Halifax Harbour
Water Quality Monitoring Program
Quarterly Report #18
(September 23 to December 17, 2008**)**

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PREFACE

The Halifax Harbour Water Quality Monitoring Project (HHWQMP) is an ongoing project, part of the Halifax Harbour Solutions Project (HRM and JWEL, 2002). It commenced in June 2004, before any of the proposed sewage treatment changes were put into effect, and is slated to continue for a year following the commission of the final plant (June 2009). The project is based on water quality surveys that include over 30 sites distributed from the Bedford Basin to the Outer Halifax Harbour. Water samples taken at 1 m and 10 m depths are analyzed for a range of parameters. In addition, continuous profiles of basic hydrographic properties (salinity, temperature and density), dissolved oxygen and fluorescence are collected. From June 2004 to June 2006 the surveys were conducted weekly and from July 2006 onward, slightly modified surveys are conducted biweekly. The sample and profile data are presented in survey reports (weekly or biweekly, as appropriate) along with ancillary data including water level, wind, rainfall and other parameters. The reports are generated as inserts into a binder (JWEL and COA, 2004). Electronic copies of the reports and data files are also delivered to the client. A detailed description of the program is contained in the introduction section of the report binder.

The weekly/biweekly data sets are reviewed on a quarterly basis (13 weeks). The main objective of the quarterly reports is to summarize and evaluate the weekly/biweekly data sets in terms of water quality objectives and concerns. The quarterly report also provides an opportunity to review the effectiveness of various aspects of the program and recommend changes that will improve the program. Project reports and data are available on the Halifax Regional Municipality (HRM) website:
http://www.halifax.ca/harboursol/waterqualitydata.html

The HHWQMP program involves an extensive network of personnel including boat operators, field technicians, laboratory technicians and their associated equipment and procedures. The study team also includes managers, oceanographers and water quality experts. The routines, procedures, report and data archive formats are evolving as the project proceeds. These are documented in the project report binder.

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1 Introduction

This quarterly report is a summary of Halifax Harbour Water Quality Monitoring Project (HHWQMP) data collected from 23 September to 17 December 2008 (surveys 165 to 171). The results of the individual surveys are documented in survey reports. In this report, the data for the period are discussed in terms of compliance/exceedance of applicable water quality guidelines (Halifax Harbour Task Force, 1990), and how they affect recommendations for program modification. An emphasis in this report is a continued assessment of the efficacy of the sampling program and of the potential introduction of systematic sampling bias in the data. This is a necessary step in the more detailed statistical analysis of the data that can occur subsequently. This report discusses just the eighteenth quarter. Every fourth quarterly report includes an annual summary of data and trends over the previous four quarters. In the interest of making each quarterly report useful as a stand-alone document, there is a significant amount of repetition of background information among the quarterly reports.

2 Reporting

The basic report format for both survey and quarterly reports is discussed in detail in the introduction of the project report binder and in Quarterly Report 1 (QR1, JWL and COA, 2004). Slight modifications and enhancements to the reports continue to be made as experience dictates. There have been no changes this quarter.

In earlier quarterly reports (up to Quarterly Report 8), the data from the center of Bedford Basin (Station G2) was compared with data collected at a nearby site by the Bedford Basin Phytoplankton Monitoring Program (BBPMP), a project of the Department of Fisheries and Oceans at Bedford Institute of Oceanography. The BBPMP discontinued the summary time series contour plots that were used for comparison purposes. The data is still available in the form of individual profile plots and time series plots at selected depths. Selected points from the BBPMP dissolved oxygen (DO) profiles are now compared with the HHWQMP DO for purposes of ground truthing. The time series contour plots of the HHWQMP data in the centre of the Basin are instructive in the description of longer term variability in the harbour and are continued in the annual summary discussions in every fourth quarterly report.

From time to time, errors are discovered in the reports after they have been issued. An Errata/Changes section is included in the Introduction section of the report binder and is updated on a quarterly basis. In addition to errors the Errata/Changes section documents the changes in the sampling program and reporting.

3 Sampling Program

Survey sampling is done on a biweekly basis as of July 2006. Sampling is conducted from one of several vessels, operated by Connors Diving Services Ltd., based at the Armdale Yacht Club. The details of the sampling program are discussed in the introduction section of the project report binder and Quarterly Report 1. The locations of the 34 regular sampling sites are included in Figure 1. These sites are a combination of historically occupied sites (Jordan, 1972), some project specific sites and identified recreational (yacht club/beach) sites. Sampling involves the collection of continuous profile data and discrete water samples at 1 and 10 m water depth. The level of analysis varies from site to site as depicted in Figure 1: CTD only (CTD only stations); CTD and coliform bacteria (Coliform stations); or CTD, bacteria, and additional contaminant analysis (Chemistry stations). In addition to the regular sites, Figure 1 includes a sample site in Dartmouth Cove (DC), established in response to public concern. At this site, a 1 m water sample and profile data are obtained. The water sample is analyzed for the full suite of parameters. This site is sampled once a month during the summer. The "supplemental sample" procedure that has been established allows water samples to be taken at additional sites, based on visual observations, at the discretion of the field team.

Sampling protocol/sample handling has been dictated by experience and specific lab directions. CTD casts are performed according to the manufacturer's recommendation and data analysis follows standard procedures. These protocols are documented in the project binder with weekly and quarterly reports.

3.1 Program Changes

There have been no program changes this quarter. A summary of the sampling and analysis schedules and relevant established criteria in place at the end of eighteenth quarter (17 December 2008) are in Table 1. This table indicates that the carbonaceous biochemical oxygen demand ($CBOD_5$) and total oil and grease (TOG) analyses, discontinued from regular sampling due to lack of detection, are now performed only for "supplemental samples".

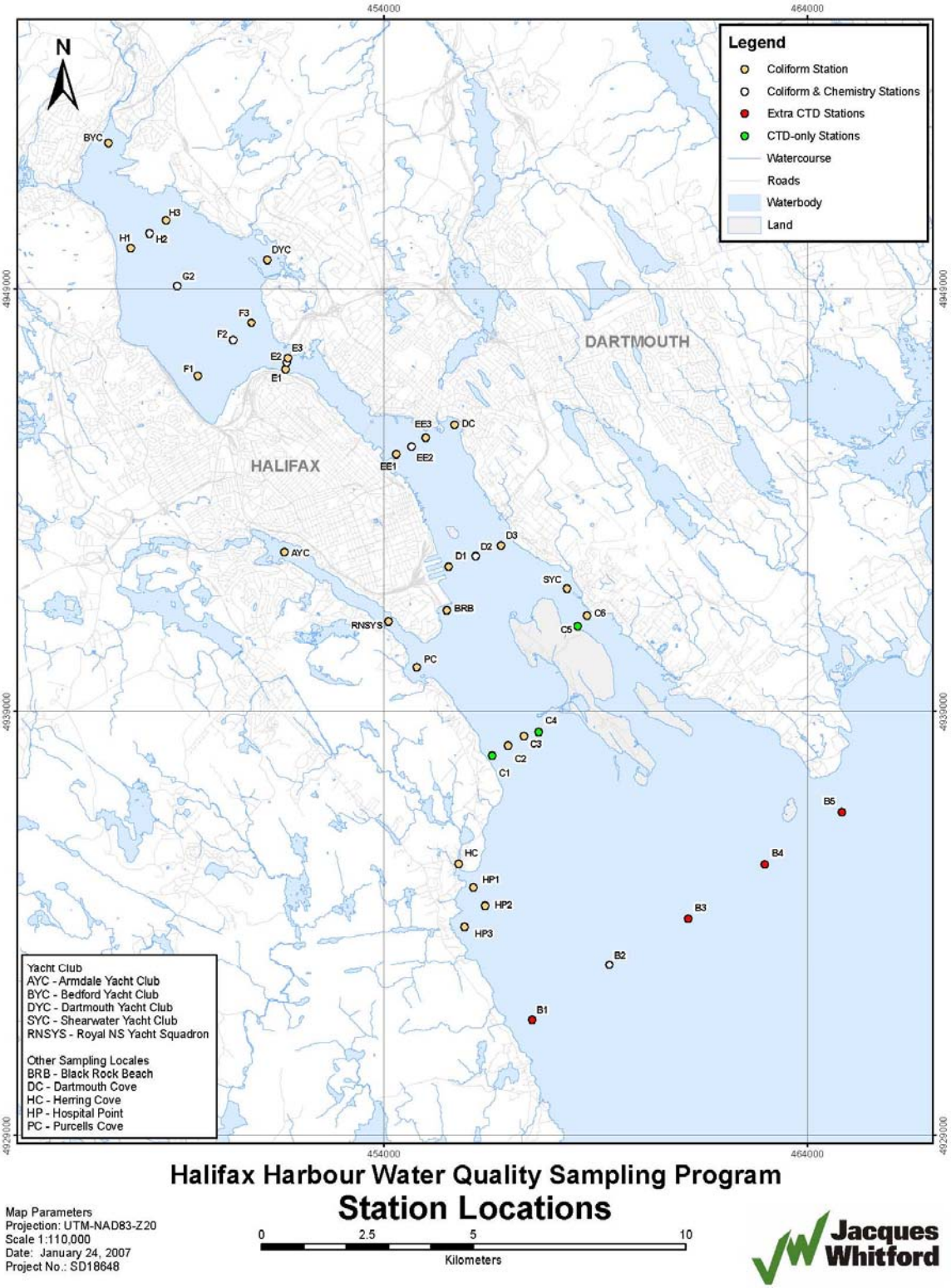

Figure 1. Halifax Inlet sample locations.

Table 1. Summary of measured parameters as of 17 December 2008.

