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Puget Sound Boatyards

Zinc, Copper, Lead, and Hardness Concentrations in Receiving Waters

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Puget Sound Boatyards

Zinc, Copper, Lead, and Hardness Concentrations in Receiving Waters

by
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Waterbody Number(s):

Strait of Juan de Fuca (East)	WA-18-0010
Fidalgo Bay/Guemes Channel	WA-03-0020
Commencement Bay (Outer)	WA-10-0010
Lake Union/Seattle Ship Canal	WA-08-9340

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Abstract

The Washington State Department of Ecology (Ecology) reissued the third Boatyard General Permit (BGP) on November 2, 2005. The BGP includes numeric benchmarks for copper that apply to stormwater runoff into adjacent waters. The primary source of copper from boatyards is antifouling paints which discourage marine growth on boat hulls. The BGP uses copper as an indicator parameter for zinc and lead, also associated with boatyard runoff.

A Pollution Control Hearings Board ruling on an appeal of the permit required Ecology or the boatyards to collect receiving water data to verify several assumptions used in formulating the copper benchmark. Ecology subsequently conducted the study in 2008-09, the results of which are reported here.

The objective of the Boatyard Receiving Water Study was to obtain data to verify or modify the metals translator and hardness assumptions used to develop the benchmarks in the current BGP. Surface water samples were collected at five locations – three marine and two freshwater – in the vicinity of Puget Sound boatyards in September 2008 and January and May 2009. The samples were analyzed for total recoverable and dissolved zinc, copper, and lead, and hardness (freshwater). Total suspended solids and salinity (marine waters) were also measured.

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Background

The Washington State Department of Ecology (Ecology) reissued the third Boatyard General Permit (BGP) on November 2, 2005 (www.ecy.wa.gov/programs/wq/permits/boatyard/index.html). The BGP includes numeric benchmarks for copper that apply to stormwater runoff from boatyards into adjacent waters. The primary source of copper from boatyards is antifouling paints which discourage algae, barnacles, and other marine growth on boat hulls. The BGP uses copper as an indicator parameter for zinc and lead, also associated with boatyard runoff.

The Northwest Marine Trade Association (NMTA) and the Puget Soundkeeper Alliance (PSA) appealed the permit. While under appeal, the permit was modified (May 2006) to correct a mistake in the lake discharge benchmark. The Pollution Control Hearings Board (PCHB) heard the appeal in July 2006 and issued a decision on January 26, 2007. The PCHB concluded that some of the assumptions used in the permit calculations were potentially flawed (www.ecy.wa.gov/programs/wq/permits/boatyard/index.html). The assumptions in question were for dissolved metals translators, hardness, and water effects ratios:

- *Metals Translators:* The aquatic life criteria for metals in freshwater and saltwater apply to the dissolved fraction. However, by federal regulation, effluent limits must be expressed as total recoverable. A "translator" must therefore be used to convert dissolved metals criteria into an effluent limitation (EPA, 1996a). Because Ecology had no boatyard data, a copper translator of 30% was used in the BGP, derived from data on shipyard discharges.

- *Hardness:* The aquatic life criteria for zinc, copper, and lead in freshwater vary with hardness. The BGP assumed a hardness of 25 mg/L. Ecology considered this value typical of western Washington waterbodies where boatyards are located on freshwater.

- *Water Effects Ratios:* The aquatic life criteria for zinc, copper, and lead are based on bioassays using laboratory water. The difference between a metal's bioavailability and effective toxicity in laboratory water compared to a receiving water can be accounted for using a water effects ratio (EPA, 1992). The water effects ratio is the LC-50 (lethal concentration for 50% of test organisms) in the receiving water compared to the LC-50 in laboratory water.

The NMTA and the PSA appealed the PCHB decision to the Washington State Superior Court in February 2007. NMTA, PSA, and Ecology reached a conditional settlement on that appeal in July 2007 (www.ecy.wa.gov/programs/wq/permits/boatyard/settlement.pdf).

The PCHB decision on the BGP appeal required Ecology or the boatyards to collect receiving water data to verify the assumptions used in formulating the copper benchmark. Ecology subsequently conducted the study in 2008-09, the results of which are reported here.

How Will Results of This Study Be Used?

The receiving water data obtained in the study will be used by the Ecology Water Quality Program for reissuance of the permit. The permit used literature values for copper water effects ratios to derive benchmarks for copper. However, when reissued, the permit will contain technology-based benchmarks and limits for copper and zinc. Lead concentrations in boatyard stormwater are being monitored and have been shown to be at or near detection levels when copper and zinc benchmarks/limits are being met.

The proposed technology-based limits will be compared to the following area-wide receiving water parameters to determine if the limits comply with water quality standards: (1) dissolved/total recoverable ratios (metals translators), (2) hardness (freshwater), and (3) background metals concentrations. Water effects ratios will not be used in this comparison and were not determined in the present study.

Project Description

The objective of the 2008-09 Boatyard Receiving Water Study was to obtain data to verify or modify the metals translator and hardness assumptions used to develop the benchmarks in the current (2006) BGP.

Water sampling was conducted at five locations in the vicinity of Puget Sound boatyards; three saltwater (marine) and two freshwater (Figure 1 and Table 1). These locations were proposed by the NMTA and PSA, and agreed to by Ecology. Surface water samples were taken at each location in September 2008 and January and May 2009. The samples were analyzed for total recoverable and dissolved zinc, copper, lead, and hardness (freshwater). Total suspended solids and salinity (marine waters) were also measured.

The study was conducted by Ecology's Environmental Assessment Program at the request of Ecology's Water Quality Program. Samples were analyzed by Ecology's Manchester Environmental Laboratory and Frontier GeoSciences, Seattle, a contract laboratory. The study followed a Quality Assurance Project Plan (Johnson, 2008) prepared according to the Ecology guidance in Lombard and Kirchmer (2004).

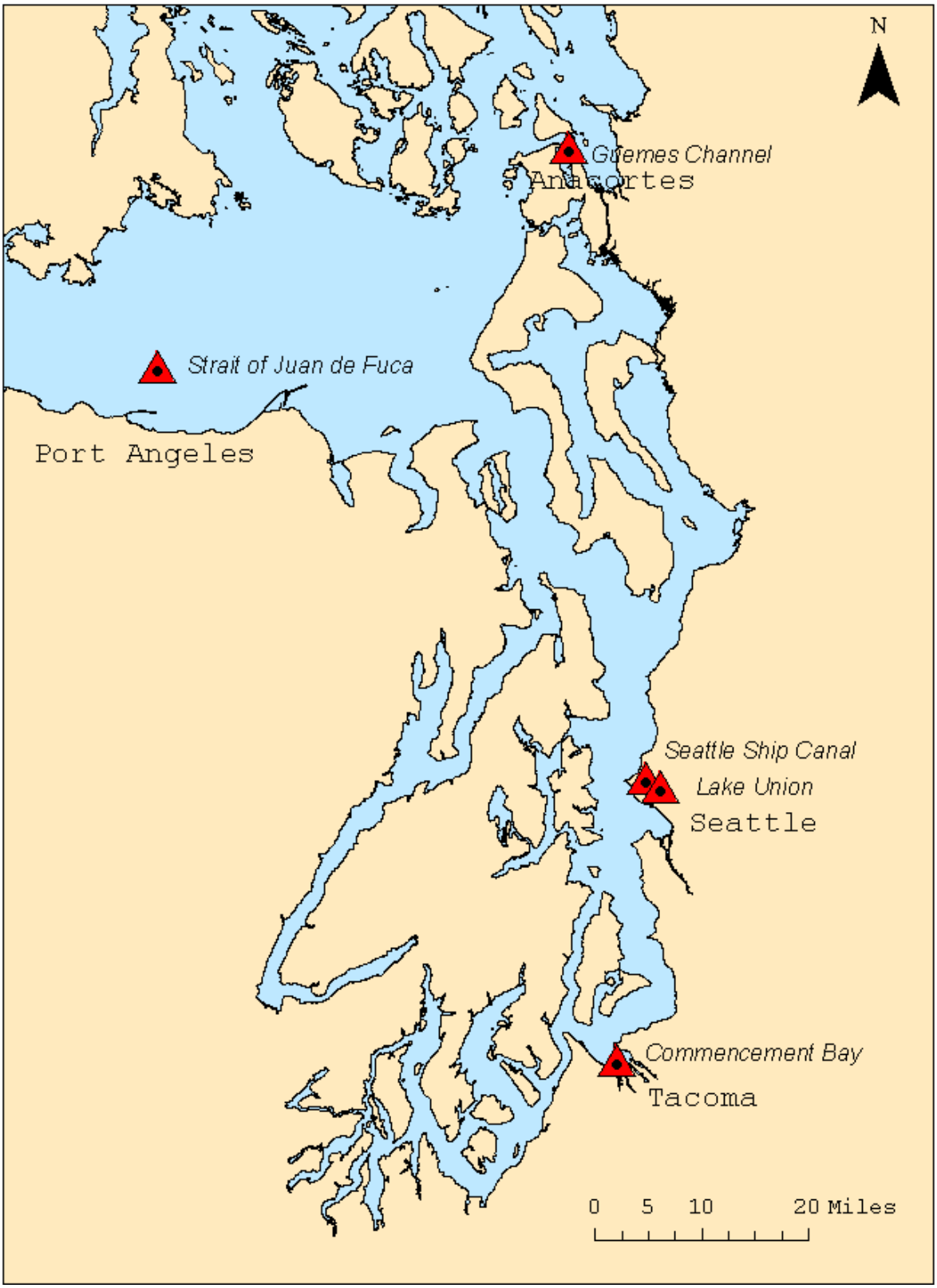

Figure 1. Sampling Locations for the 2008-09 Boatyard Receiving Water Study.

Sampling Design

Table 1 has descriptions of the five sampling stations for the Boatyard Receiving Water Study. The location of each station is shown in Figures 2 – 5. These sites were selected as being removed from local sources of contamination and representative of the receiving water as a whole.

