Copper and Zinc Levels in Des Moines, Massey, and McSorley Creeks, King County

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Cover photo: Looking west at the Des Moines Creek confluence with central Puget Sound

Copper and Zinc Levels in Des Moines, Massey, and McSorley Creeks, King County

by

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Waterbody Numbers:

Des Moines Creek	LLID 1223268474050, WA-09-2000
Des Moines Creek East Tributary	LLID 1223059474260
Massey Creek	LLID 1223259473968
McSorley Creek	LLID 1223235473729

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Abstract

The Washington State Department of Ecology conducted a study to assess levels of copper and zinc in Des Moines, Massey, and McSorley Creeks in King County, Washington. Sampling was conducted from October 2008 through December 2010. Objectives of this work were to assess the status of 303(d) water quality limited listings for copper and zinc.

Surface water was sampled twice during baseflow and three times during storm events. Analysis included dissolved and total recoverable copper and zinc as well as hardness, turbidity, and total suspended solids.

During baseflow, dissolved copper and zinc levels were low, never approaching water quality criteria. Mean dissolved copper and zinc concentrations were 1.10 and 2.39 ug/L (parts per billion), respectively. All dissolved copper results were less than 10% of the acute copper criteria, while zinc was less than 5%. The average hardness was 101 mg/L.

During storm events, dissolved copper and zinc in Des Moines Creek decreased from upstream to downstream, while hardness increased. No violations of water quality metals criteria were found at 303(d) listed sites. Mean dissolved copper and zinc concentrations measured during storms were 3.10 and 10.5 ug/L, respectively. The average storm hardness was 49 mg/L.

Recommendations include:

- Remove Des Moines, Massey, and McSorley Creeks from the 303(d) list for dissolved copper, and remove Des Moines and Massey Creeks for dissolved zinc.
- Future significant increases in impervious surfaces in the upper Des Moines Creek basin should be evaluated for potential adverse water quality effects at 200th St. during storms.
- Future evaluations of copper and zinc in the three study streams for water quality compliance should include storm monitoring to assure data are collected during critical periods.

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Introduction

Des Moines, Massey, and McSorley Creeks are small urban streams located in King County, south of SeaTac International Airport (Figure 1). Together they drain much of the city of Des Moines, while also providing drainage to portions of SeaTac, Kent, and Federal Way. Traveling through mostly high-density residential and commercial areas before directly discharging into central Puget Sound, the lower reaches of Des Moines and McSorley Creeks flow through Des Moines Beach Park and Saltwater State Park, respectively.

These streams serve as valuable habitat for many salmonids (i.e., coho, chum, and pink salmon, steelhead, and coastal cutthroat trout). Other resident species that have also been observed include rainbow trout, pumpkinseed, sunfish, largemouth bass, bluegill, bullheads, and sculpins (BioAnalyst, 1999). Over the last 10 or more years, restoration efforts have improved fish habitat in these streams.

Concerns have been raised that high copper and zinc in stormwater runoff may contribute to pre-spawn mortality (Scholz et al., 2011) observed among adult coho salmon using these study streams.

The most recent data on levels of copper and zinc measured during storm events are now over 10 years old. Current data were needed to determine if copper and zinc continue to not meet (exceed) water quality criteria during storm events and to estimate any needed load reductions. No evaluation of these toxic metals during storm events had been conducted since recent habitat improvements.

Historical Data

Data collected from 1994 to 1999 indicated levels of copper and zinc in study streams were higher than the Washington State acute water quality criteria during storm events. Monitoring of Des Moines, Massey, and McSorley Creeks found dissolved copper and zinc were meeting water quality criteria during dry-season baseflow (June to September). However, during wet-season storm events (October to May), the levels of copper and zinc were high, often exceeding criteria (Herrera, 2001).

The Herrera study sampled a total of 25 storms. In Des Moines Creek, the acute water quality criteria were exceeded in 10 samples for copper and one sample for zinc. Acute criteria were exceeded in Massey Creek in 10 copper and seven zinc samples. In McSorley Creek, the acute copper criterion was exceeded in four samples, while zinc was reported meeting criteria throughout. The Herrera study reported data for two sites in Des Moines and McSorley Creeks, and four sites in Massey Creek, for wet-season sampling. These data were the basis for 303(d) listings for study streams.

Table A1 in Appendix A presents the mean and range of copper and zinc concentrations for base and wet-season flows reported in Herrera (2001).

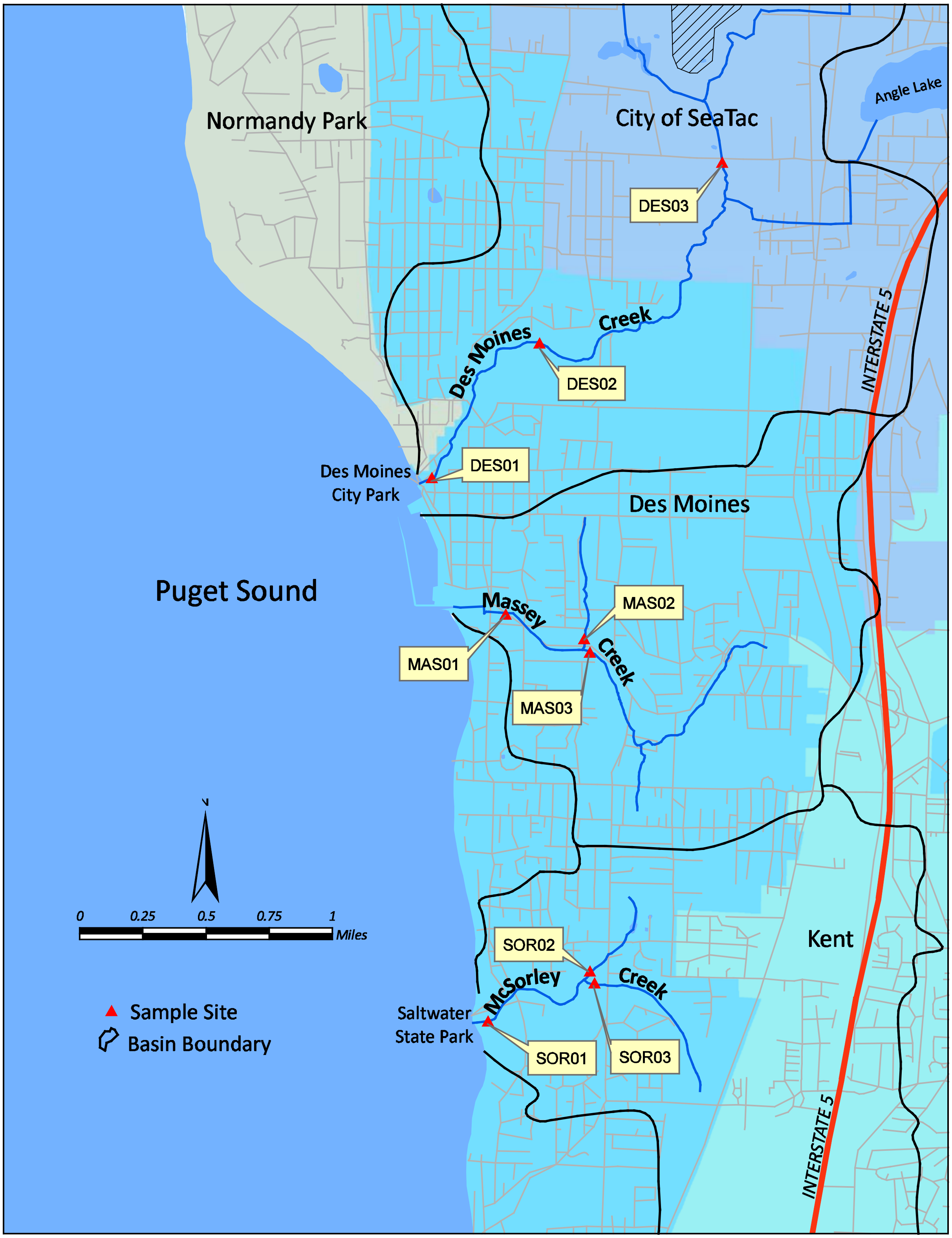

Figure 1. Study area and sample sites for the Des Moines Area Creeks Copper and Zinc Study.

Water Quality Criteria

Washington State's aquatic life criteria for copper and zinc (WAC 173-201A, 2006) are for the dissolved fraction, the portion that is most available to biological uptake. Companion analysis of hardness is also required to determine the toxicity of copper and zinc. The hardness adjustment accounts for metals binding to cations and anions which can reduce toxicity.

Hardness-based criteria are calculated as follows:

Copper Criteria

- Acute = > $(0.96)(e^{(0.9422*[\ln(hardness)]-1.464)})$.
- Chronic = > $(0.96)(e^{(0.8545*[\ln(hardness)]-1.465)})$.

Zinc Criteria

- Acute = > $(0.978)(e^{(0.8473*[\ln(hardness)]+0.8604)})$.
- Chronic = > $(0.986)(e^{(0.8473*[\ln(hardness)]+0.7614)})$.

The Washington State water quality standards require both acute and chronic criteria to be met. The acute criterion is based on a 1-hour average concentration not to be exceeded more than once every three years. Likewise, the chronic criterion is a 4-day average concentration not to be exceeded more than once every three years.

The federal Clean Water Act of 1972 requires states to restore their surface waters to be "fishable and swimmable." Section 303(d) of the Act lists those waters that have been shown to be polluted by impairment of their designated uses. For a waterbody to be 303(d) listed for toxic substances, two or more samples within a 3-year period must exceed the numeric state water quality criteria.

Potential Sources of Copper and Zinc Contamination

Copper and zinc are two heavy metals commonly found in stormwater runoff. Many of the pollutants in stormwater are associated with automobile use and maintenance (Pitt and Lolar, 2000). The wear from brake lining is thought to be a significant source of copper in stormwater. In addition, tire wear, fluid leaks, and air deposition from car exhaust also contribute to the pollutant pool in stormwater (OEC, 2007).

Other potential sources of copper to surface waters include:

- copper-based pesticides
- air emissions from fuel combustion, industry, and wood burning
- soil erosion
- landfills
- treated wood products
- domestic water discharged to drains
- architectural copper (i.e., roofs, gutters, and copper-treated shingles)

Common sources of zinc in urban settings are rooftops, streets and highways, galvanized metal including fencing and scrap, and air deposition. Other sources of zinc in stormwater include tire particles (1% by weight) and pavement wear, automobile exhaust, and culvert and pipes (Golding, 2006).

Galvanized metal is a significant source of zinc to surface waters. During storm events, roof runoff is known to carry large loads of zinc from galvanized roof components. Many roofs have gutters and downspouts made with zinc. In industrial areas, galvanized gutters, downspouts, and heating and cooling components on roofs are considered the leading source of zinc (60%), while residential roofs (7%) are less significant (Wisconsin DOT, 1997). Corrosion of galvanized roofs can be exacerbated in marine environments.

Methods

Study Design

Objectives

Objectives of the study were to:

- Provide a verification of the status of 303(d) listings for copper and zinc in Des Moines, Massey, and McSorley Creeks.
- If data warrant, estimate copper or zinc loading reductions needed to meet Washington State water quality criteria.

The study objectives were met by characterizing copper and zinc concentrations during baseflow and storm flow in Des Moines, Massey, and McSorley Creeks. Levels of dissolved and total recoverable[1] (TR) copper and zinc were monitored at stream mouths and two upstream sites. A flow station operated by the King County Hydrologic Center was active in Des Moines Creek for the first year of this study but was washed out by a storm during fall 2010. Flow was monitored at the lowest reach of Massey and McSorley Creeks by Ecology's Freshwater Monitoring Unit.

Study Sites

The study used a fixed network of three creek sites within each of the three basins (two upstream and one downstream). Creek water was sampled two times during baseflow and during the rising limb of the hydrograph for three storm events. The two upstream sites in Massey and McSorley Creeks were sampled only during the two baseflow events and the first of three storm events. The downstream station in each creek was located near discharge to Puget Sound, avoiding marine influence.

Data from the fixed station network was intended to provide copper and zinc data sets to meet the following needs:

- Verify whether copper and zinc concentrations in the three study streams violate water quality criteria, and determine if the 303(d) listings for nonattainment of beneficial uses are justified.
- Provide an estimate of copper and zinc concentrations and loads in the study streams during baseflows and storm events.
- Identify specific reaches or tributaries of concern by providing targeted data for prioritizing problem areas.

For a waterbody to be 303(d) listed for toxic substances, two or more samples within a 3-year period must exceed the numeric Washington State water quality criteria. The study plan provided for at least two samples per site during both storm events and baseflows.

[1] Total recoverable copper and zinc will be referred to in this study as TR copper and TR zinc.

The sample stations are listed in Table 1 and shown on Figure 1. The latitude and longitude of sample sites are also provided. Stations were selected based on avoidance of marine influence, access, the ability to evaluate major tributaries, and dividing the three basins for prioritizing source areas.

Table 1. Sample sites in Des Moines, Massey, and McSorley Creeks.

Watershed/Site ID	Location	Reason for Site	Latitude/Longitude[1]
Des Moines Creek/ DES01	Des Moines Beach Park near discharge to Puget Sound	Includes whole basin just above marine influence	Lat: 47.40584 Long: -122.32764
Des Moines Creek/ DES02	Just below the Des Moines Wastewater Treatment Plant	Includes Wastewater Treatment Plant, restricted area south of SeaTac Airport, and Angle Lake	Lat: 47.41178 Long: -122.32032
Des Moines Creek/ DES03	Just below Tyee Golf Course at South 200th Street	Captures upper drainage around SeaTac Airport	Lat: 47.42259 Long: -122.30538
Massey Creek/ MAS01	Above Marine View Drive	Above marine influence, includes most of basin	Lat: 47.39601 Long: -122.32166
Barnes Creek/ MAS02	Along Kent-Des Moines Road just above confluence	Isolates the major tributary to Massey Creek	Lat: 47.39443 Long: -122.31611
Massey Creek/ MAS03	Just upstream of confluence with Barnes Creek	Located mid-basin isolating the upper drainage	Lat: 47.39428 Long: -122.31599
McSorley Creek/ SOR01	Saltwater State Park near discharge to Puget Sound	Just above marine influence, includes whole basin	Lat: 47.37294 Long: -122.32343
North Fork McSorley Creek/ SOR02	Saltwater State Park upstream of confluence of the two forks	Isolates major tributary which also incorporates Midway Landfill ponds	Lat: 47.37554 Long: -122.31525
McSorley Creek/ SOR03	Saltwater State Park upstream of confluence of the two forks	Located mid-basin isolating the upper drainage	Lat: 47.37533 Long: -122.31528

1: Datum is NAD 83

Storm Monitoring

Historical data have shown significantly higher loading of copper and zinc during storm events. The present study verified that the critical period for loading from potential sources of copper and zinc to study streams is during wash-off from storms.

A total of three storms were sampled, with the first in spring 2009 and the final two during fall 2010. The Quality Assurance (QA) Project Plan originally defined the trigger to initiate storm sampling as a minimum 0.20 inch of rainfall predicted for 24 hours, preceded by a 24-hour antecedent dry period, on the rising limb of the hydrograph. The rising hydrograph assures wash-off is occurring and the storm's highest potential for loading of copper and zinc over the storm.

