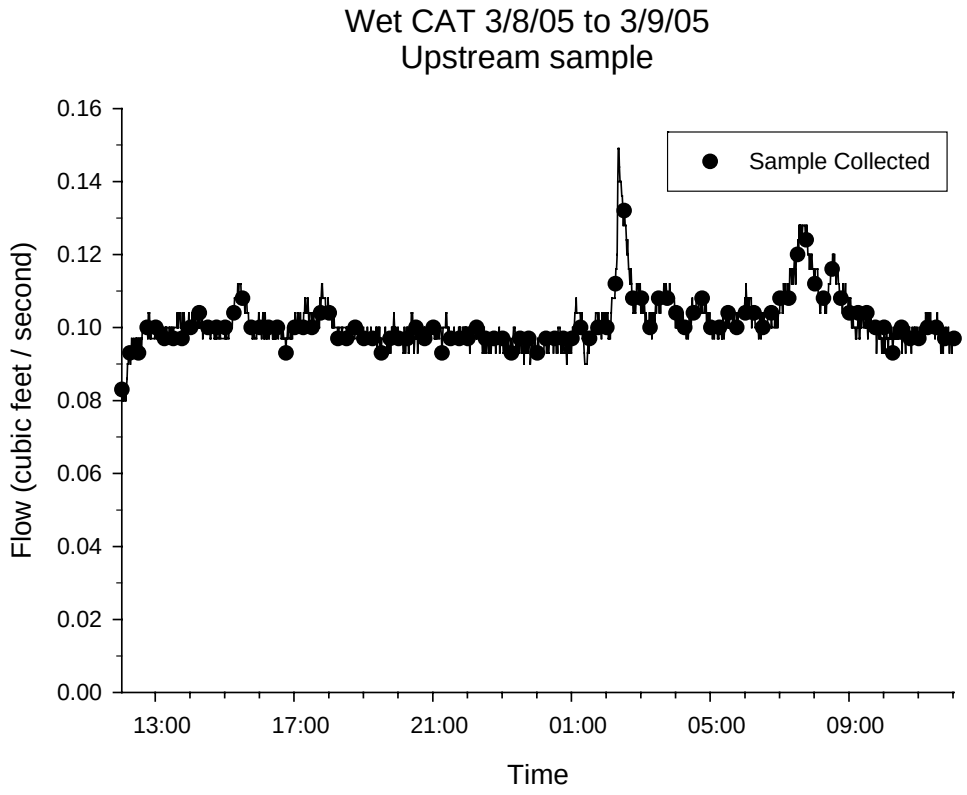


Figure A-3. Hydrograph at Wet CAT during the January 18-20, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite toxicity and chemistry samples.



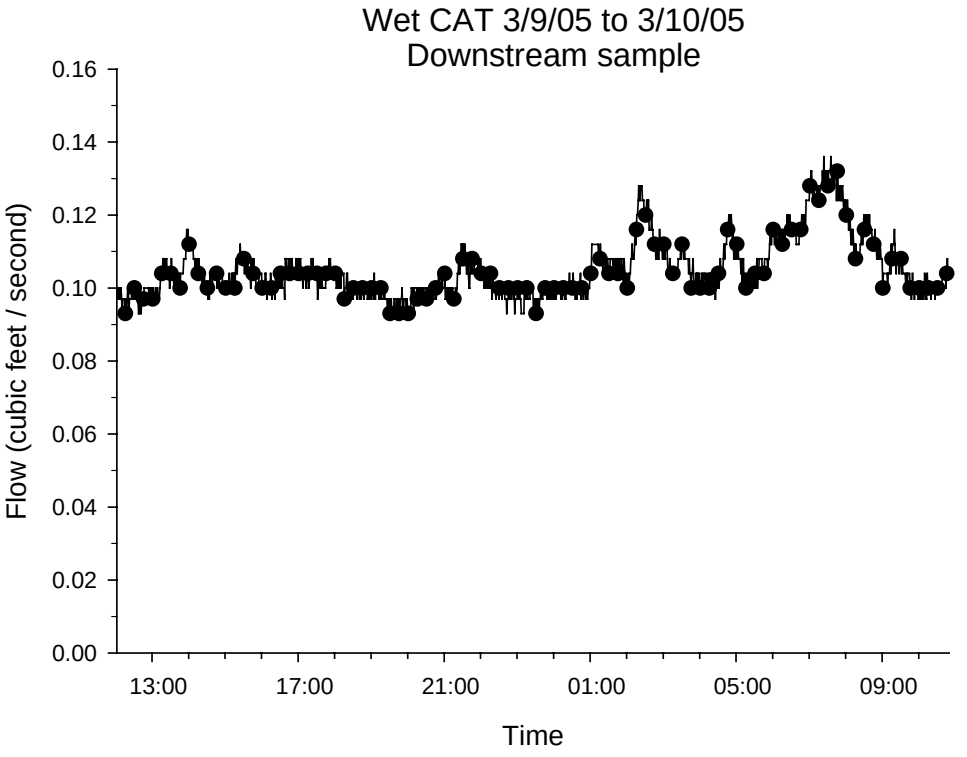


Figure A-4. Hydrograph at Wet CAT during the March 8-10, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite toxicity and chemistry samples.

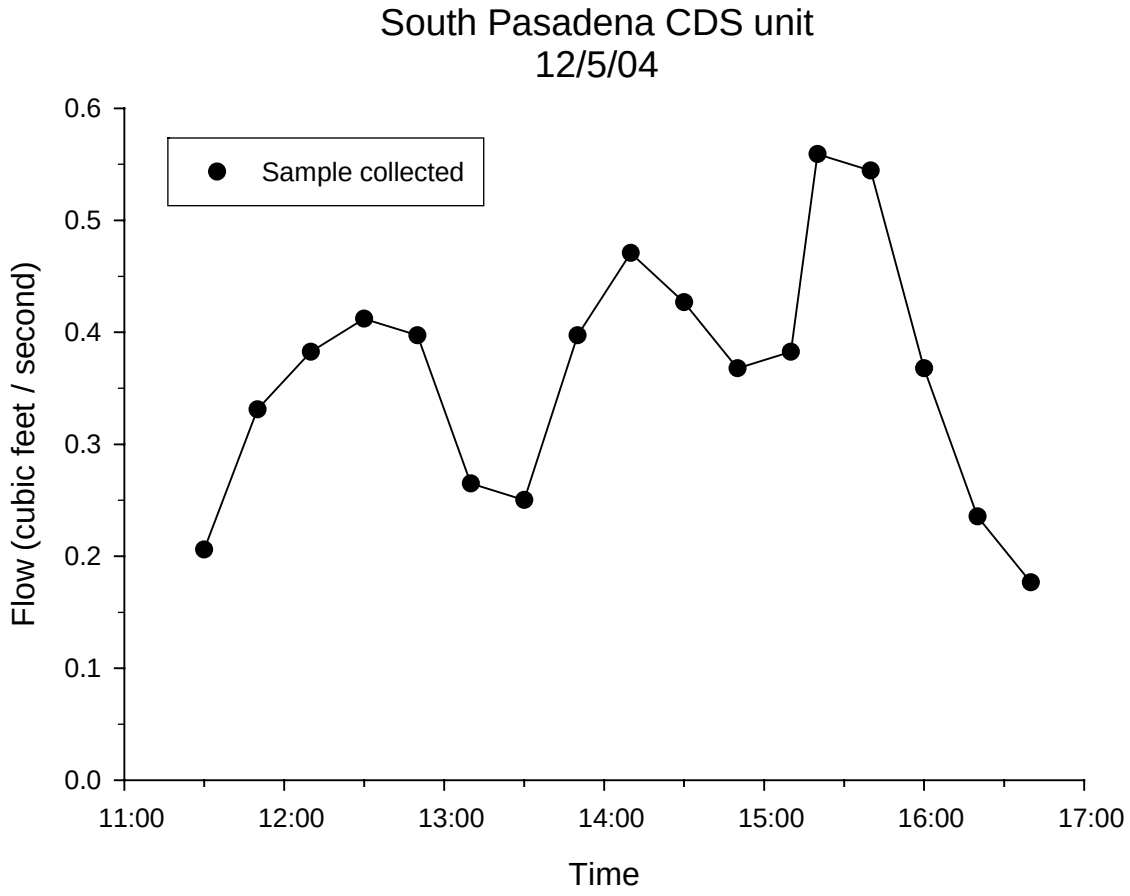


Figure A-5. Hydrograph at the South Pasadena CDS site during the December 5, 2004 storm water sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.