	RDL		Harbour Task Force Guideline	Water Use Category	Sampling Stations (refer to Fig. 1)	Sampling frequency
	value	units				
Profile Data					All	biweekly
Salinity	n/a	PSU	n/a	n/a		
Temperature	n/a	C°	n/a	n/a		
Chlorophyll *a*	n/a	ug/L	n/a	n/a		
			8	SA		
Dissolved Oxygen	n/a	mg/L	7	SB		
			6	SC		
Secchi depth	n/a	m	n/a	n/a		
Bacteria Samples					Bacteria + Chemical	biweekly
Fecal Coliform	1	cfu/ 100mL	14	SA		
			200	SB		
			none	SC		
Chemical Samples						
CBOD	5	mg/L	none		Supplemental sites	unscheduled
Ammonia Nitrogen	0.05	mg/L	none		Chemical sites	bi-weekly
			<10%			
TSS	0.5	mg/L	background	all	Chemical sites	bi-weekly
Total Oil and Grease	5	mg/L	10	all	Supplemental sites	unscheduled
Metal scan						bi-weekly
Cadmium	0.1	ug/L	9.3	all	Chemical sites	
Copper	0.1	ug/L	2.9	all	Chemical sites	
Lead	0.1	ug/L	5.6	all	Chemical sites	
Manganese	1	ug/L	100.0	all	Chemical sites	
Nickel	0.5	ug/L	8.3	all	Chemical sites	
Zinc	1	ug/L	86.0	all	Chemical sites	
Mercury	0.01	ug/L	0.025	all	Chemical sites	
Cobalt	0.1	ug/L	none		Chemical sites	
Iron	1	ug/L	none		Chemical sites	

3.2 Supplemental Samples

Based on recommendations from Quarterly Report 2, a supplemental sample protocol has been instituted to take opportunistic samples of visible water quality features in the Harbour, or to document unusual discharge conditions (e.g. bypass etc). These samples are acquired on a discretionary and exploratory basis when an interesting feature, such as a visible front, plume, or patch of visibly deteriorated water quality is encountered. It is anticipated that these samples will have lower water quality than most normal samples. As such, the samples are processed for the full range of parameters specified at the beginning of the program, including parameters which have been eliminated from normal sampling due to lack of detection.

3.3 Sampling Order

Sampling generally occurs on Tuesday, with Wednesday and Thursday as contingency days. Every survey the sampling order is varied to minimize biasing the collected data with respect to known diurnal variations in sewage load and sunlight. A variable circuit is used that results in 'quasi' random sampling, subject to certain operational constraints. This procedure is discussed in Quarterly Report 1. Wind, waves and visibility can limit operations in the Outer Harbour. Each week, a primary and an alternate sampling route are provided to the field team. If the primary route has the Outer Harbour sampled early in the day, the alternate route will have it sampled late in the program. The decision on which route to take is made between the field team and the boat operator considering the weather forecast for the day. The sampling order for each survey in the eighteenth quarter is presented in Table 2.

From time to time survey sites are missed. There are many reasons why this might occur, the primary reason is generally weather conditions. The survey details are in the individual survey reports. Table 2 lists the missed stations and any additional samples (described above) for each survey.

3.4 Data Return

In addition to the missed sites detailed above, there were other sporadic data losses generally associated with quality control issues that were discovered during data processing. These are discussed in the individual survey reports. All factors considered the overall data return for the quarter is summarized in Table 3.

3.5 Sampling Bias

There are two issues regarding potential bias in the dataset. The first is the relative bias between sites, that is, whether the statistics from one site can be compared with those from another site. The second is the absolute bias with respect to the environmental forcing, or how well the dataset represents typical conditions in the Harbour. Our sampling has operational constraints that introduce a morning/early afternoon bias to the entire dataset. It is impractical to address this fully, except to document it. The following section is a first look at potential bias with respect to time of day, water level, and rainfall during the eighteenth quarter.

Table 2. Sample collection order (green sites are CTD only).

Date	23-Sep-08	7-Oct-08	22-Oct-08	5-Nov-08	19-Nov-08	3-Dec-08	17-Dec-08
Survey	165	166	167	168	169	170	171
1	C3	AYC	AYC	AYC	BRB	C2	AYC
2	C4	RNSYS	RNSYS	RNSYS	D1	C1	RNSYS
3	C6	PC	PC	PC	EE1	HC	PC
4	C5	C2	C2	B2	F1	HP1	B2
5	SYC	C1	C1	HP3	G2	HP2	HP3
6	D3	HC	HC	HP2	H1	HP3	HP2
7	D2	HP1	HP1	HP1	BYC	B2	HP1
8	EE3	HP2	C4	HC	H3	C3	HC
9	EE2	HP3	C3	C1	H2	C4	C1
10	E3	B2	BRB	C2	DYC	C5	C2
11	E1	C3	D1	C3	F3	C6	C3
12	E2	C4	EE1	C4	F2	SYC	C4
13	F3	C5	E1	BRB	E3	D3	BRB
14	F2	C6	E3	D1	E1	EE3	D1
15	DYC	SYC	E2	D2	E2	EE2	EE1
16	H3	D3	F1	EE1	EE3	E1	F1
17	H2	EE3	G2	EE2	EE2	E3	G2
18	BYC	F3	H1	E3	D3	E2	H1
19	H1	DYC	BYC	E1	D2	F3	BYC
20	G2	H3	H2	E2	SYC	F2	H3
21	F1	BYC	H3	F2	C5	DYC	H2
22	EE1	H1	DYC	F1	C6	H3	DYC
23	D1	H2	F3	G2	PC	H2	F3
24	BRB	G2	F2	H1	RNSYS	BYC	F2
25	C1	F1	EE2	H2	AYC	H1	E1
26	C2	F2	EE3	BYC		G2	E3
27	HC	E1	D2	H3		F1	E2
28	HP1	E3	D3	DYC		EE1	EE3
29	HP2	E2	SYC	F3		D2	EE2
30	HP3	EE1	C5	EE3		D1	D3
31	B2	EE2	C6	D3		BRB	D2
32	PC	D1		SYC		PC	SYC
33	RNSYS	D2		C6		RNSYS	C6
34	AYC	BRB		C5		AYC	C5
No data			HP2, HP3, B2		C1, C2, C3, C4, HC, HP1, HP2, HP3, B2		
Supplemental							

Table 3. Quarter eighteen data return.

Chemical	Target	Achieved	Percent Return
7 sites			
NH3	98	94	
TSS	98	94	
Metal Suite	98	94	
Mercury	98	94	
Total	**392**	**376**	**96%**

Bacteria	Target	Achieved	
28 sites			
F Coliform	434	413	
Total	**434**	**413**	**95%**

Profiles	Target	Achieved	
31 sites			
C-T	238	225	
Dissolved Oxygen	238	225	
Chlorophyll	238	225	
Total	**714**	**675**	**95%**
All data records	**1540**	**1464**	**95%**

3.5.1 Time of Day

Sewage flows have significant regular diurnal variations that can affect the water quality in the Harbour on short timescales. In residential areas there are generally two flow peaks a day, the largest occurring in the morning, and the second in the evening. In systems with relatively short flow distances these generally occur around 0800 – 0900 and 2100. In commercial areas the flows are much more uniform during the day and low at night. In addition to variations in sewage load, the most obvious diurnal variation is in sunlight. Sunlight is perhaps the major contributor to the die off of bacteria, and can have effects on other parameters, particularly chlorophyll (fluorescence) and dissolved oxygen. The short term variation in sewage load is primarily an issue in the Inner Harbour, relatively close to the outfalls, however sunlight affects the entire Harbour. In Halifax there is also a significant diurnal tidal component affecting water levels. This is considered in the subsequent section.

Figure 2 shows the sampling time at each site since the start of the program in June 2004. The data from the eighteenth quarter are shown in red. In this figure the sample sites are generally sorted from north to south. There are a few patterns that emerge that have been documented previously. The stations at the north end of Bedford Basin have a smaller range of sampling times. This is because logistics dictates that the surveys never start or end in the Basin. In general, the range of sampling times increases with distance south, a

function of travel time from the Armdale Yacht club in the Northwest Arm. Even if a site is sampled first, it still takes time to travel there. Given that sampling begins at the same time every week, these effects are unavoidable. Since each survey either begins or ends in the Northwest Arm there is a built in early morning/late afternoon bias there. The procedure for selecting routes based on weather conditions also introduces a morning/afternoon bias in the Outer Harbour. This quarter the Outer Harbour was sampled in the afternoon in all but one survey.