Difficulties were encountered meeting these requirements for initiating sampling. Only the first set of storm-event samples was collected under the original sample trigger. The second and third sets of storm samples had a relaxed trigger to initiate sample collection as described below. A QA Project Plan addendum was prepared describing modifications to precipitation and flow requirements for triggering storm sampling (Coots, 2010). Changes were needed due to difficulty obtaining samples that met the original criteria.

Storm-event sampling was conducted during the rising limb of the hydrograph of study streams. Three one-hour composite samples were collected from each site during the first storm. Half of each sample was collected at the start of the hour, and the second half was collected at the end.

For the second and third storms, two composite grabs were collected per site. These composite samples were also collected at the start and end of one hour. Initiation of sampling was based on local predictions of a significant storm event and an increase in stage height of at least 0.05 foot following the onset of precipitation.

Flows

The streamflow rate for Des Moines Creek was obtained from a gaging station operated by the King County Hydrologic Information Center (11d – Des Moines Creek below SR 509, Des Moines, near mouth). Stream discharge was estimated for Des Moines Creek using stage height and rating curves developed by King County.

Ecology's Freshwater Monitoring Unit installed staff gages and developed discharge rating curves for Massey and McSorley Creeks near their mouths to allow estimates of discharge during sample collection. Gages were set at the upstream side of the box culvert at 10th Avenue for Massey Creek, and at the upstream side of the road bridge into Saltwater State Park for McSorley Creek. For upstream sites, a discharge relationship to the downstream site was developed over the course of the study.

Loads

In addition to evaluating compliance with water quality criteria, contaminant loads were estimated. Load is the total amount of the pollutant discharged over a given period of time.

Loads were estimated based on the concentration measured in a sample times the stream discharge at the time of sampling. Loading information helps direct priorities for management options as an additional way to compare site to site or stream to stream. Dissolved copper and zinc loads were estimated for sites using instantaneous flow data.

Sampling Procedures

Table 2 lists the sample size, container, preservation, and holding time for each study parameter. Sample containers were obtained from Manchester Environmental Laboratory (MEL).

Sample sites were located by a handheld global positioning system (GPS) and recorded in field books. Ecology's Environmental Assessment Program standard operating procedures (SOPs) for *Determining Global Positioning System Coordinates* were followed (Janisch, 2006).

Table 2. Sample containers, preservation, and holding times for study samples.

Parameter	Sample Size	Container	Preservative	Holding Time
Dissolved[1] copper and zinc	500 mL	500 mL Teflon or HDPE	Filter 0.45 *u*m HNO_3 to pH <2	6 Months
TR[2] copper and zinc	500 mL	500 mL Teflon or HDPE	HNO_3 to pH <2	6 Months
Hardness	100 mL	125 mL poly	H_2SO_4 to pH <2	6 Months
Turbidity	500 mL	500 mL poly	Cool to 4 ^oC	48 hours
Total suspended solids	1,000 mL	1,000 mL poly	Cool to 4 ^oC	7 days

1: Dissolved metals were field filtered (0.45 *u*m) within 15 minutes following collection (MEL, 2008).
2: Total recoverable.

Procedures for collection of metal samples followed guidance in EPA method 1669 *Sampling Ambient Water for Trace Metals at EPA Water Quality Levels* (EPA, 1995) and Ecology SOPs. Low-level metals procedures and clean techniques were employed according to Ecology's SOPs:

- Manually Obtaining Surface Water Samples (Joy, 2006).
- Collection and Field Processing of Metals Samples (Ward, 2007).

Baseflow Sampling

Historical data from the study area have shown copper and zinc levels are low during the dry season (Herrera, 2001). To ensure detection in dry-season samples, a low-level metals analysis was employed. These samples were collected following an extended dry period as single grabs.

Dry-season TR metals samples were collected directly into 500 mL Teflon containers. Dissolved metals were field filtered within 15 minutes of collection using 0.45 *u*m Nalgene filter units (#450-0045, type S). The filtrate was decanted into a new 500 mL Teflon container. Metals samples were preserved in the field to pH <2 with 1:1 nitric acid provided by MEL in Teflon vials. Containers, Nalgene filters, and acid vials were pre-cleaned by MEL, as described by Kammin et al. (1995), and sealed in plastic bags until used. Field staff wore powder-free nitrile gloves during collection and filtering of samples.

Storm-Event Sampling

Local weather forecasts and satellite imagery was monitored through the wet season for initiation of storm sampling. The first set of storm samples were composites, with half of each sample of dissolved and TR copper and zinc collected at the start and finish of one hour. Three composite samples were collected at each of the three sites per stream.

After two wet seasons of failed attempts to meet the sample initiation trigger, the requirements to initiate sampling was relaxed, allowing two more storms to be sampled. The last two sets of storm samples were collected as wrist-depth grabs from mid-channel. Two samples were collected per site, one at the start and the other at the end of an hour, again when runoff was occurring, on a rising limb of the hydrograph.

The number of sample sites was also reduced for the second and third storms. Des Moines Creek, the largest of the three drainages, was sampled at all three original sites (see Figure 1 and Table 1). Massey and McSorley Creeks were reduced from three sites to one each, located at the original downstream sites.

Field teams were deployed to streams prior to the anticipated on-set of a significant storm. The first sample was collected after rainfall began, stream turbidity increased, and staff gages located at each stream raised at least 0.05 foot. Stage height was recorded for each sample, allowing discharge to be estimated for loading and to verify samples were collected during wash-off.

Following collection and filtration, samples were put in polyethylene bags in the field, placed in ice chests at or below 4 ^{o}C, and kept in the dark. After return from the field, sample ice chests were put in a secure walk-in cooler at Ecology Headquarters and transported to MEL the following morning. All staff involved in the study followed chain-of-custody procedures throughout the sampling and analysis process (MEL, 2006).

Laboratory Procedures

MEL analyzed all project samples. Table 3 shows the sample preparation and analytical methods for the project. Metals samples were analyzed by ICP/MS (Inductively Coupled Plasma Mass Spectrometer) using EPA Method 200.8. MEL's reporting limits for dissolved copper (0.10 ug/L, parts per billion) and zinc (1.0 ug/L) were adequate to identify exceedance of water quality criteria.

Table 3. Analytical methods used for study samples.

Analyte	Sample Type	Analysis	Sample Preparation Method	Analytical Method
Copper	whole water	TR	HNO_3/HCl digest	EPA 200.8 ICP/MS
	field filtered	Dissolved	HNO_3/HCl digest field filtered and preserved	EPA 200.8 ICP/MS
Zinc	whole water	TR	HNO_3/HCl digest	EPA 200.8 ICP/MS
	field filtered	Dissolved	HNO_3/HCl digest field filtered and preserved	EPA 200.8 ICP/MS
Hardness	whole water	Total	NA	SM 2340B
Turbidity	whole water	Total	NA	SM 2130
TSS	whole water	Total	NA	SM 2540D

TR: total recoverable
TSS: total suspended solids
NA: not applicable
HNO_3: nitric acid
HCl: hydrochloric acid
EPA: U.S. Environmental Protection Agency
ICP/MS: Inductively Coupled Plasma/Mass Spectrometry
SM: Standard Methods for the Examination of Water and Wastewater, 21st Edition (APHA et al., 2005)

Data Quality Summary

MEL provided written case narratives assessing data quality for this project. The narratives include descriptions of analytical methods and a review of holding times, instrument calibration checks, blank results, surrogate recoveries, matrix spike recoveries, laboratory control samples, and laboratory duplicate analyses. The case narratives and complete data reports can be obtained from the report authors by request.

The quality assurance review verified laboratory performance met quality control (QC) specifications outlined in the analytical methods. The quality of the data reported here is considered appropriate for its intended uses. To verify results generated for the study were of the quality required, control sample results were compared to measurement quality objectives established in the QA Project Plan (Coots, 2008). All data quality results for the study are in the Appendix Tables B1 through B4.

Metals

Laboratory Quality Control

Results of the metals analyses met all measurement quality objectives for the study. No significant problems were encountered during the analyses, and no data required qualification due to QC issues. Laboratory QC samples included method blanks, spiked blanks, matrix spikes, and matrix spike duplicates.

All samples analyzed for the study met holding times specified for the analytical methods. No target analytes were detected in method blanks, with all reported as non-detects. The laboratory control samples (spike blanks) met all control requirements (85 to 115%), with recovery for copper ranging from 97 to 105%, and recovery for zinc from 97 to 107%.

Matrix spikes and matrix spike duplicates also met all control requirements (75 to 125%), with recoveries for copper matrix spikes ranging from 91 to 106% and for zinc from 84 to 108%. Control requirements for matrix spike duplicates ($\leq$ 20% RPD) were met, with relative percent differences (RPDs) ranging from 0.1 to 7% for copper and from 0.2 to 9% for zinc. The complete set of laboratory QC samples analyzed for metals are shown in Tables B3 and B4 in Appendix B.

Field Quality Assurance

Field QA samples included collection and analysis of replicates and filter blanks. Field replicates were made from two samples taken one after the other, as close to the same time and location as possible. These samples incorporate the entire sampling and analysis process and were collected during storm flows when variability is high. These samples would be expected to have the highest variability of the QC/QA samples.

Field replicate pairs for copper and zinc showed higher variability than laboratory duplicates. The RPD for the copper field replicates ranged from 1.9 to 6.8%. Zinc replicates had an outlier during the second storm event. At the upstream site in Des Moines Creek (DES03), the replicate RPD was 62%. Excluding the zinc outlier, RPDs ranged from 1.3 to 11.6%.

Reagent grade water was supplied by MEL for filter blanks. Blank filtering was conducted during collection of storm samples. Filter blanks were treated as other field samples and sent to MEL for analysis.

Copper was not detected in filter blanks at a 0.1 ug/L reporting limit. During the third storm, a zinc concentration of 3.4 ug/L was reported in the filter blank. The zinc reporting limit was 1.0 ug/L. The lowest zinc result for storm samples during that survey was 6.8 ug/L. Zinc is ubiquitous in the laboratory and environment and is of concern as a contaminant, due to all of its uses and the low concentrations measured. Data were not qualified based on field QA samples.

Conventionals

Laboratory Quality Control

No significant problems were encountered during these analyses, and few data required qualification. QC samples included method blanks, spiked blanks, laboratory duplicates, matrix spikes, and continuing calibration checks.

TSS, turbidity, and hardness results met most measurement quality objectives for the study. All holding times were met, no target analytes were detected in method blanks, and laboratory control samples (spike blanks) were within acceptable limits.

Laboratory duplicates for TSS met the $\leq$20% RPD limits for acceptability with one exception. Duplicate number B09D093-DUP1 had a 29% RPD and was “J” qualified as an estimate. Excluding the one outlier, the range for the TSS laboratory duplicate pairs was from 0 to 10% RPD with a mean of 4.2%.

The third set of storm samples collected on 12/11/2010 had five TSS samples “J” qualified as estimates due to the solids included fast-settling sands. These samples were identified as 1011036-02, -04, -05, -09, and -10.

Laboratory duplicates for turbidity were similar, with a mean RPD of about 1% and only one of six pairs having any difference.

One hardness matrix spike sample (B10K129-MS1) collected 10/24/2010 during the second storm event recovered at 130%, which is beyond the 75 – 125% control limit. MEL noted the source sample was from a different work order that was not evaluated. Additionally, with the spiking level being so low compared to the native concentration, it was not considered a significant issue and no data were qualified because of it.

Field Quality Assurance

Field replicates for TSS, turbidity, and hardness were collected to assess the precision of the entire sampling and analysis process. The field replicates consisted of two samples collected as close to the same time and place as possible. Because these results incorporate sources of both field and laboratory variability, greater RPD would be expected compared to laboratory duplicates. Field replicate pairs for TSS had a mean RPD of 6.2%, while turbidity pairs had a mean RPD of 10.2%. Hardness, being a dissolved constituent, was expected to be less variable and had a mean RPD of 1.9%.

Results and Discussion

Precipitation

Dry Season

During dry periods, impervious surfaces accumulate wash-off pollutants associated with dust, tire wear, and other debris. Storm events mobilize these pollutants to conveyance systems and surface waters. The highest concentrations of pollutants would be expected following a dry period and the on-set of a rain event. In the present study, dry-season sample events were preceded by at least five days with no measureable rainfall (Figure 2).

Rainfall data for the Des Moines area is presented in Table 4 for a general sense of how rainfall during the baseflow study period compared to historical averages. Dry-season samples were collected October 1 and 13, 2008.

Table 4. Historical and study-period monthly precipitation totals (inches).

Month	Historical Precipitation	2008 Study Precipitation	Divergence from Normal
August	1.02	2.87	+1.85
September	1.63	0.78	-0.85
October	3.19	2.17	-1.02

Bold: Sample event month

The antecedent precipitation for the two months prior to dry-season sample collection was both higher and lower than normal. The August rainfall total approached two inches higher than reported historically, while in September rainfall totaled only about one-half. October continued the drier trend, with rainfall almost a third below the historical normal.

Data used to compare historical to study-period monthly precipitation were from a NOAA/ NCDC[2] weather station (GHCND:USW00024233) within the upper Des Moines Creek basin. The weather station is located on the west side of SeaTac International Airport's new third runway, about three miles from the mouth of Des Moines Creek. The southern portion of the airport is within the headwaters of the Des Moines Creek drainage. The period of record for the NOAA station is 06/01/1948 to 07/31/2006.

[2] National Oceanic and Atmospheric Administration/National Climatic Data Center

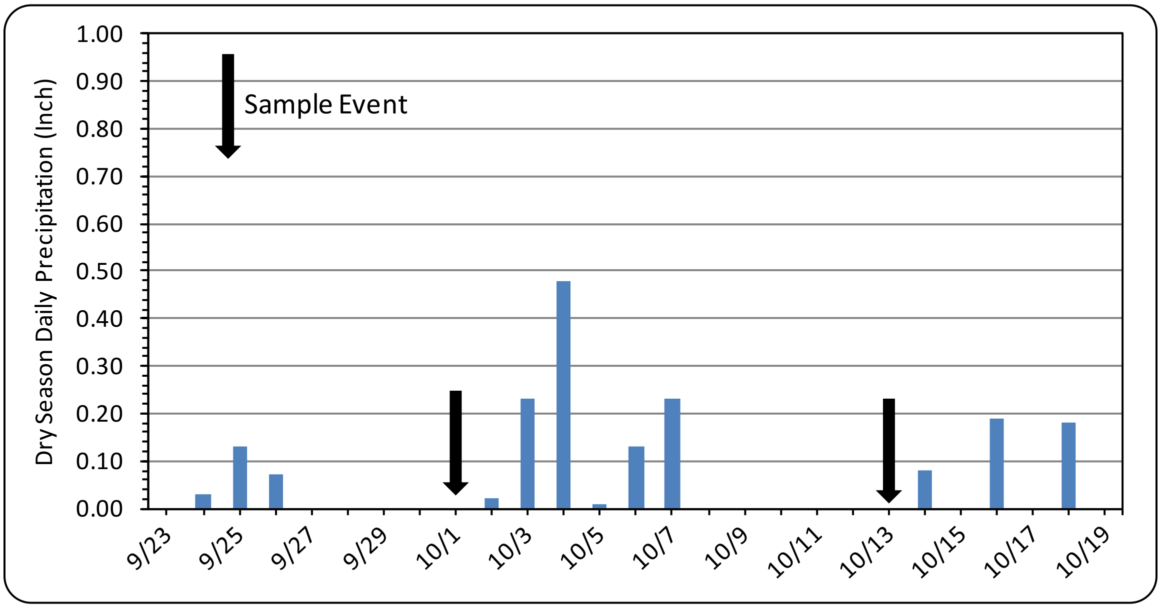

Figure 2. Baseflow daily precipitation and sample events (Sept 23 to Oct 19, 2008).

