Sediment Quality in the Lower Miramichi River Estuary and Miramichi Bay – Results of a 2007 Survey

A Report To:

The Miramichi River Environmental Assessment Committee
Miramichi, New Brunswick

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May 2008

This study was supported by
Environment Canada's Science Linkage Program

Abstract

In the fall of 2007, the Miramichi River Environmental Assessment Committee, in partnership with Environment Canada under the Science Linkage program, conducted a sediment sampling survey in the lower estuary of the Miramichi River and in Miramichi Bay to compare sediment quality in these areas with results of previous sediment surveys as an evaluation of temporal improvements in environmental quality. A total of ten sediment samples were collected and delivered to the Environment Canada Environmental Science Centre in Moncton for analyses. The sediment samples were analyzed for organic contaminants including polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB), trace metals, mercury, ammonia, sulphide, redox and sediment toxicity. The grain size distribution and the total organic carbon content were also determined. Most of the samples consisted primarily of fine-grained sediments and had low levels of total organic carbon (< 3 %). PAH were detected in all samples and a few of the samples had concentrations of individual PAH that exceeded the Interim Sediment Quality Guidelines (ISQG) established by the Canadian Council of Ministers of the Environment (CCME). All samples had measurable quantities of trace metals and most of the samples had concentrations of cadmium and arsenic that exceeded the CCME ISQG. Mercury was detected in all of the samples but none of the concentrations exceeded the ISQG. The toxicity of the sediment samples was determined using the Microtox Solid Phase test and none of the samples was toxic to the luminescent bacteria used for that test. Overall, the sediment quality in the lower estuary and in Miramichi Bay was better than the sediment quality observed in the upper estuary during the previous surveys.

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1.0 Introduction

Previous environmental quality assessments conducted on Miramichi River sediments (MREAC, 1992; Parker, 2007) indicated that some areas of the river and estuary had elevated levels of heavy metals and organic contaminants, some of which exceeded the Interim Sediment Quality Guidelines established by the Canadian Council of Ministers of the Environment (CCME, 2002). There is reason to suspect that the observed elevated concentrations of these environmental contaminants in the river's sediments was due in part to some anthropogenic input or activities that have occurred or are still occurring in the watershed. The land use history of the Miramichi watershed includes physical impacts and possible contaminants generated from base metal mining, lumber harvesting, pulp and paper production, plywood fabrication, wood treatment, petroleum storage, log drives, commercial shipping, channel dredging and municipal sewage discharges.

Information about sediment quality in the lower estuary and in Miramichi Bay was practically nonexistent (Allen et al, 2007). As this portion of the watershed may serve as a depositional area for fine-grained sediments transported down the river, there was concern about the potential for these environmental contaminants to become elevated in the sediments of the lower estuary and in the bay. An assessment of sediment quality in the lower estuary and Miramichi Bay would provide additional information about the overall environmental quality in the Miramichi River watershed and would be valuable for the economic and social sectors of the community as a basis upon which to make decisions regarding utilization, development, or disturbance within the estuary.

Significant reductions of inputs have been occurring on the Miramichi estuary in recent years. These include:

- The closure of Heath Steele Mine site (2000) and cessation of stockpiling ore at Miramichi wharves,
- Major process improvements in the pulp and paper industry and ground-wood mill (the mills were closed in late 2007)
- Improved industrial processes in the OSB and plywood mills
- Commissioning of two high capacity sewage treatment facilities for the City of Miramichi (1998 & 2006)
- Sewage treatment improvements for several smaller municipalities (since 2000)
- Remediation of fifty-five failing on-site septic systems within the watershed since 1995.
- Improvements in forest management and wood harvesting policy

In 2007, the Miramichi River Environmental Assessment Committee (MREAC) applied for financial support through the Science Linkage program of Environment Canada to conduct a sediment quality study of the lower Miramichi River estuary and of Miramichi Bay. The study proposal was approved and a set of sediment samples was collected in the late summer of 2007. This report summarizes the results of the 2007 survey and compares the results of this most recent survey to the results of the previous surveys conducted upriver to provide an overall picture of sediment quality in the estuary of the Miramichi River.

2.0 MATERIAL AND METHODS

2.1 Sample Collection

On September 13 and 14, 2007, the Miramichi River Environmental Assessment Committee (MREAC) collected sediment samples from ten (10) locations in the lower Miramichi River estuary and in Miramichi Bay. The sampling stations were identified as Site 1 through to Site 10, generally from west to east (upriver to downriver). The geographical location of each sampling station was identified using a handheld Garmin GPSMAP76 (Global Positioning System). The geographical coordinates and the location of the sampling sites are provided in Table 2.1-1 and in Figure 2.1-1.

The sediment sampling began at on the morning of September 13, 2007 and proceeded from west to east down the estuary and out into the bay. Samples MREAC-2007-01 through to MREAC-2007-05 were collected on September 13 and samples MREAC-2007-06 through to MREAC-2007-10 were collected on September 14. The tide on both sampling days was high early in the morning (0830 on September 13 and 0913 on September 14) and was falling during the sampling survey.

At each sampling location, the boat was anchored and three or more samples of the sediment were collected using a 0.0625 m^2 Van Veen grab sampler. The top 5 centimetres were removed from the grab and placed in a large plastic bowl. The three aliquots were mixed together with a hand trowel and the homogenate was then used to fill the 2 sample bottles provided by the Environment Canada Environmental Science Centre:

- 500 mL amber glass jars for chemical measurements
- 250 mL plastic bottles for toxicity testing, redox ammonia, sulphide, grain size and total organic carbon measurements

The samples for chemical analyses and toxicity tests were transported to the Environment Canada Environmental Science Centre laboratory in Moncton, NB on September 14, 2007. The samples for toxicity tests were stored at 4 ± 2^{o}C until testing began.

2.2 Physical, Chemical and Toxicological Analyses

A portion of the toxicity samples in the 250 mL plastic bottle was used to determine the grain size distribution and the total organic carbon (TOC) content of each of the sediment samples. The remainder of the sample was used for the toxicity tests. The samples in the glass bottles were analysed for a variety of chemical constituents:

- Total polychlorinated biphenyls (TPCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Total trace metals
- Total mercury

The RPC laboratory in Fredericton, NB performed the grain size distributions and the determination of total organic carbon concentration. The Environment Canada Environmental Science Centre in Moncton, NB, conducted the measurements for TPCB, PAH, metals, mercury, redox, ammonia, sulphide and sediment toxicity. The analytical methods used by the laboratories are summarized in Table 2.1-2.

The toxicity of the sediment samples was determined using the bioluminescent bacteria, *Vibrio fischeri,* following the reference method described in Environment Canada (2002). The toxicity tests also included measurement of the concentrations of ammonia, sulphide and oxidation-reduction potential (Redox) on each of the 10 samples.

Table 2.1-1 Sediment sampling locations along the Miramichi River estuary and Miramichi Bay.

