Dissolved Copper Concentrations in Two Puget Sound Marinas

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Dissolved Copper Concentrations in Two Puget Sound Marinas

by
Art Johnson

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Washington State Department of Ecology
Olympia, Washington 98504-7710

Waterbody Numbers:
WA-PS-0200: Rosario Strait
WA-03-0020: Padilla Bay, Fidalgo Bay, Guemes Channel

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Abstract

The Washington State Department of Ecology measured dissolved copper concentrations in surface water samples collected from two Puget Sound marinas in August 2006 and March 2007. Marinas have been shown to be sources of copper to the marine environment, the primary source being antifouling paints on boat hulls. The objectives of the study were to characterize and compare copper concentrations inside and outside the marinas, assess seasonal variation, and determine compliance with Washington State water quality criteria for protection of marine life.

Results showed that exceedances of acute and chronic criteria were primarily restricted to the inner parts of the marinas, where dissolved copper concentrations were higher than criteria by factors of 2 – 4. Water flowing out of the marinas during ebb tide had significantly higher copper concentrations than incoming water during flood tide, but was within criteria in most instances. Seasonal variations in copper levels were generally not observed.

Acknowledgements

The author of this report thanks the following people for their help on this study:

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- Kristin Kinney, Brandee Era-Miller, Paul Anderson, and Sara Livingston of the Washington State Department of Ecology, Environmental Assessment Program, for helping with the field work.
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Background

Marinas are potential sources of metals – especially copper – to marine waters. Young et al. (1979) was among the first to identify vessels and harbor-related activities as significant sources of copper to nearshore ecosystems. The copper comes primarily from antifouling paints which are designed to discourage barnacles, mussels, and other organisms from attaching to boat hulls. Copper is also released through underwater hull cleaning, a frequent practice. Copper is the most common pollutant found at toxic levels in marinas nationwide (USEPA, 1993).

The Shelter Island Yacht Basin (SIYB) in San Diego Bay was recently designated as an impaired waterbody for dissolved copper (California Regional Water Quality Control Board, 2005), pursuant to the federal Clean Water Act section 303(d). The California Regional Water Quality Control Board concluded that "Approximately 98 percent of the total copper loading to SIYB originates from copper-based antifouling paints applied to the hulls of recreational vessels moored in SIYB marinas. Of this total, 93 percent is attributable to copper entering the water column through passive leaching of copper from antifouling paints. The remaining five percent enters the water column during periodic underwater hull cleaning of recreational vessel hulls in the marinas. Four other insignificant sources of copper were identified in the TMDL source analysis including urban runoff, direct atmospheric deposition, marine sediment and natural background."

Copper has been analyzed in several historical studies of Puget Sound marinas. Cardwell et al. (1980a,b) found higher copper concentrations in oysters and sediment inside five Puget Sound marinas than outside. The same studies documented poor flushing of marinas. Skyline Marina on Fidalgo Island was singled out as an example, with only 8-40% of the water being exchanged over a 12-hour period.

Crecelius et al. (1989) measured contaminant loadings to Puget Sound from two marinas: the Port of Port Townsend Marina and Cap Sante Marina in Anacortes. They concluded that the water and sediment inside the marinas "were contaminated with copper…compared to samples taken outside the marinas." Copper concentrations in water samples collected at the marina entrances were significantly higher at ebb than flood, ranging from 1.3 to 5.6 μg/L (parts per billion, analyzed as total recoverable copper). Washington's current chronic and acute criteria for copper are 3.1 and 4.8 μg/L (as dissolved), respectively (WAC 173-201A). Crecelius et al. observed that most of the sediments in these marinas exceeded Puget Sound Dredge Disposal Analysis screening levels in effect at that time.

Project Description

The Washington State Department of Ecology (Ecology) Water Quality Program wanted to determine what dissolved copper concentrations currently exist in waters inside Puget Sound marinas. Special analytical methods are required to accurately measure copper in seawater due to low ambient concentrations and interferences from salts. In response to this request, the Ecology Environmental Assessment Program analyzed surface water samples from two large Puget Sound marinas during the summer (August 2006) and winter (March 2007). Sampling was conducted during periods of minimal tidal exchange. Sixty-six dissolved copper samples were analyzed in all.

The goal of the project was to provide the Water Quality Program with data that could be used in a determination of whether copper levels in and around marinas represent a significant toxicity concern. Specific objectives of the study were to:

1. Characterize dissolved copper concentrations in water inside the marinas.
2. Compare dissolved copper concentrations inside and outside the marinas.
3. Assess seasonal variation in dissolved copper concentrations.
4. Determine if Washington State water quality criteria are exceeded.

This study was conducted following a Quality Assurance Project Plan (Johnson, 2006)

Sampling Design

Marina configuration and size were assumed to be major factors influencing copper concentrations. The marinas selected for sampling were considered most likely to show effects. The selection criteria followed the Crecelius et al. (1989) study:

1. A single entrance channel to an enclosed marina.
2. Greater than 500 boats.
3. No major marina construction in the last three years.
4. No other significant metals sources in the immediate vicinity.

Based on these criteria and logistical considerations imposed by the need to sample the same tide stage at more than one location, Cap Sante Boat Haven (1,050 slips) and Skyline Marina (>500 marina and private slips) were selected for sampling. Both of these marinas are in or near Anacortes (Figures 1-3). Both have been the subject of historical water quality studies that included copper, as previously described. Both marinas conduct boatyard activities and are covered by the Boatyard General Permit.