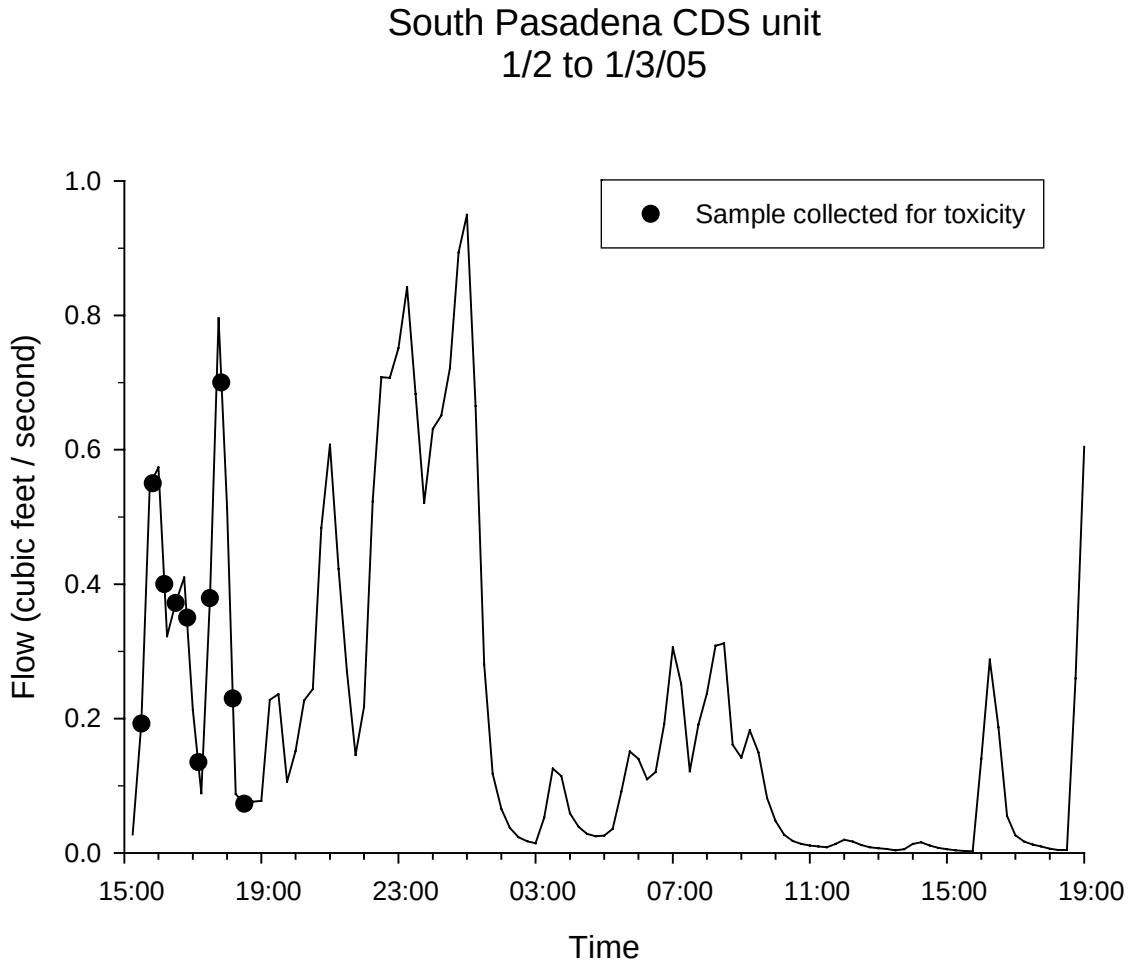


Figure A-6. Hydrograph at the South Pasadena CDS site during the January 2-3, 2005 storm water sampling event. Samples were collected at 20 min intervals from 15:30 to 18:30 for the toxicity composite (indicated by the dots). The entire hydrograph was sampled at 20 min intervals for chemical analysis.

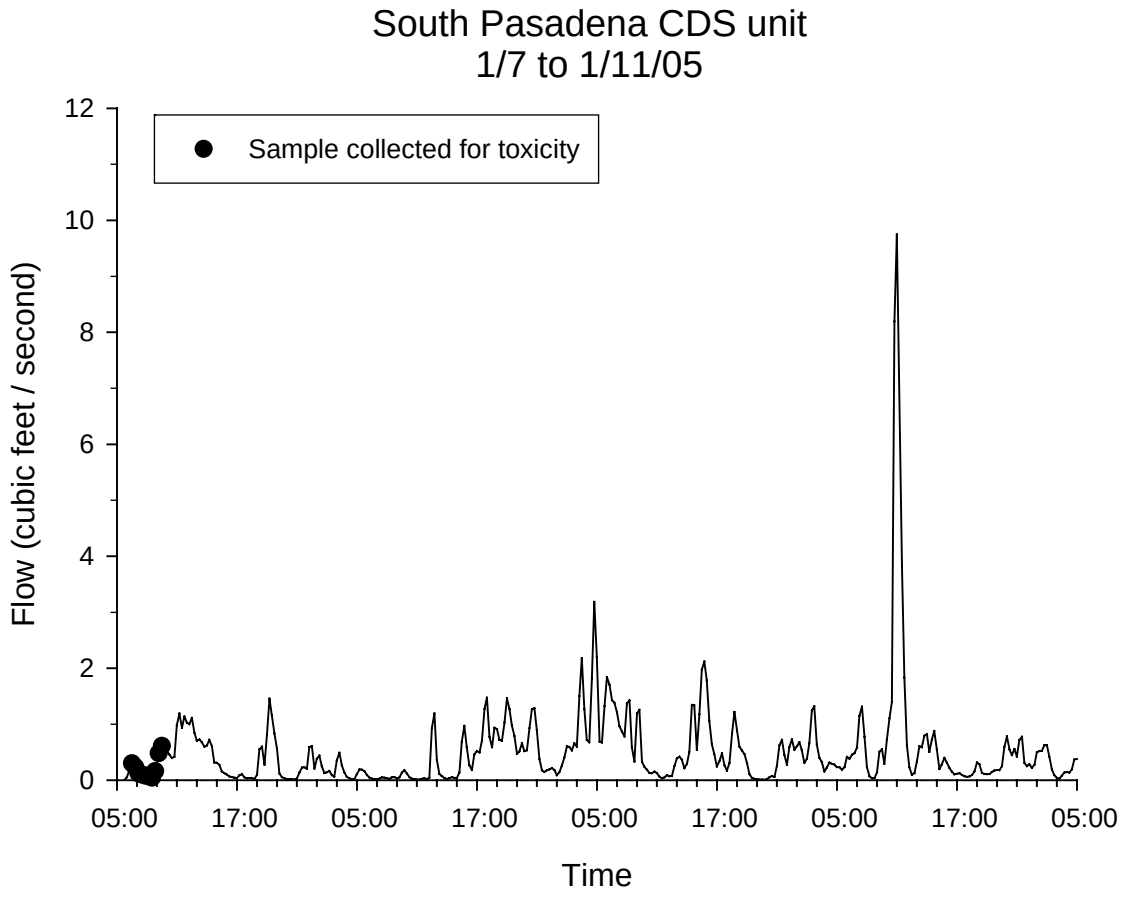


Figure A-7. Hydrograph at the South Pasadena CDS site during the January 7-11, 2005 storm water sampling event. Samples were collected at 20 min intervals from 5:30 am to 8:30 am for the toxicity composite (indicated by the dots). The entire hydrograph was sampled at 20 min intervals for chemical analysis.