Wet Season

Rain events mobilize contaminants to conveyance systems and surface waters that have accumulated on impervious surfaces during dry periods. Past results have reported and the dry-season sampling verified the wet season as the critical period for copper and zinc inputs to study streams. A total of three storm events were sampled to evaluate copper and zinc levels during wash-off, with the first in the spring of 2009 and the final two in the fall of 2010.

Rainfall data from the NOAA weather station at SeaTac Airport are compared to study-period monthly averages in Table 5. Storm-event samples were collected March 28, 2009, October 24, 2010, and December 11, 2010. The monthly antecedent precipitation for the first storm was lower than normal, January by 0.39 inch and February by about 2.50 inches. March, the month samples were collected, had the higher rainfall by almost a half-inch.

The last two storm events were sampled during October and December of 2010. Prior to the October 24 event, September rainfall was over two and a half times normal, while October was also higher at almost one and a half times normal. November had lower rainfall than normal by about 15% while December was wetter by about half.

In March 2009, the first set of storm samples was collected. This set was collected under the storm sample initiation trigger described in the QA Project Plan (Coots, 2008). Largely, the original trigger to initiate sampling was met for the last two events, referring to the 24-hour antecedent dry period, a 0.20 inch predicted rain event over 24 hours, and sample collection occurring during the rising limb of the hydrograph.

Table 5. Historical and study-period monthly wet-season precipitation totals (inches).

Month	Historical Precipitation	2009 Study Precipitation	Divergence from Normal
January	5.79	5.40	-0.39
February	4.02	1.51	-2.51
March	3.71	4.16	+0.45
		2010 Study Precipitation	
September	1.72	4.80	+3.08
October	3.50	5.24	+1.74
November	5.97	5.05	-0.92
December	5.81	8.69	+2.88

Bold: Sample event months

Figure 3 shows the second storm sampled October 24 had a rain event on October 23. Only a small amount of rainfall had occurred throughout October 23. The original sample initiation trigger considered a trace amount of rain acceptable, as long as wash-off was not occurring. During the late evening of the 23rd significant rainfall began to fall, continuing on into the 24th. The first sample was collected at 11:45 PM on the 23rd.

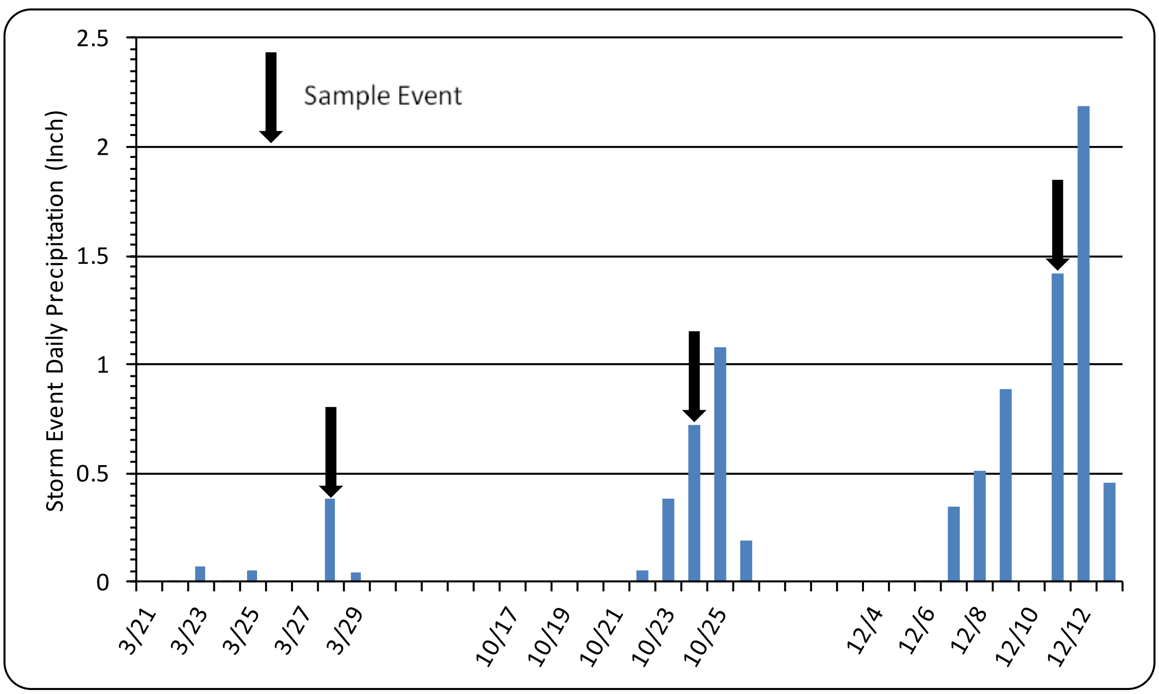

Figure 3. Wet-season daily precipitation for storm-event sample days (Mar 28, 2009, Oct 24, 2010, and Dec 11, 2010).

Turbidity and Total Suspended Solids

Turbidity and total suspended solids (TSS) are measures of suspended and settling particles in water. While turbidity determines water clarity by measuring light passing through a sample, TSS is the measure of a sample's total particle mass by filtering, drying, and weighing.

Dry Season

The complete set of dry-season results for turbidity and TSS are provided in Appendix C, Table C1.

Over the two dry-season sample surveys, turbidity was low. Results ranged from not detected at 0.5 U to 8.4 nephelometric turbidity units (NTUs) for the first event and 0.5 U to 1.8 NTU for the second. The Des Moines Creek mid-basin site (DES02) had the highest turbidity reported for the dry-season at 8.4 NTU. The next highest turbidity was 1.8 NTU at McSorley Creek upstream (SOR02).

TSS was also low during baseflow sampling. Only five of 18 samples were detected at the TSS reporting limit of 1 mg/L. Like turbidity, the DES02 site had the highest TSS for dry-season sampling. TSS ranged from not detected at 1 U to 16 mg/L. The next highest TSS was 2 mg/L.

Storm Event

Turbidity and TSS results from the study are summarized in Tables 6 and 7. The complete set of results is provided in Appendix C, Tables C2 and C3.

High variability is expected in both turbidity and TSS during storm wash-off. Suspended materials increase and decrease rapidly with the changing conditions brought on by a storm. Massey Creek had the highest mean turbidity for the study at 129 NTUs, mostly driven by the larger December storm, while Des Moines and McSorley Creeks were about the same at less than half the Massey average, also largely driven by December results.

Similar to turbidity, Massey Creek had the highest mean TSS for the study at 287 mg/L. Des Moines and McSorley Creeks were about the same, at just less than half the Massey average.

Table 6. Summary of storm-event turbidity data (NTUs).

Station	March 2009	October 2010	December 2010	Study Mean
DES01	9.0	31	105	48
DES02	8.3	26	170	68
DES03	8.7	15	44	23
MAS01	16	70	300	129
MAS02	12	NA	NA	NA
MAS03	16	NA	NA	NA
SOR01	11	6.3	118	45
SOR02	26	NA	NA	NA
SOR03	6.4	NA	NA	NA

NA: Not analyzed

Table 7. Summary of storm-event total suspended solids data (mg/L).

Station	March 2009	October 2010	December 2010	Study Mean
DES01	11	76	292	126
DES02	9.0	66	607	227
DES03	11	31	106	49
MAS01	28	168	666	287
MAS02	21	NA	NA	NA
MAS03	24	NA	NA	NA
SOR01	16	8.5	389	138
SOR02	27	NA	NA	NA
SOR03	10	NA	NA	NA

NA: Not analyzed

Copper, Zinc, and Hardness

Dry Season

Figure 4 and 5 show results for dissolved copper and zinc measured during baseflow from Des Moines, Massey, and McSorley Creeks, along with the acute hardness-based water quality criteria. Appendix C, Table C1, presents all baseflow water quality results for copper, zinc, hardness, turbidity, TSS, and the acute hardness-based water quality criteria.

Baseflow sampling confirmed that during the dry season, copper and zinc input to study streams was low and well within water quality criteria. Results for the two dry-season sample events showed dissolved copper levels were only about 3% to 10% of the acute copper criteria. Dissolved zinc was even lower, with results from about 1% to less than 5% of the acute criteria.

Dry-season hardness averaged 101 mg/L for all sites over the two sample events. This translates to mean acute copper and zinc criteria of 17.2 ug/L and 115 ug/L, respectively. The baseflow mean dissolved copper and zinc were reported at 1.10 and 2.39 ug/L, respectively.

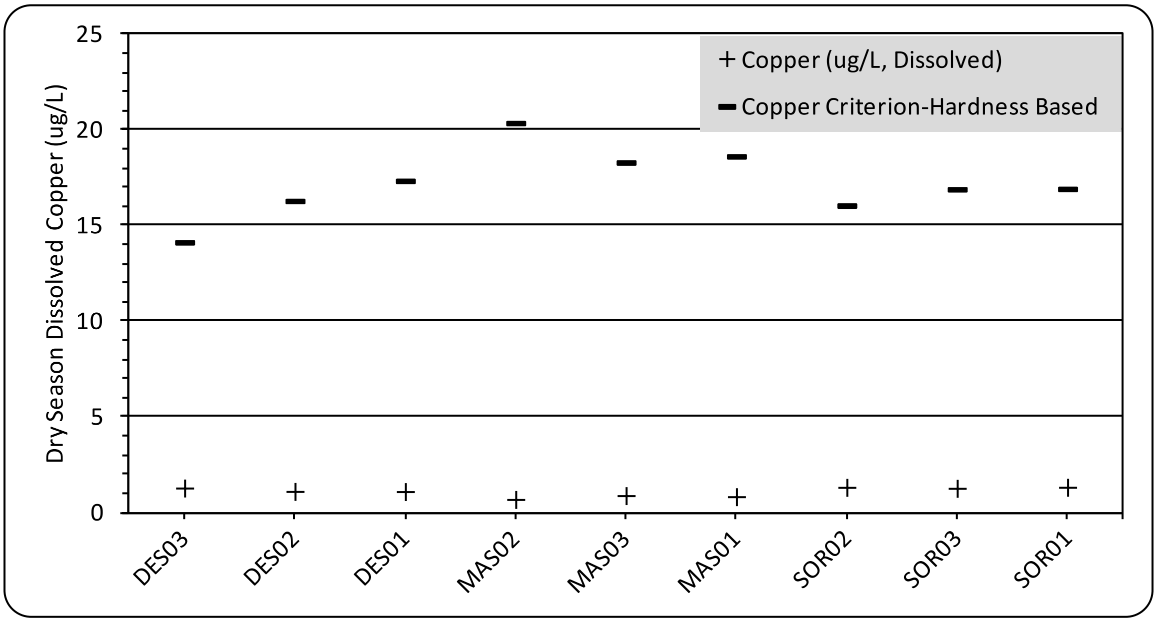

Figure 4. Dry-season dissolved copper and acute hardness-based water quality criteria.

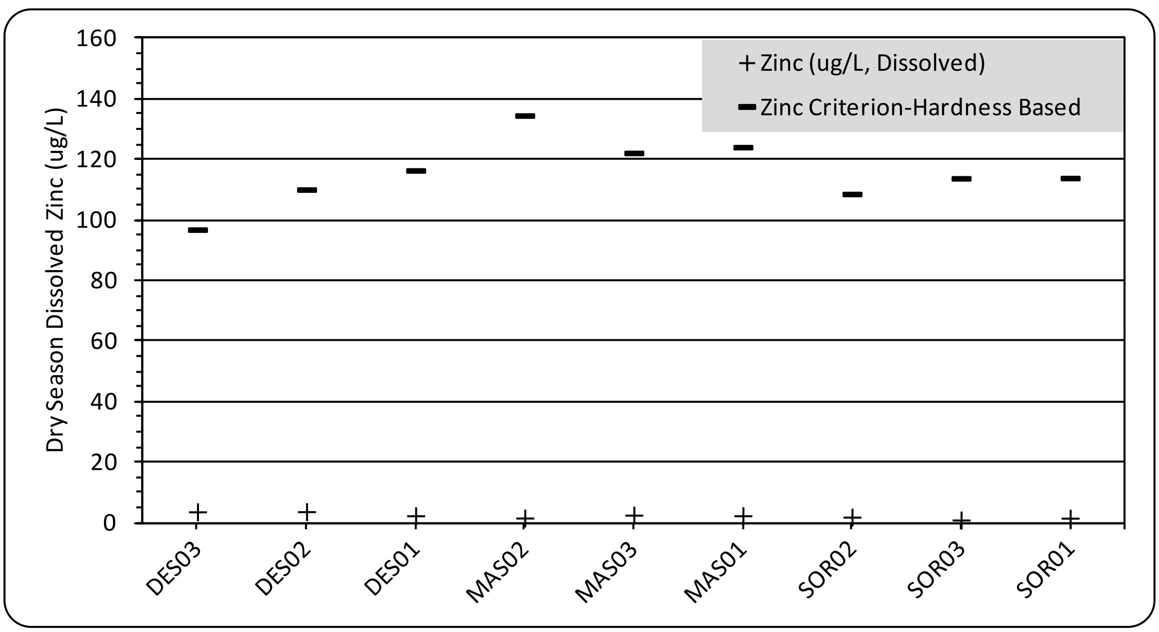

Figure 5. Dry-season dissolved zinc and acute hardness-based water quality criteria.

The dissolved forms are used when comparing copper and zinc to Washington State water quality criteria, that portion available to aquatic life. Results showed baseflow dissolved copper accounted for a study mean of 84% of the TR copper in samples (ranged from 53 to 93%). Dissolved zinc percentages compared to the TR could not be determined. Only three of 18 TR zinc samples were reported above detection for the dry season. Reporting levels were higher for TR zinc (5.0 ug/L) compared to dissolved (1.0 ug/L).

Storm Event

The storm-event results are listed in Tables 8 and 9 for dissolved copper and zinc, hardness, hardness-based acute criteria, and the study averages for each site. Complete storm-event data for copper, zinc, hardness, and acute water quality criteria are in Appendix C, Table C2 and C3. Figure D1 and D2 show results for dissolved copper and zinc measured during storm events from Des Moines, Massey, and McSorley Creeks, along with the acute hardness-based water quality criteria.

All three sites in each of the three studied streams were sampled during the first storm. Sampling continued in Des Moines Creek at all three sites, but was reduced to only downstream sites in Massey and McSorley Creeks after the first storm. Storm results for the downstream sites showed the highest dissolved copper and zinc in Des Moines, Massey, and McSorley Creeks, in decreasing order. In Des Moines Creek, concentrations of copper and zinc decreased from upstream to down, while hardness increased.

Over the first two storms, Des Moines Creek dissolved copper decreased from upstream to down. Mixed results were reported for the last storm, with the highest concentration reported at the downstream site.

Dissolved zinc decreased from upstream to downstream during the first storm, but showed mixed results for the second and third storms. The highest dissolved zinc concentrations from the second storm were reported from the mid-basin site (DES02), and for the third storm from the upstream site (DES03).