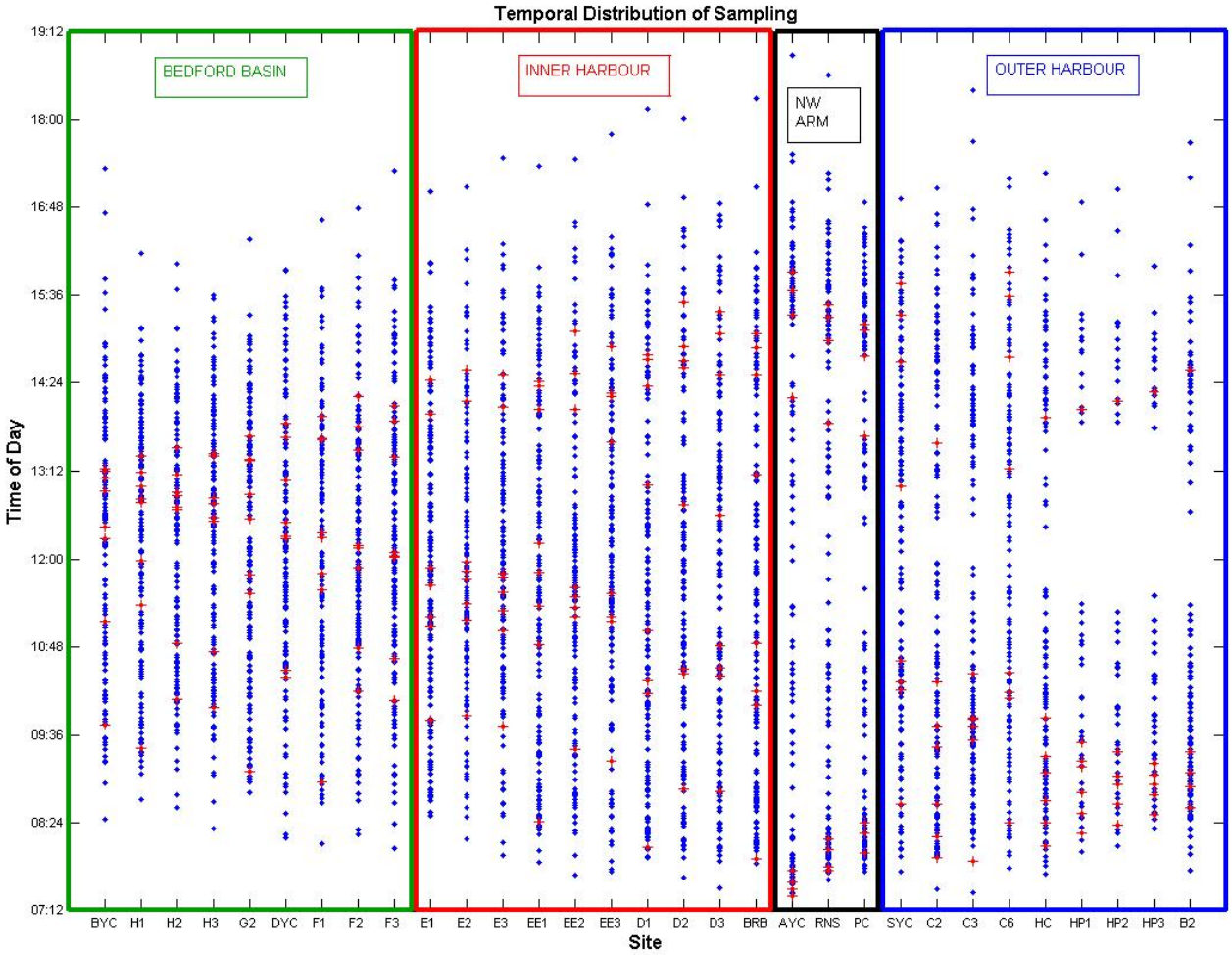

Figure 2. Temporal sampling distribution by site over entire program. Red markers denote points from 23 September to 17 December 2008.

3.5.2 Water Levels

The water level at the time of sampling can affect the results. The two most obvious considerations are whether a particular sample was taken upstream or downstream (based on flood/ebb direction) from the nearest outfall, and the variation in initial dilution, caused by variations in submergence depth, from shallow shoreline outfalls. These are both issues primarily in the Inner Harbour.

Water level variations in the Harbour are caused by the tides and meteorological forcing. The meteorologically-induced changes are mostly of longer period and, except in large storms, are much smaller in magnitude than the tides. Because of their longer duration, their effect on Harbour flushing can be significant and their impact on water quality may warrant investigation in the future. Note that the tidal currents in the Harbour are, for the most part, not that strong and may be overridden by local/regional meteorological effects (Hurlbut et al., 1990). This means, for example, that the surface current may not always be going out on a falling tide. However, the occurrence of surges is relatively random and the possibility of inducing a systematic sampling bias is small compared with that of the very regular higher frequency tides. The tides in Halifax Harbour are classified as semidiurnal, meaning that there are two high and two low tides in a day.

There is also a potential bias introduced by regular weekly/biweekly sampling. Sampling that occurs on the same day every second week could occur at the same point in the fortnightly tidal cycle (i.e. the same tidal range). An initial assessment of the tidal signal in Halifax Harbour indicates that the fortnightly cycle is sufficiently irregular (i.e. the tides are sufficiently "mixed"), that this problem is unlikely, particularly given the variation in sampling day (Tuesday or Wednesday, sometimes Thursday). This issue will be monitored and may be revisited more rigorously at a later time.

The probability distribution of water level (above chart datum) as derived from the tide gauge at the Naval Dockyard in Halifax (CHS station 490) for the period September to December 2008 is shown in Figure 3. In an ideal situation each site would be sampled in a distribution similar to the overall baseline distribution. Figure 4 shows the distribution of water levels at each site at the time of sampling (blue bars) compared to the overall water level distribution for the quarter, as represented by the red line recreated from Figure 3.

Because sampling has been switched to bi-weekly, the number of samples in a quarter has been roughly halved. Therefore a somewhat deteriorated representation of the water level range is inevitable. If more detailed analysis is performed, particularly in the Inner Harbour where water level/tidal phase is more important, the analysis may have to include the tidal phase explicitly. This quarter the water level distribution has been relatively well sampled at most sites. The exception is in the Basin where there is a high water bias.

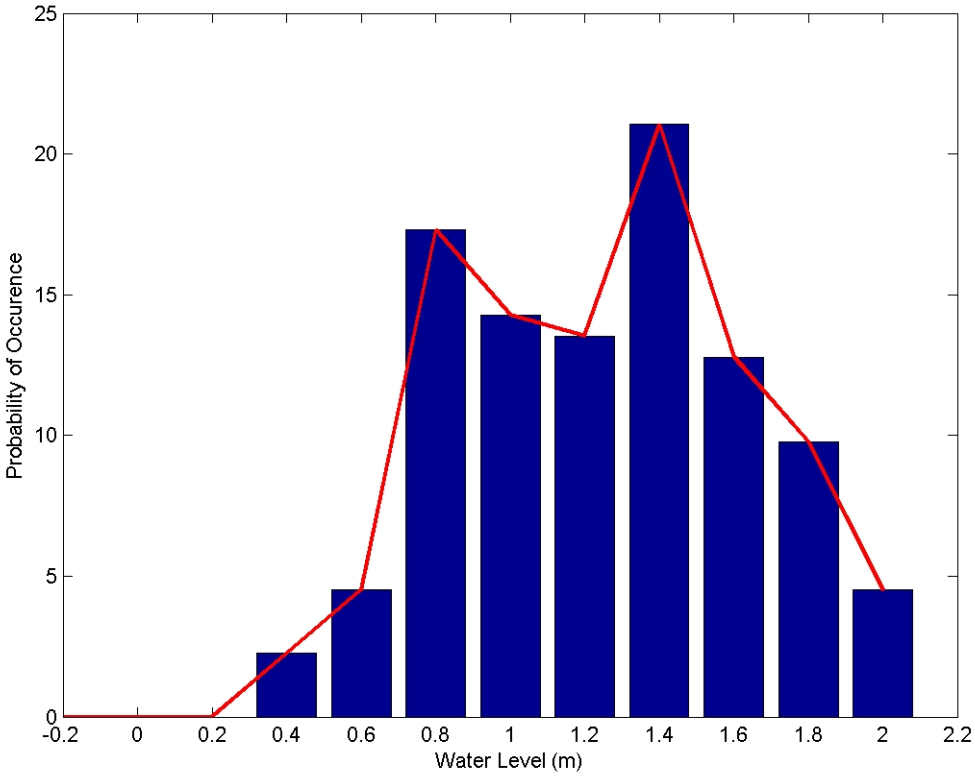

Figure 3. Probability distribution of water levels in Halifax, September to December 2008.

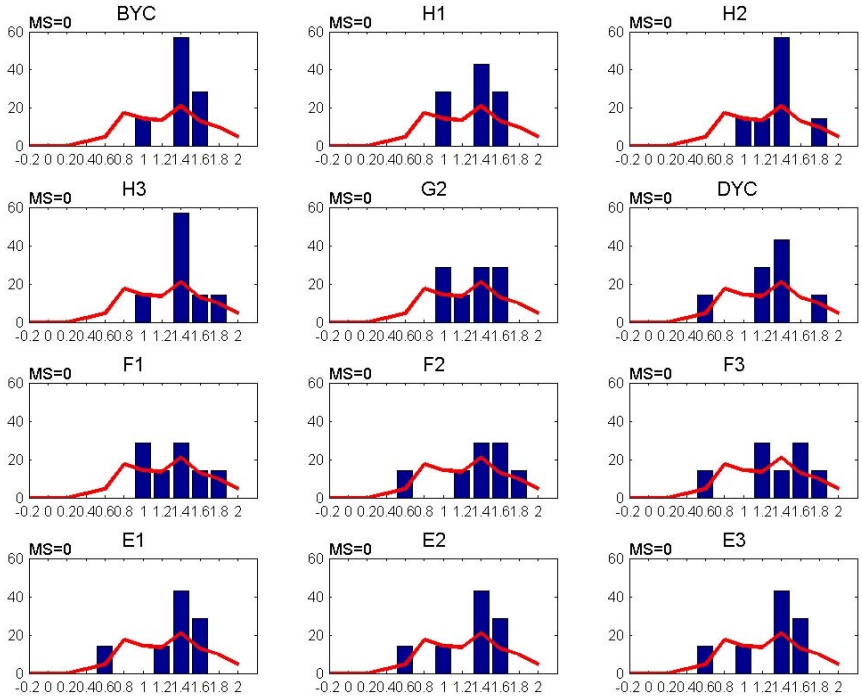

Figure 4a. Water level distribution at each site during sampling 23 September to 17 December 2008. Note: MS = Missed samples.