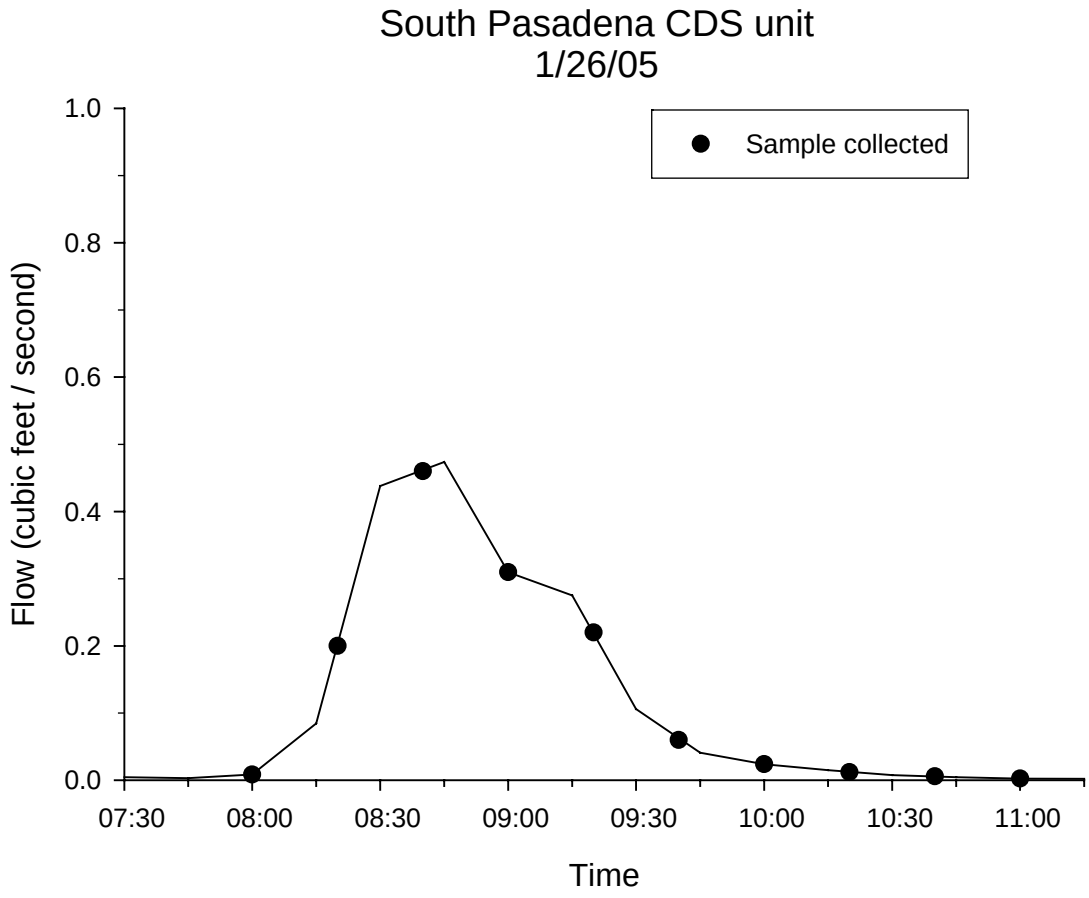


Figure A-8. Hydrograph at the South Pasadena CDS site during the January 26, 2005 storm water sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.

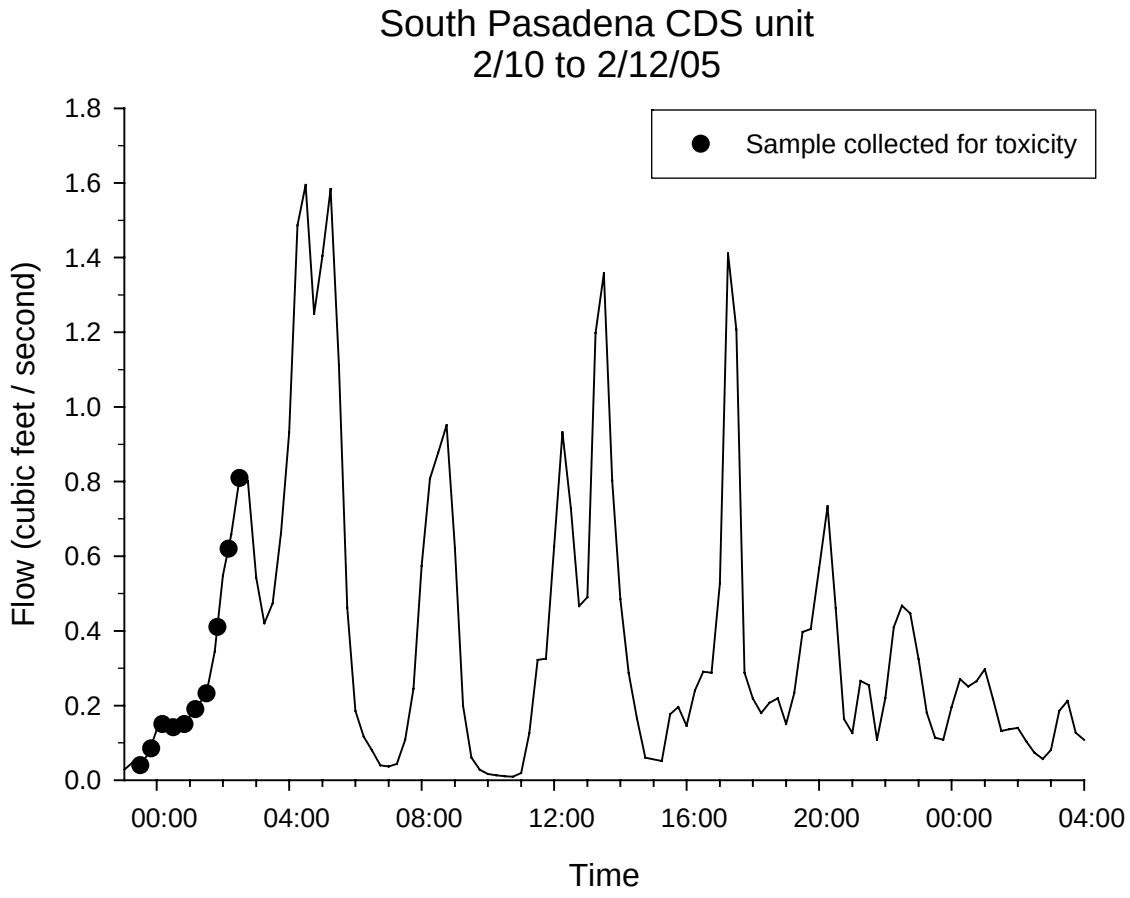
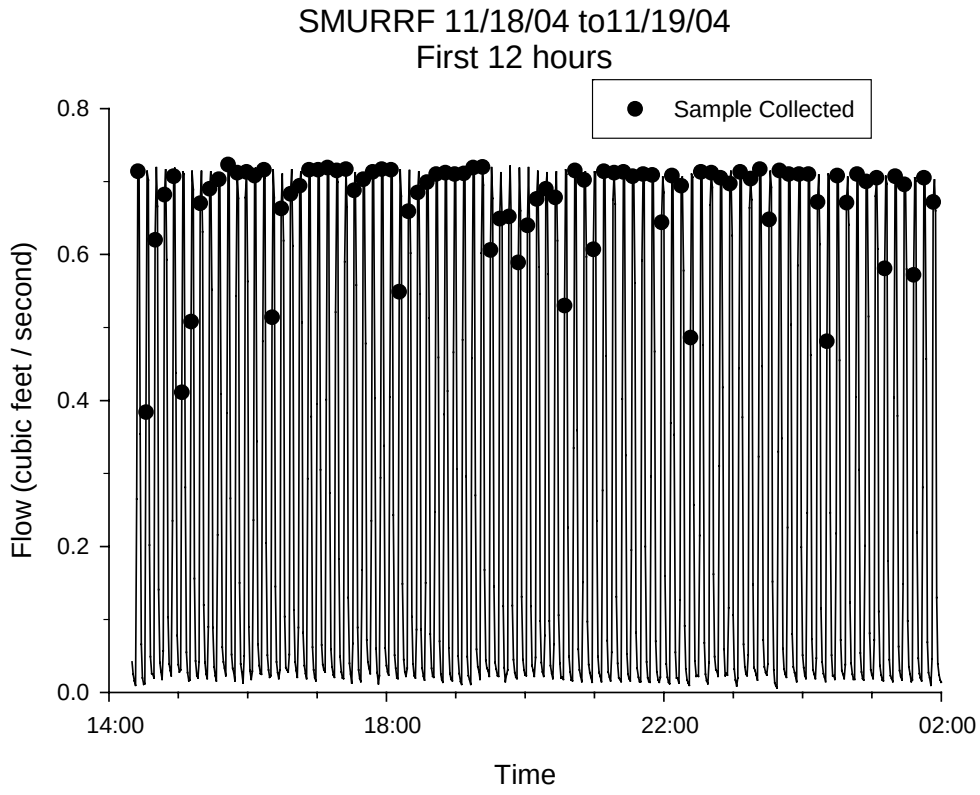


Figure A-9. Hydrograph at the South Pasadena CDS site during the February 10-11, 2005 storm water sampling event. Samples were collected at 20 min intervals from 23:30 to 2:30 am for the toxicity composite (indicated by the dots). The entire hydrograph was sampled at 20 min intervals for chemical analysis.