Cap Sante Boat Haven
Port of Anacortes
P.O. Box 297
Anacortes, WA 98221

Skyline Marina
2011 Skyline Way 203
Anacortes, WA 98221 - 2986

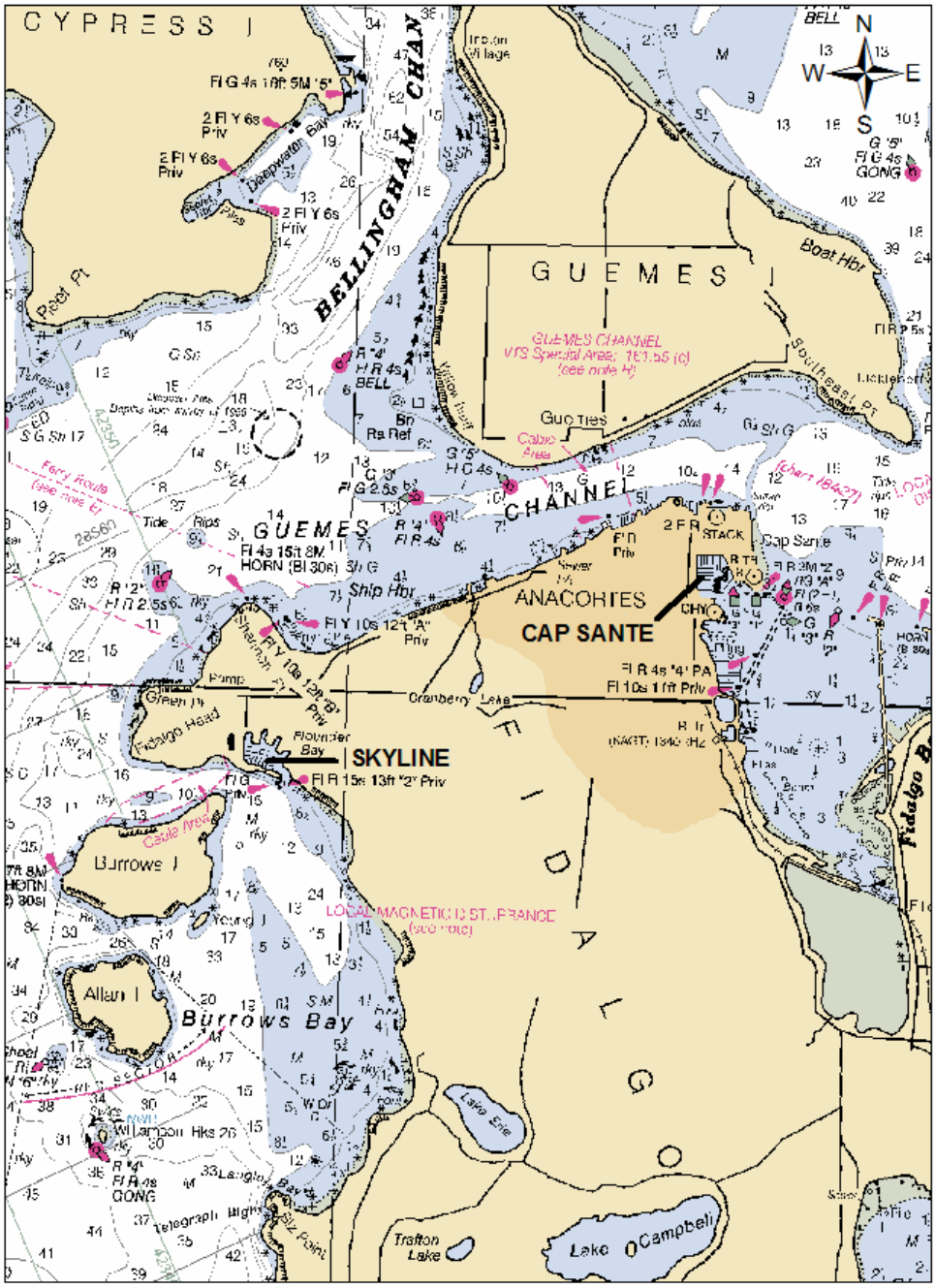

Figure 1. Anacortes Area, Showing Location of Cap Sante and Skyline Marinas

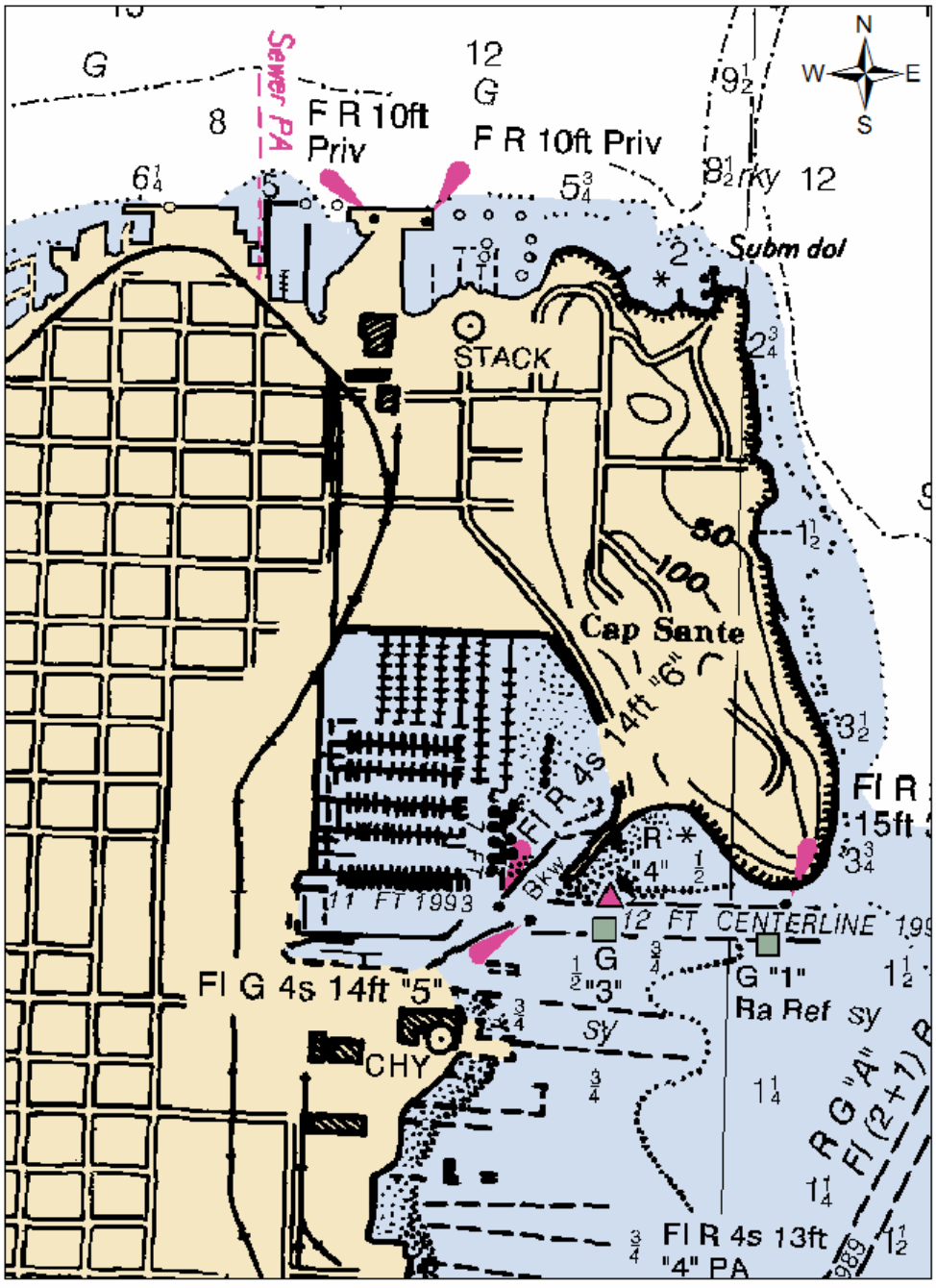

Figure 2. Cap Sante Marina, Anacortes

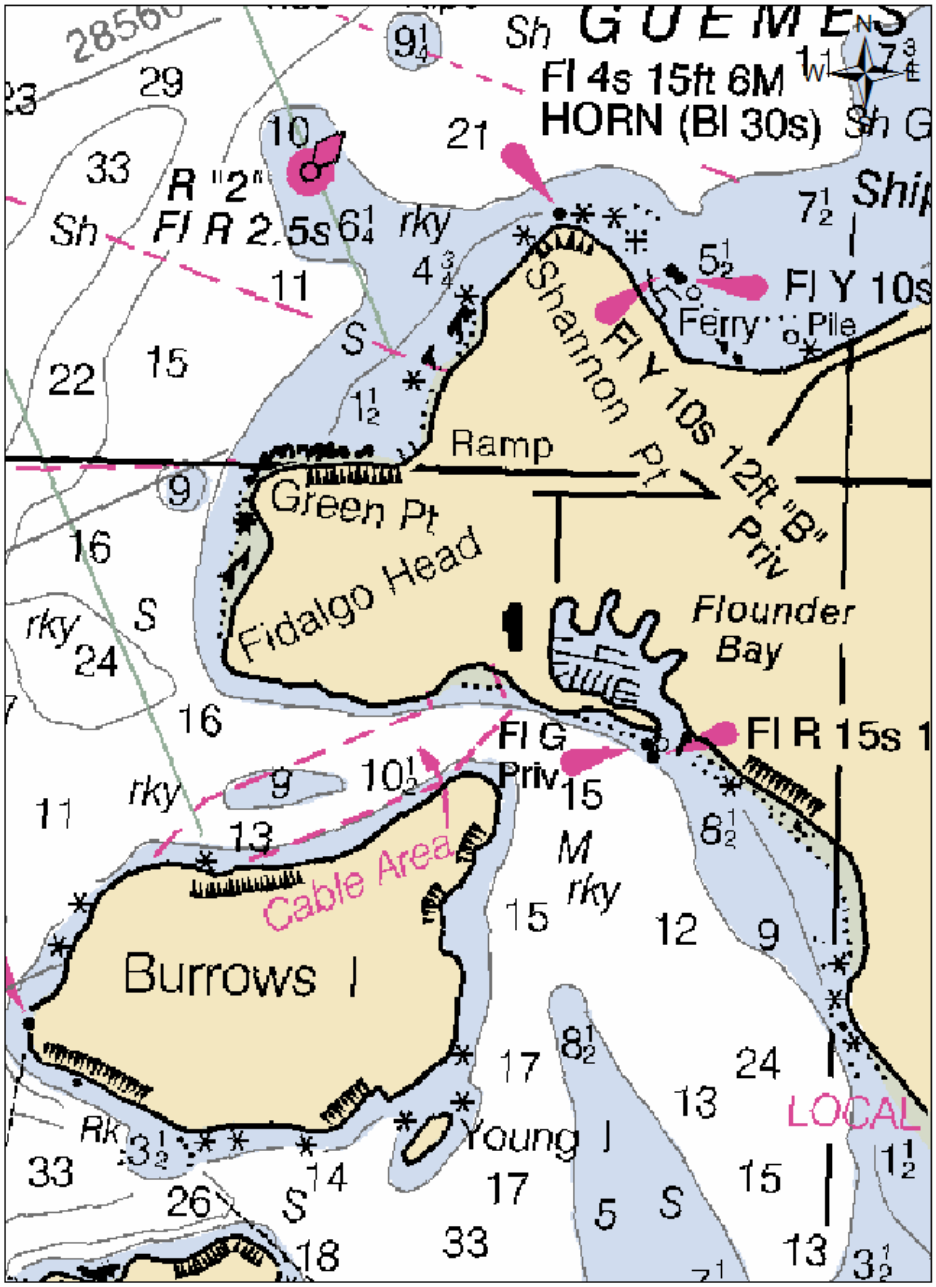

Figure 3. Skyline Marina, Anacortes

It was assumed that the highest copper concentrations occur in the summer when boating activity is at its peak. Most boaters apply bottom paint in the spring to early summer; June is the busiest month at most boat yards. Concentrations were expected to decrease over time as paints leach and hulls get foul.

Surface water samples were collected during a neap tide series (minimal tidal exchange) on August 14-16, 2006 and again on March 5-7, 2007. The range in tide heights during sample collection was -0.1 to +8.5 in