The highest dissolved copper value (6.40 ug/L) was measured during the October storm at the upstream Des Moines Creek site (DES03). It approached twice the concentration measured at other sites. Coinciding with the study's second lowest hardness result (21.0 mg/L), this higher dissolved copper value led to the only acute water quality violation for the study. Future evaluations of copper levels in Des Moines Creek should include the 200th Street site (DES03).

Dissolved zinc was within criteria throughout the study. The closest dissolved zinc result to a water quality criterion was the sample with the only dissolved copper violation. Zinc for this sample was 19.1 ug/L, and the companion hardness was 21.0 mg/L, translating to a dissolved zinc criterion of 30.50 ug/L. The highest storm flow dissolved zinc result was about 60% of criterion.

Table 8. Summary of storm-event dissolved copper, hardness, and acute criteria (ug/L).

Station	March 2009			October 2010			December 2010			Study Mean		
	Hardness[1]	Copper	Criterion[2]	Hardness	Copper	Criterion	Hardness	Copper	Criterion	Hardness	Copper	Criterion
DES01	57.6	3.42	10.12	61.7	2.27	10.80	33.2	3.43	6.02	50.8	3.04	8.99
DES02	56.6	3.57	9.95	45.3	3.48	8.07	33.2	3.17	6.02	45.0	3.41	8.02
DES03	57.5	3.76	10.10	21.0	**6.40**	3.91	20.2	3.25	3.77	32.9	4.47	5.97
Mean	*57.2*	*3.58*	*10.05*	*42.7*	*4.05*	*7.63*	*28.9*	*3.28*	*5.28*	*42.9*	*3.64*	*7.67*
MAS01	60.6	2.27	10.61	44.6	2.18	7.95	33.9	2.64	6.14	46.4	2.36	8.25
MAS02	66.4	2.56	11.57	NA	NA	NA	NA	NA	NA	NA	NA	NA
MAS03	52.5	2.37	9.27	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	*59.8*	*2.40*	*10.48*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
SOR01	56.0	2.77	9.85	56.6	2.95	9.95	32.7	2.94	5.94	48.4	2.89	8.59
SOR02	51.6	3.75	9.12	NA	NA	NA	NA	NA	NA	NA	NA	NA
SOR03	56.2	2.25	9.89	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	*54.6*	*2.92*	*9.62*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

1: Hardness expressed as $CaCO_3$.
2: Copper criterion is hardness based.
Bold: Value exceeds water quality criterion.
NA: Not analyzed.

Table 9. Summary of storm-event dissolved zinc, hardness, and acute criteria (ug/L).

Station	March 2009			October 2010			December 2010			Study Mean		
	Hardness[1]	Zinc	Criterion[2]	Hardness	Zinc	Criterion	Hardness	Zinc	Criterion	Hardness	Zinc	Criterion
DES01	57.6	10.9	71.72	61.7	14.8	76.02	33.2	8.90	44.96	50.8	11.5	64.47
DES02	56.6	12.0	70.66	45.3	21.0	58.51	33.2	7.70	44.96	45.0	13.6	58.18
DES03	57.5	12.6	71.61	21.0	19.1	30.50	20.2	13.0	29.51	32.9	14.9	44.62
Mean	*57.2*	*11.8*	*71.29*	*42.7*	*18.3*	*55.65*	*28.9*	*9.87*	*39.98*	*42.9*	*13.3*	*55.87*
MAS01	60.6	6.03	74.87	44.6	5.20	57.74	33.9	8.05	45.77	46.4	6.40	59.71
MAS02	66.4	5.43	80.90	NA	NA	NA	NA	NA	NA	NA	NA	NA
MAS03	52.5	8.23	66.30	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	*59.8*	*6.56*	*74.03*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
SOR01	56.0	9.13	70.02	56.6	13.8	70.66	32.7	13.2	44.39	48.4	12.0	61.88
SOR02	51.6	10.8	65.33	NA	NA	NA	NA	NA	NA	NA	NA	NA
SOR03	56.2	6.83	70.24	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	*54.6*	*8.92*	*68.54*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

1: Hardness expressed as $CaCO_3$.
2: Zinc criterion is hardness based.
NA: Not analyzed.

Hardness

Hardness data from the study are summarized in Table 10. Hardness averaged 46 mg/L for the three wet-season storms. This translates to a mean acute criterion of 8.12 ug/L for copper and 58.84 ug/L for zinc, over the three storms. This is slightly less than half the 101 mg/L hardness average reported for baseflow.

Table 10. Summary of storm-event hardness data (mg/L).

Station	March 2009	October 2010	December 2010	Study Mean
DES01	57.6	61.7	33.6	51.0
DES02	56.6	45.3	33.2	45.0
DES03	57.5	21.4	20.2	33.0
MAS01	60.6	44.6	33.9	46.4
MAS02	66.4	NA	NA	NA
MAS03	52.5	NA	NA	NA
SOR01	56.0	56.6	32.7	48.4
SOR02	51.6	NA	NA	NA
SOR03	56.2	NA	NA	NA

NA: Not analyzed

Mean storm-event hardness increased from upstream to down. From site to site, hardness was similar for the first event and in Des Moines Creek increased from upstream to down for the second and third storm. The lowest hardness for the study was reported for the third storm, increasing from upstream (DES03) to the downstream site.

Average storm hardness declined from the first event to the last by almost half, while storm intensity increased (Figure 3). Average hardness for the first storm was 57 mg/L, while the second and third declined to 49 and 30 mg/L, respectively. A number of reasons can cause hardness to decline, but dilution from soft rain water from larger storms likely played a significant role.

Hardness for the downstream sites located just before discharge into Puget Sound (DES01) averaged 51 mg/L at Des Moines Creek, and 46 and 48 mg/L for Massey (MAS01) and McSorley (SOR01) Creeks, respectively.

Des Moines was the only stream with samples collected at all sites for all three storms. Hardness values were similar among the three sites for the first sample event in March 2009. For the last two storm events, hardness was lowest at the upstream site and highest at the downstream site. The study mean ranged from 33 to 51 mg/L, respectively.

Antecedent rainfall may explain the decrease in hardness values from the first to the last storm event sampled. In Des Moines Creek over the three storms, intensity and antecedent rainfall increased from first to last, while hardness decreased by almost half.

Copper and Zinc Loads

Dry Season

Loads were calculated by multiplying the concentration of the pollutant by stream discharge at the time of sampling. The load is the total amount of the pollutant discharged over a given period of time, in this case per day. Estimating loads in this manner is an exercise for management of sources of pollution and not regulatory in nature. Dissolved copper and zinc loads are presented in Figures 6 and 7, respectively. These figures show baseflow dissolved copper and zinc measured at the end of the 2008 dry season for each site and sample period.

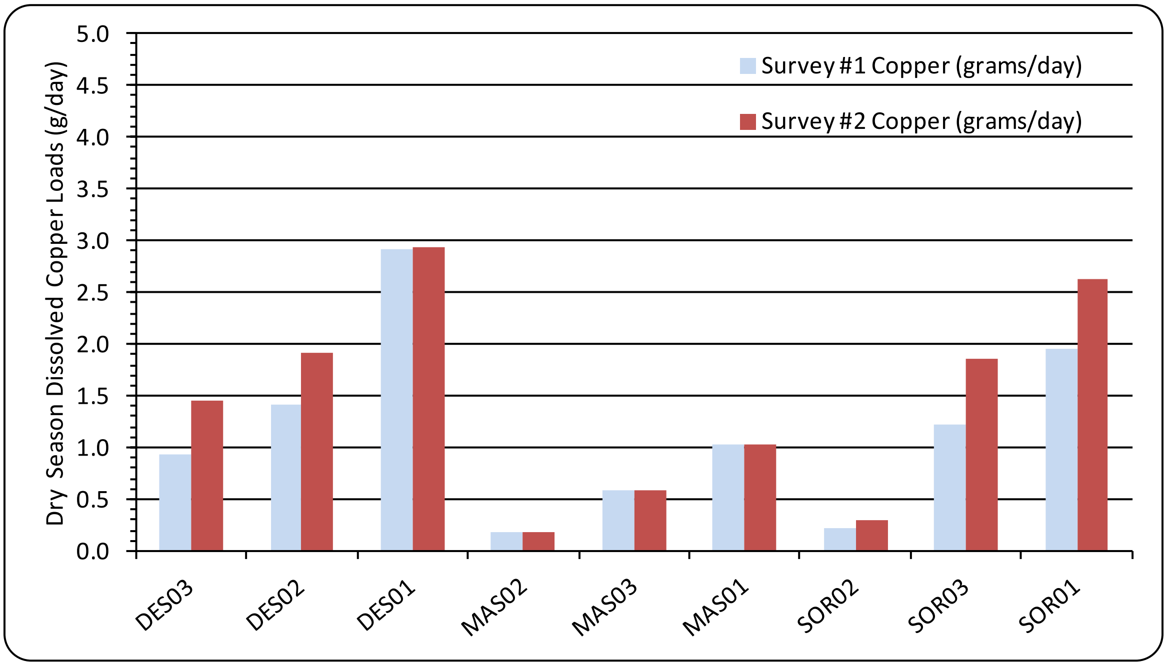

Figure 6. Dry-season dissolved copper loads.

As expected, copper loading during both baseflow surveys increased from upstream to downstream stations. Copper loads during the second survey were slightly higher than estimated for the first. Drainage areas for Massey and McSorley Creeks are smaller than Des Moines Creek. Copper loads from McSorley Creek were found to be higher than from Massey Creek and more similar to Des Moines.

Zinc loads also followed an upstream to downstream increase. Higher loads occurred during the second event for McSorley Creek, while no constant differences were seen for Des Moines or Massey Creeks. The only non-detected dissolved zinc result came from the first event from McSorley Creek's upstream station (SOR03).

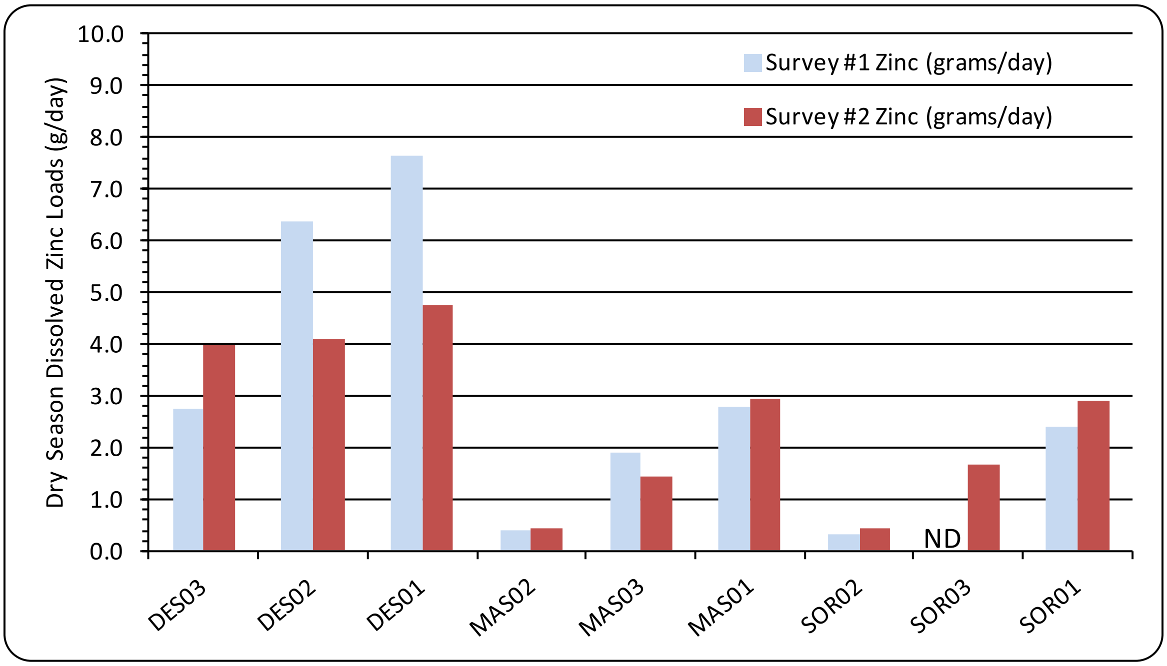

Figure 7. Dry-season dissolved zinc loads.

Des Moines Creek sample sites are all located on the mainstem. Upstream sites on Massey and McSorley Creeks (MAS02 and SOR02) are small tributaries discharging to the mainstem, just below the MAS03 and SOR03 sites (see Figure 1). The order of sites 02 and 03 for Massey and McSorley Creeks was reversed in Figures 6 and 7 to present the loads for all three streams from lower to higher discharge, headwaters to the mouth. No significant tributaries enter the lower reaches of these streams, although a number of stormwater discharges do exist.

Storm Event

Daily loads calculated for storm events likely over-estimate loading. Higher loading is expected on the rising limb of the hydrograph (Golding, 2006). Loads measured during rising flows would not be expected to continue beyond the storm or throughout a 24-hour period. Loads are another way to compare sites and streams based on the total amount of a pollutant over a given period without regard to concentration or water quality criteria.

Dissolved copper and zinc loads are summarized in Table C4 and shown in Figures 8 and 9, respectively. These tables and figures show sample-time estimated storm discharge and dissolved copper and zinc loads measured during the spring of 2009 and fall of 2010 for each site and storm.

Dissolved copper loads increased from upstream to downstream during the first storm at all sites, and also during the third storm at Des Moines Creek. Loads were higher in Massey and McSorley Creeks than in Des Moines Creek during the first storm. Contaminant loading followed the size of the storm with the first event being lowest and increasing to the third. The highest dissolved copper loads were from the third storm at the downstream sites in Massey

(MAS01) and McSorley (SOR01) Creeks. The Massey Creek site was almost six times, while the McSorley Creek site was slightly over twice, the Des Moines Creek (DES01) load.

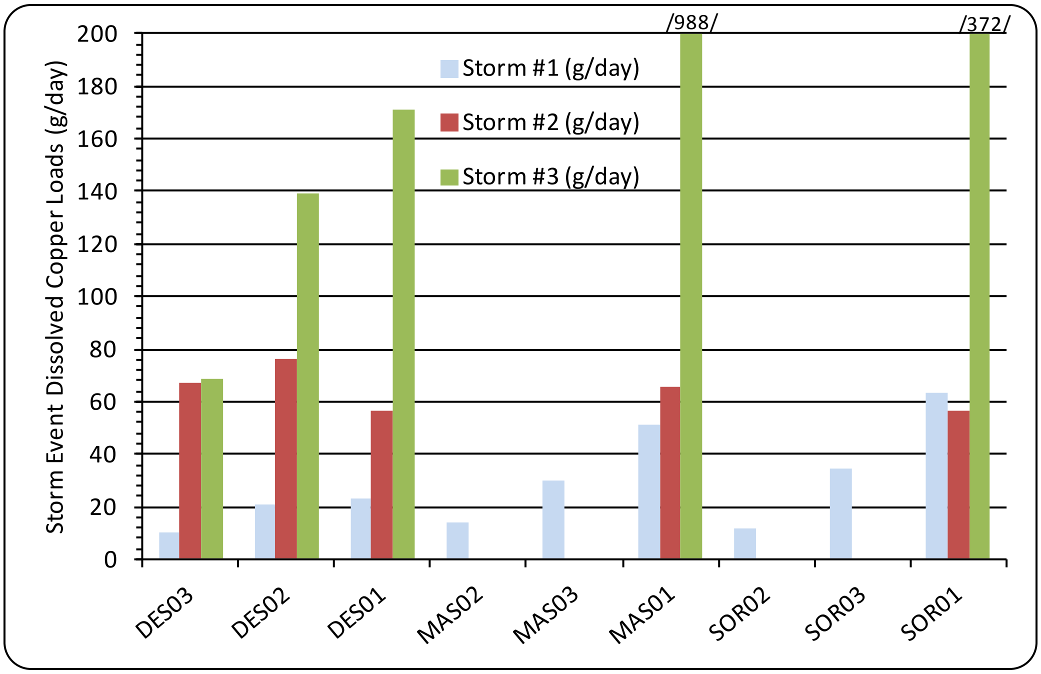

Figure 8. Storm loads for dissolved copper.