Location	Sample Identification	Latitude	Longitude
Downstream of Highway 11 Bridge	MREAC-2007-01	47°02.804'	65°27.556'
West of Middle Island	MREAC–2007-02	47°03.434'	65°27.182'
Loggieville near mouth of Black Brook	MREAC-2007-03	47°04.607'	65°22.017'
Napan Bay	MREAC-2007-04	47°04.095'	65°17.721'
Centre of Channel north of Carr Point	MREAC-2007-05	47°06.360'	65°12.370'
North shore near Rocky Point	MREAC-2007-06	47°09.372'	65°10.261'
Centre of Bay, north of Horton Creek	MREAC-2007-07	47°07.019'	65°08.879'
Bay du Vin	MREAC-2007-08	47°03.212'	65°09.651'
West of Portage Island	MREAC-2007-09	47°09.810'	65°05.417'
Baie Sainte - Anne	MREAC-2007-10	47°03.629'	64°59.121'

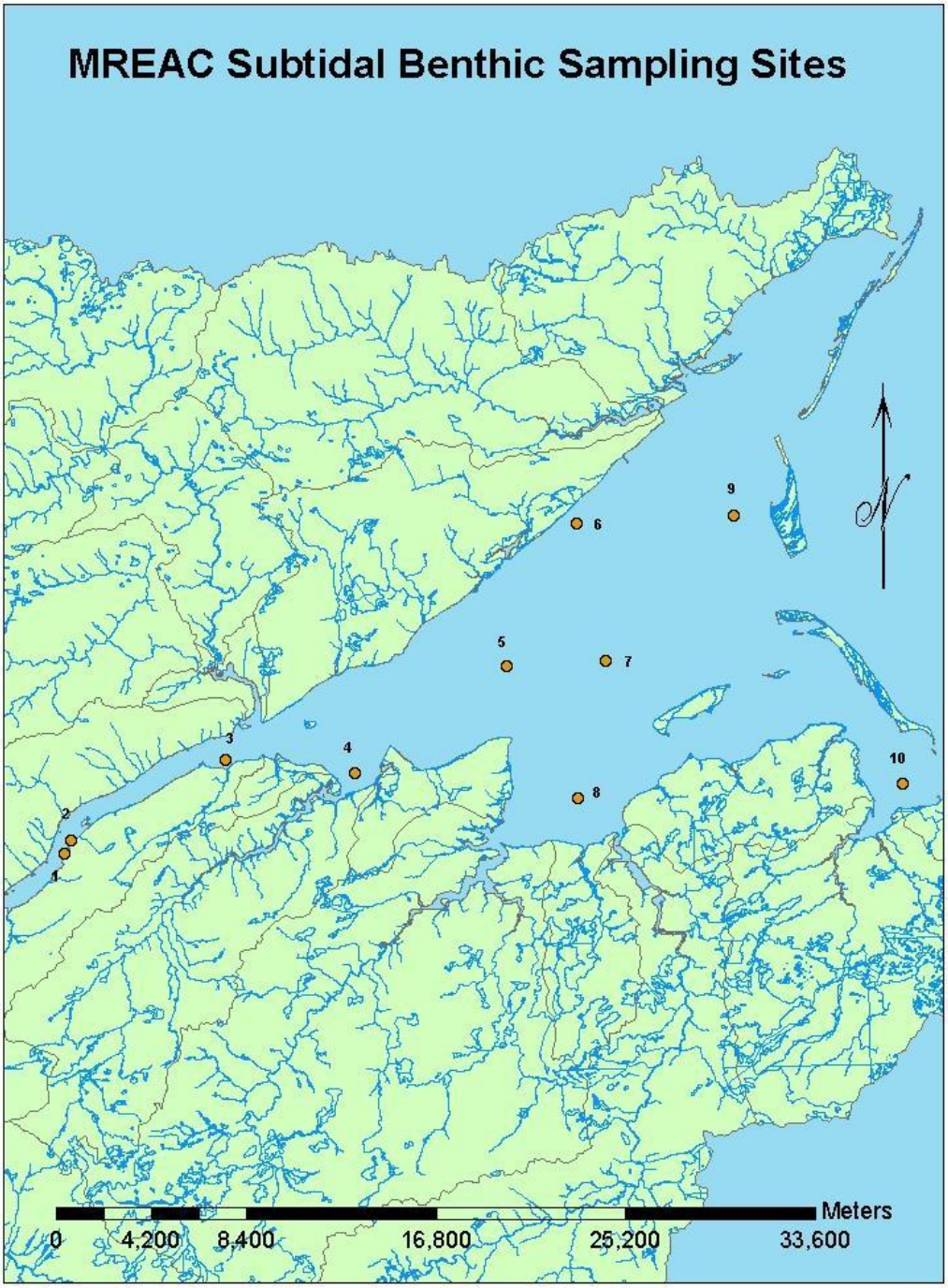


Figure 2.1-1 Sediment sampling locations for the 2007 survey conducted by MREAC.

Table 2.1-2 Methods used to conduct analyses of sediment samples collected from the Miramichi River in September 2007

Parameter	Analytical Laboratory	Method
Total PCB	Environment Canada, Moncton	USEPA 3000 series for sample preparation (3350 c for extraction, 3630c and 3640a for clean-up) USEPA 8082A for determination of concentration
PAH	Environment Canada	USEPA 3000 series for sample preparation (3350 c for extraction, 3630c and 3640a for clean-up) USEPA 8270D for determination of concentration
Trace Metals	Environment Canada	USEPA 3050B
Mercury	Environment Canada	USEPA 7470a
Grain Size	RPC, Fredericton	Sieve & Pipette (Walton - "Methods for Sampling and analysis of Marine Sediments and Dredged Materials" - Feb. 1978)
TOC	RPC, Fredericton	HCl fume pretreatment, Leco combustion/infrared (EPA/620/R-95/008 EMAP: Laboratory Methods Manual
S, NH_4, Redox	Environment Canada, Moncton	Atlantic Laboratory for Environmental Testing Standard Operating Procedure: Measurement of Redox, Ammonia and Sulfides in Sediments and Water Document I.D. SOP-TOX29 Creation Date Feb. 14, 1996 Revision Number 6

3.0 RESULTS

3.1 Physical Properties

The results of the grain size distribution measurements and the total organic carbon content are provided in Table 3.1-1. All of the samples contained some sand with the percentages ranging from 16.9 % in sample MREAC-2007-06 up to 94.0 % in sample MREAC-2007-09. Most of the samples had more than 35 % silt with the exception of MREAC-2007-02 that contained only 10.5 % silt and MREAC-2007-09 that had only 2.3 % silt. All of the samples had less than 10 % gravel. Most of the samples had between 10 % and 30 % clay content again with the exception of MREAC-2007-02 that contained only 4.4 % clay and MREAC-2007-09 that had only 3.7 % clay.

The sediment samples were of three distinct types (Figure 3.1-1). Samples MREAC-2007-02 and MREAC-2007-09 were predominantly sand. Samples MREAC-2007-01, MREAC-2007-08 and MREAC-2007-10 were about half sand and half fine-grained material. The remaining samples were primarily finer grain material (silt & clay). Generally, fine-grained sediments are indicative of depositional areas with slower current velocities and sand is found in areas with stronger currents.

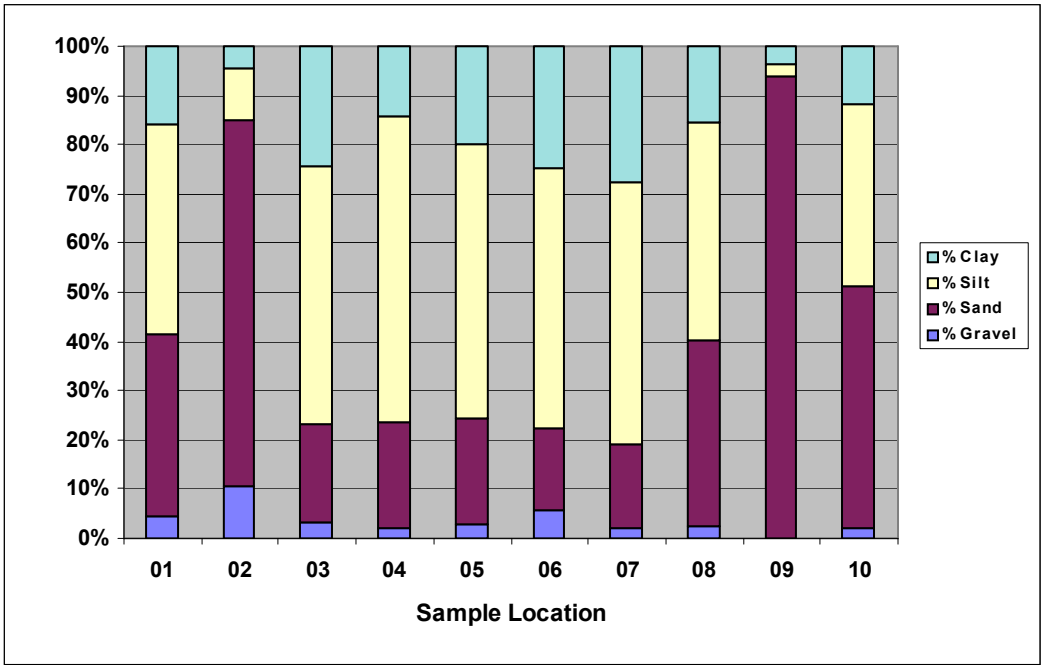
Most of the samples had total organic carbon levels of 1.6 to 4.2 percent again with the exception of the predominately sand sediments, MREAC-2007-02 and MREAC-2007-09, which both contained less than 1 % TOC.