Table 1. Description of Sampling Stations for the 2008-09 Boatyard Receiving Water Study.

Location	Description	Approx. Depth (ft.)	Comment	Latitude *	Longitude *
Port Angeles	Strait of Juan de Fuca, five miles north of Dungeness Spit light	400	True marine	48° 13.347'	-123° 24.2606'
Anacortes	Guemes Channel, East end	100	Sheltered marine without river influence	48° 31.415'	-122° 34.823'
Tacoma	Commencement Bay, 1.5 miles south of Browns Point light	390	Sheltered marine with river influence	47° 17.092'	-122° 26.510'
Seattle	Lake Union, center of south basin	40	Freshwater	47° 37.997'	-122° 20.062'
	Ship Canal, east entrance to Salmon Bay	18		47° 37.132'	-122° 21.559'

*Datum NAD 83.

Surface water samples were collected at each station once each month during September, January, and May. These dates span the period when stormwater runoff from boatyards primarily occurs and include active times for the boatyards. The sampling periods were agreed to by the parties to the PCHB settlement.

Clean sampling techniques were used. The samples were taken at a depth of approximately one meter. Surface samples were considered appropriate for this study because boatyard runoff is discharged at or near the surface. The samples were collected with a pumping system to avoid including the surface microlayer where metals and other toxic contaminants can concentrate. An aluminum hull boat, not painted with antifouling, was used as the sampling platform.

Two samples were collected each month at each location. The samples were taken in replicate to enhance the representativeness of the data. The replicates were collected approximately 20 minutes apart. Samples for dissolved metals were filtered (0.45 micron) in the field immediately on collection and acidified at the analyzing laboratory.

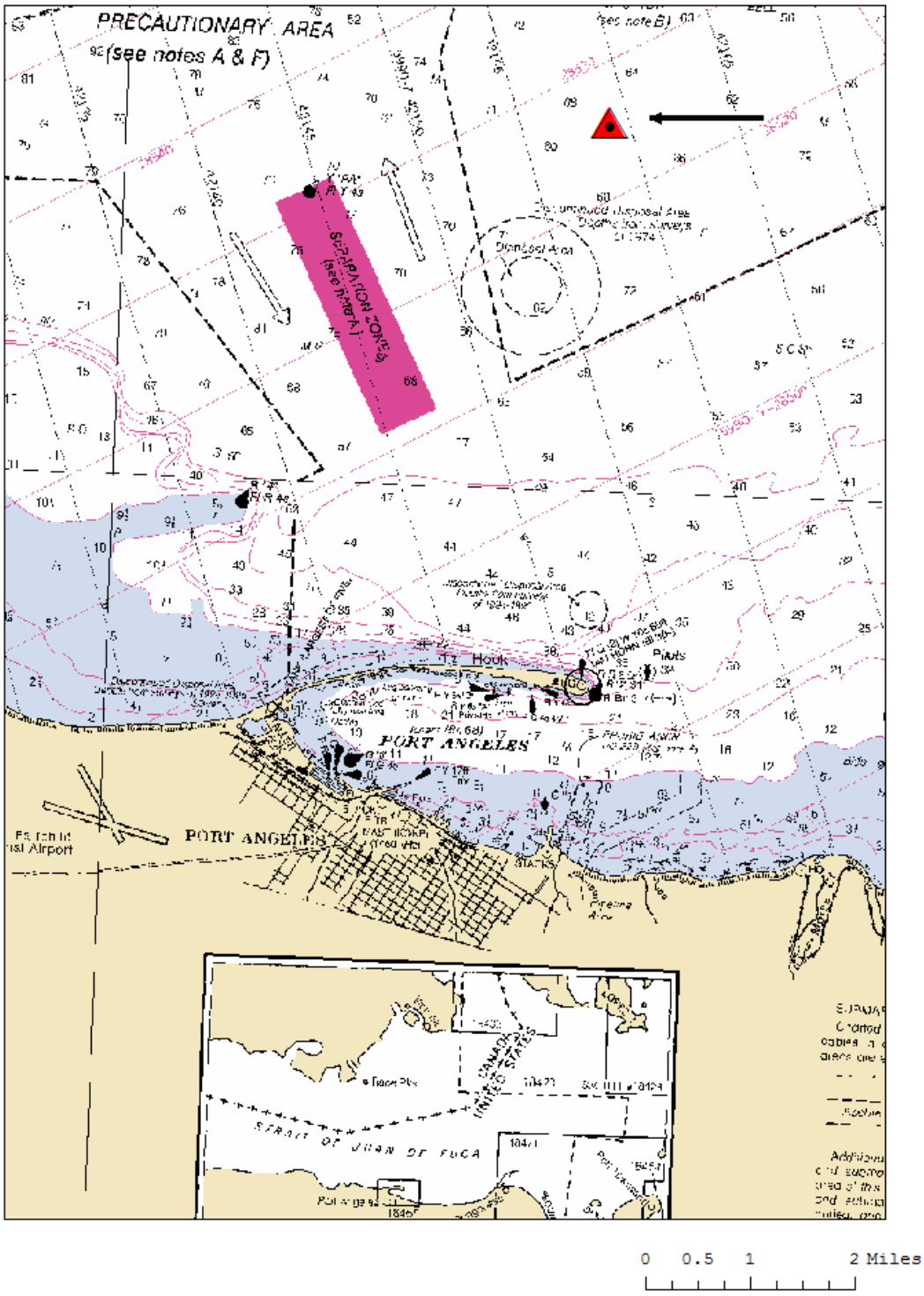

Figure 2. Sampling Station in the Strait of Juan de Fuca off Port Angeles.

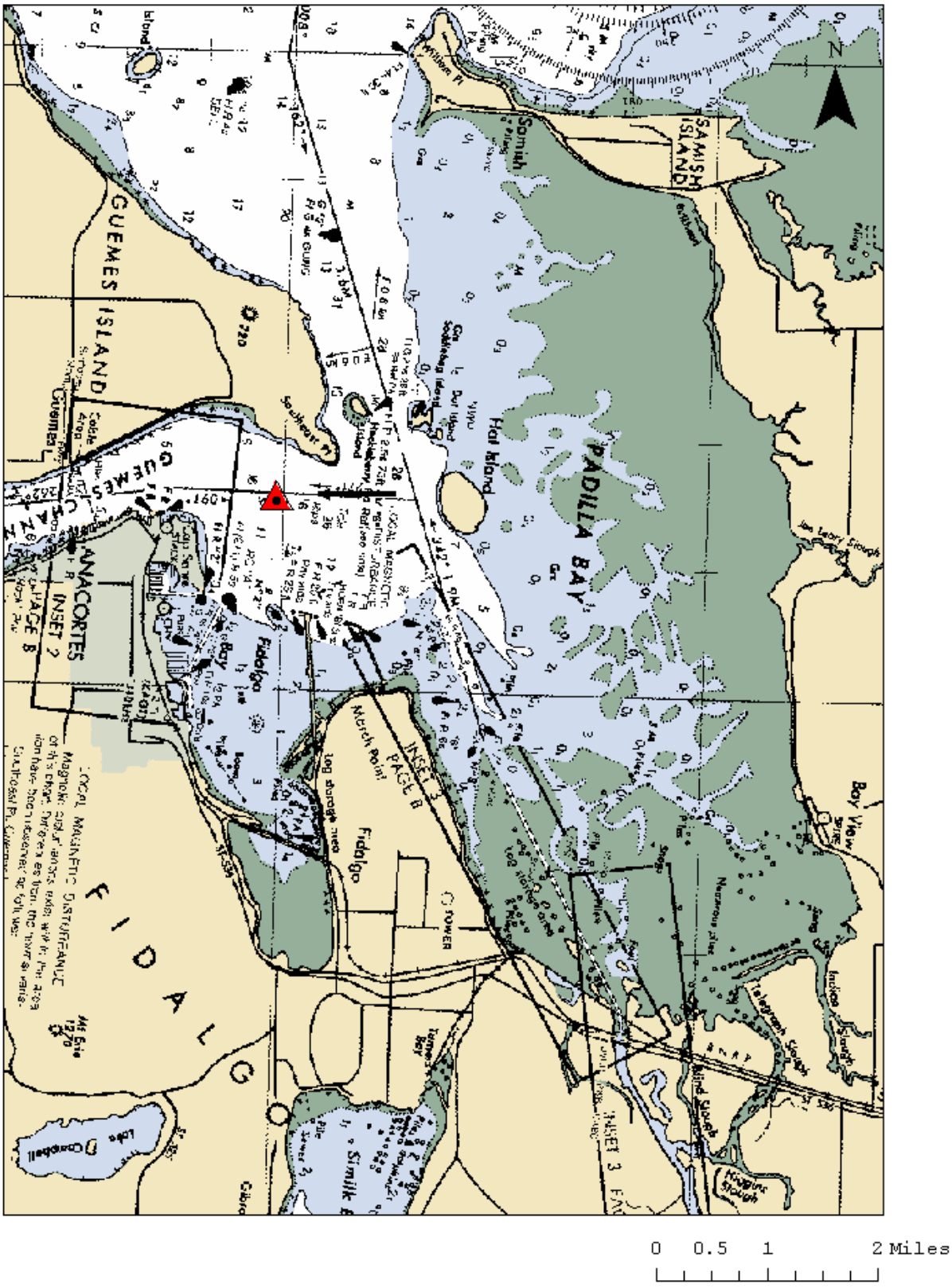

Figure 3. Sampling Station in Guemes Channel, Anacortes.