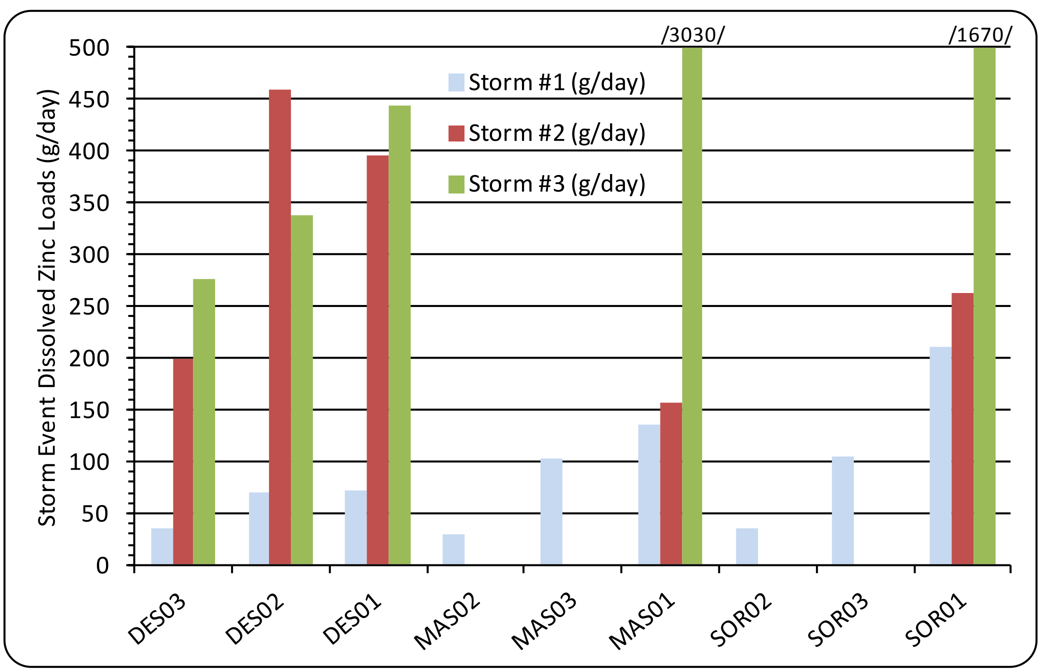

Figure 9. Storm loads for dissolved zinc.

During the first storm, dissolved zinc loading from Massey and McSorley Creeks was greater than loads estimated for Des Moines Creek. This did not hold for the second storm, where Des Moines Creek had a greater zinc load. The third storm had the downstream sites in Massey and then McSorley Creeks having the highest loads for the study, similar to copper. Estimated dissolved zinc loads in Massey and McSorley Creeks were almost seven times, and over three and a half times, loads estimated for Des Moines Creek, respectively. Massey and McSorley Creeks drainages are smaller than Des Moines Creek but showed potential for greater loading during this study.

Dissolved vs. Total Recoverable Copper and Zinc

Higher loading was expected during storm wash-off where dust and debris from roadways and impervious surfaces accumulate to be mobilized. Baseflow results showed dissolved copper averaged 84% of the TR copper in samples, ranging from 53 to 93%. Zinc comparisons were not made because so few TR zinc results were detected at a 5.0 ug/L detection limit.

Lower percentages of dissolved, compared to TR, copper and zinc were expected for storm events. Copper and zinc have an affinity to particulates that play a much greater role during storm wash-off. The percentage of dissolved, compared to the TR, copper and zinc decreased with greater storm rainfall for Des Moines and Massey Creeks. McSorley Creek during the second storm reported a sample pair analyzed for zinc with dissolved greater than the TR, a laboratory artifact (14.2 vs. 11.3 ug/L). This occasionally happens but does not reflect a true value and is likely caused by analysis of a non-homogeneous sample pair. Figures D3 and D4 in Appendix D present dissolved and TR copper and zinc by site and storm.

Table 11 shows the percentage of dissolved copper and zinc compared to the TR. The lowest percentages of dissolved were measured during the last storm event. This suggests higher amounts of rainfall during storms may lower the ratio by increasing wash-off of sediment-associated copper and zinc.

Table 11. Storm-event dissolved copper and zinc as percent of the total.

		Des Moines	Massey	McSorley
Storm #1 Mar 2009	% Dissolved of TR Copper	66.6	55.4	61.4
	% Dissolved of TR Zinc	66.2	45.1	60.6
		Des Moines	Massey	McSorley
Storm #2 Oct 2010	% Dissolved of TR Copper	36.1	16.9	78.4
	% Dissolved of TR Zinc	57.0	8.22	111[1]
	-	Des Moines	Massey	McSorley
Storm #3 Dec 2010	% Dissolved of TR Copper	15.1	8.52	14.5
	% Dissolved of TR Zinc	12.1	6.05	11.1

1: Lab artifact, dissolved zinc reported greater than TR zinc.

Comparison to Water Quality Criteria

The Washington State water quality standards for toxic metals require both acute and chronic criteria to be met. Acute criteria are based on a 1-hour average concentration not to be exceeded more than once every three years. Likewise, chronic criteria are a 4-day average concentration not to be exceeded more than once every three years (Chapter 173-201A-240, WAC).

Ecology's Water Quality Program policy for 303(d) listing a waterbody for toxic substances requires that two or more samples within a three-year period must exceed the numeric state water quality criteria.

For assessing criteria compliance for metals, the Water Quality Program has determined that a single grab sample is representative of the 1-hour average, referred to in the acute criteria. For this study, only acute criteria are applied to dissolved copper and zinc. Chronic criteria are meant to represent a 4-day average. Because storm samples were never collected over more than a 5-hour period for the first storm, and 2-hour period for the second and third storms, the chronic criteria do not apply.

In the upper Des Moines Creek basin just below 200th Street at DES03, the only exceedance of the acute water quality criteria was noted. During the second storm, copper and hardness were reported with average concentrations of 6.40 ug/L and 21.0 mg/L, respectively. Based on 21.0 mg/L hardness, the criterion for dissolved copper would be 3.91 ug/L.

Zinc did not exceed acute water quality criteria throughout the study. Dissolved zinc levels in Des Moines Creek were lower from upstream to down during the first storm event, while mixed results were found for the second and third storm events. The mean storm-event zinc levels decreased from upstream to down.

Lower hardness was measured during wet-season storm sampling, coinciding with higher levels of copper and zinc. Hardness affects toxicity of these metals, and is used as a measure of the binding potential of the water. State water quality standards for copper and zinc require the companion hardness value to determine sample-specific criteria. The higher the hardness concentration, the higher the copper and zinc water quality criteria.

Impervious surfaces in urban areas collect rain, often directed to surface waters. Storm discharge from urban streams and hardness has an inverse relationship. During storms, soft rain water falls, increasing stream flow, while hardness is diluted and lowered by the soft water inputs. Rainfall during the wet season does not benefit from percolation through the ground to increase hardness, running off instead.

Results suggest storm intensity, as measured by the daily rainfall total, may play a role in lowering hardness in study streams. Stream discharge during storms increase and were dominated by rainfall for the three study streams. Low hardness is not itself a problem but can create one by also washing off contaminants that have hardness-based toxicity.

Small urban streams, like those studied, tend to be flashy; discharge increases quickly with the onset of rain and drops quickly following the cessation. Therefore, low hardness-determined toxic effects to aquatic life can be short lived, from minutes to hours.

Load Reductions Needed

During the study, the only exceedance of water quality criteria was in the upper Des Moines Creek basin at DES03. An acute copper violation was found during the second storm. Copper and hardness were reported, with average concentrations of 6.40 ug/L and 21 mg/L, respectively. This translates to a dissolved copper criterion of 3.91 ug/L.

Table 12 presents the dissolved copper load reductions needed to meet the acute water quality criterion at DES03. The dissolved copper would need a 39% load reduction to meet a water quality criterion with 21 mg/L hardness. The allowable load is the maximum grams discharged per day of dissolved copper with a hardness of 21 mg/L.

Table 12. Des Moines Creek storm load and needed reduction at 200th Street.

Site	Storm Dissolved Copper Load (g/day)	Allowable Dissolved Copper Load (g/day)[1]	Needed Load Reduction (g/day)	Needed Percent Reduction[2]
DES03	67.2	41.0	26.2	39.0

[1] Maximum allowable grams discharged per day of dissolved copper using the study flow and 21 mg/L hardness.
[2] Percent reduction of dissolved copper = [(67.2 g/day – 41.0 g/day) / (67.2 g/day)] x 100 = **39%.**

This site had the lowest hardness reported for the study. To meet water quality criteria when dissolved copper is 6.40 ug/L would require a minimum hardness of 35.4 mg/L. This is a 69% increase in hardness over the reported 21 mg/L.

Des Moines Creek Habitat and Hydrology

Many habitat improvements have been made to the Des Moines Creek basin over the last 10 to 15 years. Des Moines Creek drains the south end of SeaTac Airport, where hydrology was altered for the development of the airport's third runway. Some wetlands along the airport's western extent were filled, and permanent loss was expected to be about 14 acres (Ecology, 2000).

The Federal Aviation Administration (FAA) limits development of avian habitat within 10,000 feet of airports/facilities to avoid aircraft bird strike hazard. Wetland loss and inability to re-establish within the upper basin could impact hardness in Des Moines Creek during storms. More data would be needed to determine the relationship of hardness in Des Moines Creek during large storms.

The upper basin of Des Moines Creek may have impervious surfaces too large for the most intense storms. Wetland retention/treatment may not be adequate to increase hardness before reaching 200th Street. Hardness increases between the upper basin site (DES03) and middle basin site (DES02) enough to maintain water quality throughout the three storms.

Comparison to Historical Data

In Table 13, study results are compared to historical levels for dissolved copper and zinc, hardness, and flow from the Herrera study (2001). Samples were collected as single grabs for the Herrera study, while this study collected composites. Results represent wet season means for downstream sites in Des Moines, Massey, and McSorley Creeks.

Table 13. Historical comparison of wet-season means at downstream sites for dissolved copper and zinc, hardness, and flow.

Stream	Site	Dissolved Copper (ug/L)	Dissolved Zinc (ug/L)	Hardness (mg/L)	Flow (cfs)
Des Moines	DES01	3.09	11.4	51.8	11.1
	DM-2[1]	4.74	12.9	54.7	15.4
Massey	MAS01	2.35	6.37	48.4	58.2
	MA-3[1]	3.75	9.73	49.7	9.70
McSorley	SOR01	2.87	11.6	49.5	23.0
	MC-2[1]	6.68	13.6	46.0	3.59

1: Herrera, 2001

Wash-off pollutants measured during storms are highly variable, so comparisons are tenuous. Metals concentrations were lower for this study compared to the historical study done over 10 years ago. This study's dissolved copper values averaged slightly more than half the average reported at the downstream sites during the Herrera study (2001). Dissolved zinc averaged about 20% less than the amount reported by Herrera.

Hardness was slightly higher at Des Moines and Massey Creeks during the Herrera study, and slightly lower at McSorley Creek. Flow measurements were most different comparing this study to the Herrera study in Massey and McSorley Creeks. This study's storm flow averages for Massey and McSorley Creeks were about 6 times greater than reported for the Herrera study. The third storm was responsible for raising the average estimated flows. The December storm's daily rainfall total approached 1.5 inches, a large storm for the season. Massey Creek had an estimated discharge of 153 cfs. This value was extrapolated from the flow curve. The stage height exceeded all flows used to develop the Massey Creek flow curve. Des Moines Creek storm-event flows estimated for this study were closer to flows measured during the Herrera study, but about 25% less.

Conclusions

Results of this 2009-10 study support the following conclusions:

- Sampling during both baseflow and storm flows verified the critical period for copper and zinc inputs to the three study streams is during wash-off of storms.
- During baseflow sampling, dissolved copper and zinc concentrations and loads were low, well within hardness-based water quality criteria.
- Critical-condition sampling during storms found dissolved copper and zinc within water quality criteria throughout the study at all 303(d) listed sites.
- Average dissolved copper and zinc in Des Moines Creek during storms were highest at the upstream site (DES03 at 200th St) and decreased downstream.
- The highest dissolved copper measured, and second lowest hardness measured was from upstream Des Moines Creek (DES03 at 200th St) during the second storm. This led to the only acute water quality criteria exceedance for the study. This site was not previously 303(d) listed for copper.
- Study data suggest there was an inverse relationship between rainfall intensity or flow and hardness. Antecedent rainfall may also play a part. The more intense the storm, the lower the hardness, corresponding to lower copper and zinc criteria.
- Wet-season results suggest habitat improvements to the study streams have improved (decreased) dissolved copper and zinc levels during storms.
- Hydrology in the upper Des Moines Creek basin was altered for the development of SeaTac Airport's third runway. Some wetlands were filled and impervious surface was added. Higher dissolved copper and zinc and lower hardness may result during major storms. More study would be needed to define this relationship.

Recommendations

Results of this 2009-10 study support the following recommendations:

- Ecology's Water Quality Program should evaluate the data collected during this study and consider removing 303(d) listings under category 5 for sites in Des Moines, Massey, and McSorley Creeks for dissolved copper and Des Moines and Massey Creeks for dissolved zinc.
- Future significant increases of impervious surfaces in the upper Des Moines Creek basin should be evaluated for potential effects on Des Moines Creek at 200th St. during storms.
- Water quality evaluations of copper and zinc in the three study streams should include storm monitoring to assure data are collected during critical periods.

References

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Appendices

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Appendix A. Historical Results

Table A1. Historical copper, zinc, hardness, and flow results and Acute Water Quality Criteria for Des Moines, Massey, and McSorley Creeks (Herrera, 2001).

Parameter	Baseflow (Mean and Range)			Storm Flow (Mean and Range)		
	Des Moines	Massey	McSorley	Des Moines	Massey	McSorley
Acute WQ Criteria (ug/L)[1]	Cu=10.2-24.8 Zn=72.6-160	Cu=15.9-23.2 Zn=108-151	Cu=13.4-21.8 Zn=92.2-143	Cu=4.6-14.8 Zn=35.4-101	Cu=3.6-19.1 Zn=28.1-127	Cu=5.6-16.2 Zn=42.1-109
Copper Dissolved (ug/L)	2.8 (1.0U-14.8)	1.6 (1.0U-11.6)	2.8 (1.0U-3.4)	3.2 (2.9-6.0)	4.4 (1.0U-35.6)	6.3 (1.2-52.4)
Zinc Dissolved (ug/L)	7.5 (3.0U-66.0)	2.3 (3.0U-14.0)	2.0 (3.0U-4.5)	18.3 (3.0U-78.0)	17.3 (3.0U-109)	11.7 (3.0U-57.0)
Hardness (mg/L)	93.8 (58.4-149)	110 (93.1-139)	96.4 (77.5-130)	49.1 (25.0-86.2)	47.3 (19.1-113)	51.4 (30.7-94.9)
Flow (cfs)[2]	1.45 (0.85-2.30)	2.24 (1.40-3.40)	0.27 (0.03-0.52)	15.4 (3.5-39.4)	9.70 (2.50-27.2)	3.60 (0.20-8.40)

1: Acute water quality criteria based on hardness data per Chapter 173-201A WAC, from Herrera (2001).
2: Flow statistics reported for the most downstream site in each basin.
U: Analyte not found at the detection limit shown.