Table 3.1-1 Grain size characteristics and total organic carbon content of sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007.

Sample Location	% Gravel [a]	% Sand [b]	% Silt [c]	% Clay [d]	TOC (%)
MREAC-2007-01	4.4	37.3	42.4	15.9	3.5
MREAC–2007-02	10.4	74.7	10.5	4.4	0.8
MREAC-2007-03	3.2	20.0	52.5	24.4	4.2
MREAC-2007-04	2.1	21.5	62.1	14.3	2.5
MREAC-2007-05	2.9	21.3	55.8	20.0	2.8
MREAC-2007-06	5.5	16.9	52.6	24.9	2.6
MREAC-2007-07	2.2	17.0	53.2	27.6	2.6
MREAC-2007-08	2.2	38.1	44.3	15.4	1.6
MREAC-2007-09	0.0	94.0	2.3	3.7	0.2
MREAC-2007-10	2.1	49.2	37.1	11.7	1.6

a - percentage of particles in test material > 2.0 mm
b - percentage of particles in test material >0.063 to 2.0 mm
c - percentage of particles in test material > 0.004 to 0.063 mm
d - percentage of particles in test material <0.004 mm

Figure 3.1-1 **Grain size distributions for sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007.**



3.2 Chemical Properties

Analytical results for individual PAH are provided in Appendix Table A-1. A summary of these analytical results for total polyaromatic hydrocarbons (TPAH) is presented in Table 3.2-1. The results for each measured PAH have been summed to give the total PAH values for each sample and these ranged from 26.5 ng/g (parts per billion) in MREAC-2007-09 up to 573.8 ng/g in MREAC-2007-03. Naphthalene, acenaphthylene and acenaphthene were not detected in any of the samples and dibenzo (a, h) anthracene was only detected in 2 samples. The highest concentrations of any of the PAH measurements were in MREAC-2007-01 that had 121.4 ng/g of fluoranthene and 107.8 ng/g of pyrene.

Total PCB was not detected in any of the samples. The detection limit for these measurements was 10 ng/g (ppb).

The results of the analyses for total metal content in the sediment samples are presented in Table 3.2.2. The laboratory analysed the samples for ten different trace metals and all of these were detected in all samples with the exception of titanium, which was not present in any of the samples. Concentrations of arsenic ranged from non-detectable in MREAC-2007-09 up to 14.9 ug/g in MREAC-2007-01. Concentrations of cadmium ranged from 1.1 ug/g up to 5.4 ug/g. Cobalt concentrations ranged from 11.2

ug/g to 32.3 ug/g and chromium concentrations ranged from 8.8 ug/g to 30.5 ug/g. Copper concentrations ranged from 3.1 ug/g up to 17.6 ug/g and nickel values ranged from 9.8 ug/g to 30.3 ug/g. Lead concentrations were all below 13.1 ug/g and lead was not detected in three of the samples. Vanadium was present in all samples with concentrations ranging from 11.0 ug/g up to 43.4 ug/g. Zinc was present in the highest concentrations of all the metals measured with values ranging from 22.5 ug/g up to 117.2 ug/g.

Mercury was detected in 9 of the 10 samples (Table 3.2-3). Sample MREAC-2007-09 did not contain a detectable concentration of mercury (< 0.02 ppm). Mercury values were low and ranged from 0.02 ug/g up to 0.09 ug/g.

The results of the measurement of ammonia, sulphide and redox are presented in Table 3.2-4. The ammonia values ranged from 7.9 to 58.3 ug/g (ppm). The sulphide levels ranged from 24.0 to 105 ug/g and the redox values ranged from –134 to 89 mV.

Table 3.2.1 Total PAH content in sediment samples collected from the Miramichi River estuary and Miramichi Bay In September 2007.

Sampling Location	Total PAH, ng/g (dry weight)
MREAC-2007-01	546.1
MREAC–2007-02	333.5
MREAC-2007-03	573.8
MREAC-2007-04	136.1
MREAC-2007-05	288.8
MREAC-2007-06	221.7
MREAC-2007-07	164.7
MREAC-2007-08	169.8
MREAC-2007-09	26.5
MREAC-2007-10	211.8

Table 3.2-2 **Metal concentrations in sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007. All results reported as ug/g dry weight (parts per million). Shaded values exceed the ISQG.**

Sample Location	Arsenic	Cadmium	Cobalt	Chromium	Copper	Nickel	Lead	Titanium	Vanadium	Zinc
MREAC-2007-01	14.9	2.1	28.1	23.4	16.6	21.8	13.1	<2.5	31.1	117.2
MREAC–2007-02	3.7	3.4	12.0	9.9	4.8	9.8	3.4	<2.5	12.7	43.4
MREAC-2007-03	12.1	1.6	27.9	28.4	14.8	24.9	10.8	<2.5	35.6	105.5
MREAC-2007-04	7.8	5.4	22.4	20.5	10.7	18.7	6.2	<2.5	26.4	68.7
MREAC-2007-05	12.9	1.8	28.2	28.8	15.0	26.7	10.4	<2.5	36.8	95.7
MREAC-2007-06	14.0	1.2	30.3	29.5	16.7	28.5	10.2	<2.5	42.9	95.5
MREAC-2007-07	13.6	1.4	32.3	30.5	17.6	30.3	11.3	<2.5	43.4	96.0
MREAC-2007-08	9.4	2.4	24.9	21.8	13.4	22.0	8.7	<2.5	30.5	81.6
MREAC-2007-09	<2.5	5.1	11.2	8.8	3.1	10.1	<2.5	<2.5	11.0	22.5
MREAC-2007-10	6.0	1.1	21.7	18.2	9.8	19.3	<2.5	<2.5	24.4	55.8
CCME ISQG	7.24	0.7	n/a	52.3	18.7	n/a	30.2	n/a	n/a	124
CCME PEL	41.6	4.2	n/a	160	108	n/a	112	n/a	n/a	271

Table 3.2-3 **Mercury concentrations in sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007. All results reported as ug/g dry weight (parts per million)**

Sample Location	Mercury, ug/g
MREAC-2007-01	0.08
MREAC–2007-02	0.02
MREAC-2007-03	0.09
MREAC-2007-04	0.04
MREAC-2007-05	0.06
MREAC-2007-06	0.06
MREAC-2007-07	0.05
MREAC-2007-08	0.05
MREAC-2007-09	<0.02
MREAC-2007-10	0.03
CCME ISQG	0.13
CCME PEL	0.7

Table 3.2-4 **Concentrations of ammonia and sulphide and the results of redox measurements on sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007**.