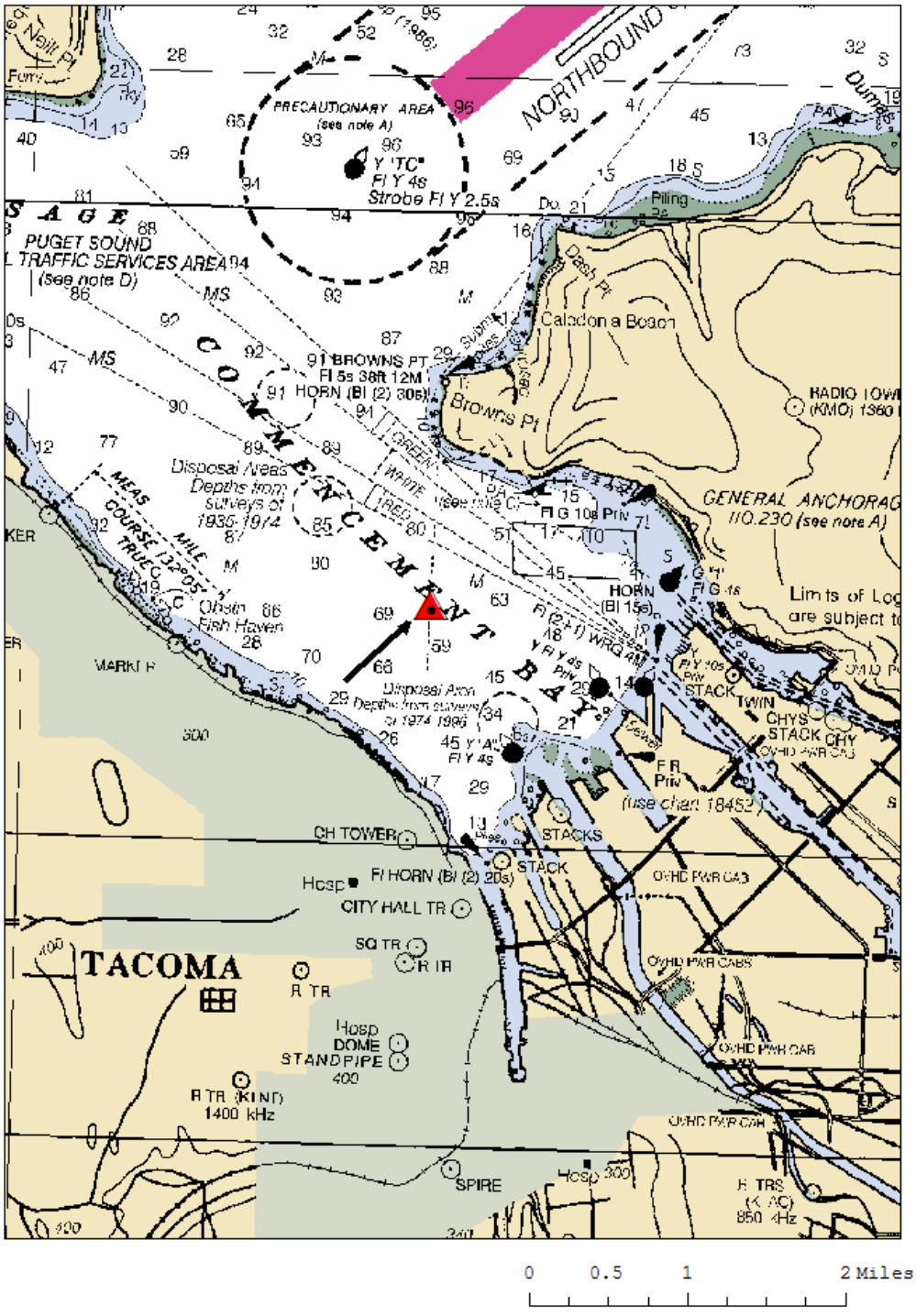

Figure 4. Sampling Station in Commencement Bay, Tacoma.

Figure 5. Sampling Stations in Lake Union and the Seattle Ship Canal, Seattle.

The marine samples were collected during an incoming tide. This was done to minimize the effect of local sources of contamination on the results. Figure 6 illustrates a typical example of how sample collection was timed with regard to tidal currents. To a large extent, logistics dictated the point within the flood tide when samples were collected.

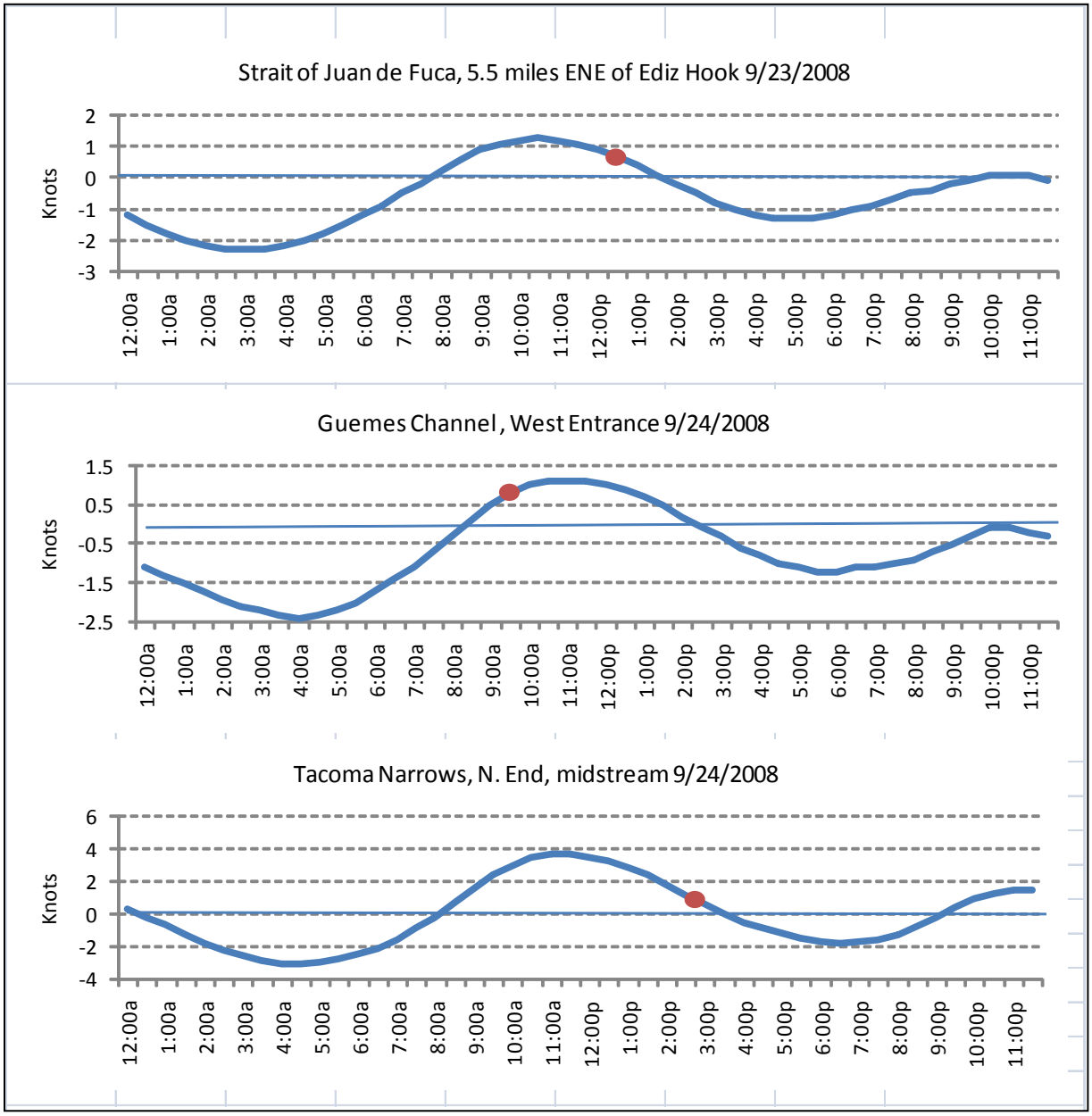

Figure 6. Current Speed and Direction for Marine Samples Collected in September 2008. *(Positive values = flood, negative values = ebb; marker indicates approximate time of sample collection; site names are tidal current stations.)*

The samples were analyzed for total recoverable and dissolved zinc, copper, and lead; hardness (freshwater); salinity (marine water), and total suspended solids.

Frontier GeoSciences analyzed the marine metals samples. Manchester Laboratory analyzed the freshwater metals samples, hardness, salinity, and total suspended solids. Low-level methods were used for metals.

Methods

Field

Sample containers, preservation, and holding times for this project are shown in Table 2. HDPE or Teflon bottles were used for marine and freshwater metals, respectively.

Table 2. Sample Containers, Preservation, and Holding Times.

Parameter	Minimum Sample Size	Container	Preservation	Holding Time
Total Recoverable zinc, copper, lead	200 mL	250/500 mL HDPE or Teflon	HNO_3 to pH<2, 4°C	6 months
Dissolved zinc, copper, lead	200 mL	250/500 mL HDPE or Teflon	Filter, HNO_3 to pH<2, 4°C*	6 months
Hardness	100 mL	125 mL poly bottle	HNO_3 to pH<2, 4°C	6 months
Salinity	300 mL	500 mL poly bottle	Cool to 4°C	28 days
Total Suspended Solids	1000 mL	1000 mL poly bottle	Cool to 4°C	7 days

*Filtered within 15 minutes of collection (Federal Register / Vol. 72, No. 57 / March 26, 2007).

Sample collection and handling followed EPA Method 1669 *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels* (EPA, 1996b). The water samples were collected with a pumping system that employed a Masterflex variable speed peristaltic pump head and drive. A short length of Masterflex-73 tubing was used in the pump head; the remainder of the tubing was ¼" I.D. Teflon. Filters for dissolved metals were Pall Corporation, GWV high-capacity, in-line sampling capsules, 0.45 micron. The first few milliliters of filtrate were discarded. The metals samples were acidified at the analyzing laboratory to avoid introducing contamination in the field and for health and safety of staff.