August and +1.4 to +7.9 in March (Anacortes, Guemes Channel). The samples were collected at the marina entrance during the last half of the ebb and last half of the flood. Figure 4 illustrates sample timing for Cap Sante Marina on August 14-16. The sampling at Skyline Marina followed a similar pattern.

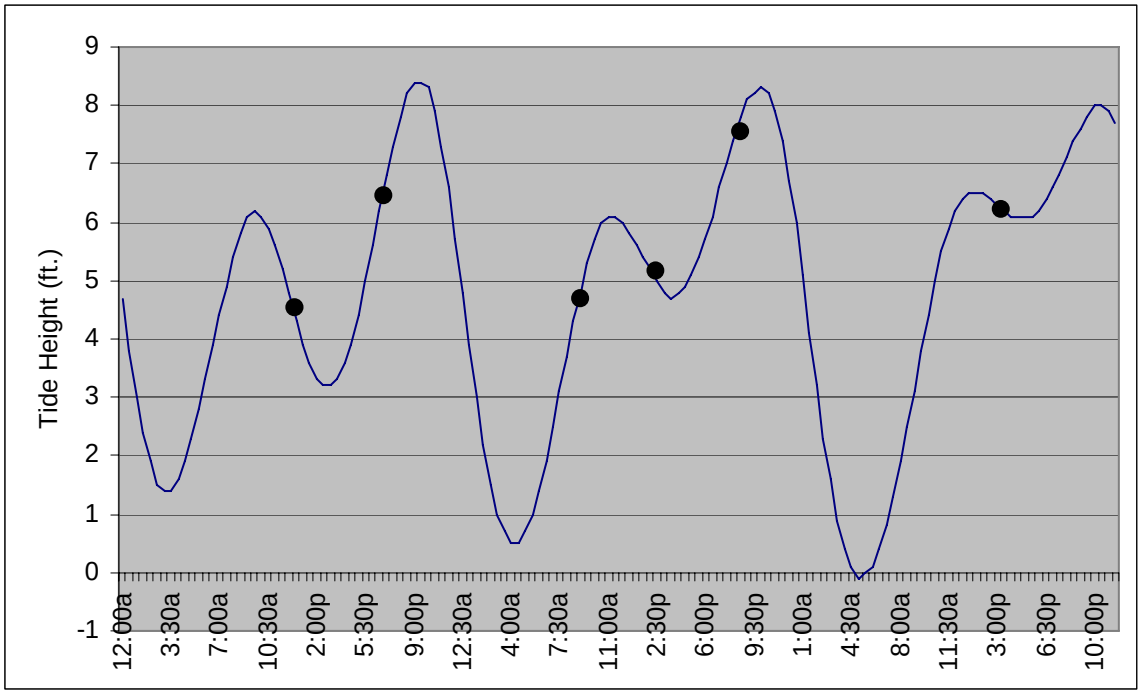

Figure 4. Tide Heights at Time of Sample Collections at Cap Sante Marina, August 14-16, 2006 (dot indicates approximate time of sample collection)

The entrance samples collected during ebb were intended to integrate water quality impacts from the marinas. The flood entrance samples were intended to reflect local background conditions outside the marina. A limited number of samples from the innermost part of the marinas were also collected, but during ebb only. These were assumed to be worst-case samples. Figure 5 and 6 show the sampling sites for Cap Sante and Skyline, respectively.