Sample Location	Sediment ammonia, ug/g (dry weight)	Sediment sulphide, ug/g (dry weight)	Redox, mV
MREAC-2007-01	14.8	64.4	89
MREAC–2007-02	12.0	24.0	- 1
MREAC-2007-03	38.8	101	- 43
MREAC-2007-04	12.5	53.6	- 71
MREAC-2007-05	20.7	54.7	11
MREAC-2007-06	24.3	105	- 68
MREAC-2007-07	58.3	67.4	- 94
MREAC-2007-08	7.9	23.5	- 37
MREAC-2007-09	13.9	27.6	89
MREAC-2007-10	15.5	95.4	- 134

3.3 Sediment Toxicity Tests

The Environment Canada laboratory reported the results of the sediment toxicity tests using the bioluminescent bacteria *Vibrio fischeri* in January 2008 (Jackman & Doe, 2008). The results are summarized here in Table 3.3-1. The full details of the test method used and the analyses of the results are provided in the Environment Canada report.

The end point for the Microtox solid phase toxicity tests is expressed as an IC50 which is the concentration of sediment (mg of sediment (dry weight) per litre of diluent water) that cause a 50 % reduction in the amount of light emitted by the luminescent bacteria, *Vibrio fischeri*. The IC50's for the toxicity tests on the 2007 samples of sediment from the lower Miramichi estuary and Miramichi Bay ranged from 1390 mg/L up to > 114,000 mg/L.

Environment Canada uses two interim guidelines to interpret the toxicity test results and to judge if the tested sediment is toxic to the luminescent bacteria (Environment Canada 2002). Using these criteria, none of the sediments would be considered to be toxic as measured by the Microtox solid phase toxicity test (Jackman and Doe, 2008).

Table 3.3-1 Results of sediment toxicity tests conducted on sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007

Sample Location	IC50	95 % Confidence Interval
MREAC-2007-01	1980	1640 – 2390
MREAC–2007-02	> 114,000	n/a
MREAC-2007-03	1880	1800 - 1960
MREAC-2007-04	27,700	23,400 – 32,700
MREAC-2007-05	6830	6340 – 7350
MREAC-2007-06	1390	1320 – 1470
MREAC-2007-07	2300	1660 – 3170
MREAC-2007-08	31,900	28,000 – 36,400
MREAC-2007-09	21,200	19,700 – 22,700
MREAC-2007-10	25,300	25,300 – 56,700

4.0 DISCUSSION

4.1 Sediment Grain Size and Total Organic Carbon

The total organic carbon (TOC) content of the ten samples ranged from 0.2 % up to 4.2 %. The TOC content was directly related to the silt/clay content of the samples and inversely related to the sand content of the samples (Figure 4.1-2 and 4.1-3). For example, sample MREAC-2007-2 had the highest sand content (94.0 %) and the lowest TOC content (0.2 %).

These graphs also indicate the values of the Pearson Correlation Coefficient (r) that provide an indication of the strength of the linear relationship of the two variables. For the comparison of these 10 samples, an r value greater than 0.55 or less than –0.55 would indicate a significant correlation (p = 0.05).

Figure 4.1-2 **Comparison of sand content to total organic carbon content for sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007**

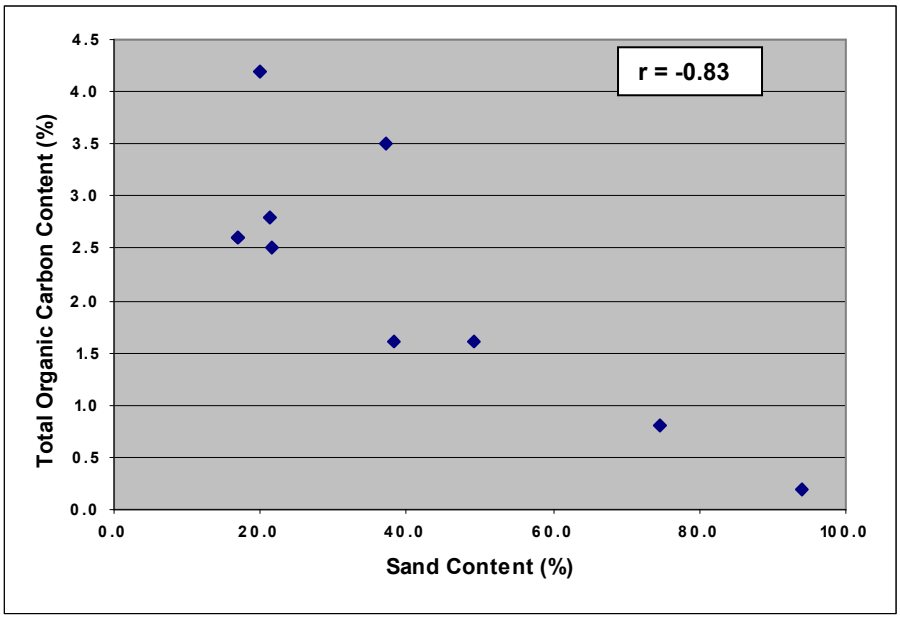
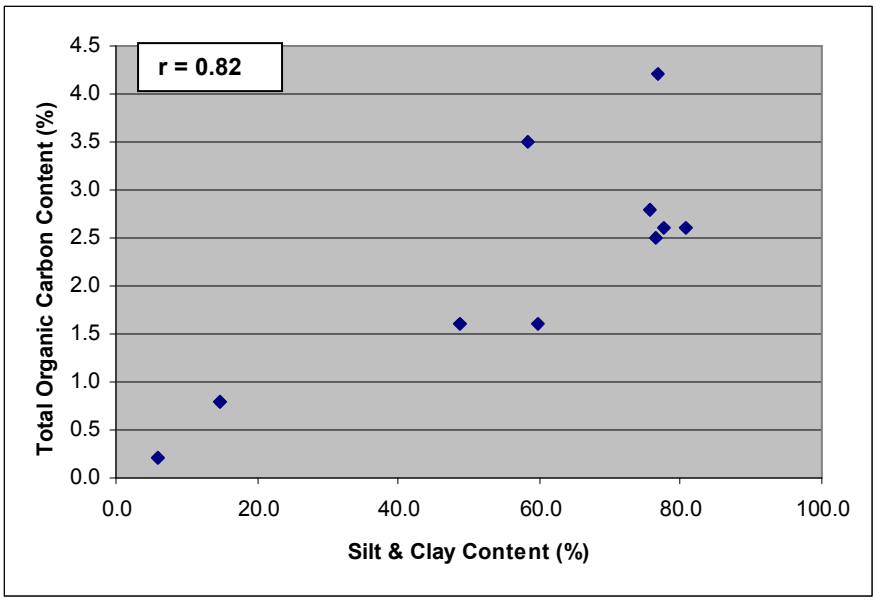


Figure 4.1-3 **Comparison of silt & clay content to total organic carbon content for sediment samples collected from the Miramichi River estuary and Miramichi Bay in September 2007**



4.2 ORGANIC CONTAMINANTS

4.2.1 Polycyclic Aromatic Hydrocarbons (PAH)

Total polycyclic aromatic hydrocarbons (TPAH) concentrations ranged from 26.5 ng/g (ppb) in sample MREAC-2007-09 up to 573.8 ng/g in sample MREAC-2007-03. Although the sample with the least silt and clay content had the lowest TPAH concentration and the samples with the higher silt & clay content had the higher concentrations of TPAH, there is no general pattern of higher concentrations of TPAH in sediments with higher percentages of fine-grained sediment (Figure 4.2-1. Fluorene was the only PAH detected in sample MREAC-2007-09 and in fact, fluorene was the only PAH measured that was detectable in all ten samples.

The Canadian Council of Ministers of the Environment has published environmental quality guidelines for marine sediments (CCME, 2002). A summary of the Marine Interim Sediment Quality Guidelines (ISQG) and Probable Effects Level (PEL) for PAH are provided in Table 4.2-1. Several of the samples collected from the lower Miramichi River estuary and Miramichi Bay in September 2007 had PAH concentrations that exceeded the ISQG. Five samples (MREAC-2007-01, -03, -05, -06 and -07) exceeded the ISQG for fluorene. The samples from locations MREAC-2007-01 and MREAC-2007-03 exceeded the ISQG for two PAH compounds (Table 4.2-1). None of the ten samples had concentrations of PAH that exceeded the PEL.