Appendix B. Data Quality Results

Table B1. Precision estimates for hardness, TSS, and turbidity, field replicates and laboratory duplicates.

Sample ID		Analysis	QA Type	Results		RPD[1]
No. 1	No. 2			No. 1	No. 2	
0904035-01	0904035-28	Hardness	field rep	39.7	40.8	2.7
1010044-06	1010044-11	Hardness	field rep	20.4	20.7	1.5
1011036-01	1011036-11	Hardness	field rep	33.1	32.6	1.5
08424088	08424089	Hardness	field rep	94.5	94.6	0.1
B09C269-MS1	B09C269-MSD1	Hardness	MS/MSD	65.2	64.9	0.4
B09C269-MS2	B09C269-MSD2	Hardness	MS/MSD	61.7	62.0	0.5
B10K129-MS1	B10K129-MSD1	Hardness	MS/MSD	117	116	0.9
B10K129-MS2	B10K129-MSD2	Hardness	MS/MSD	85.5	87.1	2.0
B10L083-MS1	B10L083-MSD1	Hardness	MS/MSD	64.8	65.0	0.2
B10L083-MS2	B10L083-MSD2	Hardness	MS/MSD	238	237	0.6
0904035-01	0904035-28	TSS	field rep	12	11	8.7
1010044-06	1010044-11	TSS	field rep	15	17	12.5
1011036-01	1011036-11	TSS	field rep	134	139	3.7
08404081	LDP1	TSS	lab dupe	16	16	0
0904035-01	B09D093-Dup1	TSS	lab dupe	16	12	29
0904035-02	B09D093-Dup2	TSS	lab dupe	9	8	10
0904035-21	B09D094-Dup1	TSS	lab dupe	21	22	2.0
0903026-38	B09D094-Dup2	TSS	lab dupe	10	9	10.5
1010044-05	B10J192-Dup1	TSS	lab dupe	56	56	0
1010044-11	B10J192-Dup2	TSS	lab dupe	18	17	5.7
1011036-01	B10L078-DUP1	TSS	lab dupe	134	128	4.0
1011036-07	B10L078-DUP2	TSS	lab dupe	507	523	3.0
0904035-01	0904035-28	Turbidity	field rep	12	11	8.7
1010044-06	1010044-11	Turbidity	field rep	10	10	0
1011036-01	1011036-11	Turbidity	field rep	39	60	42.4
08404088	LDP1	Turbidity	lab dupe	0.5 U	0.5 U	0
08424088	08424089	Turbidity	lab dupe	0.5 U	0.5 U	0
0904035-09	B09C274-DUP1	Turbidity	lab dupe	11	11	0
0904035-21	B09C275-DUP1	Turbidity	lab dupe	16	16	0
1010044-01	B10J210-DUP1	Turbidity	lab dupe	26	24	8
1011036-04	B10L079-DUP1	Turbidity	lab dupe	160	160	0

1: relative percent difference (sample difference, divided by the mean, times 100)
MS/MSD: matrix spike/matrix spike duplicate
field rep: field replicate
lab dupe: laboratory duplicate

Table B2. Quality assurance results for hardness, turbidity, and TSS laboratory control samples and method blanks.

Sample No.	Sample Date	Analysis	QA Type	Results	Units
MB08282E1	10/8/2008	Hardness	Lab Blank[1]	0.30 U	mg/L
ML08282E1	10/8/2008	Hardness	Spike Blank[2]	98	%
MB08289E1	10/15/2008	Hardness	Lab Blank	0.30 U	mg/L
MB08289E1	10/15/2008	Hardness	Spike Blank	97	%
B09C269-BLK1	3/30/2009	Hardness	Lab Blank	0.30 U	mg/L
B09C269-BS1	3/30/2009	Hardness	Spike Blank	102	%
B09D024-BLK1	3/30/2009	Hardness	Lab Blank	0.30 U	mg/L
B09D024-BS1	3/30/2009	Hardness	Spike Blank	106	%
B10K129-BLK1	11/18/2010	Hardness	Lab Blank	0.30 U	mg/L
B10K129-BS1	11/18/2010	Hardness	Spike Blank	103	%
B10L083-BLK1	12/14/2010	Hardness	Lab Blank	0.30 U	mg/L
B10L083-BS1	12/14/2010	Hardness	Spike Blank	100	%
GB08276U1	10/2/2008	Turbidity	Lab Blank	0.5 U	NTU
GL08276U1	10/2/2008	Turbidity	Spike Blank	97	%
GB08288U1	10/14/2008	Turbidity	Lab Blank	0.5 U	NTU
GL08288U1	10/14/2008	Turbidity	Spike Blank	97	%
B09C274-BLK1	3/30/2009	Turbidity	Lab Blank	0.5 U	NTU
B09C274-BS1	3/30/2009	Turbidity	Spike Blank	101	%
B09C275-BLK1	3/30/2009	Turbidity	Lab Blank	0.5 U	NTU
B09C275-BS1	3/30/2009	Turbidity	Spike Blank	100	%
B10J210-BLK1	10/25/2010	Turbidity	Lab Blank	0.5 U	NTU
B10J210-BS1	10/25/2010	Turbidity	Spike Blank	99	%
B10L079-BLK1	12/13/2010	Turbidity	Lab Blank	0.5 U	NTU
B10L079-BS1	12/13/2010	Turbidity	Spike Blank	100	%
GB08276S1	10/2/2008	TSS	Lab Blank	1 U	mg/L
GL08276S1	10/2/2008	TSS	Spike Blank	96	%
GB08288S1	10/14/2008	TSS	Lab Blank	1 U	mg/L
GB08288U1	10/14/2008	TSS	Spike Blank	98	%
B09D093-BLK1	4/1/2009	TSS	Lab Blank	1 U	mg/L
B09D093-BS1	4/1/2009	TSS	Spike Blank	95	%
B09D094-BLK1	4/1/2009	TSS	Lab Blank	1 U	mg/L
B09D094-BS1	4/1/2009	TSS	Spike Blank	109	%
B10J192-BLK1	10/25/2010	TSS	Lab Blank	1 U	mg/L
B10J192-BS1	10/25/2010	TSS	Spike Blank	95	%
B10L078-BLK1	12/13/2010	TSS	Lab Blank	1 U	mg/L
B10L078-BS1	12/13/2010	TSS	Spike Blank	98	%

1: A laboratory created sample from reagent grade water analyzed along with study samples.
2: A laboratory created sample from reagent grade water spiked with a known amount of analyte and analyzed along with study samples.

Table B3. Precision estimates for copper and zinc laboratory duplicates and field replicates.

Sample ID		Analysis	QA Type	Results		RPD
No. 1	No. 2			No. 1	No. 2	
BO9DO41-MS1	BO9DO41-MSD1	TR Copper[1]	MS/MSD[2]	28.3	27.8	2
BO9DO41-MS2	BO9DO41-MSD2	TR Copper	MS/MSD	28.4	28.7	0.8
B10K036-MS1	B10K036-MSD1	TR Copper	MS/MSD	22.0	20.6	7
B10L143-MS1	B10L143-MSD1	TR Copper	MS/MSD	30.3	31.7	5
B09C282-MS1	B09C282-MSD1	Diss Copper[3]	MS/MSD	21.8	21.9	0.4
B09C283-MS1	B09C283-MSD1	Diss Copper	MS/MSD	23.7	23.6	0.4
B10J222-MS1	B10J222-MSD1	Diss Copper	MS/MSD	20.7	21.4	3
B10L156-MS1	B10L156-MSD1	Diss Copper	MS/MSD	23.3	23.1	0.8
B09D041-MS1	B09D041-MSD1	TR Zinc	MS/MSD	42.9	42.8	0.2
B09D041-MS2	B09D041-MSD2	TR Zinc	MS/MSD	49.8	47.1	6
B10K036-MS1	B10K036-MSD1	TR Zinc	MS/MSD	23.9	21.8	9
B10L143-MS1	B10L143-MSD1	TR Zinc	MS/MSD	54.3	54.9	1
B09C282-MS1	B09C282-MSD1	Diss Zinc[3]	MS/MSD	27.5	27.7	0.6
B09C283-MS1	B09C283-MSD1	Diss Zinc	MS/MSD	31.8	32.0	0.6
B10J222-MS1	B10J222-MSD1	Diss Zinc	MS/MSD	37.0	38.2	3
B10L156-MS1	B10L156-MSD1	Diss Zinc	MS/MSD	28.0	27.8	0.7
1011036-01	1011036-11	TR Copper	field rep[4]	12.1	11.5	5
1010044-06	1010044-11	TR Copper	field rep	11.1	10.2	8
0904035-01	0904035-28	TR Copper	field rep	8.27	8.43	2
1011036-01	1011036-11	Diss Copper	field rep	3.61	3.54	2
1010044-06	1010044-11	Diss Copper	field rep	5.96	5.78	3
0904035-01	0904035-28	Diss Copper	field rep	4.90	4.58	7
1011036-01	1011036-11	TR Zinc	field rep	37.0	37.5	1
1010044-06	1010044-11	TR Zinc	field rep	28.2	26.7	5
0904035-01	0904035-28	TR Zinc	field rep	25.1	28.2	12
1011036-01	1011036-11	Diss Zinc	field rep	9.20	8.60	7
1010044-06	1010044-11	Diss Zinc	field rep	27.7	14.6	**62**
0904035-01	0904035-28	Diss Zinc	field rep	14.5	15.0	3

1: Total recoverable
2: Matrix spike/matrix spike duplicate
3: Dissolved
4: Field replicates are two samples collected as close to the same time and place as possible
Bold: Beyond control limits

Table B4. Quality assurance results for copper and zinc laboratory control samples and blanks.

Sample No.	Analysis Date	Analysis	QA Type	Results	Units
MB08282I2	10/8/2008	TR[1] Copper	Lab Blank	0.10 U	ug/L
ML08282I3	10/8/2008	TR Copper	LLRS[2]	99	%
08404084	10/1/2008	TR Copper	Matrix spike 1	98	%
08404084	10/1/2008	TR Copper	Matrix spike 2	99	%
MB08280I3	10/7/2008	TR Copper	Lab Blank	0.10 U	ug/L
MB08280I3	10/7/2008	TR Copper	LCS[3]	101	%
MB08282I2	10/8/2008	TR Zinc	Lab Blank	1.0 U	ug/L
ML08282I3	10/8/2008	TR Zinc	LLRS	111	%
08404084	10/8/2008	TR Zinc	Matrix spike 1	93	%
08404084	10/8/2008	TR Zinc	Matrix spike 2	93	%
MB08280I3	10/7/2008	TR Zinc	Lab Blank	5.0 U	ug/L
MB08280I3	10/7/2008	TR Zinc	LCS	103	%
BO9DO41-BLK1	4/7/2009	TR Copper	Lab Blank	0.10 U	ug/L
BO9DO41-BLK2	4/7/2009	TR Copper	Lab Blank	0.10 U	ug/L
BO9DO41-BS1	4/7/2009	TR Copper	LCS	104	%
BO9DO41-BS2	4/7/2009	TR Copper	LCS	103	%
BO9DO41-MS1	4/7/2009	TR Copper	Matrix Spike	100	%
BO9DO41-MSD1	4/7/2009	TR Copper	Matrix Spike Dup	98	%
BO9DO41-MS2	4/7/2009	TR Copper	Matrix Spike	100	%
BO9DO41-MSD2	4/7/2009	TR Copper	Matrix Spike Dup	101	%
B10K036-BLK1	11/09/2010	TR Copper	Lab Blank	0.10 U	ug/L
B10L143-BS1	11/09/2010	TR Copper	LCS	104	%
B10K036-MS1	11/09/2010	TR Copper	Matrix Spike	106	%
B10K036-MSD1	11/09/2010	TR Copper	Matrix Spike Dup	100	%
B10L143-BLK1	12/23/2010	TR Copper	Lab Blank	0.10 U	ug/L
B10L143-BS1	12/23/2010	TR Copper	LCS	105	%
B10L143-MS1	12/23/2010	TR Copper	Matrix Spike	91	%
B10L143-MSD1	12/23/2010	TR Copper	Matrix Spike Dup	98	%
B09C282-BLK1	3/31/2009	Diss[4] Copper	Lab Blank	0.10 U	ug/L
B09C283-BLK1	3/31/2009	Diss Copper	Lab Blank	0.10 U	ug/L
B09C282-BS1	3/31/2009	Diss Copper	LCS	102	%
B09C283-BS1	3/31/2009	Diss Copper	LCS	104	%
B09C282-MS1	3/31/2009	Diss Copper	Matrix Spike	97	%
B09C282-MSD1	3/31/2009	Diss Copper	Matrix Spike Dup	97	%
B09C282-MS1	3/31/2009	Diss Copper	Matrix Spike	99	%
B09C283-MSD1	3/31/2009	Diss Copper	Matrix Spike Dup	99	%
B10J222-BLK1	10/27/10	Diss Copper	Lab Blank	0.10 U	ug/L
B10J222-BS1	10/27/10	Diss Copper	LCS	97	%
B10J222-MS1	10/27/10	Diss Copper	Matrix Spike	93	%
B10J222-MSD1	10/27/10	Diss Copper	Matrix Spike Dup	96	%

Table B4 con't. Quality assurance results for copper and zinc laboratory control samples and blanks.