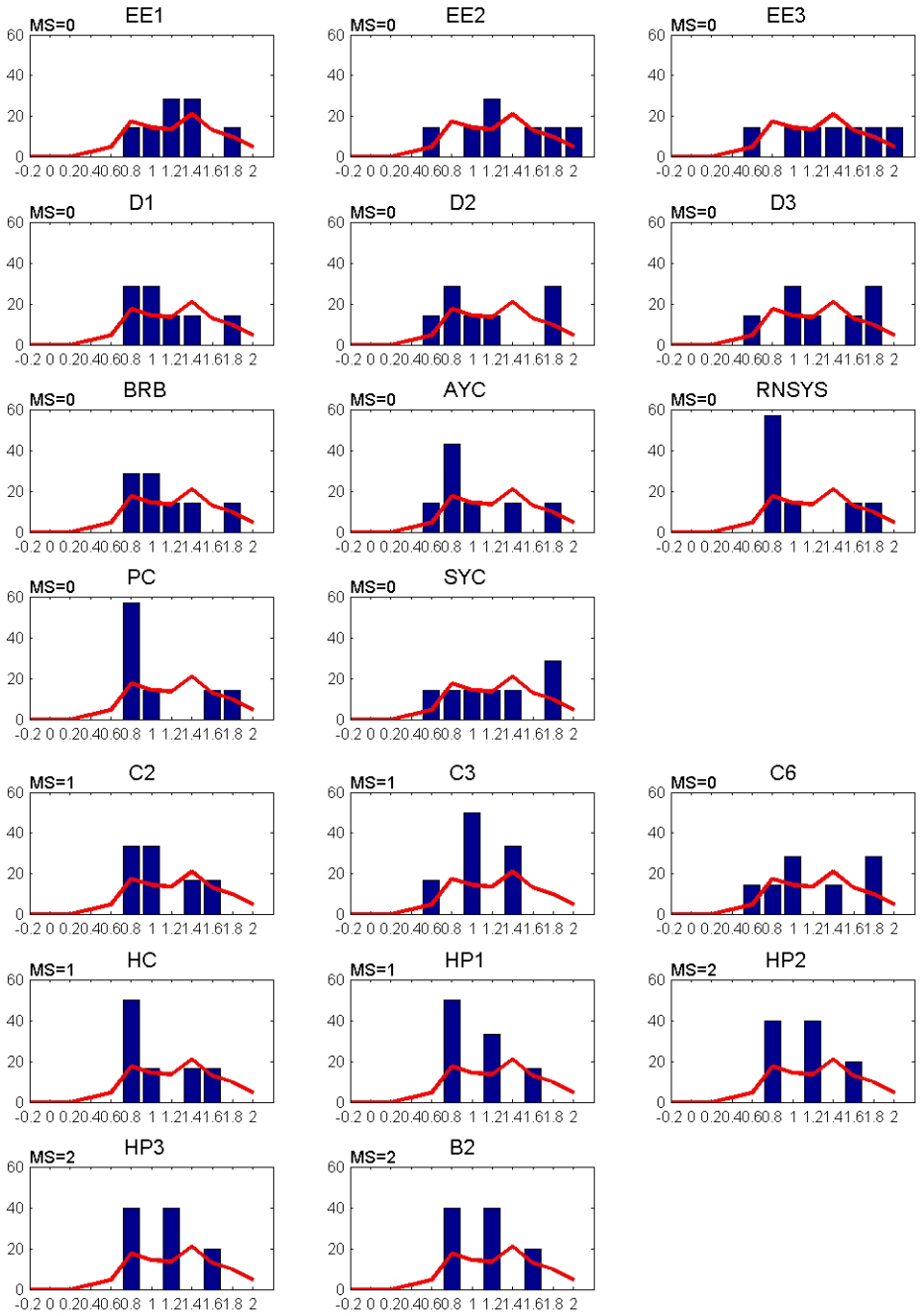

Figure 4b. Water level distribution at each site during sampling 23 September to 17 December 2008. Note: MS = Missed samples.

3.5.3 Precipitation

Rainfall affects both the sewage loads and the dynamics of the Harbour. In a combined sewer system, like in Halifax, increased flow due to a rainfall event can mobilize material that has collected in the sewer pipes in low flow conditions resulting in quite high loads. Additionally, in response to the increased fresh water input, the harbour can become more stratified, enhancing estuarine circulation. The combination of increased flow and stratification can have a significant effect on the near field behaviour of the plumes from the outfalls. These effects lag the rainfall and persist for a period of time after the rain stops. The duration of the impact, of course, depends on the magnitude of the rain event and the condition of the watershed. For purposes of discussion we have, somewhat arbitrarily, selected a three day (72 hour) precipitation window for our analysis. The red line in Figure 5 depicts the probability distribution of precipitation integrated over the current and previous two days for this quarter (23 Sept to 17 Dec 2008). The blue bars on this plot represent a similar analysis performed for sampling days only. The plot indicates that the precipitation distribution was relatively well sampled.

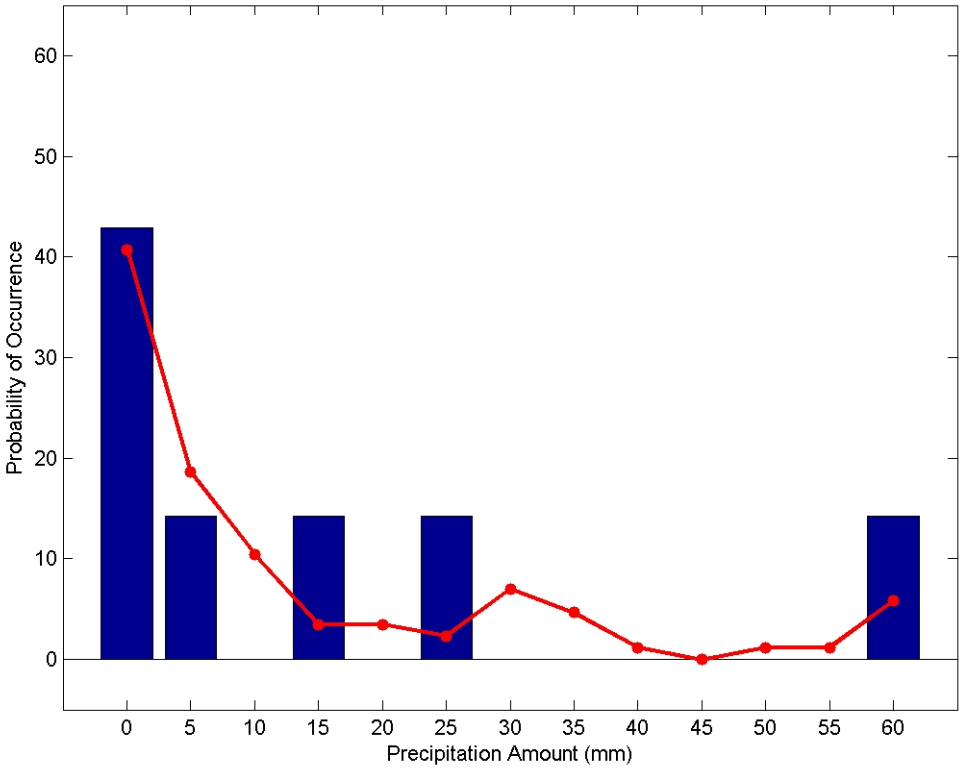

Figure 5. Probability distribution of cumulative 72 hour rainfall, 23 September to 17 December 2008.

4 Water Quality Results and Discussion

Results of the water quality sampling are discussed in the following sections with emphasis on compliance with water quality guidelines, and any need for modifications to the program. The final connections to the Dartmouth STP occurred just before the start of the quarter. Both the Halifax and Dartmouth plants are fully functioning.

4.1 Fecal Coliform

4.1.1 Out-of-Range Values

The adaptive lab procedure, using different fecal coliform detection ranges for different sites, developed as a result of previous recommendations, has reduced the number of out-of-range values significantly. For this quarter there is one out of range value in the 10m sample at EE1. This is the closest sample site to the Halifax STP outfall. The high value may be due to a malfunction of the disinfection system. It would not be expected that this would be a regular occurrence.

4.1.2 Quarterly Means

The Guidelines for Canadian Recreational Water Quality (GCRWQ) (Health and Welfare Canada 1992) evaluate the compliance with bacterial water quality criteria based on geometric mean. The geometric mean, G, of n values is defined as:

$$G(x_1,x_2,x_3,\ldots,x_n) = (x_1 \cdot x_2 \cdot x_3 \cdot \ldots \cdot x_n)^{1/n}$$

To compute geometric mean, some adjustments to the data are required. Zeros are not valid in the calculation, so ones (1's) are substituted for all zero values. The result of this is that there will be no zero counts reported at any site. An appropriate interpretation of a reported mean value of one, then, is that it is equivalent to "less than or equal to" one. Out of range values are reported by the lab as >10,000 in the units reflective of the resolution of the analysis being performed. For this analysis out of range values are replaced by 10,000.

Maps representing the geometric mean values over all samples for the eighteenth quarter are presented in Figure 6. In this figure, values in red exceed swimming guidelines (200 cfu/100 mL); values in blue exceed shellfishing guidelines (14 cfu/100 mL); and values in green indicate suitability for either activity. Separate maps are presented for the 1 and 10m samples.

These maps indicate that the geometric mean values over the quarter were well below the 200 cfu/100mL level at all sampling sites. Interestingly this includes the area around Herring Cove, an area normally affected by the Tribune Head outfall that remains untreated at this time. The magnitude of the concentrations and the spatial distribution is similar in both the 1 and 10m samples. This is likely at least in part to the increased vertical mixing of effluent due to the outfall diffusers.