Figure 4.2-1 **Comparison of total PAH to the silt and clay content of the sediment samples.**

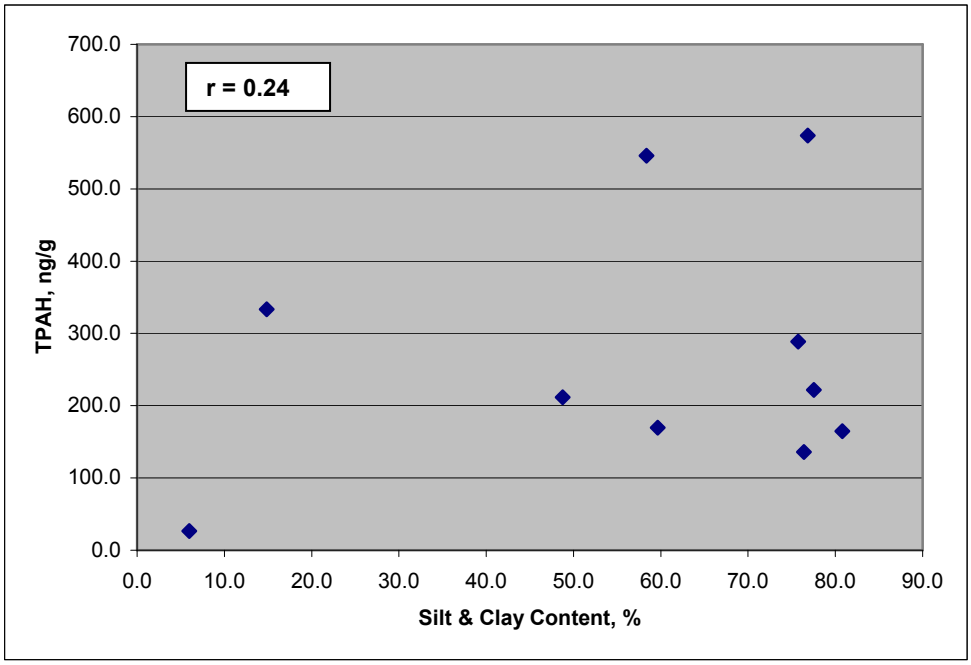


Table 4.2-1 **Interim Sediment Quality Guideline (ISQG) and Probable Effects Level (PEL) for polycyclic aromatic hydrocarbons (PAH) in marine sediments (CCME 2002). Shaded values indicate concentrations that exceed the ISQG.**

PAH	ISQG (ng/g or ppb)	PEL (ng/g or ppb)	MREAC-2007-01	MREAC-2007-03
Naphthalene	34.6	391	< 5	< 5
Acenaphthylene	5.87	128	< 5	< 5
Acenaphthene	6.71	88.9	< 5	< 5
Fluorene	21.2	144	25.2	37.6
Phenanthrene	86.7	544	39.9	44.3
Anthracene	46.9	245	14.6	15.9
Fluoranthene	113	1494	121.4	81.4
Pyrene	153	1398	107.8	70.7
Benzo(a)anthracene	74.8	693	41.6	37.5
Chrysene	108	846	44.2	45.4
Benzo(b)fluoranthene	n/a	n/a	34.9	59.5
Benzo(k)fluoranthene	n/a	n/a	37.9	57.1
Benzo(a)pyrene	88.8	763	37.4	63.6
Indenopyrene	n/a	n/a	21.0	36.5
Dibenz(a,h)anthracene	6.22	135	5.3	9.4
Benzo(g,h,i)perylene	n/a	n/a	17.9	27.6

4.2.2 Polychlorinated Biphenyls (PCB)

The 2007 sediment samples were measured for total PCB (TPCB) concentrations and no TPCB were detected in any of the samples. The detection limit for these analyses was 10.0 ng/g (ppb). The CCME interim sediment quality guideline (ISQG) for total PCB is 21.5 ng/g (ppb) so all of the samples were well below that guideline concentration.

4.3 METALS AND MERCURY

The 2007 sediment samples were analyzed for 10 different trace metals and mercury. Titanium was not detected in any of the samples with a method detection limit of 2.5 ug/g (ppm). With a couple of exceptions, the other 9 metals were detected in all of the samples. The CCME ISQG and PEL for trace metals in marine sediments are provided in Table 3.2-2 (CCME 2002). The CCME has not yet established ISQG or PEL for cobalt, titanium and vanadium.

4.3.1 Arsenic

Arsenic was detected in all of the samples with the exception of MREAC-2007-09. The concentrations of arsenic measured in seven of the samples exceeded the ISQG but no sample exceeded the PEL. The highest concentration of arsenic (14.9 ug/g) was measured in sample MREAC-2007-01. The concentration of arsenic was related to the grain size of the sediments with the higher concentrations of arsenic occurring in the samples with the higher fine-grained sediment content (Figure 4.3-1). The concentration of arsenic was also directed correlated to the total organic carbon content of the samples ($r = 0.76$).

4.3.2 Cadmium

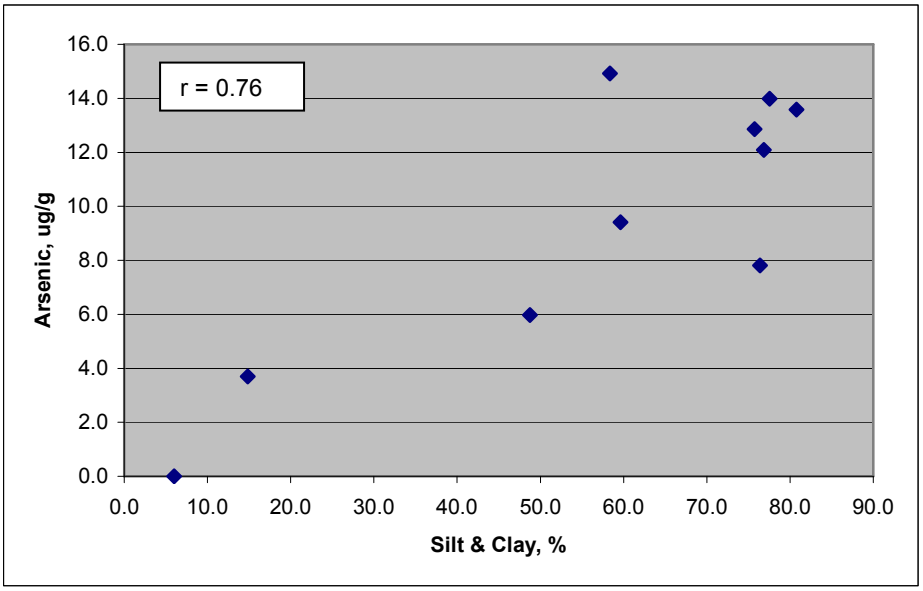
All ten samples had detectable concentrations of cadmium with values ranging from 1.1 ug/g up to 5.4 ug/g. The CCME ISQG for cadmium is set at 0.7 ug/g (CCME 2002) and all samples exceeded that value. The PEL for cadmium in marine sediments is established at 4.2 ug/g and two of the samples (MREAC-2007-04 and MREAC-2007-09) exceeded that value. There was not a significant correlation between grain-size and cadmium content ($r = -0.5$) or TOC and cadmium ($r = -0.5$).