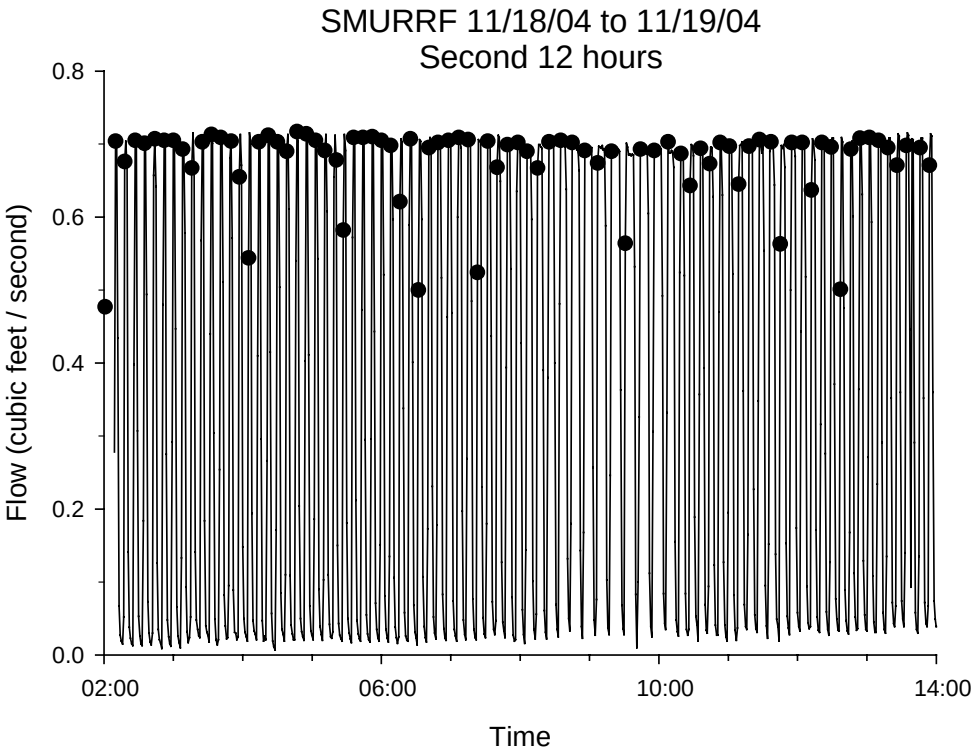
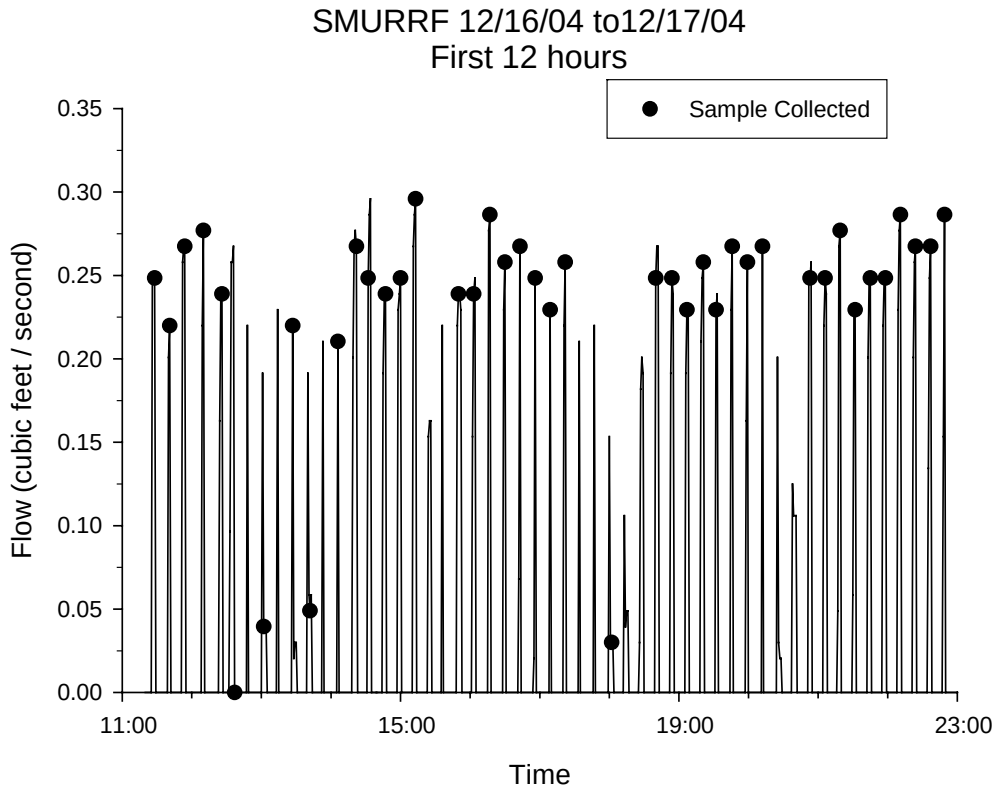


Figure A-10. Hydrograph at SMURRF during the November 18-19, 2004 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite sample.



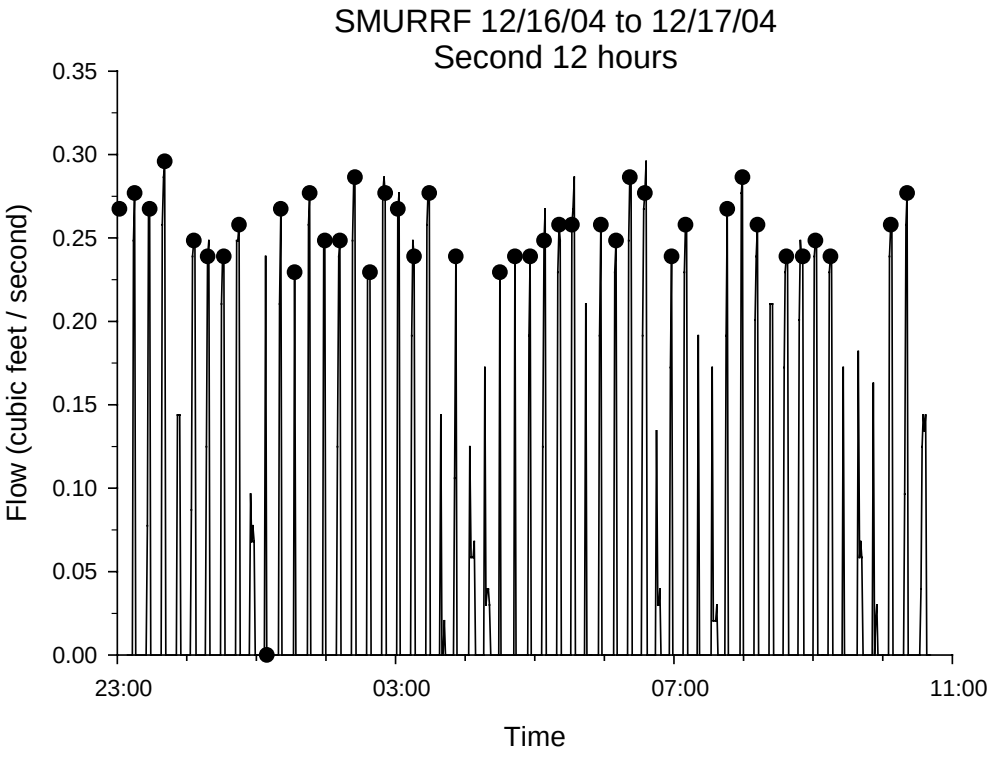
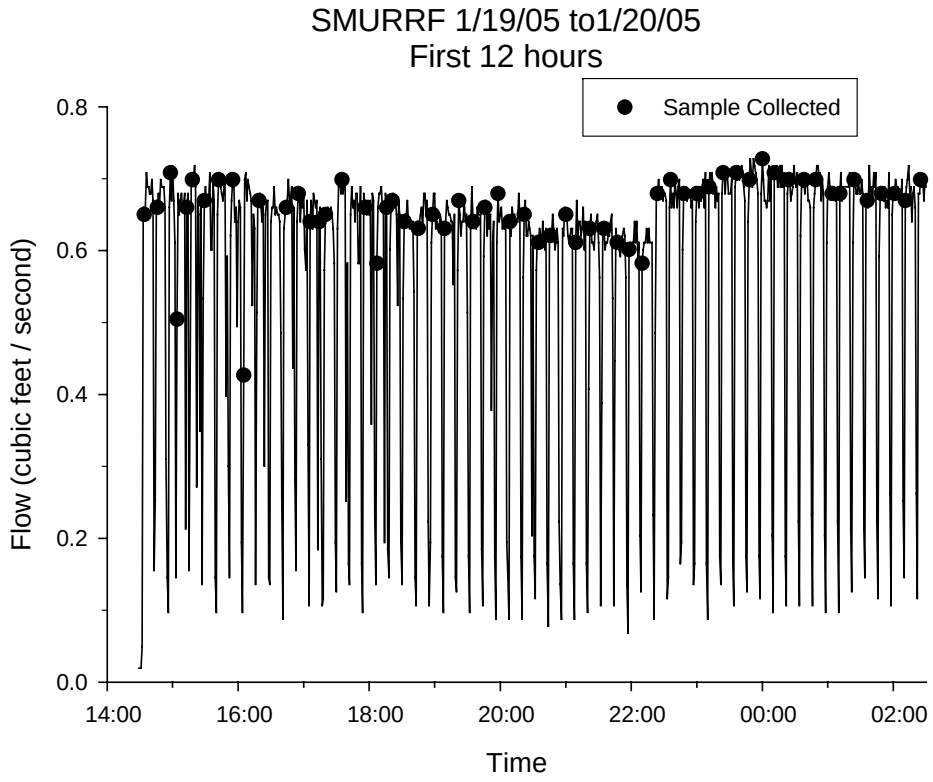