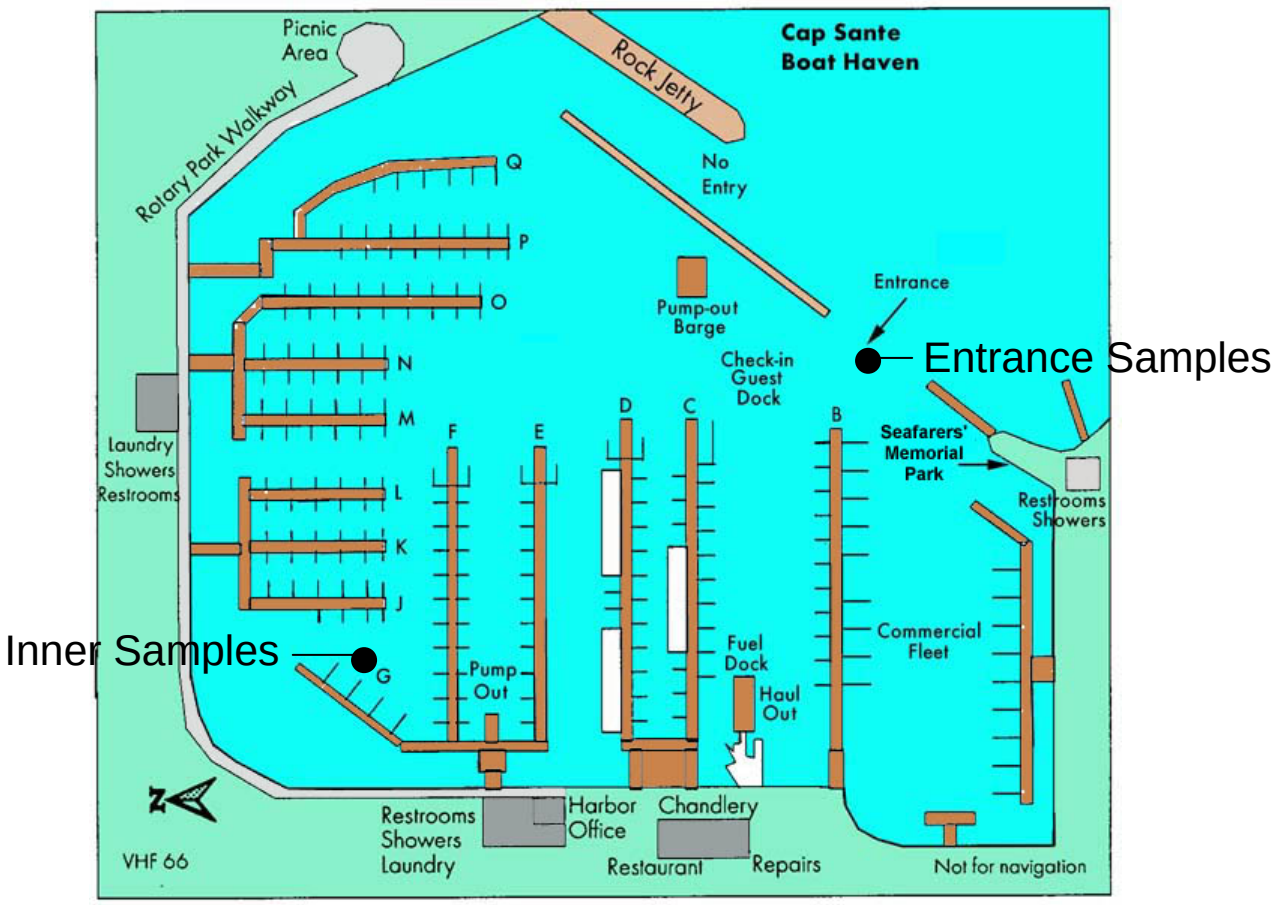

Figure 5. Sampling Sites at Cap Sante Marina

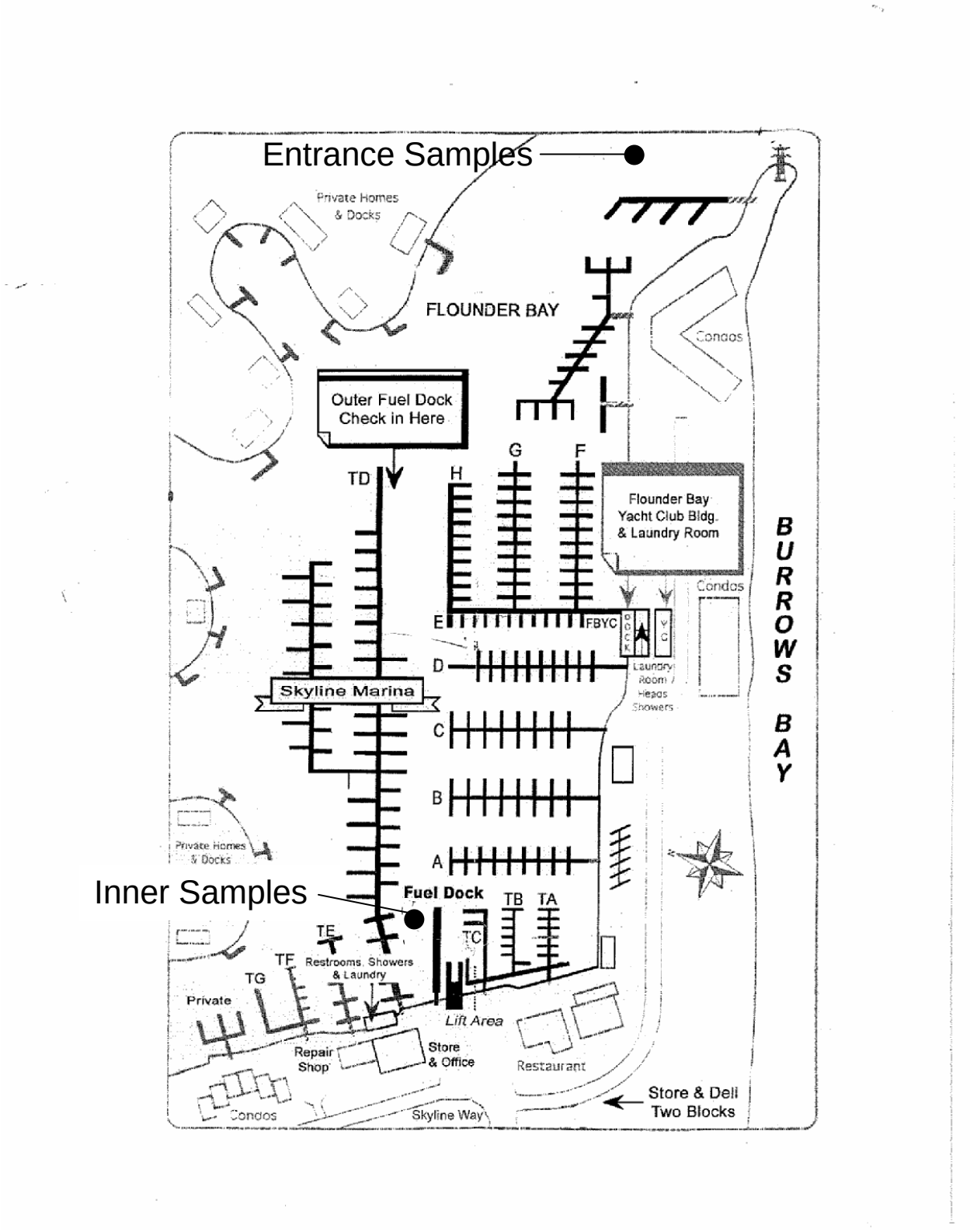

Figure 6. Sampling Sites at Skyline Marina

The sampling design for the study is summarized in Table 1. Six ebb and six flood samples were collected at each marina over a three-day period during August 2006 and again during March 2007. Two ebb and two flood samples were collected at the entrance each day. Three inner marina samples were collected over the same three-day period, one each day during ebb. A total of 66 samples, including field quality control (QC) samples, were analyzed for dissolved copper during the study. Ancillary parameters included salinity, total suspended solids (TSS), turbidity, and temperature.

Table 1. Sampling Design for 2006-07 Marina Copper Study
[number of samples]

Location/ Sample Type	Site	Day-1 Ebb	Day-1 Flood	Day-2 Ebb	Day-2 Flood	Day-3 Ebb	Day-3 Flood	Subtotals
Cap Sante	Marina entrance	2	2	2	2	2	2	12
Skyline	Marina entrance	2	2	2	2	2	2	12
Cap Sante	Inner marina	1		1		1		3
Skyline	Inner marina	1		1		1		3
Subtotals		6	4	6	4	6	4	30
Split samples		1	1					2
Transfer blank		1						1
Subtotals		8	5	6	4	6	4	33
							Total Samples for Study (x2) =	66

Copper was analyzed at Frontier Geosciences, Inc., an accredited Ecology contractor. The method employed Cobalt-APDC coprecipitation with analysis by ICP-MS. This is a modification of EPA methods 1638 and 1640. Detection limits of 0.02 to 0.04 ug/L were achieved (parts per billion).