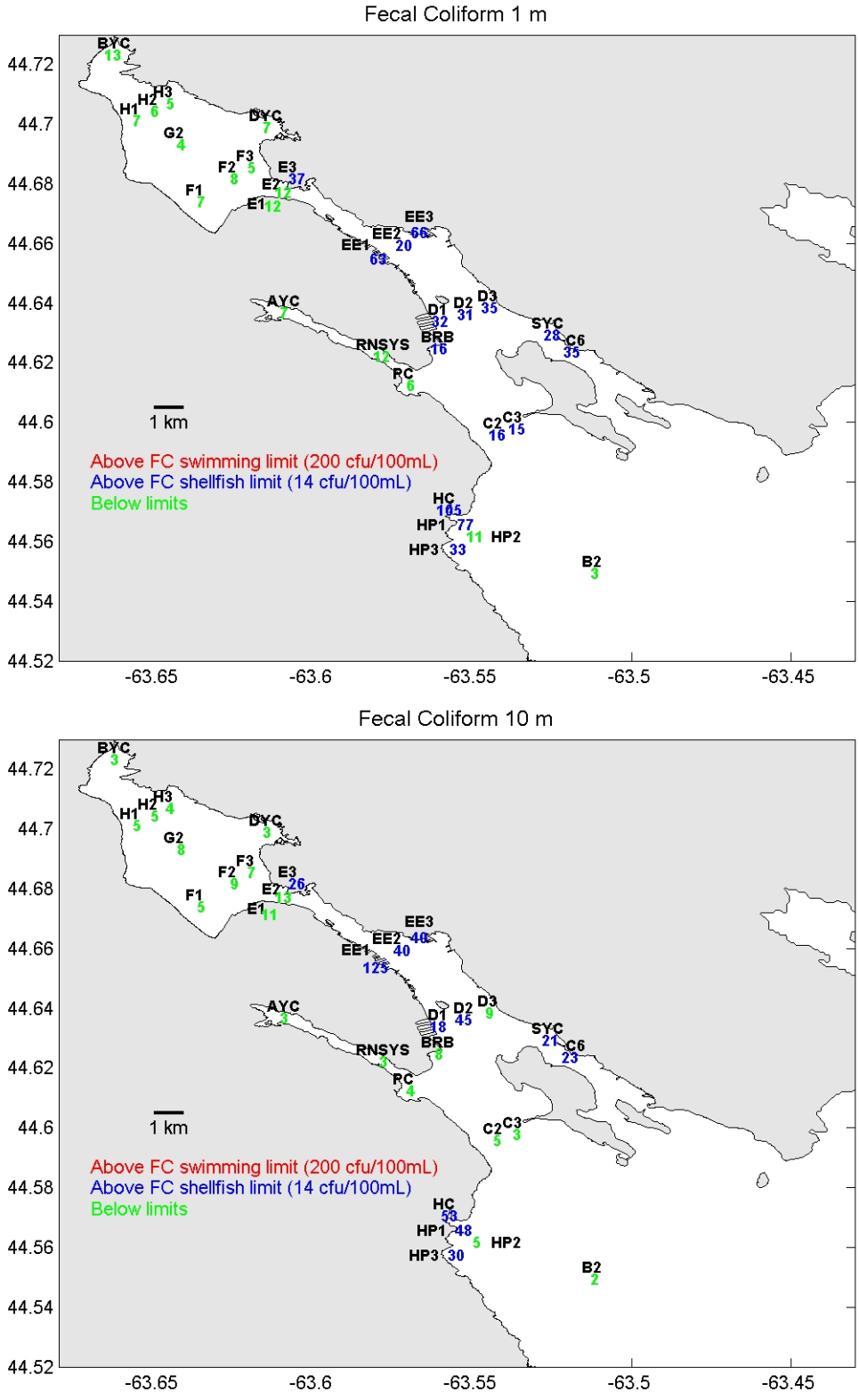

Figure 6. Fecal coliform geometric means (cfu/100mL) at 1m and 10m, 23 September to 17 December 2008.

4.1.3 Guideline Exceedance

As presented in Quarterly Report 1, the Harbour Task Force fecal coliform guidelines (Harbour Task Force, 1990) are interpreted using the methodology for swimming areas, presented in the Guidelines for Canadian Recreational Water Quality (Health and Welfare Canada, 1992). The recreational guidelines specify that in swimming areas, the geometric mean of at least five fecal coliform values taken within 30 days should not exceed 200 cfu/100mL, and any sample with values >400 cfu/100mL should trigger re-sampling. This strictly applies only to areas classified SB (recreational) by the Task Force (Table 1). The implications for areas classified SA and SC are discussed subsequently. The original weekly sampling regimen resulted in five samples within 30 days and allowed a fairly rigorous application of this analysis. The change to biweekly sampling in quarter nine means that the data do not meet the criteria of five samples within 30 days. The analysis is continued using a three sample floating average to meet the 30 day window but sacrifice the five sample criteria. We feel that the analysis, though no longer a rigorous application of the criteria, remains instructive.

Interpreting this procedure in our context results in a biweekly assessment, at three levels:

1. ACCEPTABLE, defined as a geometric mean <200 cfu/100mL
2. QUESTIONABLE, geometric mean <200 cfu/100mL but one or more samples >400 cfu/100mL
3. UNACCEPTABLE, geometric mean >200 cfu/100mL.

In the following discussion the terms “acceptable”, “questionable” and “unacceptable” will refer to these primary contact levels and not the Harbour Task Force SA, SB and SC guidelines. These guidelines will be discussed subsequently.

Tables 4 and 5 show the results of the analysis for the 1 m and 10 m samples respectively. The tables represent the floating 30 day geometric mean and, in parentheses, the number of samples (max 3) used in the average. The values are colour coded to represent acceptable (green), questionable (yellow) and unacceptable (red) levels. This quarter there were hardly any occurrences of “unacceptable” water quality. The few that do occur are either in the Inner Harbour, in section EE, or at the HP sites, near the Tribune Head outfall.

Task Force Guidelines

Most of the sites that historically were regularly deemed unacceptable for swimming are in the Inner Harbour that is classified SC by the Halifax Harbour Task Force. There are no Task Force limits on bacteria in this area. The greatest number of Task Force guideline exceedances, have normally occurred in the class SB areas just outside the Inner Harbour; that is, in the southern Basin, Black Rock Beach and the Northwest Arm, particularly the PC and RNSYS sites. In this quarter there were no class SB guideline exceedances. The Outer Harbour is the only region classified SA. This has a lower requirement (14 cfu/100 mL) than the swimming criteria. The sites within the Task Force

"Outer Harbour" boundaries are B2, HC and the HP section. This quarter HC (Herring Cove) never meets the SA guideline and the HP sites seldom meet the guideline. The plume from the Tribune Head outfall periodically affects these sites. This quarter, site B2 meets the SA criteria all of the time.

Table 4. 30 day geometric mean (number of samples) of 1 m fecal coliform concentrations (cfu/100 ml).

	Outer Harbour							Northwest Arm			Eastern Pass		Inner Harbour		
	B2	HP1	HP2	HP3	HC	C2	C3	PC	RNSYS	AYC	C6	SYC	BRB	D1	D2
Survey165	2 (3)	14 (3)	2 (3)	5 (3)	269 (3)	4 (3)	4 (3)	2 (3)	4 (3)	3 (3)	53 (3)	18 (3)	4 (3)	6 (3)	11 (3)
Survey166	3 (3)	76 (3)	8 (3)	3 (3)	230 (3)	9 (3)	16 (3)	1 (3)	5 (3)	3 (3)	38 (3)	37 (3)	6 (3)	16 (3)	31 (3)
Survey167	3 (2)	85 (3)	24 (2)	3 (2)	158 (3)	5 (3)	5 (3)	1 (3)	3 (3)	4 (3)	45 (3)	14 (3)	4 (3)	16 (3)	6 (3)
Survey168	3 (2)	490 (3)	24 (2)	70 (2)	50 (3)	18 (3)	14 (3)	3 (3)	8 (3)	7 (3)	32 (3)	21 (3)	18 (3)	49 (3)	26 (3)
Survey169	1 (1)	857 (2)	1 (1)	700 (1)	37 (2)	11 (2)	6 (2)	8 (3)	10 (3)	6 (3)	27 (3)	14 (3)	21 (3)	43 (3)	31 (3)
Survey170	3 (2)	229 (2)	5 (2)	265 (2)	17 (2)	70 (2)	73 (2)	19 (3)	27 (3)	10 (3)	18 (3)	27 (3)	82 (3)	187 (3)	166 (3)
Survey171	5 (2)	61 (2)	65 (2)	285 (2)	77 (2)	125 (2)	150 (2)	35 (3)	52 (3)	15 (3)	25 (3)	61 (3)	65 (3)	113 (3)	107 (3)

	Inner Harbour							Bedford Basin								
	D3	EE1	EE2	EE3	E1	E2	E3	F1	F2	F3	DYC	G2	H1	H2	H3	BYC
Survey165	10 (3)	18 (3)	8 (3)	40 (3)	2 (3)	3 (3)	38 (3)	1 (3)	1 (3)	1 (3)	6 (3)	1 (3)	2 (3)	2 (3)	2 (3)	6 (3)
Survey166	25 (3)	23 (3)	18 (3)	40 (3)	2 (3)	3 (3)	13 (3)	2 (3)	1 (3)	1 (3)	4 (3)	1 (3)	2 (3)	2 (3)	2 (3)	10 (3)
Survey167	7 (3)	20 (3)	8 (3)	50 (3)	4 (3)	4 (3)	9 (3)	1 (3)	5 (3)	1 (3)	2 (3)	2 (3)	2 (3)	1 (3)	1 (3)	4 (3)
Survey168	39 (3)	110 (3)	12 (3)	67 (3)	9 (3)	6 (3)	9 (3)	3 (3)	7 (3)	1 (3)	1 (3)	2 (3)	2 (3)	1 (3)	1 (3)	7 (3)
Survey169	33 (3)	183 (3)	20 (3)	119 (3)	29 (3)	22 (3)	33 (3)	9 (3)	17 (3)	3 (3)	3 (3)	5 (3)	3 (3)	3 (3)	3 (3)	9 (3)
Survey170	139 (3)	323 (3)	120 (3)	146 (3)	67 (3)	50 (3)	53 (3)	52 (3)	27 (3)	18 (3)	16 (3)	11 (3)	19 (3)	18 (3)	12 (3)	20 (3)
Survey171	107 (3)	127 (3)	80 (3)	105 (3)	98 (3)	97 (3)	155 (3)	97 (3)	85 (3)	81 (3)	59 (3)	50 (3)	111 (3)	84 (3)	43 (3)	57 (3)

Note: Red indicates exceedance of swimming criteria (geometric mean >200). Yellow denotes "questionable" water quality, resampling is indicated (mean < 200, but one or more samples >400). Green indicates compliance with criteria.