4.3.3 Chromium

Chromium was detected in all sediment samples with concentrations ranging from 8.8 ug/g up to 30.5 ug/g. The CCME ISQG for chromium is established at 52.3 ug/g (CCME 2002) and the PEL for chromium in marine sediments is established at 160 ug/g. None of the samples had chromium concentrations that exceeded the ISQG or the PEL. The lowest concentrations of chromium were measured in the two sediment samples that had the highest portion of sand and the highest chromium concentration was

observed in sample MREAC-2007-07 which also had the highest content of fine-grained sediment. There was a significant correlation between the concentration of chromium and the fine-grained material content of the samples (r = 0.82).

Figure 4.3-1 Relationship of arsenic concentration to the fine-grained sediment content of the sediment samples.



4.3.4 Copper

Copper was detected in all samples but none of the concentrations exceeded the CCME ISQG of 18.7 ug/g or the PEL of 160 ug/g. The lowest concentrations of copper were measured in the two sediment samples that had the highest portion of sand and the highest copper concentrations were observed in the samples with the highest content of fine-grained sediment (Figure 4.3–2). The correlation between copper concentration and fine-grained sediment content was significant (r = 0.896).

4.3.5 Lead

Lead was detected in 8 of the ten samples (detection limit 2.5 ug/g). Lead was not measured in MREAC-2007-09 and MREAC-2007-10. The CCME ISQG for lead has been established at 30.2 ug/g (CCME 2002) and the PEL was established at 112 ug/g. Lead concentrations did not exceed the ISQG or the PEL in any of the samples. The samples indicated that for the most part, concentrations of lead were directly related to the content of fine-grained sediments (Figure 4.3-3). The only exception to this pattern was MREAC-2007-10, which consisted of about 50 % fine-grained sediment but did not contain any detectable lead.

4.3.6 Zinc

Zinc was detected in all of the 2007 samples and was present at concentrations higher than any of the other metals. The CCME ISQG for zinc has been established at 124 ug/g (CCME 2002) and the PEL for zinc in marine sediments is established at 271 ug/g. None of the samples exceeded these guidelines. As with most of the other metals, the concentration of zinc was directly related to proportion of fine-grained material in the sediment samples (Figure 4.3-4).

4.3.7 Mercury

Mercury was detected in all of the samples with the exception of MREAC-2007-09. The CCME ISQG for mercury in marine sediments has been established at 0.13 ug/g (CCME 2002) and the PEL has been set at 0.7 ug/g. None of the samples exceeded the ISQG value. There was a pattern of a direct relationship between the content of fine-grained sediments and mercury concentration (Figure 4.3-5).

4.3.8 Overall Summary for Metals

1. Titanium was not detected in any of the samples
2. Arsenic was detected in all of the samples but one. The concentrations of arsenic measured in seven of the samples exceeded the ISQG.
3. All ten samples had detectable concentrations of cadmium. All samples exceeded the CCME ISQG for cadmium and 2 samples exceeded the PEL.
4. Chromium, copper and zinc were detected in all samples but none of the samples had concentrations that exceeded the ISQG or the PEL.
5. Lead was detected in 8 of the ten samples but the concentrations measured did not exceed the ISQG or the PEL.
6. Mercury was detected in all of the samples but one. No samples exceeded the ISQG value.
7. Generally, metal concentrations were higher in samples that had a higher proportion of fine-grain sediment and the metal concentrations were lower in the samples that had a high sand content.

Figure 4.3-2 **Relationship of copper concentrations to the fine-grained sediment content of the sediment samples.**

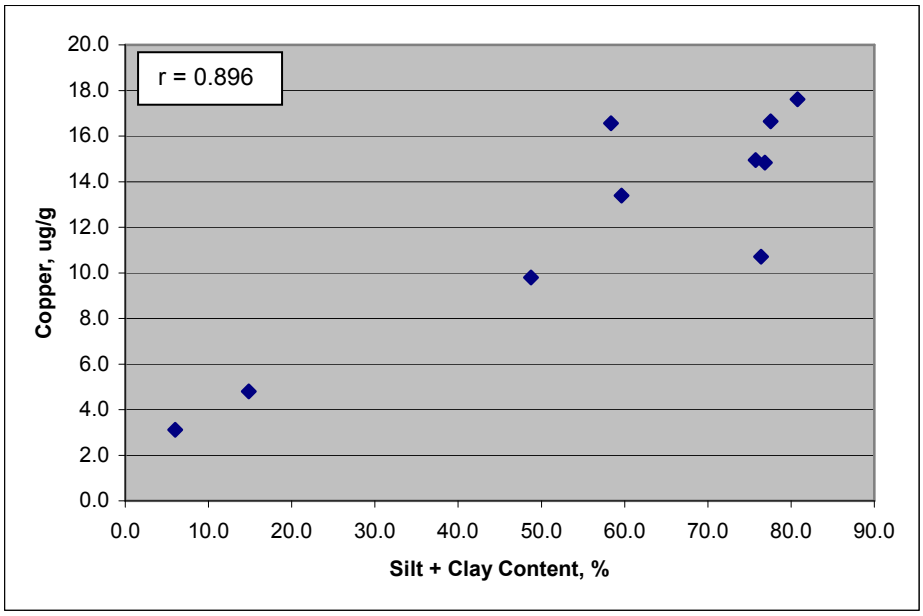


Figure 4.3-3 **Relationship of lead concentrations to the fine-grained sediment content of the sediment samples.**

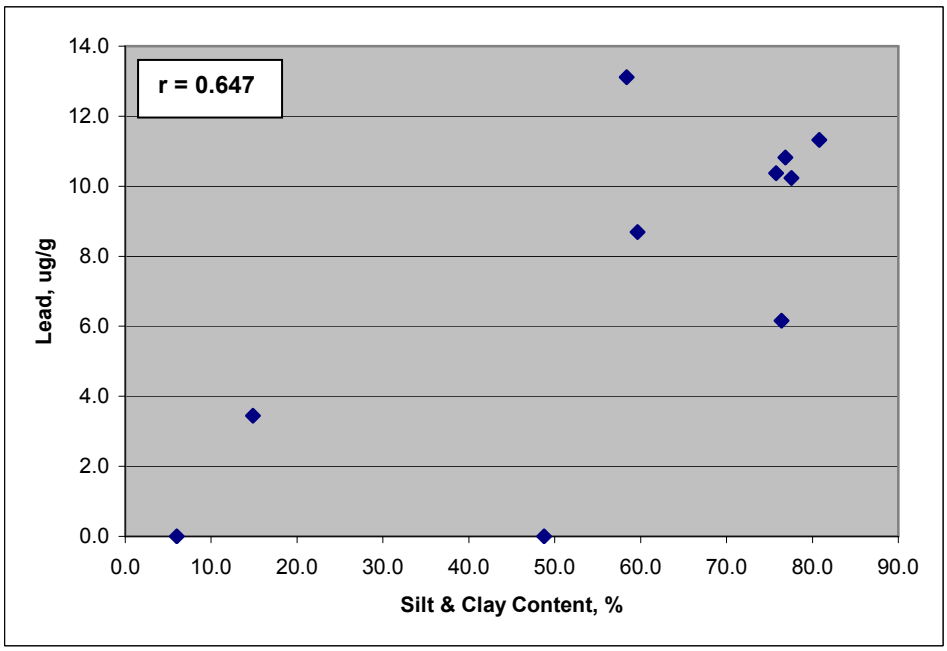


Figure 4.3-4 **Relationship of zinc concentrations to the fine-grained sediment content of the sediment samples**