Methods

Field Procedures

Sample containers, preservation, and holding times for the marina samples are shown in Table 2.

Table 2. Field Procedures for 2006-07 Marina Copper Study

Parameter	Container	Preservation	Holding Time
Copper	500 mL poly bottle	Cool to 4°C*	6 months**
Salinty	500 mL poly bottle	Cool to 4°C	28 days
TSS	1 L poly bottle	Cool to 4°C	7 days
Turbidity	500 mL poly bottle	Cool to 4°C	48 hours

*filtered and acidified at the laboratory within 24 hours of collection
**acidified sample

Sampling methods for copper followed the guidance in EPA Method 1669: *Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels*. Field personnel wore non-talc nitrile gloves and took care not to introduce contamination in the samples. Surface water samples were taken from an inflatable boat (unpainted hull) in the center of the entrance channel. The samples were collected from the bow by hand, directly into the sample bottles, with the boat moving forward. The samples in the inner marina were collected with the sample bottle attached to the end of a seven-foot plastic pole.

The samples were quickly sealed and labeled, put in double polyethylene bags (copper samples only), and placed in a cooler with ice. The sample containers for dissolved copper were obtained from Frontier Geosciences, Inc. The copper samples were transported directly to Frontier within 24 hours of collection. The TSS, turbidity, and salinity samples were held on ice for next day transport to Manchester Laboratory. Chain of custody was maintained.

Water temperature was recorded at the time of sample collection. The latitude and longitude of each sampling site was determined from a Global Positioning System (GPS) (Appendix A).

Laboratory Procedures

The samples were analyzed by Frontier Geosciences and the Ecology Manchester Environmental Laboratory, according to the methods shown in Table 3. A summary of the copper method follows.

Table 3. Laboratory Procedures for 2006-07 Marina Copper Study

Analysis	Method	Laboratory
Dissolved Copper	FGS SOP -032	Frontier
Salinity	SM2520	Manchester
TSS	EPA 160.2	Manchester
Turbidity	EPA 180.1	Manchester

The copper samples were filtered through acid cleaned 0.45µm filter units within 24 hours of collection and then preserved to 0.099% (v/v) with concentrated nitric acid (HNO_3). The Co-APDC digestion/extraction of the samples for analysis of dissolved copper was performed according to FGS SOP-032. 200 ml of each sample was placed into an extraction vessel. Cobalt and APDC solutions were added to each pH-adjusted sample. The samples were extracted overnight.

Extracts were filtered through a 0.2-µm membrane filter, and the precipitate was collected on the filters. Each filter was folded and placed in a Teflon vial. Concentrated HNO_3 was added to each filter to destroy the organic APDC complex. Each sample was diluted up to 10 mL with 5% HNO_3 and heated on a hotplate at approximately 85°C for 30 minutes. Preparation blanks, reference materials, matrix duplicates, and matrix spike/matrix spike duplicates were also prepared in exactly the same manner as the samples.

The samples were analyzed by ICP-MS on a Perkin-Elmer Elan 6000. Internal standardization with ^{74}Ge was utilized. The daily analytical run began with a 7-point standard curve, spanning the entire analytical range of interest, with continued calibration verification standards (CCVs) run every 10 samples. The daily standard curve was calculated using the initial calibration blank correction and a linear regression forced through zero. The results are corrected for the mean of the preparation blanks.

Data Quality

No difficulties were encountered in the analysis of project samples, and all quality control analyses were within acceptable limits. The data are usable as reported. Case narratives from Frontier and Manchester describing the quality of the data and results on QC samples are available on request.

Field duplicate samples were analyzed to provide estimates of analytical variability in the copper data (Table 4). The duplicates were prepared by filling two separate sample containers from the same set of grabs. Duplicate results agreed within 10% or better. Results on duplicate samples were averaged for use in this report.

Table 4. Precision of Duplicate Samples Analyzed for Dissolved Copper (ug/L, parts per billion)

Date	Sample No./Result		RPD (%)*
15-Aug	334286	334292	
	1.19	1.08	9.7
15-Aug	334284	334293	
	0.30	0.30	0
6-Mar	104086	104087	
	1.54	1.59	3.2
6-Mar	104088	104089	
	6.65	6.26	6.0

*relative percent difference (range as percent of duplicate mean)

Three of the March 2007 samples (104080, 104082, and 104100) were inadvertently preserved prior to rather than after filtration. The reported values for these samples are therefore for acid soluble copper rather than dissolved. Results on comparable samples analyzed for dissolved copper show that the acid soluble results do not differ substantially (Table 5). This is likely due to the low amounts of particulate matter in the samples.

The relative percent difference (RPD) between acid soluble and dissolved results on split samples, replicate samples, and samples collected within 24 hours of each other at the same site and tide stage agreed within 0.2 to 11% (Table 5). These RPDs are similar to what was seen in split samples analyzed for dissolved copper (Table 4). The acid soluble results were also within

range of the dissolved concentrations measured in other samples at these same sites. Because the acid soluble and dissolved results are comparable, the data for the three samples in question are used along with the dissolved data without further qualification.

Table 5. Comparison Between Split or Similar Type Samples Analyzed for Acid Soluble and Dissolved Copper (ug/L, parts per billion)

Sample No.	Date	Time	Location	Tide	Prep. Method	Result
Split Samples						
104100	5-Mar	1012	Cap Sante/Inner	Ebb	Acid Soluble	11.0
104101	"	"	"	"	Dissolved	10.2
					RPD* (%)	7.5
Replicate Samples						
104080	5-Mar	1110	Skyline/Entance	Ebb	Acid Soluble	1.65
104081	"	1115	"	"	Dissolved	1.84
					RPD (%)	11
One Day Apart						
104082	5-Mar	1130	Skyline/Inner	Ebb	Acid Soluble	6.66
104088	6-Mar	1040	"	"	Dissolved	6.65
					RPD (%)	0.2

*relative percent difference (range as percent of duplicate mean)

Transfer blanks were analyzed to detect copper contamination arising from sample containers, preservation, or sample handling. The blanks were prepared using a sample bottle filled with Frontier Geosciences blank water. The bottle was opened in the field and its contents transferred to a new bottle, in essence mimicking the grab sampling procedure. Copper was not detected in either blank at or below 0.04 ug/L (August) or 0.02 ug/L (March).

The complete data for the study, including results on field QC samples, are in Appendix B.

Results and Discussion

Cap Sante Marina

The data obtained on general water conditions in Cap Sante Marina are summarized in Table 6. TSS and turbidity were low during both the ebb and the flood, including in the inner marina. Salinity, TSS, and turbidity levels were similar in August and March.