An aluminum hull sampling vessel, not painted with antifouling, was used as the sampling platform. The samples were taken at a depth of approximately one meter. The intake tubing for the peristaltic pump was held out five feet from the downwind side of the boat on a Dacron line suspended from a PVC pole. A polyethylene bottle filled with sand was used to weight the line. Being in the downwind position, the tubing intake was unaffected by the slick formed by the drifting boat. The engine was turned off during sample collection

The tubing, filters, and seawater metals bottles (HDPE) were acid-cleaned at Frontier GeoSciences and sealed in plastic bags. Sample bottles for freshwater metals and other parameters were obtained through Manchester Laboratory. Manchester's metals bottles (Teflon) were cleaned according to their Clean Room Standard Operating Procedure, and sealed in plastic bags.

New filters were used for each dissolved metals sample. Separate tubing was used for seawater sites and freshwater sites. To reduce the potential for cross-contamination, the sites known or assumed to be the cleanest were sampled first, e.g., Strait of Juan de Fuca sampled before Guemes Channel, Lake Union sampled before the Seattle Ship Canal. The tubing was cleaned between sites by pumping one liter of reagent water. The reagent water was provided by Frontier GeoSciences. Non-talc gloves were worn by sampling personnel. All containers and lids were rinsed with a small amount of sample before filling, except for hardness bottles which contained acid preservative.

Sampling stations were located by GPS and visual fixes. Field data and observations were recorded in a bound notebook of waterproof paper.

All samples were labeled with site name, date, and a unique sample number; placed in plastic bags; and stored on ice for transport. The field team transported the seawater metals samples to Frontier GeoSciences at the end of each sampling period. The remaining samples were returned to Ecology headquarters and transported by courier to Manchester Laboratory. Chain-of-custody was maintained throughout.

Laboratory

Table 3. Analytical Methods.

<table>
<tr><th>Matrix</th><th>Analysis</th><th>Sample Preparation Method</th><th>Analytical Method</th><th>Laboratory</th></tr>
<tr><td rowspan="5">Seawater</td><td>Copper</td><td>RP</td><td>ICP/MS FGS-109/054</td><td rowspan="3">Frontier Geosciences</td></tr>
<tr><td>Lead</td><td>APDC/RP</td><td>ICP/MS FGS-032/054</td></tr>
<tr><td>Zinc</td><td>RP</td><td>ICP/MS FGS-109/054</td></tr>
<tr><td>Salinity</td><td>- -</td><td>SM 2520</td><td rowspan="9">Manchester</td></tr>
<tr><td>Total Suspended Solids</td><td>- -</td><td>EPA 160.2</td></tr>
<tr><td rowspan="9">Freshwater</td><td>Copper (total recoverable)</td><td rowspan="3">acid digest</td><td rowspan="6">ICP/MS EPA 200.8</td></tr>
<tr><td>Lead (total recoverable)</td></tr>
<tr><td>Zinc (total recoverable)</td></tr>
<tr><td>Copper (dissolved)</td><td rowspan="3">none</td></tr>
<tr><td>Lead (dissolved)</td></tr>
<tr><td>Zinc (dissolved)</td></tr>
<tr><td>Hardness</td><td>- -</td><td>ICP EPA 200.7</td></tr>
<tr><td>Total Suspended Solids</td><td>- -</td><td>EPA 160.2</td></tr>
</table>

RP = Reductive precipitation.
APDC = Ammonium pyrolidine dithiocarbamate extraction.
ICP/MS = Inductively Coupled Plasma / Mass Spectrometry.
SM = Standard method.

Data Quality

Data Verification

Manchester Laboratory conducted a review of all chemistry data and contract laboratory case (Frontier GeoSciences) narratives. Manchester verified that (1) methods and protocols specified in the Quality Assurance Project Plan were followed; (2) all calibrations, checks on quality control, and intermediate calculations were performed for all samples; and (3) the data were consistent, correct, and complete, with no errors or omissions. Evaluation criteria included the acceptability of holding times, instrument calibration, procedural blanks, spike sample analyses, precision data, check standards, laboratory control sample and reference material analyses, and appropriateness of data qualifiers assigned. Manchester prepared written data verification reports based on the results of their data review. These reviews are available from the lead author on request.

The project lead reviewed the laboratory data packages and data verification reports. To determine if measurement quality objectives were met, results for check standards, laboratory control samples, reference materials, duplicate samples, and matrix spikes were compared to quality control limits. Method and field blank results were examined to verify there was no significant contamination of the samples. To evaluate whether the targets for reporting limits were met, the results were examined for non-detects and to determine if any values exceeded the lowest concentration of interest.

Based on these assessments, the data were either accepted, accepted with appropriate qualifications, or rejected and the samples re-analyzed.

Overall, the data reported here are of good quality and useable as qualified. Two shortcomings should be noted:

1. Although filter blanks were low (see below), results for the dissolved metals fraction exceeded the total measurement in about half the samples collected from the Strait of Juan de Fuca (Straits). The Straits have low levels of zinc, copper, and lead. Most of the zinc and copper is in dissolved form which makes it difficult to differentiate between dissolved and total at these low concentrations. The dissolved zinc and copper results are included in Appendix A but not in the summary statistics. Lead concentrations in the Straits are at or below detection limits of the analytical method employed.

2. Zinc concentrations in the freshwater samples from Lake Union and the Ship Canal were below Manchester's reporting limit for total recoverable zinc (5.0 ug/L). At the request of the project lead, Manchester provided estimated results between the method reporting limit and method detection limit (1.0 ug/L). The degree of confidence in the total recoverable zinc data reported here for freshwater is lower than for the other results.

Field Blanks

Field blanks were analyzed to detect metals contamination arising from the pumping and filtration system, sample containers, or sample handling (Table 4). The blanks used reagent water provided by Frontier GeoSciences. Pump blanks and filter blanks were prepared by pumping blank water through the sampling system. A bottle blank was also analyzed for Manchester Laboratory's sample containers for freshwater metals. The bottle blank consisted of a sample bottle filled with blank water at Manchester, carried unopened into the field, and treated as a sample. One set of pump, filter, and bottle blanks was prepared for each of the three sample collections for the study.

In most instances, the pump and filter blanks were at or below detection limits. The pump blanks showed a consistent low level of zinc in Frontier GeoSciences' reagent water, 0.12-0.22 ug/L. The January pump blank had some copper contamination (0.55 ug/L). Although this appeared to be an isolated incident, a similar copper concentration was found in one of the associated field samples (0.58 ug/L, Port Angeles #0901004-03). This result was not included in the statistics presented in this report.

The Manchester bottle blanks also showed a consistent low-level zinc background, 0.69 – 1.2 ug/L. Copper and lead were below detection limits.

Table 4. Results on Field Blanks.

Sample No.	Type	Date	Zinc	Copper	Lead
394134	FG pump blank	24-Sep-08	0.22	0.007 U	0.006 U
394135			0.08 U	0.02 J	0.006 U
0901004-05		7-Jan-09	0.12	0.55	0.006 U
0901004-6			0.05 U	0.01	0.006 U
0905035-09		5-May-09	0.18 J	0.01 J	0.016 J
0905035-10			0.05 U	0.03 J	0.006 UJ
8394148	MEL bottle blank	25-Sep-08	1.2 J	0.10 U	0.10 U
0901004-20		8-Jan-09	0.77 J	0.10 U	0.10 U
0905035-19		6-May-09	0.69 J	0.10 U	0.10 U

FG = Frontier Geosciences (seawater metals).
MEL = Manchester Environmental Laboratory (freshwater metals).
U = not detected.
J = estimated value.

Duplicate Analyses

Selected samples were analyzed in duplicate (laboratory splits) to provide estimates of analytical variability. The results for metals and hardness are summarized in Table 5. Relative percent difference (RPD) is the absolute value of the difference between duplicates expressed as a percent of the duplicate mean.

The quality control limit for metals duplicates was ±20%. In the majority of instances, the zinc, copper, and lead duplicates agreed within 10% or better, with one total copper duplicate slightly exceeding 20% (23%). Two results substantially exceeded quality control limits: 37% for total recoverable lead, and 62% for total recoverable zinc. The hardness duplicates were always in agreement. The results from the duplicate analyses were averaged for use in this report.

Table 5. Precision of Duplicate Analyses for Metals and Hardness.

Analyzing Laboratory/ Sample No.	Date	Zinc (ug/L)		Copper (ug/L)		Lead (ug/L)		Hardness (mg/L)
		Total Rec.	Diss.	Total Rec.	Diss.	Total Rec.	Diss.	
Frontier GeoSciences (seawater samples)								
8394136/37	24-Sep-08	0.68	0.46	0.43	0.33	0.043	0.006 U	NA
8394136/37 lab dup.		0.69	0.43	NA	NA	0.047	0.006 U	NA
	RPD =	**1%**	**7%**	**- -**	**- -**	**9%**	**0%**	**- -**
0901004-07/08	7-Jan-09	0.83	0.61	0.41	0.33	0.046 J	0.006 U	NA
0901004-07/08 dup.		0.88	0.57	0.42	0.35	0.043 J	0.006 U	NA
	RPD =	**6%**	**7%**	**2%**	**6%**	**7%**	**0%**	**- -**
0905035-05/06	5-May-09	0.87 J	0.52	0.49 J	0.31	0.048 J	0.006 UJ	NA
0905035-05/06 dup.		1.7 J	0.50	0.62 J	0.33	0.070 J	0.006 UJ	NA
	RPD =	**62%**	**4%**	**23%**	**6%**	**37%**	**0%**	**- -**
Manchester Laboratory (freshwater samples)								
8394144/45	25-Sep-08	4.9 J	1.8	3.5	2.5	0.087 J	0.010 J	43
8394144/45 lab dup.		4.7 J	1.6	3.5	2.5	0.083 J	0.009 J	43
	RPD =	**4%**	**12%**	**1%**	**0%**	**5%**	**11%**	**0%**
0901004-16/17	8-Jan-09	4.2 J	2.4	2.1	1.8	0.17	0.022	39
0901004-16/17 dup.		4.6 J	2.5	2.1	1.8	0.17	0.020	39
	RPD =	**8%**	**2%**	**1%**	**1%**	**2%**	**10%**	**0%**
0905035-15/16	6-May-09	2.3 J	1.0 U	1.8	1.6	0.17	0.023	39
0905035-15/16 dup.		2.3 J	1.0 U	1.8	1.6	0.17	0.022	39
	RPD =	**0%**	**0%**	**2%**	**1%**	**2%**	**4%**	**0%**

Rec. = Recoverable.
Diss. = Dissolved.
Dup. = Duplicate.
RPD = Relative percent difference.
U = Not detected.
J = Estimated value.
NA = Not analyzed.