Table 5. 30 day geometric mean (number of samples) of 10 m fecal coliform concentrations (cfu/100 mL).

	Outer Harbour							Northwest Arm			Eastern Pass		Inner Harbour		
	B2	HP1	HP2	HP3	HC	C2	C3	PC	RNSYS	AYC	C6	SYC	BRB	D1	D2
Survey165	1 (3)	90 (3)	1 (3)	16 (3)	52 (3)	3 (3)	2 (3)	1 (3)	2 (3)	3 (3)	44 (3)	30 (3)	4 (3)	11 (3)	21 (3)
Survey166	2 (3)	103 (3)	1 (3)	13 (3)	39 (3)	3 (3)	3 (3)	1 (3)	1 (3)	1 (3)	18 (3)	6 (3)	5 (3)	10 (3)	38 (3)
Survey167	2 (2)	68 (3)	1 (2)	13 (2)	35 (3)	3 (3)	1 (3)	1 (3)	2 (3)	1 (3)	29 (3)	10 (3)	4 (3)	7 (3)	31 (3)
Survey168	4 (2)	25 (3)	6 (2)	55 (2)	36 (3)	1 (3)	1 (3)	2 (3)	2 (3)	1 (3)	21 (3)	19 (3)	6 (3)	25 (3)	46 (3)
Survey169	4 (1)	74 (2)	36 (1)	17 (1)	34 (2)	2 (2)	1 (2)	4 (3)	5 (3)	2 (3)	40 (3)	27 (3)	8 (3)	55 (3)	55 (3)
Survey170	3 (2)	12 (2)	20 (2)	18 (2)	17 (2)	20 (2)	4 (2)	9 (3)	6 (3)	4 (3)	25 (3)	24 (3)	23 (3)	101 (3)	104 (3)
Survey171	2 (2)	48 (2)	39 (2)	43 (2)	93 (2)	96 (2)	24 (2)	26 (3)	11 (3)	7 (3)	13 (3)	15 (3)	23 (3)	23 (3)	99 (3)

	Inner Harbour							Bedford Basin								
	D3	EE1	EE2	EE3	E1	E2	E3	F1	F2	F3	DYC	G2	H1	H2	H3	BYC
Survey165	1 (3)	100 (3)	15 (3)	26 (3)	2 (3)	3 (3)	7 (3)	2 (3)	3 (3)	3 (3)	2 (3)	4 (3)	3 (3)	2 (3)	1 (3)	3 (3)
Survey166	2 (3)	38 (3)	22 (3)	33 (3)	5 (3)	5 (3)	9 (3)	3 (3)	2 (3)	4 (3)	2 (3)	4 (3)	3 (3)	2 (3)	2 (3)	4 (3)
Survey167	3 (3)	38 (3)	17 (3)	58 (3)	7 (3)	5 (3)	18 (3)	2 (3)	3 (3)	4 (3)	1 (3)	5 (3)	2 (3)	1 (3)	1 (3)	3 (3)
Survey168	14 (3)	144 (3)	111 (3)	49 (3)	26 (3)	15 (3)	48 (3)	3 (3)	8 (3)	8 (3)	1 (3)	3 (3)	2 (3)	1 (3)	2 (3)	2 (3)
Survey169	22 (3)	311 (3)	136 (3)	50 (3)	32 (3)	20 (3)	68 (3)	5 (3)	24 (3)	10 (3)	4 (3)	5 (3)	5 (3)	5 (3)	5 (3)	2 (3)
Survey170	45 (3)	509 (3)	400 (3)	52 (3)	49 (3)	86 (3)	54 (3)	12 (3)	33 (3)	20 (3)	6 (3)	9 (3)	16 (3)	19 (3)	13 (3)	3 (3)
Survey171	45 (3)	135 (3)	40 (3)	49 (3)	24 (3)	39 (3)	51 (3)	14 (3)	37 (3)	16 (3)	15 (3)	38 (3)	21 (3)	48 (3)	18 (3)	6 (3)

Note: Red indicates exceedance of swimming criteria (geometric mean >200). Yellow denotes "questionable" water quality, resampling is indicated (mean < 200, but one or more samples >400). Green indicates compliance with criteria

4.2 Ammonia Nitrogen

Ammonia nitrogen is an important component in the nutrient balance in an estuary, and in high concentrations has potential for toxic effects; however, there is currently no marine water quality guideline for ammonia (CCME, 1999). The values obtained for this period are shown in Table 6. In addition, the quarterly mean and max values are plotted by station in Figure 7. The laboratory "reportable detection limit" (RDL) for ammonia nitrogen is 0.05 mg/L. For the purpose of computing statistics, the RDL/2, or 0.025 mg/L was used for values below detection. Missed samples are excluded from the calculations.

Ammonia Nitrogen has consistently been present at levels that are around the detection limit of 0.05 mg/L. This quarter 80% of samples had detectable concentrations. The overall mean concentration was about 0.8 mg/L. Overall, there does not appear to be a simple correlation between ammonia concentrations and meteorological events/oceanographic conditions, as is seen in the coliform data.

Table 6. Ammonia nitrogen summary (mg/L).
Note: green highlights indicate values below detection limits (0.05 mg/L). For statistics 0.025 mg/L was used for values below detection.

1m	B2	D2	EE2	E2	F2	G2	H2	mean	max
165 (23 Sep 08)	0.11	0.22	0.11	0.07	0.08	0.10	0.10	0.11	0.22
166 (7 Oct 08)	ND	ND	0.05	ND	ND	0.06	0.09	0.03	0.09
167 (22 Oct 08)	missed	0.10	0.11	0.11	0.13	0.09	0.10	0.11	0.13
168 (5 Nov 08)	ND	0.08	0.07	0.07	0.06	0.07	0.12	0.07	0.12
169 (19 Nov 08)	missed	ND	ND	ND	0.05	0.06	0.06	0.03	0.06
170 (3 Dec 08)	ND	0.08	0.07	0.07	0.06	0.07	0.12	0.07	0.12
171 (17 Dec 08)	ND	0.10	0.07	0.11	0.08	0.09	0.10	0.08	0.11
mean	0.04	0.09	0.07	0.07	0.07	0.08	0.10	0.07	
max	0.11	0.22	0.11	0.11	0.13	0.10	0.12		0.22

10m	B2	D2	EE2	E2	F2	G2	H2	mean	max
165 (23 Sep 08)	0.23	0.14	0.12	0.11	0.14	0.21	0.11	0.15	0.23
166 (7 Oct 08)	ND	ND	ND	ND	ND	0.09	0.08	0.02	0.09
167 (22 Oct 08)	missed	0.11	0.10	0.10	0.12	0.09	0.08	0.10	0.12
168 (5 Nov 08)	ND	0.11	0.09	0.08	0.07	0.08	0.09	0.07	0.11
169 (19 Nov 08)	missed	ND	0.42	0.05	0.06	0.06	0.07	0.11	0.42
170 (3 Dec 08)	ND	0.11	0.09	0.08	0.07	0.08	0.09	0.07	0.11
171 (17 Dec 08)	ND	0.13	0.05	0.09	0.08	0.06	0.08	0.07	0.13
mean	0.07	0.09	0.13	0.08	0.08	0.10	0.09	0.09	
max	0.23	0.14	0.42	0.11	0.14	0.21	0.11		0.42

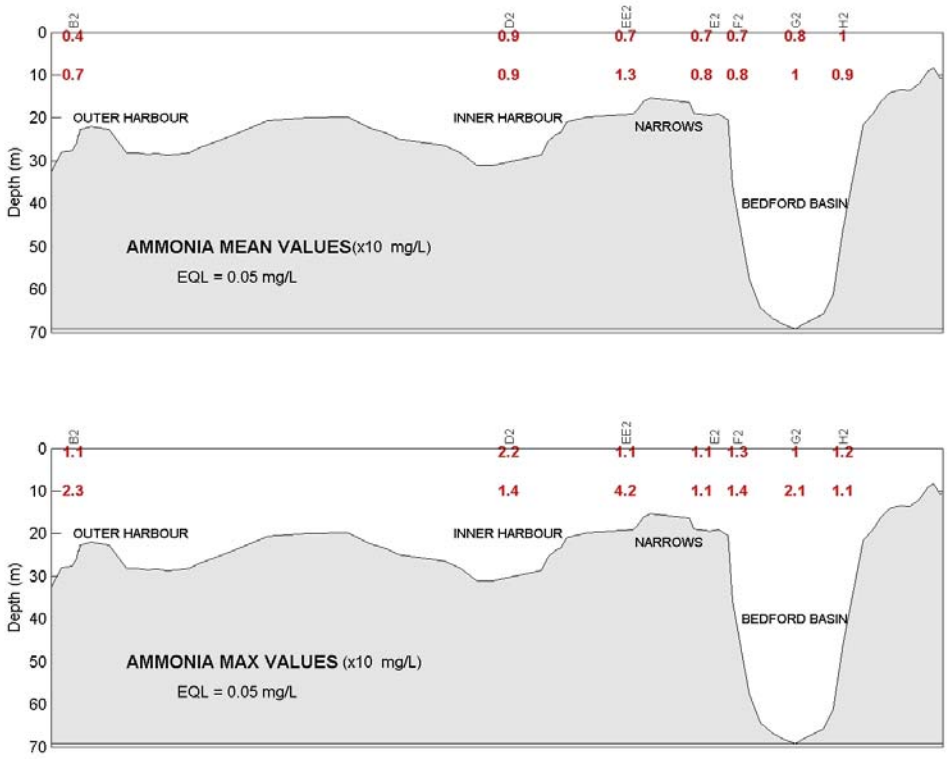

Figure 7. Mean and maximum values of ammonia nitrogen (X10 mg/L) over all eighteenth quarter samples.