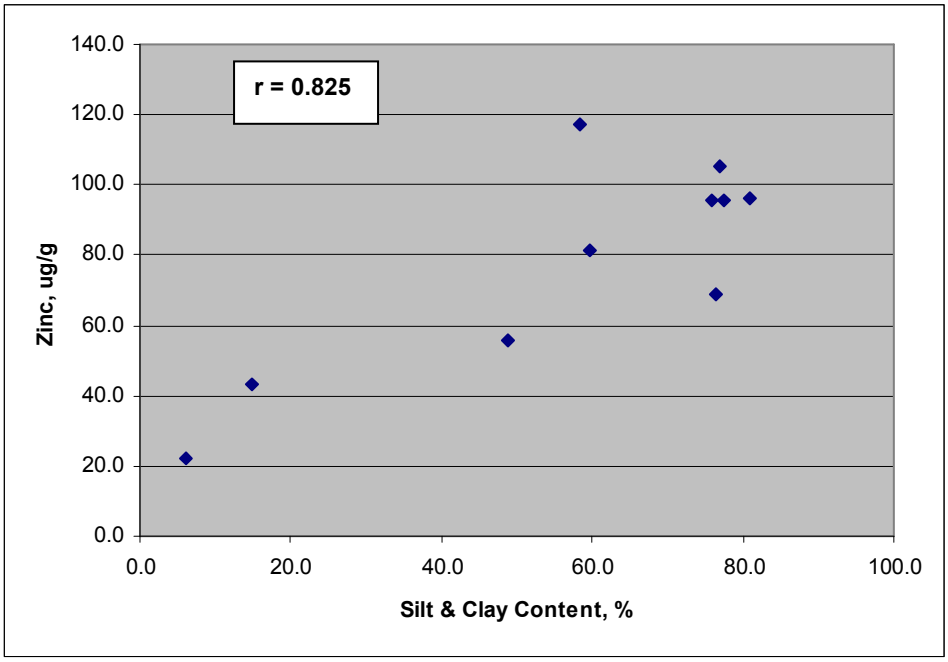
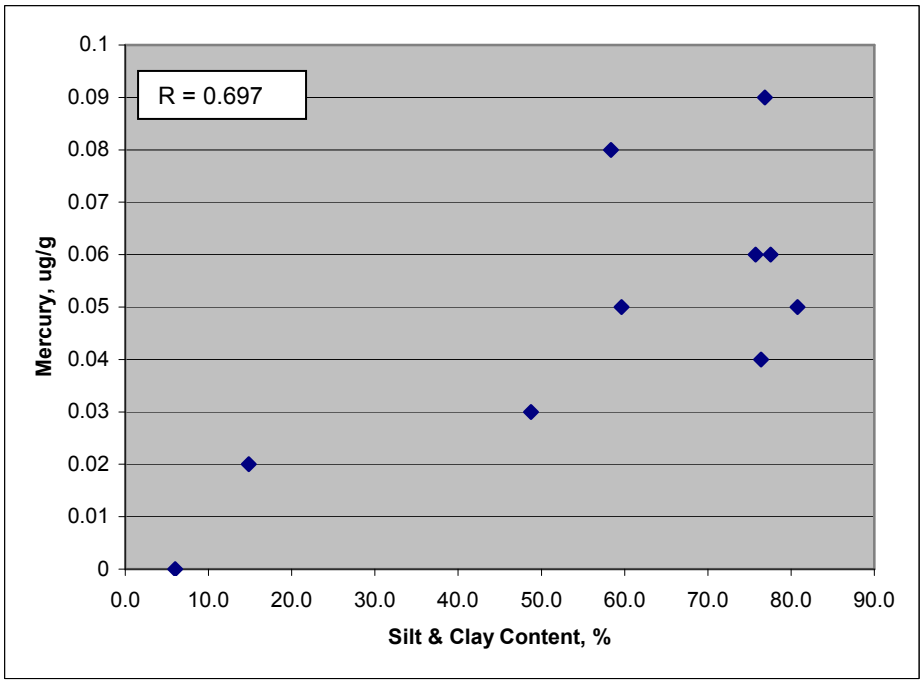


Figure 4.3-5 **Relationship of mercury concentrations to the fine-grained sediment content of the sediment samples**



4.4 Ammonia, Sulphide and Redox

The presence of ammonia in sediments is an indicator of organic enrichment with higher values of ammonia signifying increased enrichment. There are no Canadian guidelines for acceptable concentrations of ammonia in marine sediments. Although there is a general pattern of higher ammonia levels in the sediment samples than had the higher content of fine-grained material, that relationship is not strong (r = 0.499). Intuitively, one would expect organic material transported down the river to settle out in depositional areas that would be identified by increased content of fine-grained sediments.

Sulphide is generated in marine sediments by the anaerobic decomposition of organic material. Higher concentrations of sulphide are indicative of increased organic enrichment and anaerobic (lack of oxygen) conditions in the sediments. The CCME has not established marine sediment quality criteria for sulphide. At NB salmon farms, a site classification system has been developed to define the quality of the sediment under and around the marine net pens used for raising salmon. If a salmon farm has sediment containing sulphide levels in excess of 1500 micromoles (uM) but less than 3000 uM, it would be classified as Hypoxic A and would be defined as "may be causing adverse environmental effects to the marine sediments under the net pens" (New Brunswick, 2006). The Environment Canada laboratory measured the sulphide concentrations in the 2007 sediment samples as mg/L and converted the results to micrograms of sulphur per dry weight gram of sediment (ug/g). Table 4.4-1 provides the conversion of the values measured by Environment Canada to uM. These values were obtained by multiplying the values measured as mg/L by 31.18665211 (the inverse of the molecular weight of sulphur, (1) / (32.065). Only the sediment sample from location MREAC-2007-10 had a sediment sulphide concentration in excess of 1500 uM and this sediment would be classified as Hypoxic A under the system used for marine salmon farms. This is an indication that there may be some organic enrichment of the sediment at this location.

The Redox measurements are also an indication of organic enrichment and the presence of anaerobic decomposition of deposited organic material. Clean, aerobic sediment will generally have a positive Redox value while a negative redox measurement can point toward reduced oxygen concentrations in the sediment and higher negative values (greater than – 100 mV) can be indicative of anaerobic conditions. Only one sample, MREAC-2007-10, had a redox measurement that exceeded – 100 mV.

So overall, there are some signs of moderate organic enrichment at a few of the sampling locations but there is not strong evidence of any problem sites with anoxic conditions.

As well, it should be pointed out that sulphide and redox measurements are most accurate in assessing organic enrichment of sediments in a water body when performed immediately following sample collection. The conditions of sample handling and storage can impact these values. The samples reported on here were collected on September 13 and 14th and were stored at 4^{o} C in sealed containers for a month before the measurements were performed on October 18. The method used by the environment Canada laboratory is quite valid for determining sediment conditions prior to starting the

sediment toxicity tests. However, the application of these sulphide and redox results for describing conditions in the estuary and the bay at the time of sampling is limited.

Table 4.4-1 Sulphide concentrations in the 2007 sediment samples from the Miramichi Estuary and Miramichi Bay.

Sample Location	Sulphide, mg/L	Sulphide, ug/g	Sulphide, micromoles (uM)
MREAC-2007-01	38.7	64.4	1206.9
MREAC–2007-02	20.8	24.0	648.7
MREAC-2007-03	30.8	101.0	960.5
MREAC-2007-04	38.3	53.6	1069.7
MREAC-2007-05	28.0	54.7	873.2
MREAC-2007-06	46.0	105.0	1434.5
MREAC-2007-07	31.3	67.4	976.1
MREAC-2007-08	14.7	23.5	458.4
MREAC-2007-09	39.8	27.6	1241.2
MREAC-2007-10	64.9	95.4	2024.0

4.5 SEDIMENT TOXICITY TESTS

The end point for the Microtox solid phase toxicity tests is expressed as an IC50 which is the concentration of sediment (mg of sediment (dry weight) per litre of diluent water) that cause a 50 % reduction in the amount of light emitted by the luminescent bacteria, *Vibrio fischeri*. The IC50's for the toxicity tests on the 2007 samples of sediment from the lower Miramichi estuary and Miramichi Bay ranged from 1390 mg/L up to > 114,000 mg/L.