Results[1]

Rainfall

Precipitation amounts during the 2008-09 Boatyard Receiving Water Study are shown for three nearby weather stations in Table 6. The detailed data are in Appendix B.

Table 6. Precipitation Preceding and During Day of Sample Collection.

Time Period	Bellingham*	SeaTac†	Tacoma**
September 2008 Samples			
5-Day Antecedent Rainfall	0.69	0.69	0.35
Day of Sample Collection	0.05	0.12	0.03
January 2009 Samples			
5-Day Antecedent Rainfall	1.1	4.1	0.01
Day of Sample Collection	1.9	0.03	0
May 2009 Samples			
5-Day Antecedent Rainfall	0.47	1.4	0.28
Day of Sample Collection	0.30	0.89	0.85

*Bellingham 3 SSW (www7.ncdc.noaa.gov/CDO/cdo).
†Seattle-Tacoma, WA (www.weather.gov/climate/).
**Tacoma #1 (www7.ncdc.noaa.gov/IPS/coop/coop.html).

Sample timing for this study was dictated by the tides. Although there was rain prior to or during most sampling collections, the study was not timed to correspond to stormwater runoff events.

Between 1/3 inch and four inches of rain fell during the five days prior to each sample collection, except for the Commencement Bay samples of January 2009. A major rainstorm that caused widespread flooding in western Washington developed during the course of the January field work. The timing and track of the storm was such that samples for the Strait of Juan de Fuca, Guemes Channel, Lake Union, and Seattle Ship Canal were collected before runoff impacts became evident. The Commencement Bay samples were the last scheduled to be collected. Due to concerns about water quality effects of the rising Puyallup River, these samples were delayed until January 21, which was preceded by dry weather.

Most samples were collected on days with drizzle or rain. Exceptions included the Strait of Juan de Fuca samples for September and the Commencement Bay samples for January, when conditions were dry.

[1] The complete results for project samples are in Appendix A.

Suspended Solids

The total suspended solids (TSS) data from the study are summarized in Table 7. In this table and elsewhere, the term "replicate" refers to two separately collected samples.

TSS averaged 4 mg/L (parts per million) in the Strait of Juan de Fuca, increasing slightly to 5-6 mg/L in Guemes Channel and Commencement Bay. Concentrations were uniformly low in Lake Union and the Seattle Ship Canal, 1 - ≤2 mg/L. Only minor differences in TSS levels were observed over the course of the study.

Table 7. Summary of Total Suspended Solids Data.
(mg/L; mean ± range of two replicate samples)

Waterbody	September 2008			January 2009			May 2009			Overall Mean
Strait of Juan de Fuca	3	±	1	4	±	0	4	±	1	4
Guemes Channel	5	±	1	7	±	2	6	±	2	6
Commencement Bay	5	±	0	7	±	1	4	±	0	5
Lake Union	≤2			≤2	*		≤2	*		≤2
Ship Canal	<1			1	±	0	2	±	0	1

*Not detected in replicate sample; detection limit used to calculate mean concentration.

Salinity

Salinity remained relatively constant in the Straits and Guemes Channel, 30-32 g/Kg (parts per thousand) on average (Table 8). Lower and more variable salinities were recorded in Commencement Bay, 24-29 g/Kg, reflecting the influence of the Puyallup River.

Table 8. Summary of Salinity Data.
(g/Kg, mean ± range of two replicate samples)

Waterbody	September 2008			January 2009			May 2009			Overall Mean
Strait of Juan de Fuca	31	±	0	31	±	0	32	±	0	31
Guemes Channel	29	±	0	30	±	0	31	±	0	30
Commencement Bay	27	±	1	24	±	0	29	±	0	27

Zinc

The zinc results are summarized in Table 9. Total recoverable zinc ranged from 0.36 ug/L in the Strait of Juan de Fuca to 3.9 ug/L in Lake Union, on average (parts per billion). Concentrations progressively increased by factors of 2 going from the Straits to Guemes Channel to Commencement Bay. Zinc concentrations were similar in Lake Union and the Ship Canal.

Total recoverable zinc levels appeared to decrease over the course of the study in Commencement Bay, Lake Union, and the Ship Canal. A similar trend was not observed in the Straits or Guemes Channel.

Dissolved zinc concentrations in the Straits were too low to measure accurately with the methods employed in this study. Most of the dissolved zinc results for the Straits approached or exceeded the total, as described previously (see Data Quality). For the other waterbodies, average dissolved zinc values were in the range of 0.51 ug/L (Guemes Channel) to 1.8 ug/L (Lake Union).

Table 9. Summary of Zinc Data.

(ug/L; mean ± range of two replicate samples)

Waterbody	September 08			January 09			May 09			Overall Mean
Total Recoverable Concentrations										
Strait of Juan de Fuca	0.37	±	0.06	0.27	±	0.06	0.43	±	0.01	0.36
Guemes Channel	0.69	±	0	0.81	±	0.05	0.98	±	0.29	0.82
Commencement Bay	2.2	±	0.7	1.3	±	0.1	1.0	±	0.04	1.5
Lake Union	4.9	±	0.05	4.3	±	0.1	2.6	±	0.3	3.9
Ship Canal	4.7	±	0.2	3.5	±	0.3	2.5	±	0.3	3.5
Dissolved Concentrations										
Strait of Juan de Fuca	D>T			D>T			D>T			D>T
Guemes Channel	0.45	±	0	0.60	±	0.01	0.48	±	0.04	0.51
Commencement Bay	1.9	±	0.8	1.1	±	0	0.80	±	0.02	1.3
Lake Union	1.8	±	0.05	2.5	±	0.04	<1.0			1.8
Ship Canal	1.6	±	0.1	1.7	±	0.05	1.1	±	0.05	1.4

D>T = dissolved result exceeded total.

Copper

Table 10 has a summary of the copper data. Total recoverable copper concentrations were about 50% lower (55-65%) than total recoverable zinc, on average. As seen for zinc, concentrations increased by a factor of approximately 2 between the Straits and Guemes Channel, and between Guemes Channel and Commencement Bay. Overall average concentrations ranged from 0.23 ug/L in the Straits to 2.5 ug/L in Lake Union. Lake Union and the Ship Canal had comparable copper concentrations.

As with zinc, there was an apparent trend toward decreasing total recoverable copper concentrations over time in Commencement Bay, Lake Union, and the Ship Canal, but not in the Straits or Guemes Channel.

Accurate dissolved copper data were not obtained for the Straits. Dissolved copper at the other stations averaged 0.33 ug/L in Guemes Channel, increasing to 2.0 ug/L in Lake Union.

Table 10. Summary of Copper Data.

(ug/L; mean ± range of two replicate samples)

Waterbody	September 08			January 09			May 09			Overall Mean
Total Recoverable Concentrations										
Strait of Juan de Fuca	0.27	±	0.01	0.19	*		0.24	±	0.02	0.23
Guemes Channel	0.45	±	0.02	0.41	±	0.01	0.50	±	0.05	0.45
Commencement Bay	1.1	±	0.2	0.88	±	0.06	0.58	±	0.01	0.84
Lake Union	3.5	±	0.04	2.1	±	0	1.7	±	0.03	2.5
Ship Canal	3.2	±	0	1.8	±	0.2	1.8	±	0.1	2.3
Dissolved Concentrations										
Strait of Juan de Fuca	D>T			D>T			D>T			D>T
Guemes Channel	0.32	±	0.01	0.34	±	0.005	0.34	±	0.02	0.33
Commencement Bay	0.84	±	0.19	0.63	±	0.01	0.41	±	0.01	0.63
Lake Union	2.5	±	0.03	1.8	±	0.05	1.6	±	0	2.0
Ship Canal	2.3	±	0.01	1.6	±	0.1	1.5	±	0.04	1.8

*replicate result rejected due to apparent contamination.
D>T = dissolved result exceeded total.

Lead

Lead levels were low in all areas (Table 11). Total concentrations averaged 0.009-0.044 ug/L at the marine stations and an order of magnitude higher at the freshwater stations, 0.14-0.17 ug/L.

Dissolved lead was at or below detection limits (0.006 ug/L) in the Straits and Guemes Channel, but was occasionally detectable in Commencement Bay. The average and maximum dissolved lead concentrations observed in Commencement Bay were ≤0.012 ug/L and 0.033 ug/L, respectively.

In contrast to the results for zinc and copper, there was a progressive increase in total recoverable lead levels in Lake Union and the Ship Canal. Concentrations approximately doubled from September to May.

Table 11. Summary of Lead Data.