Table 6. General Water Quality Conditions in **Cap Sante Marina**

				Range of Values			
Date	Location	Tide	N =	Temp. (^{o}C)	Salinity (o/oo)	TSS (mg/L)	Turbidity (NTU)
August 2006	Entrance	Ebb	6	13.3 - 15.3	30.5 - 30.5	4 - 7	0.9 - 1.3
	"	Flood	6	13.2 - 14.3	30.5 - 30.5	3 - 9	1.6 - 2.0
	Inner	Ebb	3	12.7 - 15.6	30.5 - 30.5	2 - 6	0.7 - 1.1
March 2007	Entrance	Ebb	6	7.5 - 8.3	30.0 - 30.0	2 - 4	0.7 - 0.9
	"	Flood	6	8.0 - 8.5	30.0 - 30.0	4 - 7	0.8 - 1.4
	Inner	Ebb	3	7.8 - 8.4	30.0 - 30.0	1 - 3	0.5 - 0.9

The dissolved copper concentrations measured in Cap Sante are summarized in Table 7 and Figure 7. Copper concentrations were highest in the inner part of the marina, followed by the marina entrance during ebb. Concentrations at these locations ranged from 3.3 to 12 ug/L and 1.4 to 4.0 ug/L, respectively (parts per billion). The lowest concentrations were consistently observed at the entrance during flood, 0.33 to 2.0 ug/L.

On average, copper concentrations in the entrance were 3 to 4 times higher during ebb than during flood. The differences between ebb and flood were statistically significant in both August and March (Mann-Whitney, $p \leq 0.01$).

Copper levels in the entrance did not differ significantly between August and March. This held true for both the ebb and the flood. The limited number of samples collected in the inner marina suggests copper levels may have been higher in March by about a factor of 2.

Table 7. Dissolved Copper Concentrations in **Cap Sante Marina** (parts per billion)

Date	Location	Tide	N =	Dissolved Copper (ug/L) mean	median	min	max
Aug. 2006	Entrance	Ebb	6	3.1	3.3	1.8	4.0
	"	Flood	6	0.79	0.55	0.33	2.0
	Inner	Ebb	3	5.1	5.5	3.3	6.4
March 2007	Entrance	Ebb	6	2.3	2.7	1.4	3.0
	"	Flood	6	0.86	0.78	0.67	1.1
	Inner	Ebb	3	9.2	11	5.0	12

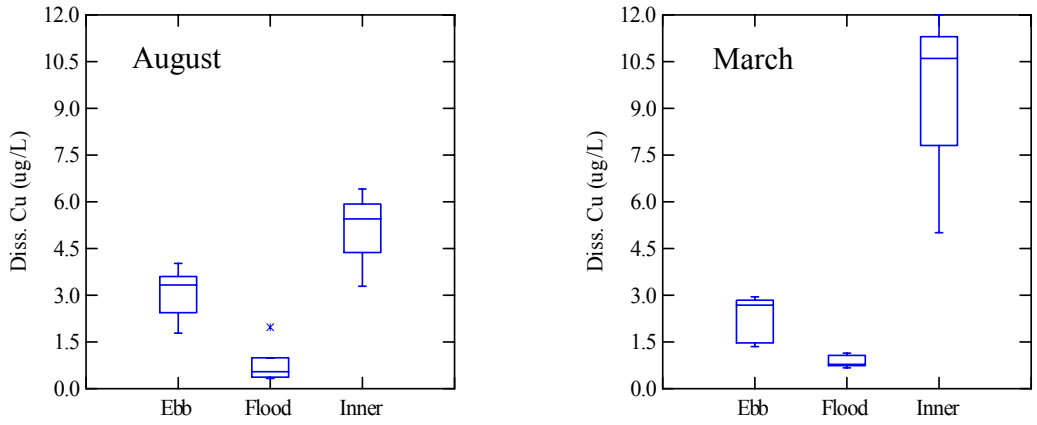

Figure 7. Dissolved Copper Concentrations at **Cap Sante Marina** During August 2006 and March 2007.

NOTE: The box plots in this report show measures of central tendency (median), sample variability (inter-quartile range), and outliers. The median is the horizontal line through the box. The upper and lower ends of the box are the first and third quartiles (50% of the values). The whiskers extend to within a factor of 1.5 times the interquartile range. Asterisks and open circles are outside and far outside values, respectively.

Skyline Marina

Temperature, salinity, TSS, and turbidity at Skyline Marina (Table 8) were similar to Cap Sante.

Table 8. General Water Quality Conditions in **Skyline Marina**

Date	Location	Tide	N =	Range of Values			
				Temp. (^{o}C)	Salinity (o/oo)	TSS (mg/L)	Turbidity (NTU)
August 2006	Entrance	Ebb	6	12.3 - 13.8	30.5 - 31.0	3 - 6	0.9 - 1.3
	"	Flood	6	12.0 - 13.3	30.5 - 31.0	4 - 6	0.7 - 1.2
	Inner	Ebb	3	13.5 - 14.9	31.0 - 31.0	4 - 6	0.9 - 1.0
March 2007	Entrance	Ebb	6	7.9 - 8.3	30.0 - 30.0	3 - 6	0.9 - 2.0
	"	Flood	6	7.9 - 8.7	30.0 - 30.0	3 - 7	0.7 - 1.3
	Inner	Ebb	3	8.6 - 8.8	28.0 - 30.0	2 - 3	0.5 - 0.9

The dissolved copper data for Skyline are summarized in Table 9 and Figure 8.

Table 9. Dissolved Copper Concentrations in **Skyline Marina** (parts per billion)

Date	Location	Tide	N =	Dissolved Copper (ug/L)			
				mean	median	min	max
Aug. 2006	Entrance	Ebb	6	1.7	1.8	0.38	2.8
	"	Flood	6	0.32	0.31	0.28	0.39
	Inner	Ebb	3	6.1	6.2	4.8	7.2
March 2007	Entrance	Ebb	6	1.9	1.7	1.5	2.7
	"	Flood	6	0.39	0.37	0.35	0.47
	Inner	Ebb	3	5.9	6.5	4.7	6.7

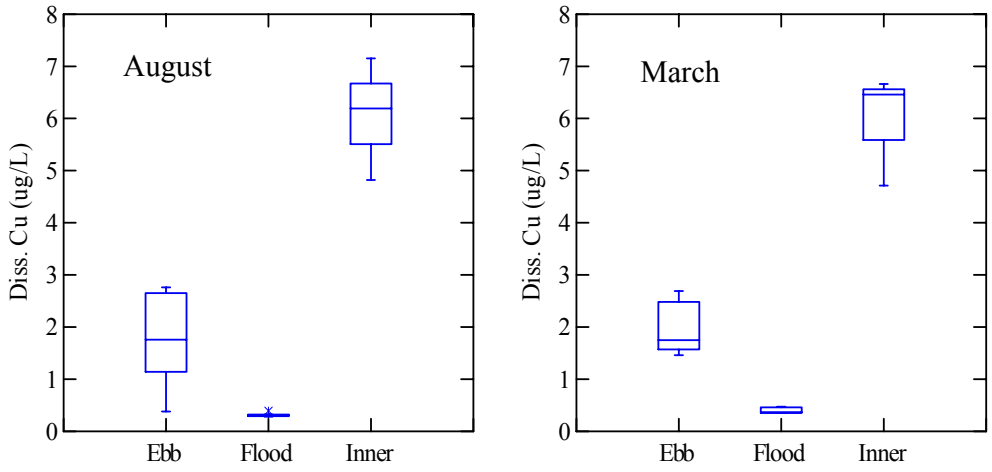

Figure 8. Dissolved Copper Concentrations at **Skyline Marina** During August 2006 and March 2007.

As with Cap Sante, copper concentrations progressively decreased going from the inner marina, to the entrance at ebb, to the entrance at flood. Concentrations ranges were 4.7 to 7.2, 0.38 to 2.8, and 0.28 to 0.47 ug/L, respectively. The average copper concentration at the entrance during ebb was about 5 times higher than the average concentration during flood. The differences were statistically significant (Mann-Whitney, $p \leq 0.01$).