Figure A-11. Hydrograph at SMURRF during the December 16-17, 2004 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite sample.



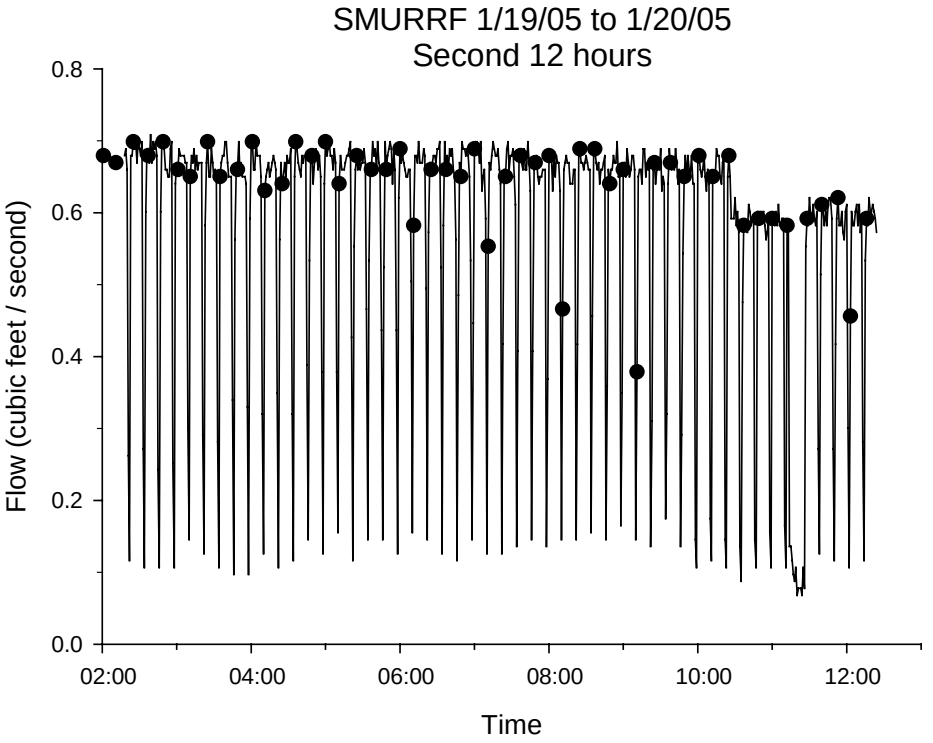
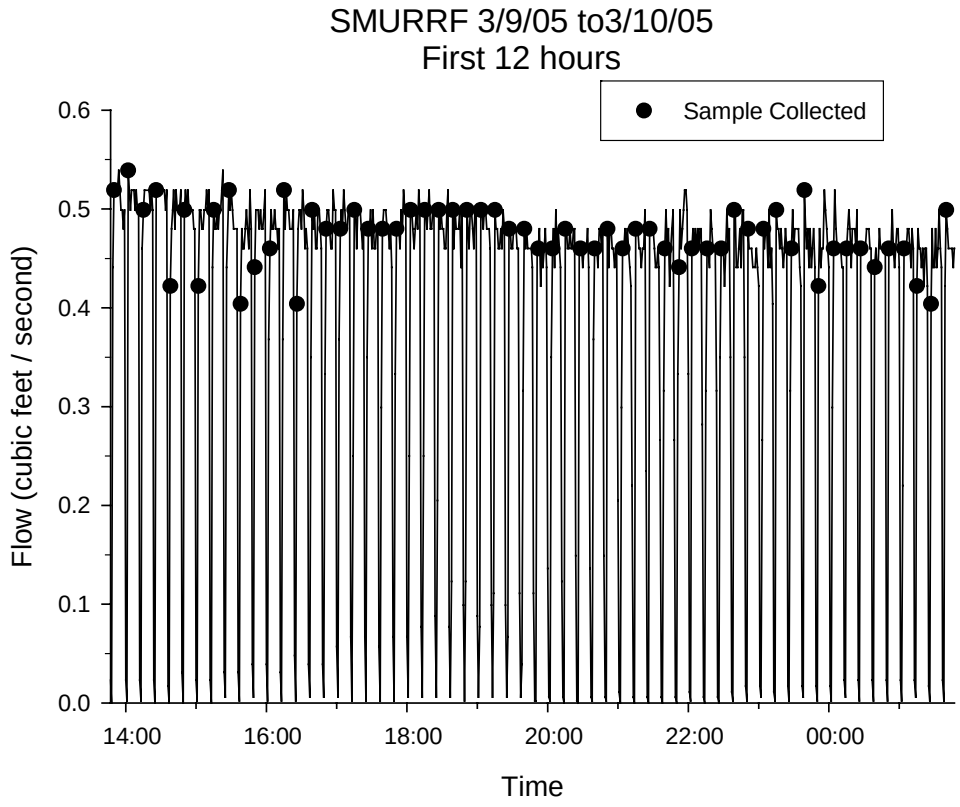


Figure A-12. Hydrograph at SMURRF during the January 19-20, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite sample.