(ug/L; mean ± range of two replicate samples)

Waterbody	September 08			January 09			May 09			Overall Mean
Total Recoverable Concentrations										
Strait of Juan de Fuca	≤0.007	*		0.010	±	0.002	0.010	±	0.002	0.009
Guemes Channel	0.047	±	0.002	0.045	±	0.001	0.053	±	0.007	0.048
Commencement Bay	0.041	±	0.012	0.063	±	0.006	0.028	±	0.006	0.044
Lake Union	0.083	±	0.003	0.17	±	0.001	0.17	±	0	0.14
Ship Canal	0.14	±	0.03	0.17	±	0.005	0.20	±	0.01	0.17
Dissolved Concentrations										
Strait of Juan de Fuca	D>T			<0.006			<0.006			<0.006
Guemes Channel	<0.006			<0.006			<0.006			<0.006
Commencement Bay	<0.006			≤0.020	*		≤0.009	*		≤0.012
Lake Union	0.012	±	0.003	0.020	±	0.001	0.023	±	0	0.018
Ship Canal	0.010	±	0.001	0.017	±	0	0.024	±	0	0.017

*not detected in replicate sample; detection limit used to calculate mean concentration.
D>T = dissolved result exceeded total.

Hardness

The hardness data for the freshwater sites is summarized in Table 12. Hardness was the same in Lake Union and the Ship Canal. The average value was 40 mg/L. There appeared to be a modest trend toward decreasing hardness from September through May, from 43 to 39 to 38 mg/L.

Table 12. Summary of Hardness Data.
(*mg/L; mean ± range of two replicate samples*)

Waterbody	September 2008			January 2009			May 2009			Overall Mean
Lake Union	43	±	1	39	±	0	38	±	0	40
Ship Canal	43	±	0	39	±	0	38	±	0	40

Discussion

Comparison with Water Quality Criteria

Results from the Boatyard Receiving Water Study are compared to the Washington State aquatic life criteria for zinc, copper, and lead in Table 13. These criteria apply to the dissolved fraction. The freshwater criteria also vary with hardness. The overall mean hardness value measured in Lake Union and the Ship Canal, 40 mg/L, was used to calculate the criteria (TSDCALC.XLS www.ecy.wa.gov/programs/eap/pwspread/pwspread.html).

As can be seen in Table 13, the concentrations of dissolved zinc, copper, and lead measured in this study were all well within aquatic life criteria. Copper came closest to approaching the chronic criterion, lower by a factor of 2 in freshwater and by a factor of 3 in marine waters (maximum values). Zinc and lead concentrations were 1 to 2 orders of magnitude lower than the criteria.

Table 13. Washington State Water Quality Criteria for Protection of Aquatic Life Compared to Maximum Concentrations Observed in Present Study. *(ug/L)*

Metal	Marine Criteria*		Maximum Dissolved Concentration Observed in Present Study	Location
	Chronic	Acute		
Dissolved Zinc	81	90	2.6	Commencement Bay
Dissolved Copper	3.0	4.8	1.0	
Dissolved Lead	8.1	210	0.033	
	Freshwater Criteria†			
	Chronic	Acute		
Dissolved Zinc	48	53	2.5	Lake Union
Dissolved Copper	5.2	7.2	2.5	
Dissolved Lead	0.92	24	0.024	Ship Canal

*WAC 173-201A.
†@40 mg/L hardness (overall present study mean for Lake Union and Ship Canal).

Dissolved:Total Ratios

One objective of this study was to measure the ratio of dissolved to total metals, particularly for copper. By federal regulation, effluent limits must be expressed as the total amount. A "translator" must therefore be used to convert dissolved metals criteria into an effluent limitation (EPA, 1996a). Because Ecology had no boatyard data, a copper translator of 0.30 (30% dissolved) was used in the Boatyard General Permit, derived from data on shipyard discharges.

Table 14 shows the mean and 90th percentile values for the dissolved:total recoverable zinc, copper, and lead ratios observed in the present study. Due to the low dissolved concentrations, this ratio could not be determined for zinc or copper in the Strait of Juan de Fuca, or for lead at any of the marine sites. The ratios for zinc in freshwater are flagged because the total concentration was an approximate value below reporting limits (see Data Quality section).

Table 14. Summary of Dissolved:Total Recoverable Ratios Measured in Present Study.

Waterbody	Mean	90th percentile	N=
Zinc			
Strait of Juan de Fuca	- -	- -	- -
Guemes Channel	0.64	0.72	6
Commencement Bay	0.81	0.85	6
Lake Union	~0.43	~0.53	5
Ship Canal	~0.42	~0.47	6
Copper			
Strait of Juan de Fuca	- -	- -	- -
Guemes Channel	0.74	0.80	6
Commencement Bay	0.74	0.78	6
Lake Union	0.82	0.90	6
Ship Canal	0.82	0.89	6
Lead			
Strait of Juan de Fuca	- -	- -	- -
Guemes Channel	- -	- -	- -
Commencement Bay	- -	- -	- -
Lake Union	0.13	0.15	6
Ship Canal	0.10	0.12	6

- - = Could not be determined.
~ = Approximate; total concentration was below reporting limit.

Comparison with Other Data

In many past studies of metals concentrations in marine and fresh waters, detection limits have not been low enough to quantify the low concentrations typical of uncontaminated waterbodies. For seawater, much of the historical metals data is biased high because the analytical method did not account for interferences caused by the salt matrix.

A review was conducted to identify low-level zinc, copper, and lead data that have been obtained by methods appropriate for comparison with the present study. Five studies were found:

- National Oceanic and Atmospheric Administration (NOAA), Pacific Marine Environmental Laboratory (Paulson et al., 1988).
- Battelle Marine Sciences Laboratory (Crecelius, 1998).
- Ecology (Johnson and Summers, 1999).
- King County Department of Natural Resources (King County, 2001; Mickelson, 2009).
- CH2M Hill (2008).

These data are summarized as means and compared to present study results in Tables 15 (zinc), 16 (copper), and 17 (lead).

In most cases there is good agreement among studies. A few observations follow:

- The zinc concentrations measured in the present study are generally similar to or lower than those measured by other investigators. NOAA, however, found lower zinc levels in Commencement Bay. This may be due to NOAA pooling data for surface layer and bottom water samples.
- There is a lack of comparable data for dissolved zinc in Lake Union and the Ship Canal.
- There is good agreement among studies on total and dissolved copper. Here again, NOAA reports relatively low Commencement Bay concentrations, possibly for the reason noted above.
- NOAA found much higher lead concentrations compared to the other studies. The NOAA samples date back to 1980-1984. This period coincides with EPA's phase-down program designed to minimize the lead content of leaded gasoline, initiated in 1973. By 1988, the total lead usage in gasoline had been reduced to <1% of the amount of lead used in the peak year of 1970 (EPA, 1996c).
- Except for NOAA, there is good agreement on total and dissolved lead. Dissolved lead concentrations are poorly known in the Straits and Anacortes areas.

Table 15. Comparison with Other Low-Level Metals Data: Zinc.

(mean concentration in ug/L)

Waterbody	Paulson et al. (1988) (N=2-39)	Crecelius (1998) (N=10)	Johnson and Summers (1999) (N=3)	King County (unpublished) (N=7-24)	CH2M Hill (2008) (N=18)	Present Study (N=6)
Total Recoverable Zinc						
Strait of Juan de Fuca and Admiralty Inlet	0.34	NA	NA	0.42	NA	0.36
Guemes Channel and Fidalgo Bay	NA	0.45	NA	NA	NA	0.82
Commencement Bay	0.53	1.6	NA	NA	NA	1.5
Lake Union	NA	NA	NA	5.3	NA	3.9
Ship Canal	4.5	NA	NA	2.7	<5	3.5
Dissolved Zinc						
Strait of Juan de Fuca and Admiralty Inlet	0.19	NA	NA	B	NA	D>T
Guemes Channel and Fidalgo Bay	NA	D>T	NA	NA	NA	0.51
Commencement Bay	0.48	1.2	2.0	NA	NA	1.3
Lake Union	NA	NA	NA	B	NA	1.8
Ship Canal	3.9	NA	NA	B	<5	1.4

Paulson data are for April and December 1983, except 1980-84 for Seattle Ship Canal.
Crecelius data are for June 1997 (Anacortes) and July 1997 (Commencement Bay).
Johnson and Summers data are for November 1997, March 1998, and August 1998.
King County data are for 1997-2000, except 2000-2008 for Seattle Ship Canal.
CH2M Hill data are for April 2007.
NA = not analyzed.
D>T = dissolved results exceeded total.
B = blank contamination.

Table 16. Comparison with Other Low-Level Metals Data: Copper.

(mean concentration in ug/L)

Waterbody	Paulson et al. (1988) (N=2-39)	Crecelius (1998) (N= 10)	Johnson and Summers (1999) (N=3)	King County (unpublished) (N=3-5)	CH2M Hill (2008) (N=18)	Present Study (N=6)
Total Recoverable Copper						
Strait of Juan de Fuca and Admiralty Inlet	0.21	NA	NA	0.45	NA	0.23
Guemes Channel and Fidalgo Bay	NA	0.50	NA	NA	NA	0.45
Commencement Bay	0.35	0.96	NA	NA	NA	0.84
Lake Union	NA	NA	NA	2.9	NA	2.5
Ship Canal	1.9	NA	NA	2.3	2.7	2.3
Dissolved Copper						
Strait of Juan de Fuca and Admiralty Inlet	0.14	NA	NA	0.37	NA	D>T
Guemes Channel and Fidalgo Bay	NA	0.42	NA	NA	NA	0.33
Commencement Bay	0.30	0.66	0.61	NA	NA	0.63
Lake Union	NA	NA	NA	2.6	NA	2.0
Ship Canal	1.7	NA	NA	2.1	2.0	1.8

Paulson data are for April and December 1983, except 1980-84 for Seattle Ship Canal.
Crecelius data are for June 1997 (Anacortes) and July 1997 (Commencement Bay).
Johnson & Summers data are for November 1997, March 1998, and August 1998.
King County data are for 1997-2000, except 2000-2008 for Seattle Ship Canal.
CH2M Hill data are for April 2007.
NA = not analyzed.
D>T = dissolved results exceeded total.

Table 17. Comparison with Other Low-Level Metals Data: Lead.