4.3 Carbonaceous Biochemical Oxygen Demand

Further to a recommendation in Quarterly Report 2, $CBOD_5$ analysis for regular samples ceased on 25 May 2005, due to lack of detectable values. $CBOD_5$ analysis continues for supplemental samples, where there have been detectable values. There has been no $CBOD_5$ analysis this quarter.

4.4 Total Suspended Solids

A summary of the TSS values for this quarter is shown in Table 7. There were no samples that were below the RDL of 0.5 mg/L. The quarterly mean and max values are plotted by station in Figure 8. There is some temporal variability; about a factor of two or more in survey mean values. This quarter the levels are relatively low with an overall mean of about 2.5 mg/L. Overall, as with ammonia, there does not appear to be a simple correlation between TSS concentrations and meteorological events/oceanographic conditions. There are occasional higher values that seem to be associated with more extreme events (e.g. storms, plankton blooms etc). These events are generally identifiable visually and are usually documented in field notes.

Table 7. Summary of TSS data (mg/L).

1m	B2	D2	EE2	E2	F2	G2	H2	mean	max
165 (23 Sep 08)	1.8	2.9	2.0	1.9	3.6	2.3	6.8	3.0	6.8
166 (7 Oct 08)	1.0	2.0	2.0	3.0	3.0	4.0	2.0	2.4	4.0
167 (22 Oct 08)	missed	1.0	2.0	2.0	4.0	4.0	5.0	3.0	5.0
168 (5 Nov 08)	1.0	1.0	1.0	2.0	3.0	3.0	1.0	1.7	3.0
169 (19 Nov 08)	missed	4.2	3.2	4.1	4.4	1.8	3.6	3.6	4.4
170 (3 Dec 08)	1.0	1.0	1.0	2.0	3.0	3.0	1.0	1.7	3.0
171 (17 Dec 08)	1.1	2.0	2.0	2.3	2.0	5.0	5.0	2.8	5.0
mean	1.2	2.0	1.9	2.5	3.3	3.3	3.5	2.6	
max	1.8	4.2	3.2	4.1	4.4	5.0	6.8		6.8

10m	B2	D2	EE2	E2	F2	G2	H2	mean	max
165 (23 Sep 08)	4.1	2	2	1.5	1.5	2.9	4.5	2.6	4.5
166 (7 Oct 08)	4.0	3.0	3.0	5.0	2.0	6.0	1.0	3.4	6.0
167 (22 Oct 08)	missed	1.0	2.0	2.0	2.0	2.8	4.0	2.3	4.0
168 (5 Nov 08)	1.0	2.0	4.0	1.0	1.0	5.0	2.0	2.3	5.0
169 (19 Nov 08)	missed	1.5	1.8	2.7	3.0	2.2	2.3	2.3	3.0
170 (3 Dec 08)	1.0	2.0	4.0	1.0	1.0	5.0	2.0	2.3	5.0
171 (17 Dec 08)	0.9	5.0	1.0	5.0	2.0	2.0	1.0	2.4	5.0
mean	2.2	2.4	2.5	2.6	1.8	3.7	2.4	2.5	
max	4.1	5.0	4.0	5.0	3.0	6.0	4.5		6.0

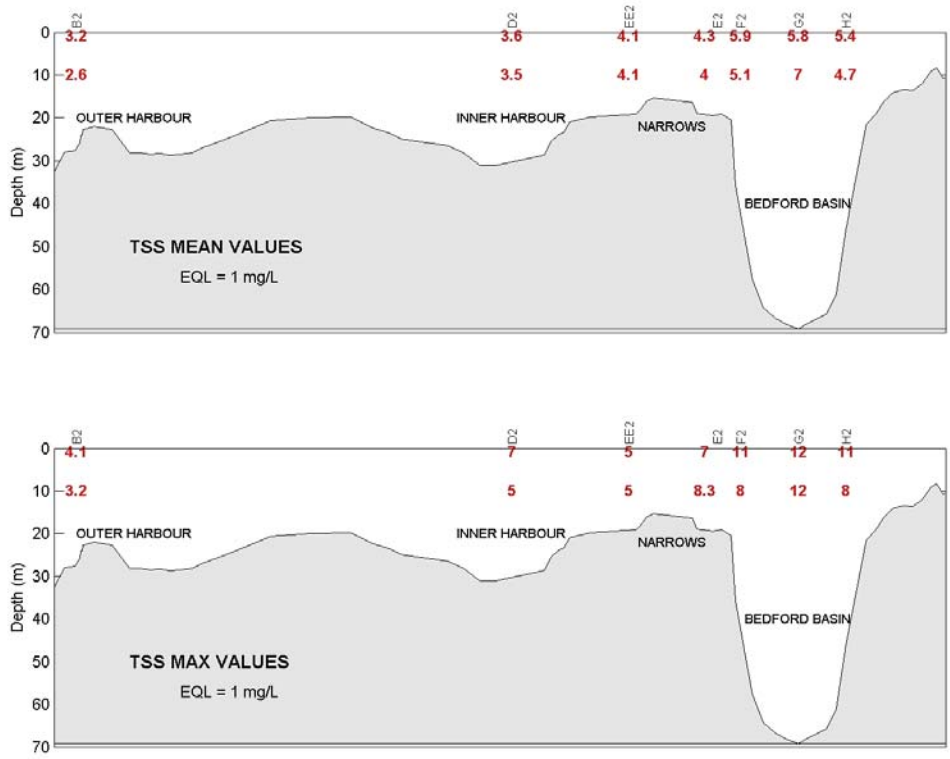

Figure 8. Mean and maximum values of total suspended solids (mg/L) over all eighteenth quarter samples.

4.5 Total Oil and Grease

Based on recommendations in Quarterly Report 5 regular sampling for total oil and grease was discontinued in, survey 73 (23 Nov 06). The analysis is retained for supplemental samples. This quarter there has been no total oil and grease analysis.

4.6 Metals

The results of the metals analysis are summarized in Figure 9. For this plot the non-detectable values are considered zero. Through the whole quarter there was a single copper guideline exceedance. In survey 169 (19 Nov 08), a copper concentration of 4.4 µg/L was recorded at site F2-10m. Aside from this sample, this plot shows that of the metals for which guidelines exist, copper, manganese and zinc regularly have detectable levels. Lead, nickel and mercury are occasionally detectable, while cadmium was not detected. Iron is regularly detected, but has no guideline. Note that cobalt is also measured but has no guideline and is not regularly detectable, so it is not reported. The metal regularly closest to the exceedance level is copper with a mean value under 20% of the guideline.

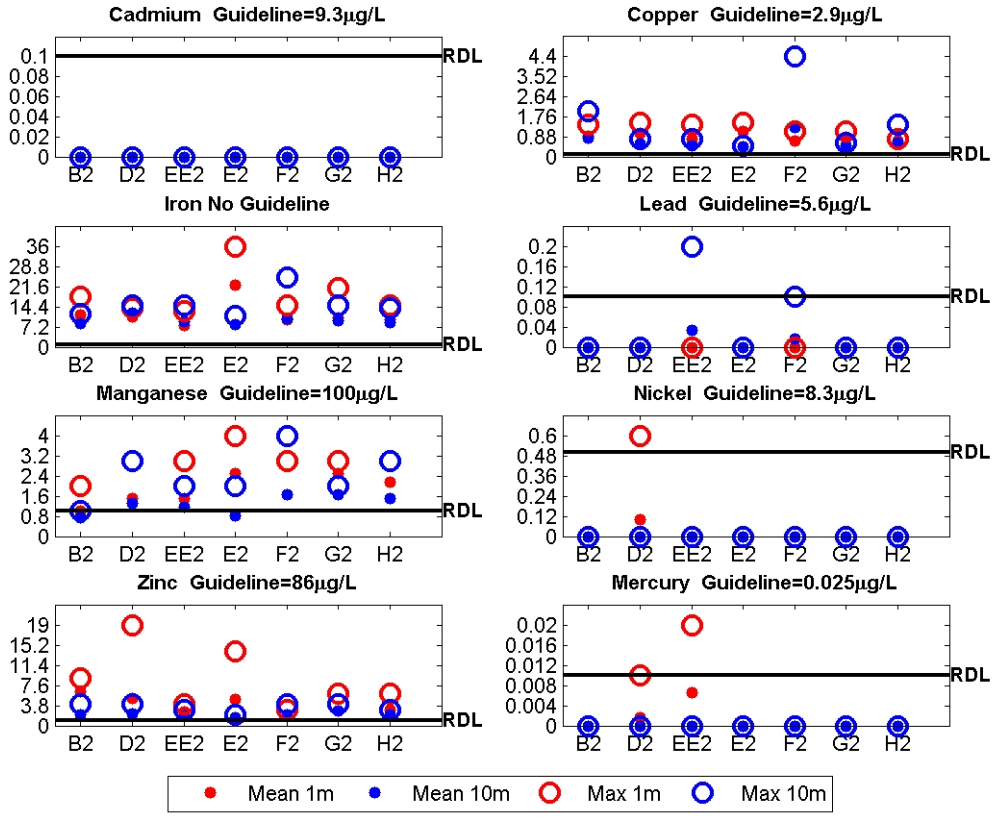

Figure 9. Mean and maximum values of metals (µg/L) over all eighteenth quarter samples.

4.7 Profile Data

The CTD used in this program measures continuous profiles of temperature, salinity, fluorescence and dissolved oxygen with depth. In early quarterly reports (up to Quarterly Report 8) the profile data was compared to the BBPMP data from the centre of Bedford Basin. This provided a check on the ranges and quality of the data collected for this survey. BBPMP has discontinued the time series contour plots so this comparison is no longer feasible. However, the contour plots of profile time series are useful in visualizing the longer term variation in the state of the harbour. These plots will be continued in the annual summary section of every fourth quarterly report (12, 16 and 20).