Sample No.	Analysis Date	Analysis	QA Type	Results	Units
B10L156-BLK1	12/20/2010	Diss Copper	Lab Blank	0.10 U	ug/L
B10L156-BS1	12/20/2010	Diss Copper	LCS	101	%
B10L156-MS1	12/20/2010	Diss Copper	Matrix Spike	100	%
B10L156-MSD1	12/20/2010	Diss Copper	Matrix Spike Dup	99	%
B09D041-BLK1	4/7/2009	TR Zinc	Lab Blank	5.0 U	ug/L
B09D041-BLK2	4/7/2009	TR Zinc	Lab Blank	5.0 U	ug/L
B09D041-BS1	4/7/2009	TR Zinc	LCS	105	%
B09D041-BS2	4/7/2009	TR Zinc	LCS	107	%
B09D041-MS1	4/7/2009	TR Zinc	Matrix Spike	89	%
B09D041-MSD1	4/7/2009	TR Zinc	Matrix Spike Dup	89	%
B09D041-MS2	4/7/2009	TR Zinc	Matrix Spike	108	%
B09D041-MSD2	4/7/2009	TR Zinc	Matrix Spike Dup	95	%
B10K036-BLK1	11/09/10	TR Zinc	Lab Blank	5.0 U	ug/L
B10K036-BS1	11/09/10	TR Zinc	LCS	104	%
B10K036-MS1	11/09/10	TR Zinc	Matrix Spike	102	%
B10K036-MSD1	11/09/10	TR Zinc	Matrix Spike Dup	92	%
B10L143-BLK1	12/23/2010	TR Zinc	Lab Blank	5.0 U	ug/L
B10L143-BS1	12/23/2010	TR Zinc	LCS	106	%
B10L143-MS1	12/23/2010	TR Zinc	Matrix Spike	86	%
B10L143-MSD1	12/23/2010	TR Zinc	Matrix Spike Dup	90	%
B09C282-BLK1	3/31/2009	Diss Zinc	Lab Blank	1.0 U	ug/L
B09C283-BLK1	3/31/2009	Diss Zinc	Lab Blank	1.0 U	ug/L
B09C282-BS1	3/31/2009	Diss Zinc	LCS	99	%
B09C283-BS1	3/31/2009	Diss Zinc	LCS	102	%
B09C282-MS1	3/31/2009	Diss Zinc	Matrix Spike	84	%
B09C282-MSD1	3/31/2009	Diss Zinc	Matrix Spike Dup	85	%
B09C283-MS1	3/31/2009	Diss Zinc	Matrix Spike	105	%
B09C283-MSD1	3/31/2009	Diss Zinc	Matrix Spike Dup	105	%
B10J222-BLK1	10/27/10	Diss Zinc	Lab Blank	1.0 U	ug/L
B10J222-BS1	10/27/10	Diss Zinc	LCS	97	%
B10J222-MS1	10/27/10	Diss Zinc	Matrix Spike	87	%
B10J222-MSD1	10/27/10	Diss Zinc	Matrix Spike Dup	93	%
B10L156-BLK1	12/20/2010	Diss Zinc	Lab Blank	1.0 U	ug/L
B10L156-BS1	12/20/2010	Diss Zinc	LCS	102	%
B10L156-MS1	12/20/2010	Diss Zinc	Matrix Spike	100	%
B10L156-MSD1	12/20/2010	Diss Zinc	Matrix Spike Dup	98	%

1: Total recoverable
2: Low level reference standard
3: Laboratory control sample, spiked blank
4: Dissolved

Appendix C. Water Quality Results

Table C1. Baseflow water quality results from Des Moines, Massey, and McSorley Creeks, 2008.

Sample ID	Site ID[2]	Sample Date	Hardness	Turbidity	TSS	Copper (ug/L)		Zinc (ug/L)		Acute WQ Criteria[1]	
			(mg/L)	(NTU)	(mg/L)	Dissolved	TR	Dissolved	TR	Copper	Zinc
08404080	DES01	10/1/2008	106	**1.0**	1 U	**1.10**	**1.26**	**2.9**	5.0 U	17.98	120.24
08404081	DES02	10/1/2008	100	**8.4**	**16**[3]	**1.11**	**2.09**	**5.0**	**7.3**	17.02	114.45
08404082	DES03	10/1/2008	87.0	**0.7**	1 U	**1.20**	**1.38**	**3.5**	5.0 U	14.92	101.71
08404083	MAS01	10/1/2008	113	**0.8**	1 U	**0.84**	**0.91**	**2.3**	5.0 U	19.09	126.93
08404084	MAS02	10/1/2008	125	**0.8**	**2**	**0.67**	**0.78**	**1.5**	5.0 U	21.00	138.27
08404085	MAS03	10/1/2008	111	**0.6**	1 U	**0.89**	**0.99**	**2.9**	5.0 U	18.77	125.03
08404086	SOR01	10/1/2008	103	**1.0**	1 U	**1.14**	**1.25**	**1.4**	5.0 U	17.50	117.35
08404087	SOR02	10/1/2008	96.4	**1.7**	**2**	**1.13**	**1.50**	**1.6**	5.0 U	16.44	110.95
08404088	SOR03	10/1/2008	104	0.5 U[3]	1 U	**1.02**	**1.10**	1.0 U	5.0 U	17.66	118.31
08424080	DES01	10/13/2008	98.9	**0.5**	1 U	**1.11**	**1.48**	**1.8**	**5.8**	16.84	113.38
08424081	DES02	10/13/2008	90.9	**0.7**	1 U	**1.12**	**1.42**	**2.4**	5.0 U	15.55	105.56
08424082	DES03	10/13/2008	77.2	**0.9**	1 U	**1.39**	**1.95**	**3.8**	**6.3**	13.33	91.91
08424083	MAS01	10/13/2008	106	**0.8**	1 U	**0.84**	**1.12**	**2.4**	5.0 U	17.98	120.24
08424084	MAS02	10/13/2008	117	**0.7**	**2**	**0.72**	**0.97**	**1.7**	5.0 U	19.73	130.73
08424085	MAS03	10/13/2008	105	**0.6**	1 U	**0.90**	**1.12**	**2.2**	5.0 U	17.82	119.28
08424086	SOR01	10/13/2008	95.8	**0.6**	1 U	**1.53**	**1.93**	**1.7**	5.0 U	16.34	110.36
08424087	SOR02	10/13/2008	91.5	**1.8**	1 U	**1.53**	**1.95**	**2.2**	5.0 U	15.65	106.15
08424088	SOR03	10/13/2008	94.5	0.5 U[3]	1 U[3]	**1.54**	**1.81**	**1.4**	5.0 U	16.13	109.09

1: Acute water quality criteria are based on hardness and the dissolved fraction
2: See Figure 1
3: Result is a mean of a replicate pair
Bold: Visual aid to detected analytes

Table C2. Storm-event water quality results from Des Moines, Massey, and McSorley Creeks, March 2009.

Sample ID	Site ID[2]	Sample Date	Hardness	Turbidity	TSS	Copper (ug/L)		Zinc (ug/L)		Acute WQ Criteria[1]	
			(mg/L)	(NTU)	(mg/L)	Dissolved	TR	Dissolved	TR	Copper	Zinc
0904035-01	DES01-1[3]	3/28/2009	40.2	12.0	12 J	4.74	8.35	14.8	26.6	7.21	52.88
0904035-02	DES01-2	3/28/2009	73.2	5.6	8	2.45	3.70	9.3	11.5	12.68	87.86
0904035-03	DES01-3	3/28/2009	59.4	10.0	12	3.06	5.11	8.6	15.4	10.42	73.61
0904035-04	DES02-1	3/28/2009	72.1	6.0	8	3.93	6.43	14.1	18.9	12.50	86.74
0904035-05	DES02-2	3/28/2009	48.9	8.9	9	3.10	6.93	10.1	22.8	8.67	62.42
0904035-06	DES02-3	3/28/2009	48.7	10.0	10	3.68	5.93	11.8	18.3	8.64	62.21
0904035-07	DES03-1	3/28/2009	75.7	7.2	13	2.02	3.37	6.8	12.0	13.09	90.40
0904035-08	DES03-2	3/28/2009	55.0	7.8	8	4.94	6.45	15.9	19.8	9.69	68.96
0904035-09	DES03-3	3/28/2009	41.9	11.0	12	4.33	7.10	15.2	20.5	7.50	54.77
0904035-10	MAS01-1	3/28/2009	73.8	12.0	20	2.06	3.58	5.6	12.2	12.78	88.47
0904035-11	MAS01-2	3/28/2009	58.4	8.4	10	2.34	3.39	6.0	9.7	10.25	72.56
0904035-12	MAS01-3	3/28/2009	49.7	29.0	53	2.42	6.33	6.5	25.9	8.81	63.29
0904035-13	MAS02-1	3/28/2009	77.7	10.0	19	2.45	3.57	5.8	8.2	13.42	92.42
0904035-14	MAS02-2	3/28/2009	63.1	7.2	10	2.48	3.29	5.2	7.9	11.03	77.48
0904035-15	MAS02-3	3/28/2009	58.3	19.0	34	2.74	4.96	5.3	13.3	10.23	72.45
0904035-16	MAS03-1	3/28/2009	60.8	12.0	15	2.28	3.95	6.9	15.6	10.65	75.08
0904035-17	MAS03-2	3/28/2009	53.6	11.0	15	2.38	3.90	10.7	14.6	9.46	67.47
0904035-18	MAS03-3	3/28/2009	43.0	26.0	41	2.45	6.36	7.1	28.6	7.68	55.98
0904035-19	SOR01-1	3/28/2009	65.0	5.1	5	2.35	3.12	8.1	7.7	11.34	79.45
0904035-20	SOR01-2	3/28/2009	54.5	13.0	20	3.19	5.17	9.1	18.9	9.60	68.43
0904035-21	SOR01-3	3/28/2009	48.4	16.0	22	2.77	4.98	10.2	18.5	8.59	61.88
0904035-22	SOR02-1	3/28/2009	52.0	19.0	14	4.02	6.22	10.0	18.0	9.19	65.76
0904035-23	SOR02-2	3/28/2009	50.0	38.0	46	3.80	10.2	10.9	38.4	8.86	63.61
0904035-24	SOR02-3	3/28/2009	52.9	22.0	22	3.42	6.32	11.6	24.9	9.34	66.73
0904035-25	SOR03-1	3/28/2009	58.1	8.0	8	2.54	3.56	7.5	10.5	10.20	72.24
0904035-26	SOR03-2	3/28/2009	57.6	5.8	12	1.99	2.98	6.4	7.8	10.12	71.72
0904035-27	SOR03-3	3/28/2009	52.8	5.5	9	2.21	2.79	6.6	7.0	9.32	66.62

1: Acute water quality criteria are based on hardness and the dissolved fraction
2: See Figure 1
3: Result is the mean of a replicate pair
J: Result is an estimate

Table C3. Storm-event water quality results from Des Moines, Massey, and McSorley Creeks, October and December 2010.

Sample ID	Site ID[2]	Sample Date	Hardness	Turbidity	TSS	Copper (ug/L)		Zinc (ug/L)		Acute WQ Criteria[1]	
			(mg/L)	(NTU)	(mg/L)	Dissolved	TR	Dissolved	TR	Copper	Zinc
1010044-01	DES01-1	10/23/10	71.6	26.0	58	2.12	8.69	19.6	21.1	12.42	86.23
1010044-04	DES01-2	10/24/10	51.8	36.0	93	2.42	9.46	10.0	32.8	9.16	65.55
1010044-02	DES02-1	10/24/10	47.9	28.0	76	3.20	10.3	17.1	30.9	8.51	61.34
1010044-05	DES02-2	10/24/10	42.7	23.0	56	3.75	8.96	24.9	31.1	7.63	55.65
1010044-03	DES03-1	10/24/10	21.4	20.0	45	**6.93**	16.5	17.0	51.2	3.98	30.99
1010044-06	DES03-2[3]	10/24/10	20.6	10.0	16	**5.87**	10.6	21.2	27.4	3.84	30.01
1010044-07	MAS01-1	10/24/10	53.0	75.0	180	2.10	14.2	5.6	71.0	9.36	66.83
1010044-08	MAS01-2	10/24/10	36.2	65.0	155	2.25	11.6	4.8	55.5	6.53	48.38
1010044-09	SOR01-1	10/24/10	55.1	7.1	10.0	2.69	4.00	13.3	13.4	9.70	69.07
1010044-10	SOR01-2	10/24/10	58.1	5.4	7.0	3.20	3.51	14.2	11.3	10.20	72.24
1011036-01	DES01-1[3]	12/11/10	32.8	50.0	136	3.58	11.8	8.9	37.2	5.95	44.50
1011036-04	DES01-2	12/11/10	33.6	160	447 J	3.28	29.5	8.9	118	6.09	45.42
1011036-02	DES02-1	12/11/10	33.2	130	457 J	3.28	25.2	8.1	97.4	6.02	44.96
1011036-05	DES02-2	12/11/10	33.2	210	756 J	3.06	35.6	7.3	162	6.02	44.96
1011036-03	DES03-1	12/11/10	20.2	55.0	139	<u>3.15</u>	20.8	13.3	83.7	3.77	29.51
1011036-06	DES03-2	12/11/10	20.1	32.0	73	<u>3.35</u>	15.0	12.8	54.6	3.75	29.39
1011036-07	MAS01-1	12/11/10	37.1	270	507	2.82	26.2	9.3	86.8	6.69	49.40
1011036-08	MAS01-2	12/11/10	30.7	330	824	2.45	35.8	6.8	180	5.59	42.08
1011036-09	SOR01-1	12/11/10	32.5	55.0	221 J	3.04	13.0	14.3	70.2	5.90	44.16
1011036-10	SOR01-2	12/11/10	32.8	180	557 J	2.83	27.5	12.0	167	5.95	44.50

1: Acute water quality criteria are based on hardness and the dissolved fraction
2: See Figure 1
3: Results are the mean of a replicate pair
Bold: Result exceeds acute water quality criteria
Underlined: Result would exceed chronic water quality criterion
J: Result is considered an estimate, sample contained fast-settling sands

Table C4. Summary of storm-event dissolved copper and zinc loads (grams/day).

Site	Storm #1[1]		Storm #2		Storm #3	
	cfs	Copper	cfs	Copper	cfs	Copper
DES01	2.74	22.9	10.2	56.6	20.4	171
DES02	2.41	21.1	8.95	76.2	17.9	139
DES03	1.15	10.6	4.29	67.2	8.62	68.5
MAS01	9.17	50.9	12.3	65.6	153 J	988
MAS02	2.18	13.7	NA	NA	NA	NA
MAS03	5.14	29.8	NA	NA	NA	NA
SOR01	9.40	63.7	7.8	56.3	51.7	371
SOR02	1.32	12.1	NA	NA	NA	NA
SOR03	6.26	34.5	NA	NA	NA	NA
Site	cfs	Zinc	cfs	Zinc	cfs	Zinc
DES01	2.74	73.1	10.2	369	20.4	444
DES02	2.41	70.8	8.95	460	17.9	337
DES03	1.15	35.5	4.29	200	8.62	276
MAS01	9.17	135	12.3	156	153 J	3030
MAS02	2.18	29.0	NA	NA	NA	NA
MAS03	5.14	103	NA	NA	NA	NA
SOR01	9.40	210	7.8	263	51.7	1670
SOR02	1.32	34.9	NA	NA	NA	NA
SOR03	6.26	105	NA	NA	NA	NA

1: Storm #1 Oct 28, 2009; Storm #2 October 24, 2010; Storm #3 December 11, 2010.
J: Value is an estimate due to stage height exceeding the flow curve measurements.
cfs: Cubic feet per second.