(mean concentration in ug/L)

Waterbody	Paulson et al. (1988) (N=2-39)	Crecelius (1998) (N= 10)	Johnson and Summers (1999) (N=3)	King County (unpublished) (N=7-14)	CH2M Hill (2008) (N=18)	Present Study (N=6)
Total Recoverable Lead						
Strait of Juan de Fuca and Admiralty Inlet	0.38	NA	NA	0.015	NA	0.009
Guemes Channel and Fidalgo Bay	NA	0.039	NA	NA	NA	0.048
Commencement Bay	0.83	0.098	NA	NA	NA	0.044
Lake Union	NA	NA	NA	<0.50	NA	0.14
Ship Canal	0.34	NA	NA	0.12	NA	0.17
Dissolved Lead						
Strait of Juan de Fuca and Admiralty Inlet	0.015	NA	NA	<0.005	NA	<0.006
Guemes Channel and Fidalgo Bay	NA	<0.0061	NA	NA	NA	<0.006
Commencement Bay	0.028	0.012	0.018	NA	NA	≤0.012
Lake Union	NA	NA	NA	<0.50	NA	0.018
Ship Canal	0.13	NA	NA	<0.025	NA	0.017

Paulson data are for April and December 1983, except 1980-84 for Seattle Ship Canal.
Crecelius data are for June 1997 (Anacortes) and July 1997 (Commencement Bay).
Johnson and Summers data are for November 1997, March 1998, and August 1998.
King County data are for 1997-2000, except 2000-2008 for Seattle Ship Canal.
NA = not analyzed.

Ecology's Puget Sound Toxics Loading Analysis

Ecology is currently conducting a study to characterize concentrations of toxic chemicals in marine waters and selected tributaries of Puget Sound (Coots and Osterberg, 2009). The data are being collected in support of the Puget Sound Toxics Loading Analysis. The study is analyzing metals and a range of organic compounds at four Puget Sound stations that include the Eastern Strait of Juan de Fuca and the main basin of Puget Sound north of Commencement Bay (Figure 7). Total and dissolved zinc, copper, and lead are among the chemicals being analyzed. Clean sampling techniques and low-level analytical methods are being used.

An effort is being made to improve on the dissolved results for low-level zinc and copper associated with the present study. If successful, this study may fill the data gaps that currently exist for metals translators specific to zinc and copper in the Straits. As of this writing, it is uncertain if improved results will be obtained for lead, where data gaps also exist. The issue here is primarily one of achievable detection limits.

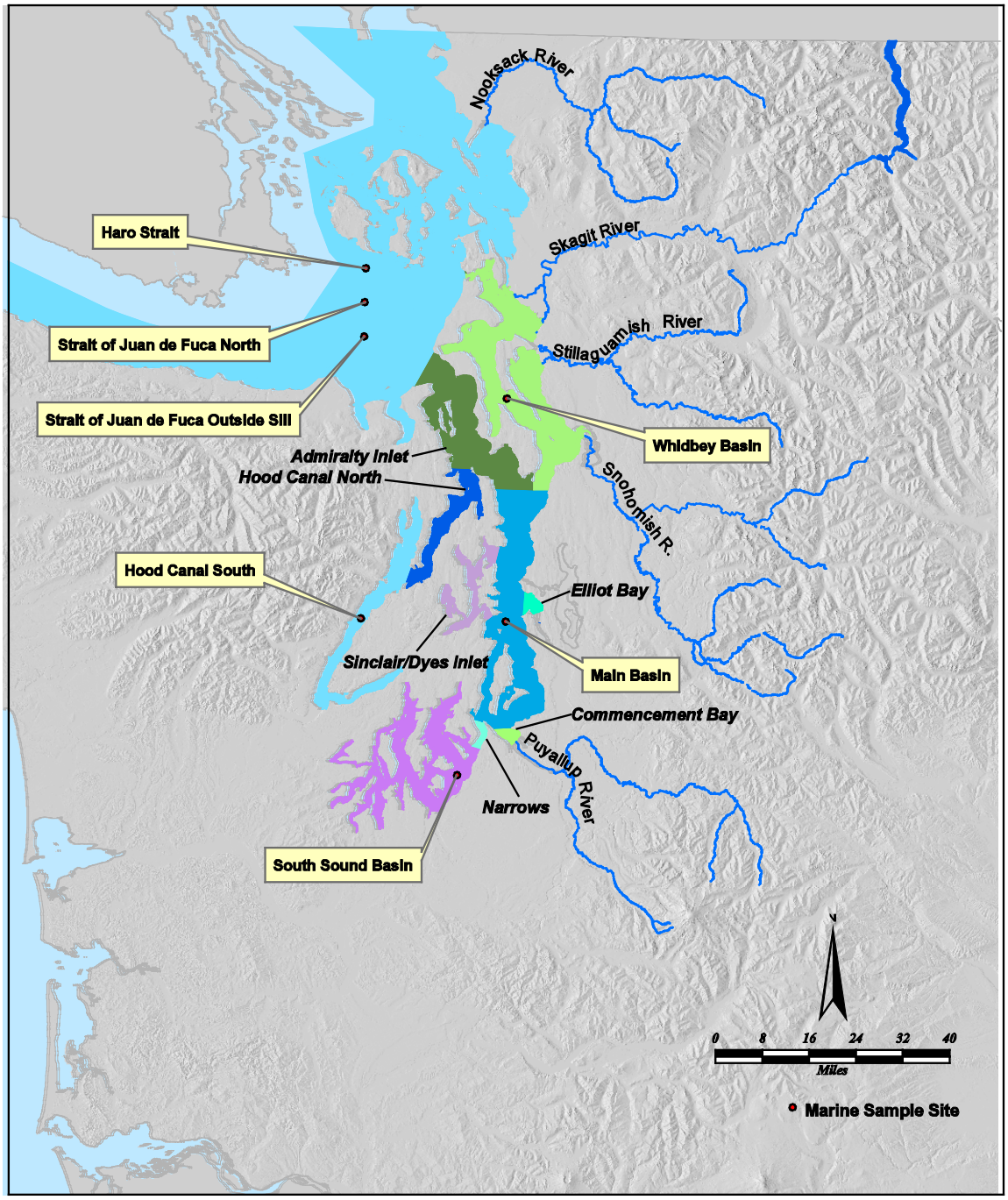

Figure 7. Sampling Stations for Ecology's Toxics Monitoring Study in Puget Sound.
(from Coots and Osterberg, 2009)

Summary

Total recoverable and dissolved zinc, copper, and lead, hardness, and ancillary water quality parameters were analyzed in five receiving waters for Puget Sound boatyards in September 2008 and January and May 2009. The objective was to obtain data to verify or modify the metals translator and hardness assumptions used to develop the benchmarks in the current Boatyard General Permit.

Major findings include the following:

- Overall mean total recoverable zinc concentrations ranged from 0.36 ug/L in the Strait of Juan de Fuca to 3.9 ug/L in Lake Union. The dissolved:total recoverable ratios (metals translators) for zinc averaged 0.64 in Guemes Channel, 0.81 in Commencement Bay, and about 0.4 in Lake Union and the Seattle Ship Canal. Dissolved zinc concentrations were too low to measure accurately in the Strait of Juan de Fuca. The accuracy of the ratio for Lake Union and the Ship Canal is uncertain.

- Overall mean total recoverable copper concentrations ranged from 0.23 ug/L in the Strait of Juan de Fuca to 2.5 ug/L in Lake Union. The dissolved:total recoverable ratios for copper averaged 0.74 in Guemes Channel and Commencement Bay, and 0.82 in Lake Union and the Seattle Ship Canal. Dissolved copper concentrations were too low to measure accurately in the Strait of Juan de Fuca.

- Overall mean total recoverable lead concentrations ranged from 0.009 ug/L in the Strait of Juan de Fuca to 0.17 ug/L in the Seattle Ship Canal. The dissolved:total recoverable ratios for lead averaged 0.13 in Lake Union and 0.10 in the Seattle Ship Canal. Dissolved lead concentrations were too low to measure accurately in the Strait of Juan de Fuca, Guemes Channel, and Commencement Bay.

- Hardness averaged 40 mg/L in Lake Union and the Seattle Ship Canal.

- The concentrations of dissolved zinc, copper, and lead measured in this study were all well within Washington State's aquatic life criteria. Copper came closest to approaching (violating) the chronic criterion, lower by a factor of 2 in freshwater and by a factor of 3 in marine waters (maximum values).

- The metals concentrations measured in the present 2008-09 study are generally in good agreement with results from other investigations that have employed clean sampling techniques and low-level analytical methods. Dissolved lead concentrations are poorly known in the Strait of Juan de Fuca and Anacortes areas.

Recommendation

Better data are needed on dissolved zinc and copper in the Strait of Juan de Fuca, and dissolved lead in Puget Sound marine waters in general. Improved data for these metals may become available through the Puget Sound Toxics Loading Analysis study currently in progress.

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Appendices

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Appendix A. Results from Analyzing Boatyard Receiving Water Samples

Appendix A-1. Results from Boatyard Receiving Water Samples Collected in September 2008.