4.7.1 Salinity and Temperature

The temperature, salinity and density (derived from temperature and salinity) profile data provides valuable information on the physical state of the harbour that is very useful in interpreting the water quality data in the weekly surveys. The data is discussed in that context in the survey reports. As time series, the data is useful in characterizing changes in the state of the harbour on meteorological (storms etc) and seasonal timescales. The most interesting point is probably the centre of Bedford Basin as this reflects not only the near surface (upper 20 m) response to wind and rain, but also shows the effects of the periodic intrusion of dense shelf bottom water into the Basin (forced by local and shelf-wide meteorological events). This longer term variation is discussed in the annual summaries.

4.7.2 Fluorescence

The HHWQMP reported values of Chlorophyll *a* are un-calibrated, generated using the default values provided with the Seabird instrument software. As such, though the units are mg/m^3, they are really more of a measure of fluorescence than of a true measure of the mass concentration of phytoplankton. The conversion to biomass is highly dependant on many factors, including species and condition of plankton present, and is approximate even when fully calibrated with water samples. However, the un-calibrated fluorescence values can be useful when considered on a relative basis. This comparison is probably more valid within a survey, where conditions are more likely to be consistent over the harbour, than between surveys which occur under different conditions. The more separated in time and space, the more uncertain the comparison. Nonetheless, due to the large variability in natural plankton concentrations, the data provides useful information on the relative spatial and temporal variability of phytoplankton activity.

The phytoplankton in Halifax Harbour generally exhibit more or less typical estuarine behaviour in the winter. That is, low productivity (<5 mg/m^3) during the winter followed by the strongest bloom of the year (40-80 mg/m^3) as sunlight returns in the spring (typically March). After the spring bloom, when light is plentiful, the behaviour seems to be affected by anthropogenic nutrient input. There are sporadic phytoplankton blooms throughout the summer and into the fall. These blooms can be close to the spring bloom in magnitude (30-40 mg/m^3) and occur until the drop in light levels in late fall and winter. There is a less distinct fall bloom that does not appear to be significantly different in intensity, based on fluorescence, than the blooms occurring throughout the summer. Phytoplankton blooms tend to start in the Basin and migrate outward to the rest of the harbour. The profile maximum values, particularly in summer, generally decrease in magnitude and occur lower in the water column further out of the harbour. The data in the Basin generally represents the maximum concentrations observed and is representative of the timing of phytoplankton activity in the remainder of the harbour. During this quarter there were relatively consistent low fluorescence levels, with maximum values of 15-20 mg/m^3. At the end of the quarter the levels drop. In the final survey the maximum level observed was about 5 mg/m^3.

4.7.3 Dissolved Oxygen

Comparison between dissolved oxygen determinations by different methods/instruments has proven uncertain. Part of this uncertainty is due to the vagaries of the instruments themselves. Additionally, small variations in processing procedures, particularly with "alignment" procedures, that assign depths to the DO measurements obtained with the CTD, can add uncertainty. The CTD sensors are quite stable, but tend to lose sensitivity with time. Due to the nature of the CTD itself, they cannot be user calibrated. Starting with survey 151 (11 Mar 2008) near-surface DO concentrations have been measured using a handheld, easily calibrated, YSI DO meter. This data combined with available data from the BBPMP and the LOBO data buoy in the NW Arm, are used to calculate a scale factor for the CTD data. The YSI data and the scale factor computation are included in the individual survey reports.

The Harbour Task Force Class SA, SB and SC water use classifications have guidelines for dissolved oxygen of 8.0, 7.0 and 6.0 mg/L respectively. Class SA pertains to the Outer Harbour and Class SC pertains to the Narrows and Inner Harbour. The remainder of the harbour is classified as SB. Based on the appropriately scaled HHWQMP data, there was the usual persistent class SB exceedance in the deeper water in Bedford Basin. In addition to this, at the beginning of the quarter (survey 165, 23 Sep 08), there was relatively oxygen poor water at the bottom everywhere causing exceedances of class SA and SB guidelines at most sites. There was also some slightly oxygen depressed water (just under 8.0 mg/L) at the bottom in the Outer Harbour in survey 167 (22 Oct 08). These were the only guideline exceedances.

4.8 Supplemental Sample

There were no supplemental samples this quarter.

5 Summary

For each item, a brief statement of summary is provided along with any changes that occurred during the quarter and any new or ongoing issues.

5.1 Reporting

Survey Reports

The report analysis/presentation has been refined and is essentially in final form. There may be periodic changes required to accommodate any changes in data collection.

Changes
- None

Quarterly Reports

The quarterly report discussion is limited to the data of that quarter. Every fourth quarterly report includes a section reviewing the data over the last year. Each quarterly report contains a discussion of any supplementary samples taken in the quarter.

Changes
- None

5.2 Sampling Program

The sampling route selection continues as per the end of the ninth quarter. As of that time the routes were modified to always either start or end in the Northwest Arm, where the survey boat is based. This was done based on travel time considerations and does introduce an early morning/late afternoon bias into the NW Arm data. The morning sampling may coincide with the peak diurnal sewage flows and may result in a bias in water quality samples near the chain rock outfall (e.g. RNSYS, PC). This is also a function of the plume trajectory at the time of sampling. This should be considered in a detailed analysis of RNSYS and PC water quality data. Starting at the end of quarter 15, near-surface DO measurements have been made using a handheld YSI DO meter. This is used to ground truth the CTD DO sensor. The sampling sites remain as at the end of quarter 10. The last change has been the addition of the HP sites. The sample analysis remains the same as at the end of quarter nine. The last modification was the addition of the high resolution metals analysis.

Changes
- None

5.3 Water Quality Parameters

Fecal Coliform

In this quarter the both the Halifax and Dartmouth Sewage Treatment Plants were fully functional. This has resulted in very (relatively) low fecal coliform values in most of the harbour. There are no sites with quarterly geometric mean fecal coliform concentrations greater than 200 cfu/100 mL. The only real guideline exceedance is the class SA guideline near the Tribune Head outfall in the Outer Harbour.

As of quarter 10, there has been periodic additional bacteria monitoring initiated in the Northwest Arm. The purpose is to establish storm-induced transients in the Arm. This is not strictly part of this project and the data is reported under separate cover. However, the monitoring includes surface samples for both fecal coliform and enterococci. This data will allow a comparison of the two tracers and if desired to evaluate the use of fecal coliform for a proxy for enterococci in the Harbour. The current Canadian Environmental Quality Guidelines (ceqg-rcqe.ccme.ca) recommend enterococci over fecal coliform as a tracer of human waste contamination in salt water.

Changes
- None

Ammonia Nitrogen

Ammonia nitrogen has consistently been present at levels that are around the detection limit of 0.05 mg/L. There does seem to be some significant (i.e. greater than random) temporal variability but the reason is not clear. There does not seem to be a simple correlation between ammonia concentrations and meteorological/oceanographic conditions, as is evident in the coliform data.

Ammonia nitrogen is an attractive tracer as it is routinely monitored in sewage treatment facilities and, therefore, has quantifiable source strength in sewage. Recognizing nitrogen as the key nutrient in marine systems, and the potential importance that nutrients have in the Harbour oxygen dynamics, additional species of nitrogen should continue to be considered for monitoring.

Changes
- None

$CBOD_5$

Based on recommendations in Quarterly Report 2, $CBOD_5$ was dropped from regular analysis in survey 49 (25 May 2005). Until that time there were an insignificant number of regular samples with detectable $CBOD_5$ at the 5 mg/L level. $CBOD_5$ has been retained as a tracer for the supplemental sampling program. There was no $CBOD_5$ monitoring this quarter.

Changes
- None

Total Suspended Solids

The TSS values in the harbour are generally moderate with no obvious strong correlation in space or time with oceanographic or sewage loading conditions. This quarter the mean level was relatively low at about 2.5 mg/L. There are at times higher values that seem to be associated with more extreme events (e.g. storms, plankton blooms etc). These events are generally identifiable visually and are usually documented in field notes. The only clear spatial pattern is that the TSS is in general lower in the Outer Harbour at B2.

Changes:
- None

Total Oil and Grease

Based on recommendations in QR #5, total oil and grease was dropped from regular analysis in survey 75 (23 Nov 05), due to lack of detection. It is retained in supplemental sample analysis. There was no TOG monitoring this quarter.

Changes
- None

Metals

In general the metals with guidelines are present at levels well below the guidelines. The metal that is consistently closest to exceeding the guideline is copper. In this quarter the mean copper values are less than 30% of the 2.9 µg/L guideline. There were no guideline exceedances measured in this quarter. The current analysis is providing a reasonable assessment of the important metals concentrations in the Harbour.

Changes:
- None

Fluorescence

Un-calibrated fluorescence provides a relative measure of chlorophyll and hence phytoplankton activity throughout the Harbour. The HHWQMP data allows for the gross identification of phytoplankton activity and is particularly useful in the interpretation of the DO data. The fluorescence data could also be useful to add a spatial interpretation to the detailed phytoplankton analysis at the BBPMP site.

During this quarter there were relatively consistent moderate fluorescence levels until the last two surveys when the levels dropped to levels approaching the annual minimum values.

Changes
- None

Dissolved Oxygen

To date, oxygen levels as measured in the program, are generally relatively high in surface waters, and chronically low in the deep water of Bedford Basin. This is consistent with the existing understanding that Bedford Basin is a fjord, in which depressed oxygen in bottom water is typical. The appropriately scaled HHWQMP data indicates that there was the normal guideline exceedance in the Basin bottom water. Other than this, in the first half of the quarter there were occasions where the bottom water dropped below the class SA and even the class SB guideline.

Changes
- None

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