Appendix D. Figures

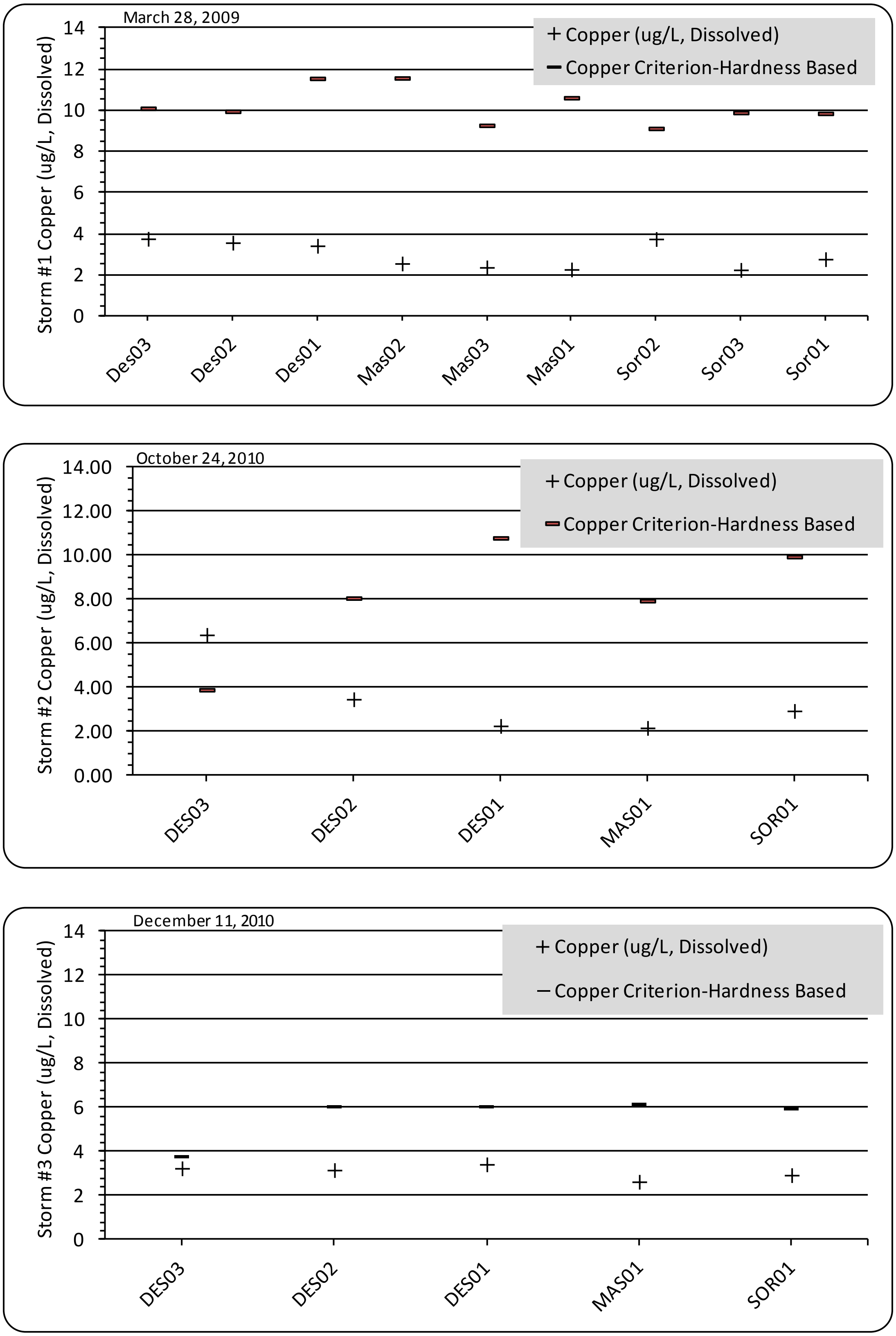

Figure D1. Storm-event dissolved copper, Des Moines, Massey, and McSorley Creeks.

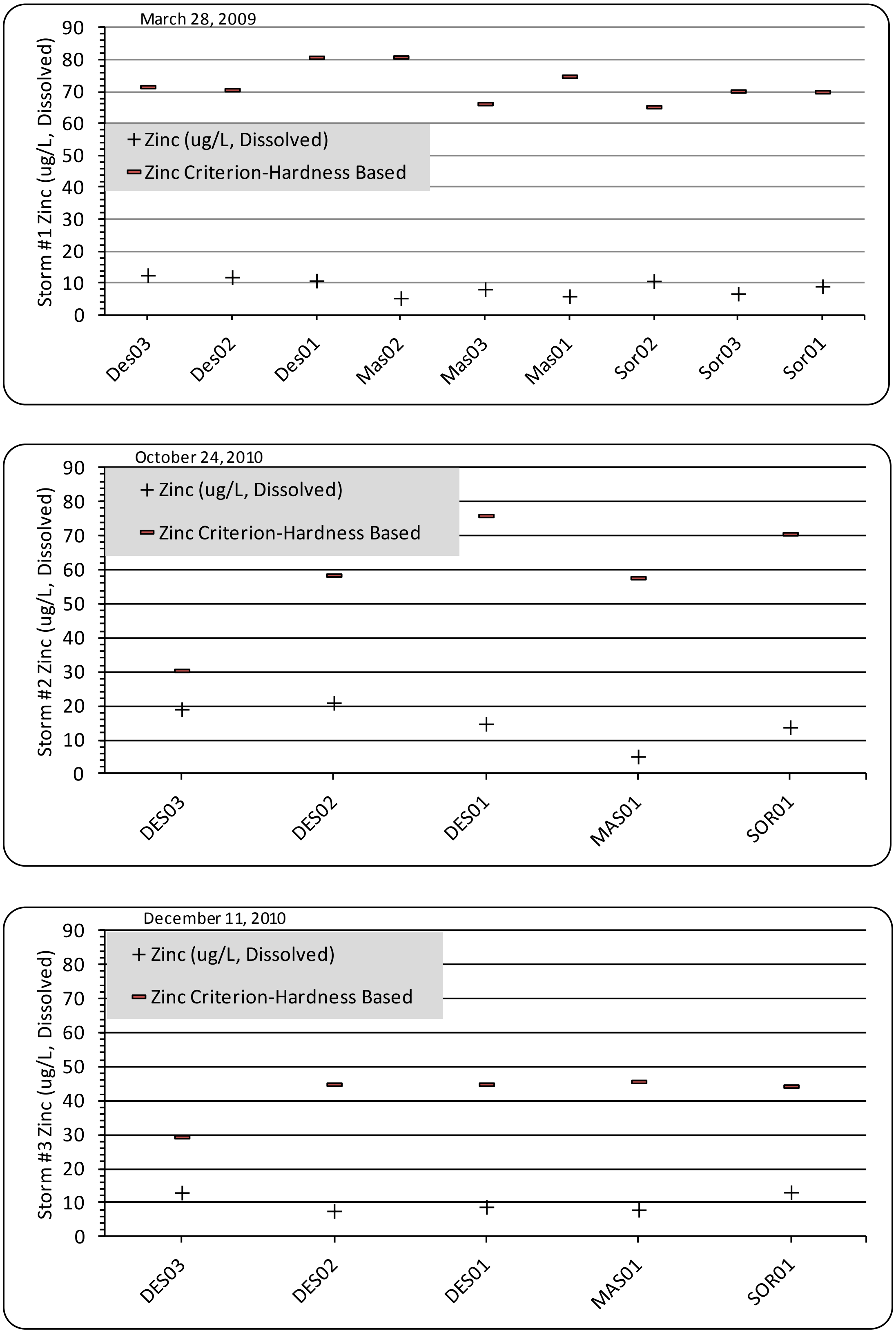

Figure D2. Storm-event dissolved zinc, Des Moines, Massey, and McSorley Creeks.

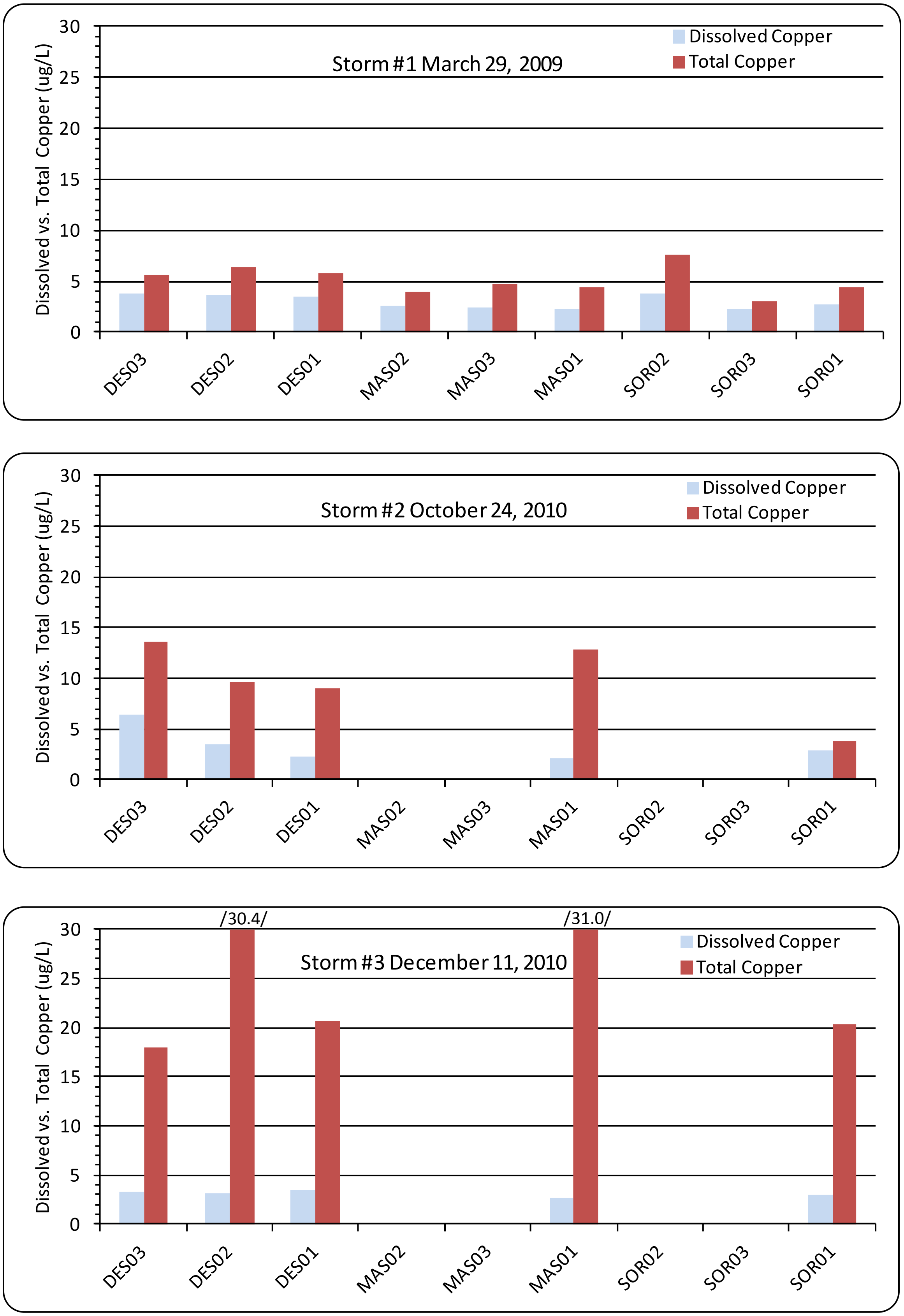

Figure D3. Storm-event dissolved to TR copper comparison.

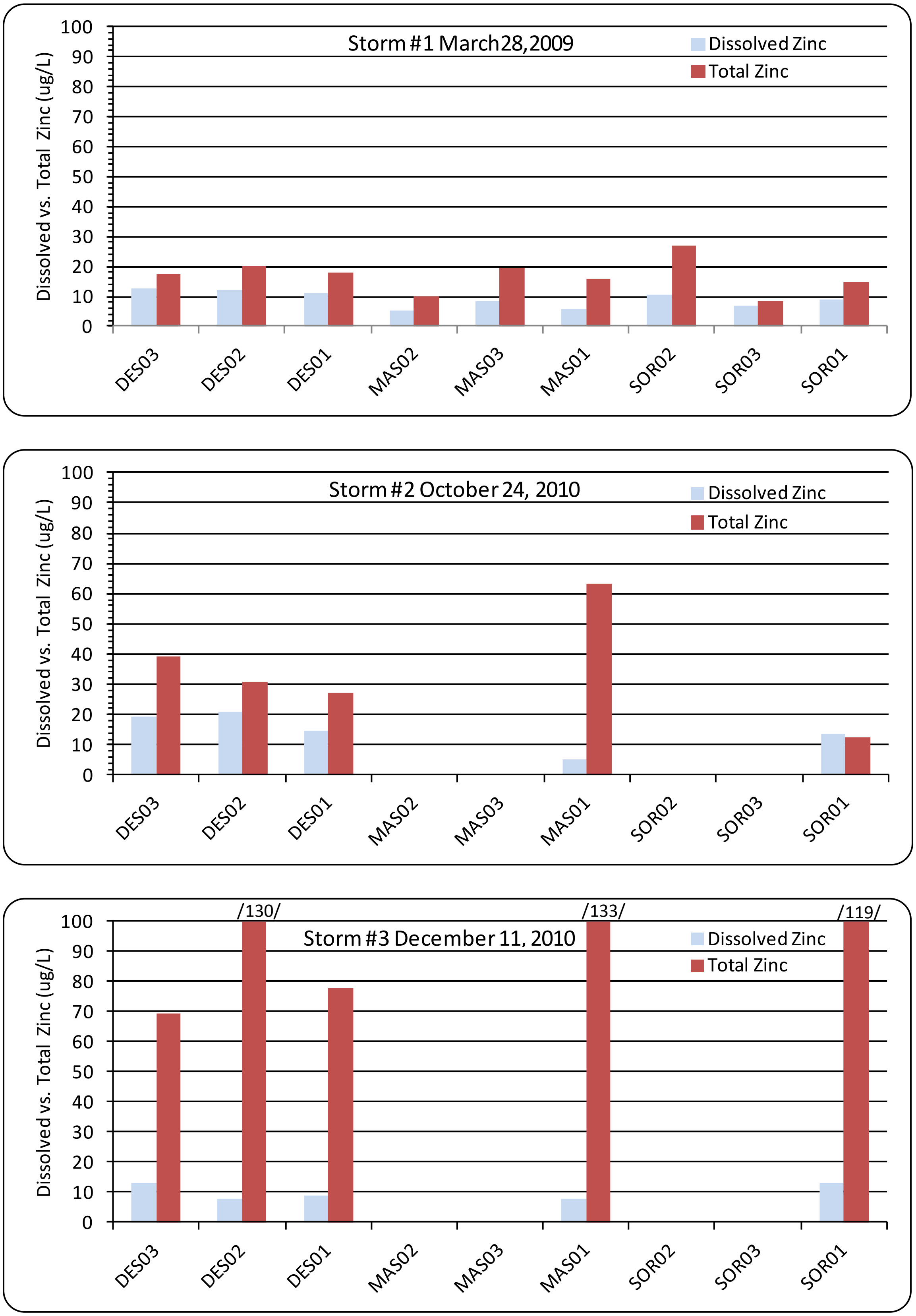

Figure D4. Storm-event dissolved vs. TR zinc comparison.

Appendix E. Glossary, Acronyms, and Abbreviations

Glossary

Baseflow: Groundwater discharge to a surface stream or river. The component of total streamflow that originates from direct groundwater discharges to a stream.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the Total Maximum Daily Load (TMDL) program.

Exceeds standards/criteria: Does not meet standards/criteria.

Hardness: The concentration of minerals in water (e.g., calcium, magnesium).

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property, whose values determine environmental characteristics or behavior.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Salmonid: Fish that belong to the family *Salmonidae*. Any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Acronyms and Abbreviations

Cu	Copper
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
SOP	Standard operating procedures
TR	Total recoverable
TSS	Total suspended solids
WAC	Washington Administrative Code
Zn	Zinc

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
mg	milligrams
mg/L	milligrams per liter (parts per million)
mL	milliliters
ng/L	nanograms per liter (parts per trillion)
NTU	nephelometric turbidity unit
ug/L	micrograms per liter (parts per billion)