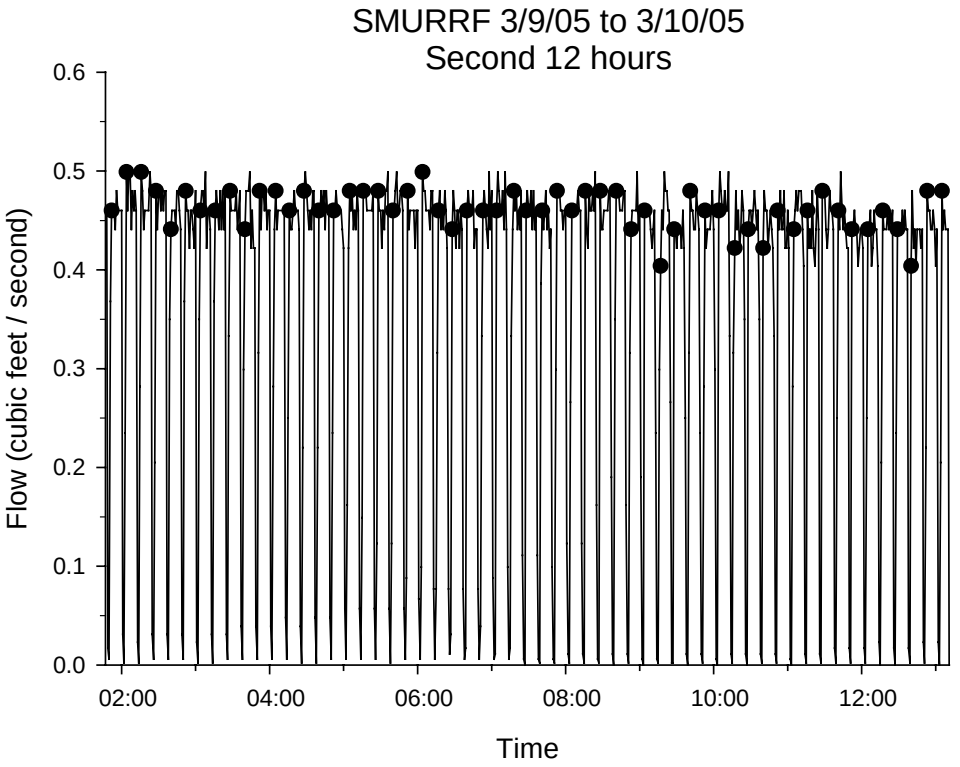


Figure A-13. Hydrograph at SMURRF during the March 9-10, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the composite sample.

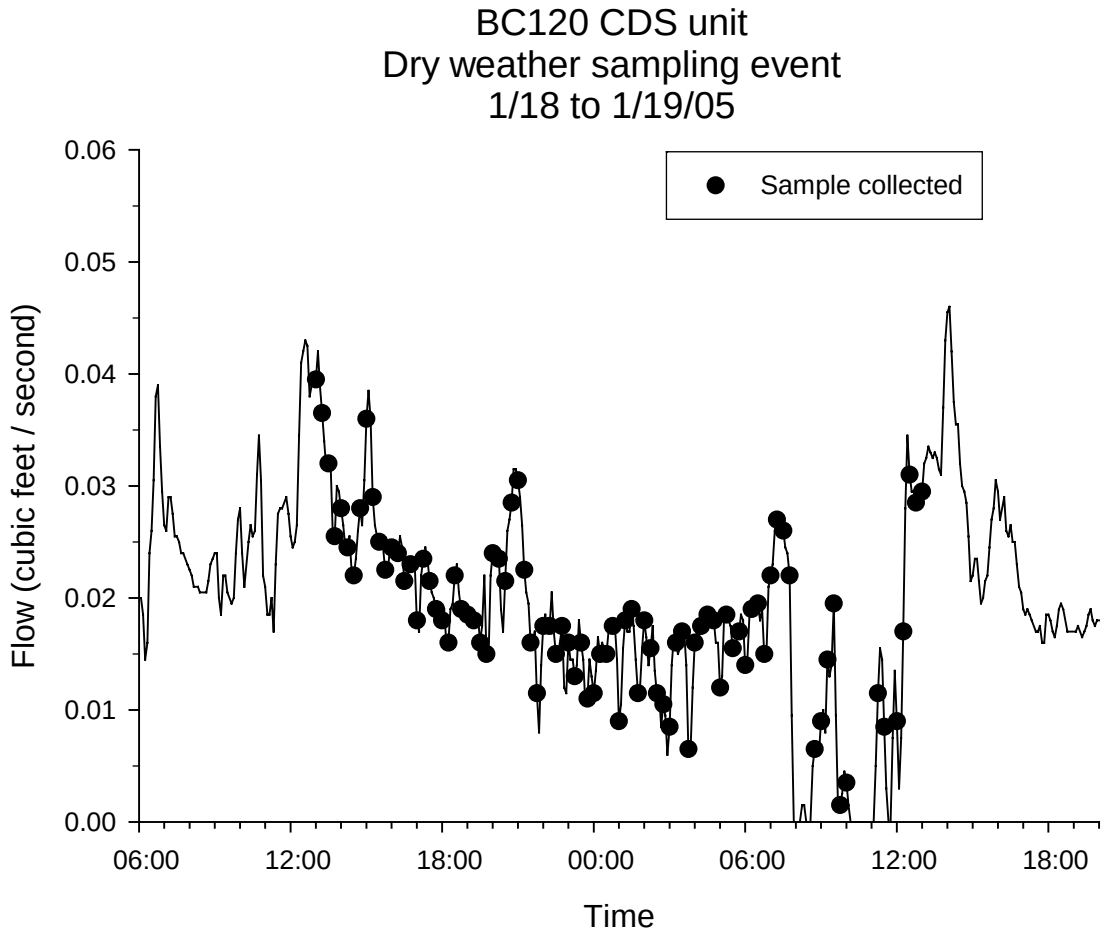


Figure A-14. Hydrograph at BC120 during the January 18-19, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.

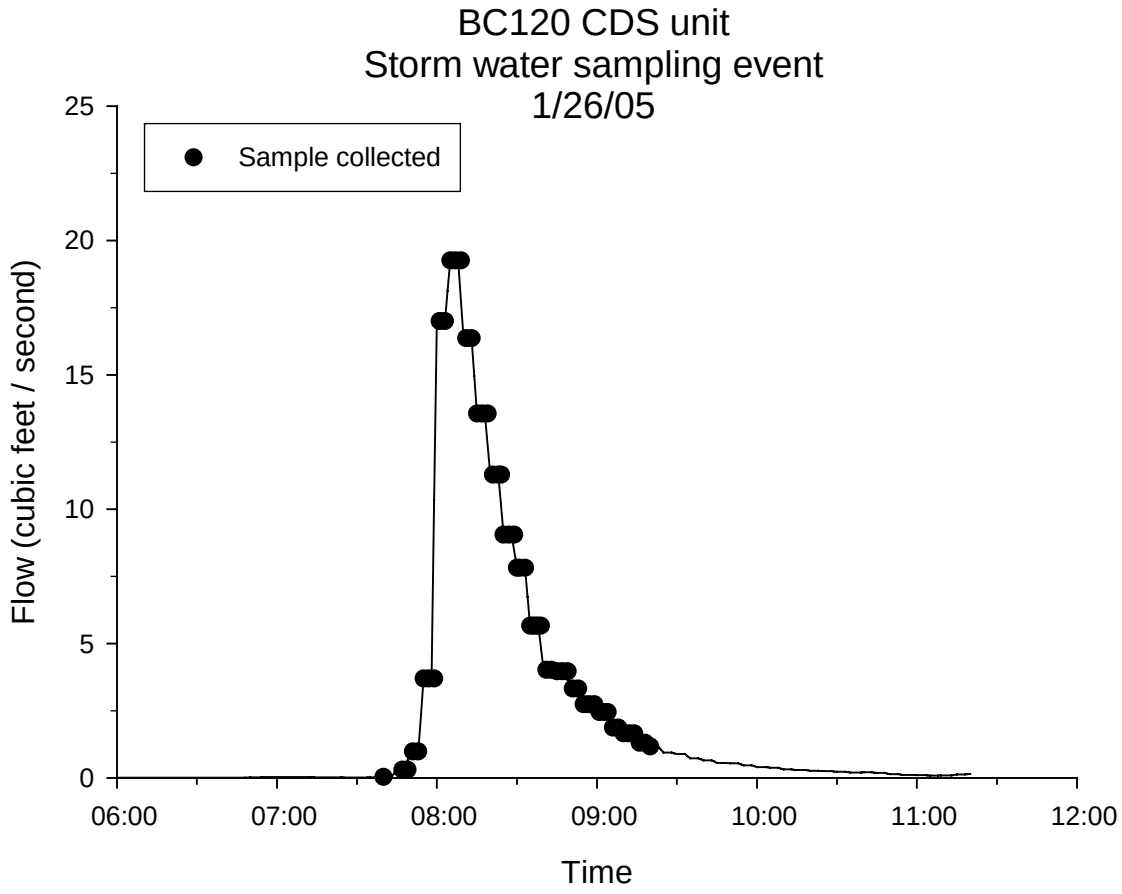


Figure A-15. Hydrograph at BC120 during the January 26, 2005 storm water sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.