Here again, copper levels in the entrance did not differ significantly between August and March for either the ebb or the flood. The samples from the inner part of Skyline Marina also had similar copper concentrations in August and March.

The copper concentrations measured at Cap Sante were significantly higher than those observed at Skyline, both for the ebb ($p = 0.02$) and flood ($p<0.01$). The higher concentrations seen during flood at Cap Sante suggest an effect from local sources of copper in Fidalgo Bay. Dissolved copper was twice as high at Cap Sante during flood (0.79 to 0.86 ug/L) than in the corresponding samples at Skyline (0.32 to 0.39 ug/L). Crecelius (1998) reported the background concentration of dissolved copper for this area (Guemes Channel/Padilla Bay) to be 0.42 ug/L. This finding agrees closely with the results for Skyline flood waters.

Marine Copper Criteria

Figures 9 and 10 compare the dissolved copper concentrations measured during this study with Washington State acute and chronic water quality criteria for protection of marine life (173-210A WAC). The acute criterion, 4.8 ug/L, is a 1-hour average concentration not to be exceeded more than once every three years on the average (Figure 9). The chronic criterion, 3.1 ug/L, is a 4-day average concentration not to be exceeded more than once every three years on the average (Figure 10). The figures plot the ratio of the dissolved copper concentration measured in the marinas divided by the criterion. Values greater than 1.0 exceed the criterion.

The dissolved copper criteria were exceeded primarily in the inner parts of the marinas. Acute exceedances of criteria were generally by factors of 2 or less. Copper concentrations in these areas typically exceeded the chronic criterion by a factor of 2, with some samples exceeding by factors of 3 to 4.

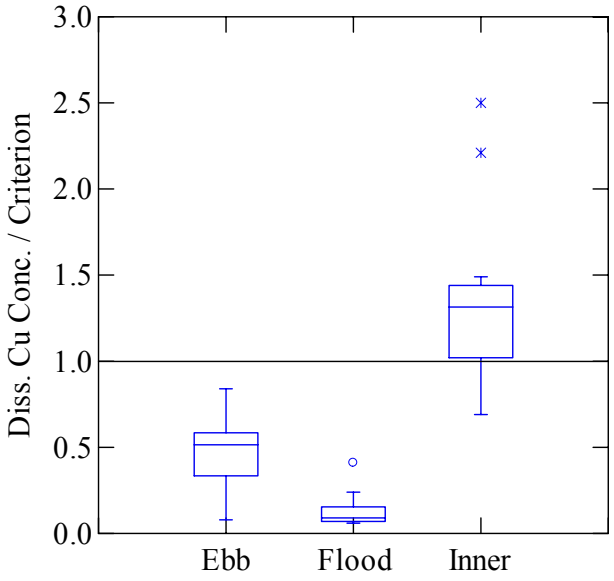

Figure 9. **Acute Criterion** Exceedances for Dissolved Copper in Cap Sante and Skyline Marinas, August 2006 and March 2007 (values >1 exceed the acute criterion)

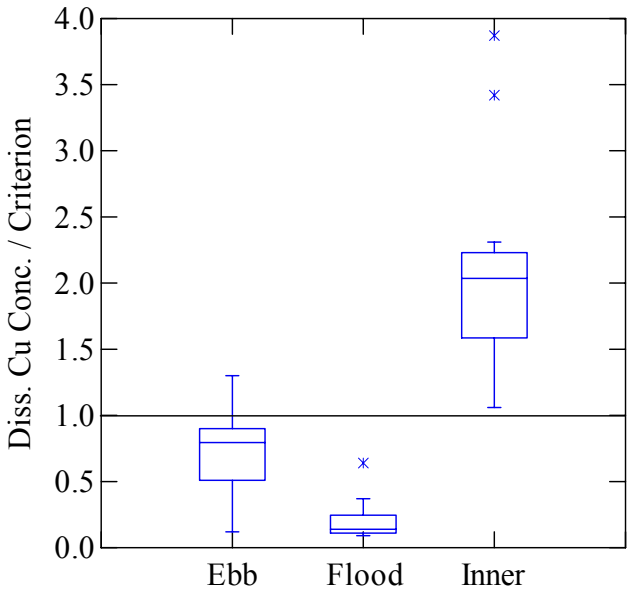

Figure 10. **Chronic Criterion** Exceedances for Dissolved Copper in Cap Sante and Skyline Marinas, August 2006 and March 2007 (values >1 exceed the chronic criterion)

Table 10 summarizes the criteria exceedances in terms of frequency (number of samples exceeding / total samples analyzed). Overall, 83% of the inner marina samples (10 out of 12) exceeded the acute copper criterion. All of the inner samples (100%) exceeded the chronic criterion. The only exceedances of the chronic criterion at the marina entrances were in three of the six Cap Sante samples collected during the August ebb. These exceedances, however, were marginal, by factors of 1.2 to 1.3.

Table 10. Exceedance Frequency of the Marine Copper Criteria at Cap Sante and Skyline Marinas, August 2006 and March 2007 (percent of samples exceeding)

Marina	Location	Tide	N =	Acute Criterion	Chronic Criterion
Cap Sante	Inner	Ebb	6	83%	100%
	Entrance	Ebb	12	0%	25%
	Entrance	Flood	12	0%	0%
Skyline	Inner	Ebb	6	83%	100%
	Entrance	Ebb	12	0%	0%
	Entrance	Flood	12	0%	0%
Combined Data	Inner	Ebb	12	83%	100%
	Entrance	Ebb	24	0%	13%
	Entrance	Flood	24	0%	0%

Conclusions and Recommendations

Conclusions

Results of this study point to the inner portions of the two marinas investigated as being the primary water quality concern for dissolved copper. The fact that the inner marina samples consistently exceeded criteria in samples collected six months apart suggests that a similar situation likely occurs throughout the year, at least during periods of minimal tidal exchange.

Copper levels at the marina entrances were generally meeting marine aquatic life criteria during ebb tide and always meeting criteria during flood. Although the marinas were causing a significant increase in dissolved copper, the concentrations did not appear high enough to cause toxicity in adjacent waters, based on a comparison with water quality criteria. Seasonal changes in copper levels were generally not apparent.

Recommendations

This study focused on marina configurations and tidal exchange conditions that increased the likelihood of detected significant copper contamination. The extent to which the findings apply to other Puget Sound marinas is unknown. To better gauge the extent of the problem, it is recommended that a screening-level survey be conducted to measure dissolved copper concentrations in limited numbers of water samples collected at marinas in other locations. The sampling effort should be weighted toward the inner parts of the marinas. A few samples within each marina should suffice. Samples should also be collected to determine the local background for copper.

If additional water samples are collected, the analysis should include total recoverable copper. Establishing the total recoverable:dissolved ratio could be useful if it is concluded that discharge limits should be established for copper in marinas and boatyards.