MEL No.	Location	Date	Sample	Zinc (ug/L)		Copper (ug/L)		Lead (ug/L)		TSS (mg/L)	Salinity (g/Kg)	Hardness (mg/L)
				Total Rec.	Diss.	Total Rec.	Diss.	Total Rec.	Diss.			
8394130/31	Port Angeles	23-Sep-08	#1	0.43	0.47 *	0.26	0.33 *	0.006 U	0.006 J*	4	31.3	NA
8394132/33			#2	0.31	0.36 *	0.28	0.31 *	0.008 J	0.010 J*	2	31.2	NA
8394136/37	Anacortes	24-Sep-08	#1	0.68	0.46	0.43	0.33	0.043	0.006 U	5	29.4	NA
8394136/37 – lab duplicate			#1	0.69	0.43	NA	NA	0.047	0.006 U	6	29.4	NA
8394138/39			#2	0.69	0.45	0.47	0.31	0.048	0.006 U	5	29.4	NA
8394140/41	Commencement Bay	24-Sep-08	#1	2.9	2.6	1.3	1.0	0.052	0.006 U	5	26.7	NA
8394142/43			#2	1.6	1.1	0.81	0.65	0.029 J	0.006 U	5	27.9	NA
8394144/45	Lake Union	25-Sep-08	#1	4.9 J	1.8	3.5	2.5	0.087 J	0.010 J	2 U	NA	43
8394144/45-lab duplicate			#1	4.7 J	1.6	3.5	2.5	0.083 J	0.009 J	2 U	NA	43
8394146/47			#2	4.9 J	1.8	3.6	2.4	0.080 J	0.015 J	1 U	NA	44
8394149/50	Ship Canal	25-Sep-08	#1	4.5 J	1.5	3.2	2.3	0.11	0.011 J	1 U	NA	43
8394151/52			#2	4.8 J	1.7	3.2	2.4	0.16	0.009 J	1 U	NA	43
394134	FG pump blank	24-Sep-08	- -	0.22	- -	0.01 U	- -	0.006 U	- -	NA	NA	NA
394135	FG filter blank	24-Sep-08	- -	- -	0.08 U	- -	0.02 J	- -	0.006 U	NA	NA	NA
8394148	MEL bottle blank	25-Sep-08	- -	1.2 J	- -	0.1 U	- -	0.1 U	- -	NA	NA	NA

Rec. = Recoverable.
Diss. – Dissolved.
*dissolved result exceeds total.
U = not detected.
J = estimated value.
NA = not analyzed.
FG = Frontier Geosciences (marine metals).
MEL = Manchester Environmental Laboratory (freshwater metals and TSS, salinity, and hardness).

Appendix A-2. Results from Boatyard Receiving Water Samples Collected in January 2009.

MEL No. (0901004-)	Location	Date	Sample	Zinc (ug/L)		Copper (ug/L)		Lead (ug/L)		TSS (mg/L)	Salinity (g/Kg)	Hardness (mg/L)
				Total Rec.	Diss.	Total Rec.	Diss.	Total Rec.	Diss.			
01/02	Port Angeles	6-Jan-09	#1	0.2	0.26 *	0.19	0.24 *	0.008 J	0.006 U	4	31.0	NA
03/04			#2	0.3	0.23 J	0.58 †	0.21	0.011 J	0.006 U	4	31.0	NA
07/08	Anacortes	7-Jan-09	#1	0.8	0.61	0.41	0.33	0.046 J	0.006 U	9	30.3	NA
07/08-lab duplicate			#1	0.9	0.57	0.42	0.35	0.043 J	0.006 U	9	30.3	NA
10/11			#2	0.8	0.60	0.40	0.33	0.046 J	0.006 U	5	30.3	NA
12/13	Commencement Bay	21-Jan-09	#1	1.2	1.1	0.82	0.62	0.057 J	0.006 U	7	23.8	NA
14/15			#2	1.3	1.1	0.93	0.64	0.069 J	0.033 J	6	23.8	NA
16/17	Lake Union	8-Jan-09	#1	4.2 J	2.4	2.1	1.8	0.17	0.022	2 U	NA	39
16/17-lab duplicate			#1	4.6 J	2.5	2.1	1.8	0.17	0.020	2 U	NA	39
18/19			#2	4.2 J	2.5	2.1	1.9	0.17	0.019 J	1	NA	39
21/22	Ship Canal	8-Jan-09	#1	3.8 J	1.6	1.6	1.5	0.16	0.017 J	1	NA	39
23/24			#2	3.2 J	1.7	2.0	1.7	0.17	0.017 J	1	NA	39
05	FG pump blank	7-Jan-09	- -	0.1	- -	0.55	- -	0.006 U	- -	NA	NA	NA
06	FG filter blank	7-Jan-09	- -	- -	0.05 U	- -	0.01	- -	0.006 U	NA	NA	NA
20	MEL bottle blank	8-Jan-09	- -	0.77 J	- -	0.1 U	- -	0.1 U	- -	NA	NA	NA

*dissolved result exceeds total.
† apparent contamination.
U = not detected.
J = estimated value.
NA = not analyzed.
FG = Frontier Geosciences (marine metals).
MEL = Manchester Environmental Laboratory (freshwater metals and TSS, salinity, and hardness).

Appendix A-3. Results from Boatyard Receiving Water Samples Collected in May 2009.

MEL No. (0905035-)	Location	Date	Sample	Zinc (ug/L)		Copper (ug/L)		Lead (ug/L)		TSS (mg/L)	Salinity (g/Kg)	Hardness (mg/L)
				Total Rec.	Diss.	Total Rec.	Diss.	Total Rec.	Diss.			
01/02	Port Angeles	7-May-09	#1	0.42	0.31	0.25	0.27 *	0.008 J	0.006 UJ	4	32.2	NA
03/04			#2	0.43	0.41	0.22	0.26 *	0.011 J	0.006 UJ	3	32.1	NA
05/06	Anacortes	5-May-09	#1	0.87 J	0.52	0.49 J	0.31	0.048 J	0.006 UJ	4	30.7	NA
05/06-lab duplicate			#1	1.7 J	0.50	0.62 J	0.33	0.070 J	0.006 UJ	4	30.7	NA
07/08			#2	0.69	0.44	0.45	0.35	0.046	0.006 UJ	7	30.6	NA
11/12	Commencement Bay	6-May-09	#1	1.1	0.78	0.57	0.42	0.034	0.006 UJ	4	29.2	NA
13/14			#2	1.0	0.81	0.59	0.40	0.022 J	0.011 J	4	29.2	NA
15/16	Lake Union	6-May-09	#1	2.3 J	1.0 U	1.8	1.6	0.17	0.023	2 U	NA	39
15/16-lab duplicate			#1	2.3 J	1.0 U	1.8	1.6	0.17	0.022	2 U	NA	39
17/18			#2	2.9 J	1.0	1.7	1.6	0.17	0.023	2	NA	38
20/21	Ship Canal	6-May-09	#1	2.2 J	1.1	1.7	1.4	0.19	0.024	2	NA	38
22/23			#2	2.8 J	1.0	1.9	1.5	0.20	0.024	2	NA	38
09	FG pump blank	5-May-09	- -	0.18 J	- -	0.01 J	- -	0.016 J	- -	NA	NA	NA
10	FG filter blank	5-May-09	- -	- -	0.05 U	- -	0.03 J	- -	0.006 UJ	NA	NA	NA
19	MEL bottle blank	6-May-09	- -	0.69 J	- -	0.10 U	- -	0.10 U	- -	NA	NA	NA

*dissolved result exceeds total.
U = not detected.
J = estimated value.
NA = not analyzed.
FG = Frontier Geosciences (marine metals).
MEL = Manchester Environmental Laboratory (freshwater metals and TSS, salinity, and hardness).

Appendix B. Precipitation at Nearby Weather Stations During and Preceding the Day of Sample Collection (24-hour amounts in inches)

Date	Bellingham*	SeaTac†	Tacoma**	
18-Sep-08	0	T	0	
19-Sep-08	0	T	0	
20-Sep-08	0.26	0.54	0.27	
21-Sep-08	0.38	0.02	0.08	
22-Sep-08	0.05	0.01	0	
23-Sep-08	0	0	0	
24-Sep-08	**0.05**	0.12	**0.03**	
25-Sep-08	0.04	**0.09**	0	
				(Tacoma)
1-Jan-09	0.32	0.71	0	(15-Jan-09)
2-Jan-09	0.10	0.12	0	(16-Jan-09)
3-Jan-09	0.02	T	0.01	(17-Jan-09)
4-Jan-09	0.02	0.57	0	(18-Jan-09)
5-Jan-09	0.41	0.04	0	(19-Jan-09)
6-Jan-09	0.55	1.2	0	(20-Jan-09)
7-Jan-09	**1.9**	2.3	**0**	(21-Jan-09)
8-Jan-09	0.87	**0.03**	0	(22-Jan-09)
29-Apr-09	NA	T	NA	
30-Apr-09	NA	0	NA	
1-May-09	0	0	0	
2-May-09	0	0.32	0.06	
3-May-09	0.47	0.10	0.21	
4-May-09	0	0.36	0.01	
5-May-09	**0.30**	0.59	0.60	
6-May-09	0.37	**0.89**	**0.85**	

Day of sample collection for present study in bold font.
T = trace.
NA = not available.
*Bellingham 3 SSW (www7.ncdc.noaa.gov/CDO/cdo).
†Seattle-Tacoma, WA (www.weather.gov/climate/).
**Tacoma #1 (www7.ncdc.noaa.gov/IPS/coop/coop.html).

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Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Bioassay: Standard biological test. Usually a laboratory test which exposes organisms to the medium of interest (example: amphipod exposure to sediment). Results indicate the toxicity of the medium to that particular organism.

Boatyard: A place where boats are built, maintained, or stored.

Effluent: An out flowing of water from a natural body of water or from a man-made structure.

Hardness: A measure of the dissolved solids in a water sample (e.g., calcium, magnesium).

Marine water (seawater): salt water.

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

Receiving waters: Waters that are subject to pollution discharge**.**

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: The suspended particulate matter in a water sample as retained by a filter.

Acronyms and Abbreviations

BGP	Boatyard General Permit
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
g/Kg	Grams per kilogram (parts per thousand)
GPS	Global Positioning System
HDPE	High-density polyethylene
mg/L	Milligrams per liter (parts per million)
N	Number
NAD	North American Datum
NMTA	Northwest Marine Trade Association
PSA	Puget Soundkeeper Alliance
PVC	Polyvinyl chloride
Ship Canal	Seattle Ship Canal
Straits	Strait of Juan de Fuca
WAC	Washington Administration Code
µg/L	Micrograms per liter (parts per billion)