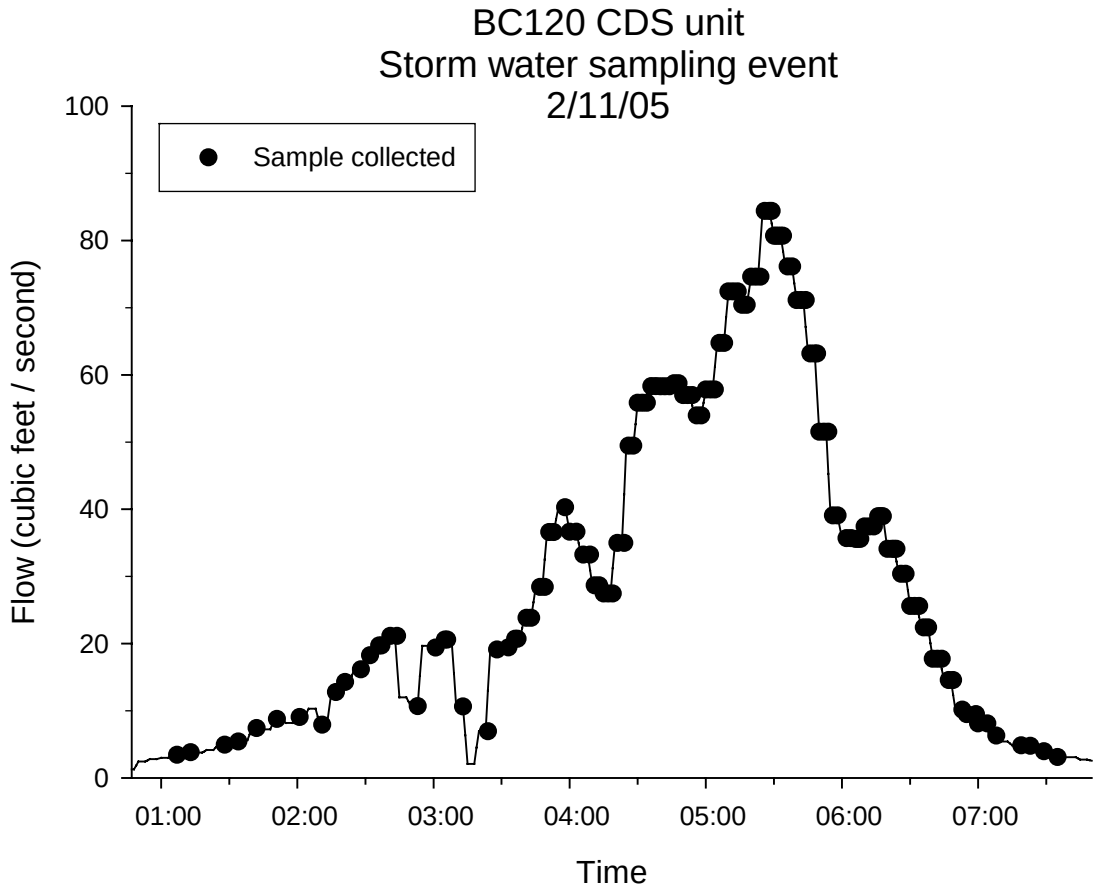


Figure A-16. Hydrograph at BC120 during the February 11, 2005 storm water sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.

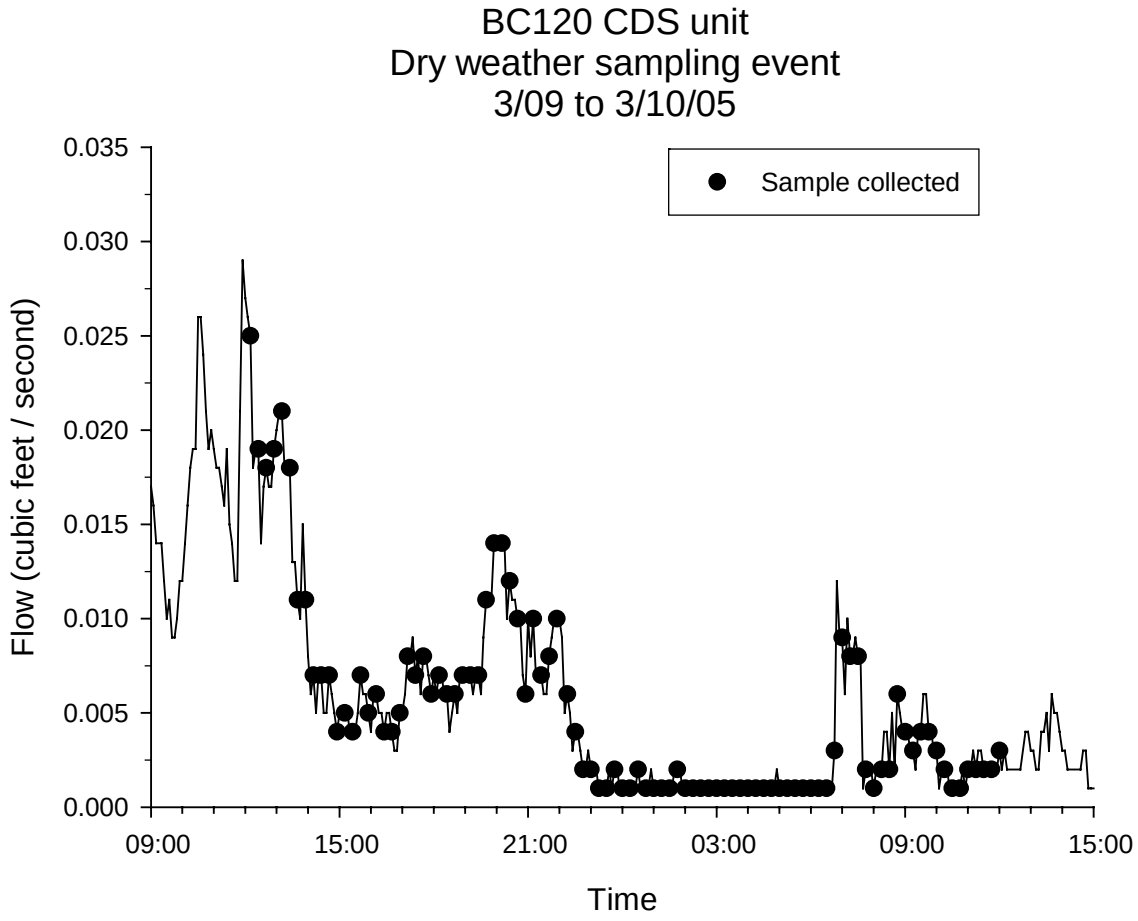
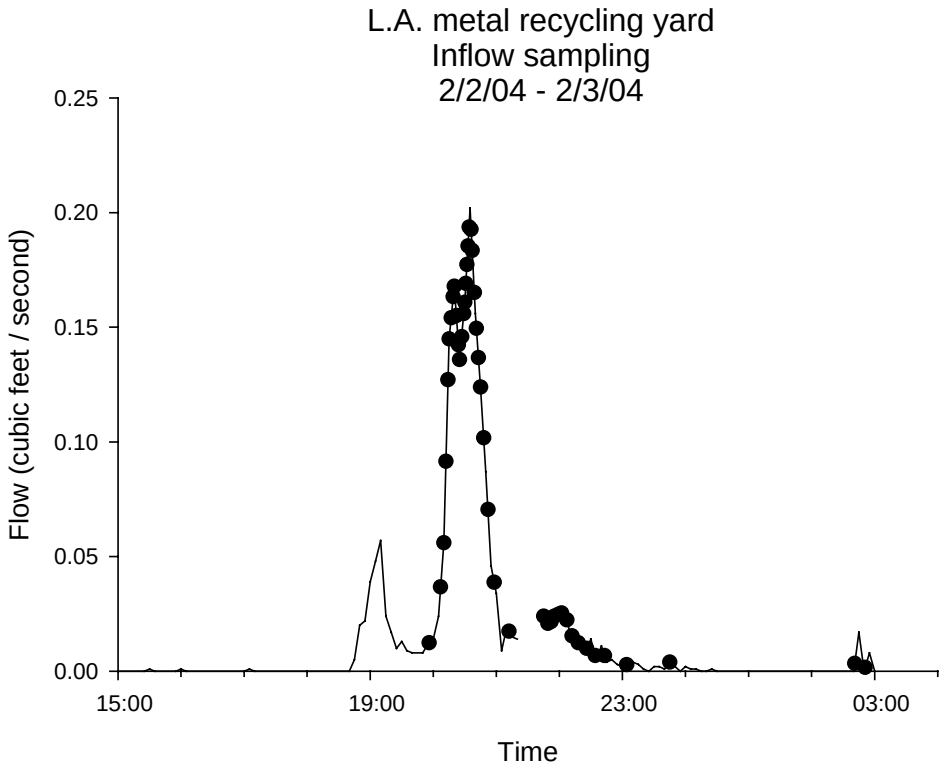


Figure A-17. Hydrograph at BC120 during the March 9-10, 2005 dry weather sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.