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Appendices

Appendix A. Sampling Locations at Cap Sante and Skyline Marinas

Table A1. Location of Sampling Sites for 2006-07 Marina Copper Study

Sampling Site	Description	Latitude*	Longitude*
Cap Sante Marina			
Entrance	Center of entrance channel	48° 30' 42"	122° 36' 21"
Inner Marina	Off G dock, slip 16	48° 30' 53"	122° 36' 30"
Skyline Marina			
Entrance	Center of entrance channel	48° 29' 26"	122° 40' 35"
Inner Marina	Between fuel dock and TD dock	48° 29' 34"	122° 40' 57"

*NAD 83

Appendix B. Data

Table B1. Data from Ecology's 2006-07 Marina Copper Study

Sample No.	Marina	Location	Tide	Date	Time	Diss. Cu (ug/L)		TSS (mg/L)	Turbidity (NTU)		Salinity (o/oo)	Temp. (°C)
August 2006 Samples												
334280	Skyline	Entrance	Ebb	14	1305	2.76		5	1.3		30.5	12.3
334281	Skyline	Entrance	Ebb	14	1320	2.65		3	1.1		31.0	- -
334286	Skyline	Entrance	Ebb	15	1530	1.19		4	0.8		30.5	13.7
334292	Field split of sample #334286			15	1530	1.08		NA	1.0		30.5	- -
334287	Skyline	Entrance	Ebb	15	1600	1.89		6	1.3		30.5	13.8
334290	Skyline	Entrance	Ebb	16	1437	1.62		5	1.2		31.0	12.5
334291	Skyline	Entrance	Ebb	16	1452	0.38		4	1.2		30.5	12.6
334282	Skyline	Entrance	Flood	14	1950	0.32		5	1.2		31.0	12.7
334283	Skyline	Entrance	Flood	14	2003	0.39		6	1.1		30.5	12.7
334284	Skyline	Entrance	Flood	15	1005	0.30		5	1.0		31.0	12.0
334293	Field split of sample #334284			15	1005	0.30		4	1.0		31.0	- -
334285	Skyline	Entrance	Flood	15	1020	0.29		5	0.7		30.5	12.0
334288	Skyline	Entrance	Flood	15	1940	0.28		5	0.9		31.0	12.3
334289	Skyline	Entrance	Flood	15	1955	0.31		4	0.9		31.0	13.3
334307	Skyline	Inner	Ebb	14	1340	7.15		4	1.1	J	31.0	13.5
334308	Skyline	Inner	Ebb	15	1550	4.82		6	1.0		31.0	14.9
334309	Skyline	Inner	Ebb	16	1420	6.19		4	0.9		31.0	14.1
334295	Cap Sante	Entrance	Ebb	14	1205	3.08		6	0.9	J	30.5	13.4
334296	Cap Sante	Entrance	Ebb	14	1220	3.57		7	0.9	J	30.5	13.3
334301	Cap Sante	Entrance	Ebb	15	1410	4.02		6	0.9		30.5	15.0
334302	Cap Sante	Entrance	Ebb	15	1425	3.60		5	1.1		30.5	15.3
334305	Cap Sante	Entrance	Ebb	16	1530	2.44		6	1.2		30.5	15.0
334306	Cap Sante	Entrance	Ebb	16	1545	1.78		4	1.3		30.5	15.1
334297	Cap Sante	Entrance	Flood	14	1905	0.52		6	1.8	J	30.5	13.8
334298	Cap Sante	Entrance	Flood	14	1910	0.57		4	2.0	J	30.5	14.0
334299	Cap Sante	Entrance	Flood	15	0900	0.37		3	1.6		30.5	13.3
334300	Cap Sante	Entrance	Flood	15	0915	0.33		9	1.6		30.5	13.2
334303	Cap Sante	Entrance	Flood	15	2030	1.97		5	1.6		30.5	14.3
334304	Cap Sante	Entrance	Flood	15	2045	0.99		4	1.6		30.5	14.3
334310	Cap Sante	Inner	Ebb	14	1125	6.41		2	0.7	J	30.5	12.7
334311	Cap Sante	Inner	Ebb	15	1445	5.45		5	0.8		30.5	15.2
334312	Cap Sante	Inner	Ebb	16	1605	3.29		6	1.1		30.5	15.6
334294	Field Blank	- -	- -	15	0905	0.04	U	NA	NA		NA	- -

Table B1 (continued)

Sample No.	Marina	Location	Tide	Date	Time	Diss. Cu (ug/L)		TSS (mg/L)	Turbidity (NTU)		Salinity (o/oo)	Temp. (^{o}C)
March 2007 Samples												
Sample No.	Marina	Location	Tide									
104080	Skyline	Entrance	Ebb	5	1110	1.65	A	4	1.1	J	30.0	7.9
104081	Skyline	Entrance	Ebb	5	1115	1.84		4	0.9	J	30.0	- -
104085	Skyline	Entrance	Ebb	6	1130	1.46		5	2.0		30.0	8.3
104086	Skyline	Entrance	Ebb	6	1135	1.54		6	1.9		30.0	- -
104087	Field split of sample #104086			6	1135	1.59		6	1.8	J	30.0	- -
104093	Skyline	Entrance	Ebb	7	1150	2.69		5	1.5		30.0	8.3
104094	Skyline	Entrance	Ebb	7	1155	2.48		3	1.5		30.0	- -
104083	Skyline	Entrance	Flood	5	1710	0.35		4	0.7	J	30.0	8.3
104084	Skyline	Entrance	Flood	5	1715	0.38		3	0.7	J	30.0	- -
104091	Skyline	Entrance	Flood	6	1655	0.46		7	1.3		30.0	8.7
104092	Skyline	Entrance	Flood	6	1700	0.47		6	1.1		30.0	- -
104096	Skyline	Entrance	Flood	7	1730	0.35		3	1.2		30.0	7.9
104097	Skyline	Entrance	Flood	7	1735	0.35		4	1.1		30.0	- -
104082	Skyline	Inner	Ebb	5	1130	6.66	A	2	0.5	U	30.0	8.8
104088	Skyline	Inner	Ebb	6	1040	6.65		2	0.6		30.0	8.4
104089	Field split of sample #104088			6	1040	6.26		3	0.7		30.0	- -
104095	Skyline	Inner	Ebb	7	1130	4.71		2	0.9		30.0	8.6
104098	Cap Sante	Entrance	Ebb	5	0910	1.35		3	0.7	J	30.0	7.5
104099	Cap Sante	Entrance	Ebb	5	0915	1.47		2	0.9	J	30.0	- -
104104	Cap Sante	Entrance	Ebb	6	0930	2.72		3	0.9	J	30.0	7.8
104105	Cap Sante	Entrance	Ebb	6	0935	2.64		3	0.9	J	30.0	- -
104109	Cap Sante	Entrance	Ebb	7	1025	2.95		4	0.8		30.0	8.3
104110	Cap Sante	Entrance	Ebb	7	1020	2.81		4	0.9		30.0	- -
104111	Field split of sample #104110			7	1020	2.86		4	0.8		30.0	- -
104102	Cap Sante	Entrance	Flood	5	1604	0.77		5	0.8	J	30.0	8.2
104103	Cap Sante	Entrance	Flood	5	1609	0.74		4	1.0	J	30.0	- -
104107	Cap Sante	Entrance	Flood	6	1540	1.14		7	1.1		30.0	8.5
104108	Cap Sante	Entrance	Flood	6	1545	1.07		5	1.2		30.0	- -
104113	Cap Sante	Entrance	Flood	7	1625	0.67		5	0.8		30.0	8.0
104114	Cap Sante	Entrance	Flood	7	1640	0.79		5	1.4		30.0	- -
104100	Cap Sante	Inner	Ebb	5	1012	11.0	A	3	0.8	J	28.0	7.9
104101	Field split of sample #104100			5	1012	10.2		2	1.0	J	28.0	- -
104106	Cap Sante	Inner	Ebb	6	1000	12.0		1	0.5	J	29.5	7.8
104112	Cap Sante	Inner	Ebb	7	1100	5.01		3	0.7		30.0	8.4
104090	Field Blank	- -	- -	6	1710	0.02	U	NA	NA		NA	- -

U = not detected at or above reported value
J = estimated value (holding time exceeded)
NA = not analyzed
A = analyzed as acid soluble copper