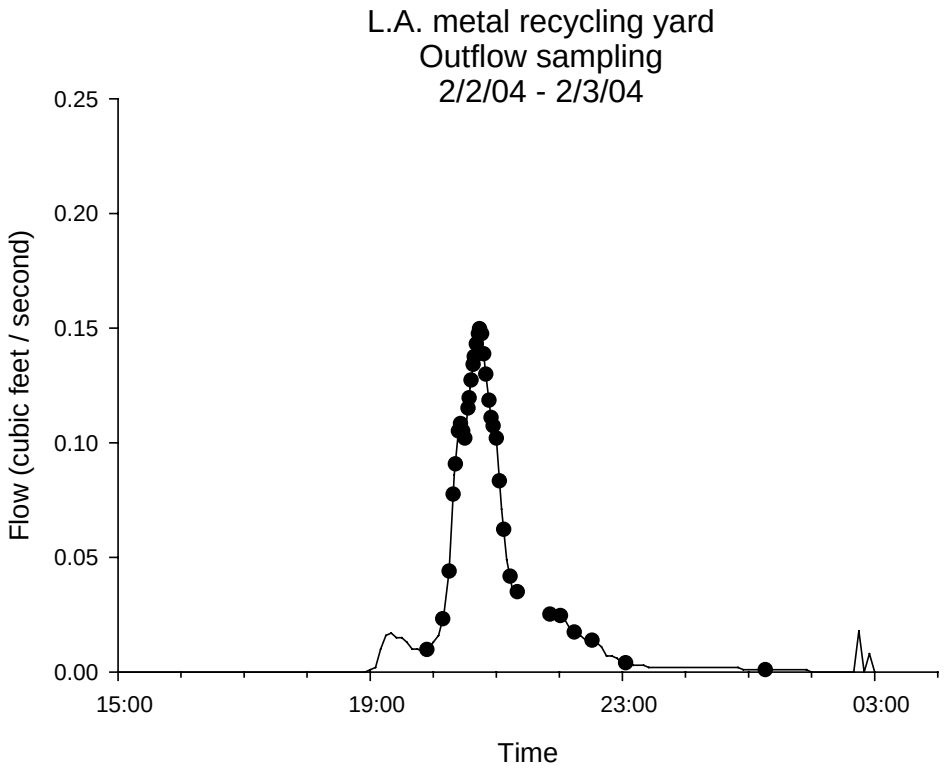
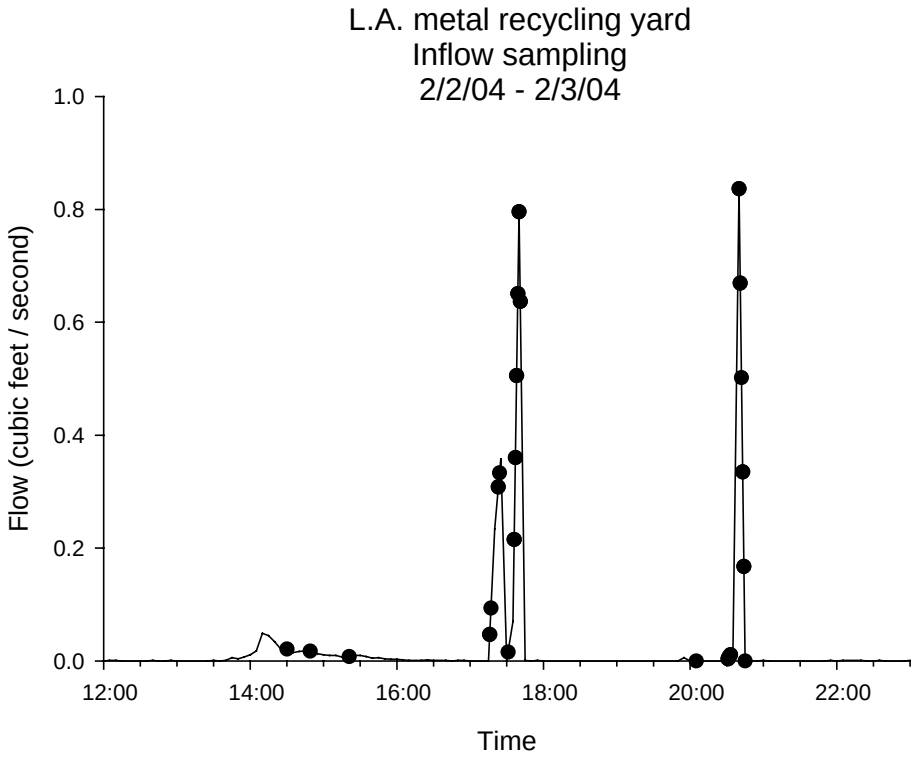


Figure A-18. Hydrographs at L.A. metal recycling yard during the February 2-3, 2005 wet weather sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.



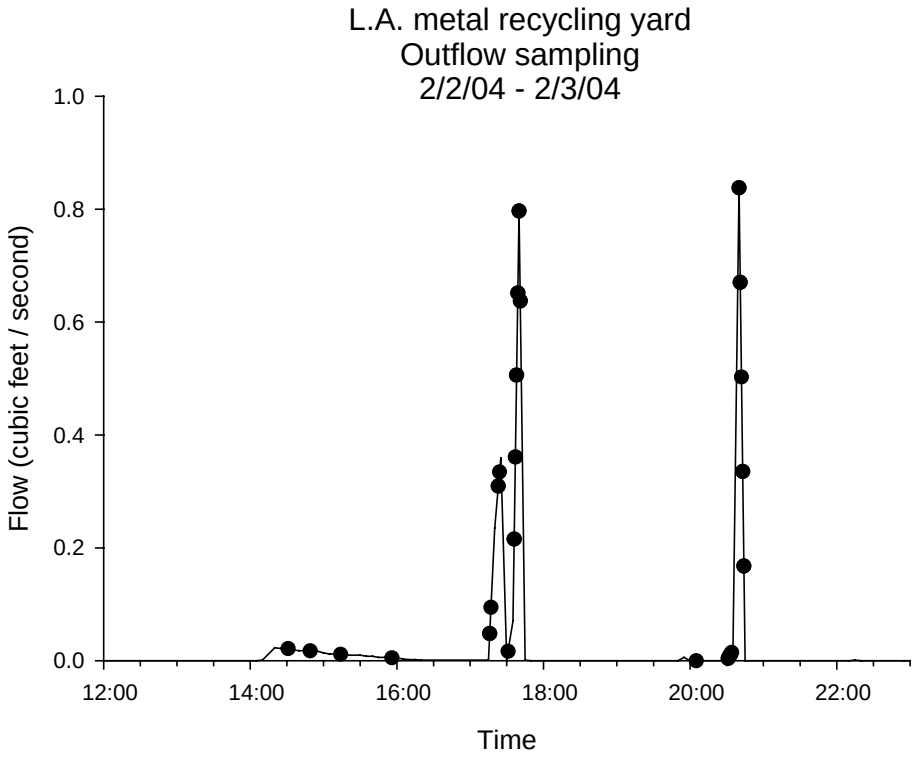


Figure A-19. Hydrographs at L.A. metal recycling yard during the February 18, 2005 wet weather sampling event. Dots (●) indicate when the samples were collected for the toxicity and chemistry composite samples.