Environment Canada uses two interim guidelines to interpret the toxicity test results and to judge if the tested sediment is toxic to the luminescent bacteria (Environment Canada 2002). Using these criteria, none of the sediments would be considered to be toxic as measured by the Microtox solid phase toxicity test (Jackman and Doe, 2008).

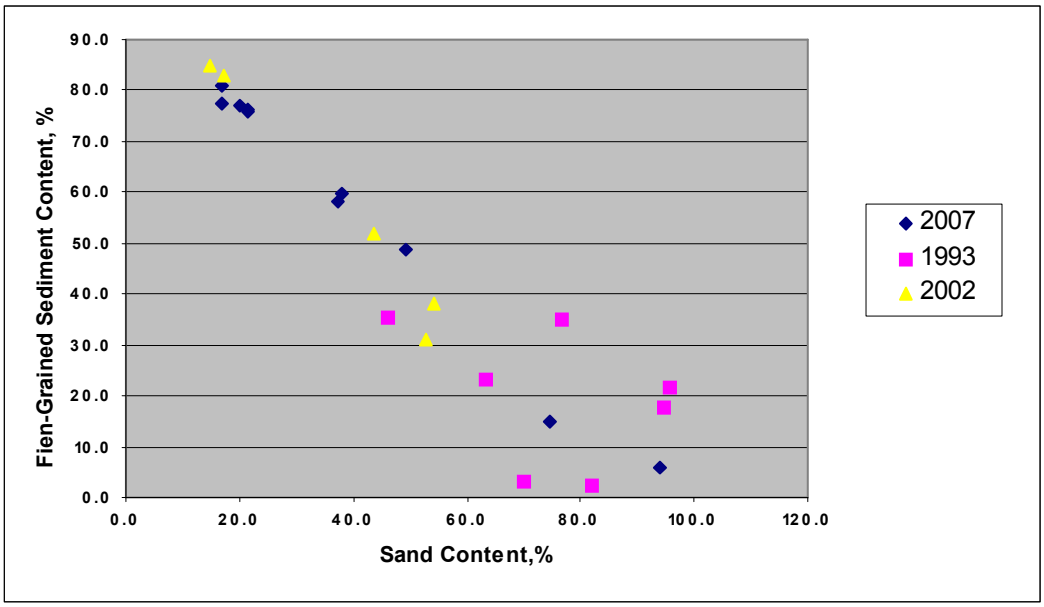
4.6 COMPARISON TO SEDIMENT QUALITY UPSTREAM

Similar sediment surveys were conducted in 1993 and 2002 at locations in the estuary upstream of the 2007 sampling locations. The previous samples were collected from just above the town of Newcastle down as far as the Highway 11 Bridge at Chatham and the results were reported previously (Parker, 2007). A total of 8 samples were collected in 1993 and the 2002 survey consisted of 5 samples. As with the 2007 survey, the 1993 and 2002 sediment samples were analyzed for grain size, total organic carbon, trace metals, persistent organic compounds, and sediment toxicity.

4.6.1 Comparison of Grain Size Distribution

Figure 4.6-1 compares the sand and silt content of the three sets of sediment samples. In general, the samples from higher up in the estuary (1993 and 2002) contain more sand and less fine-grained sediment compared to the 2007 samples that with a couple of exceptions are primarily silt. This indicates that the lower estuary and bay are primarily depositional areas where fine-grained material that is transported down the river settles to the bottom.

Figure 4.6-1 **Comparison of sand content and fine-grain sediment content for sediment samples collected from the Miramichi River in 1993, 2002 and 2007.**



4.6.2 Total Organic Carbon

Total organic carbon ranged from 0.2 % up to 21 % for the 23 samples (Table 4.6-1). The lowest TOC was for sample MREAC-2007-09 and the sample with the highest TOC was MREAC-2002-04. Twenty (20) of the 23 samples (87 %) had total organic carbon content of less than 5 % and 13 of the samples (57 %) had TOC values of less than 3 %. Generally, the TOC was lower in the 2007 samples that were collected in the lower estuary and in the bay compared to the two previous surveys conducted farther upstream in the river.

Table 4.6-1 Total organic carbon content for the three sets of sediment samples from the Miramichi River.

Sample Identifier	Total Organic Carbon, %
EC-1993-01	3.6
EC-1993-02	5.6
EC-1993-03	3.9
EC-1993-04	0.3
EC-1993-05	2.7
EC-1993-06	0.2
EC-1993-07	2.2
EC-1993-08	6.8
MREAC-2002-01	4.2
MREAC-2002-02	4.6
MREAC-2002-03	3.2
MREAC-2002-04	21.0
MREAC-2002-05	2.6
MREAC-2007-01	3.5
MREAC-2007-02	0.8
MREAC-2007-03	4.2
MREAC-2007-04	2.5
MREAC-2007-05	2.8
MREAC-2007-06	2.6
MREAC-2007-07	2.6
MREAC-2007-08	1.6
MREAC-2007-09	0.2
MREAC-2007-10	1.6

4.6.3 Organic Contaminants

4.6.3.1 Polycyclic Aromatic Hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons were found in most of the sediment samples from the three surveys. In 1993, 7 of 8 samples contained detectable concentrations of PAH and in 2002, all 5 samples had measurable amounts of PAH. All of the 2007 samples contained PAH. All of the samples were analyzed for 16 individual PAH and the pattern for detection was similar, that is the same individual PAH show up in most of the samples. Phenanthrene, fluoranthene and pyrene were detected in all samples except EC-1993-06. Anthracene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k) fluoranthene, benzo(a)pyrene and indeno(1,2,3-cd) pyrene were detected in the majority of the samples.

Only one sample, MREAC-2002-03 contained all 16 PAH compounds while 3 samples, EC-1993-03, MREAC-2002-01 and MREAC-2002-04, had measurable concentrations of 15 PAH compounds. One sample (EC-1993-06) had no detectable PAH.

The CCME interim sediment quality guidelines for individual PAH are summarized in Table 4.2-1. For the 1993 survey results, sample EC-1993-03 exceeded the ISQG for 9 individual PAH while sample EC-1993-02 exceeded the ISQG for fluoranthene. For the 2002 samples, MREAC-2002-03 exceeded the ISQG for 8 individual PAH while 3 samples exceeded the ISQG for fluoranthene. In 2007, 5 samples exceeded the ISQG for fluorene, one sample exceeded the ISQG for fluoranthene and one sample exceeded the ISQG for dibenz (a, h) anthracene.

When one calculates the total PAH (TPAH) concentrations for all of the samples by summing the individual concentrations for the 16 PAH measured, the concentrations of TPAH are generally lower in the 2007 samples (Figure 4.6-2). In 1993, half of the samples (4 of 8) had a TPAH contents greater than 0.5 ppm. For the 2002 samples, 3 of the 5 samples had TPAH in excess of 0.5 ppm and all samples had TPAH values in excess of 0.2 ppm. For the most recent survey, only 2 of the 10 samples (20 %) had concentrations of TPAH that exceeded 0.5 ppm and 6 of the 10 samples had TPAH concentrations of 0.2 ppm or less. The TPAH values from the 2007 survey were not significantly different when compared to the 1993 results and the 2002 results using a Student's t-test ($p = 0.5$).

There are a few explanations for the lower concentrations of contaminants in the lower estuary and the bay compared to the upper estuary – distance, dilution and time. The source of the PAH in the sediments of the Miramichi River estuary can be attributed to wastes from industrial operations, hydrocarbon spills and storm runoff from the municipal areas. The 2007 samples were collected farther down the river and out into the bay so they are farther removed from the potential sources of the contaminants. The lower estuary is wider and deeper than the portion of the river between Chatham and Newcastle so any contaminants being transported downriver would become more diluted as they are mixed with the large volumes of water present in the lower estuary and Miramichi Bay. Many of the suspected sources of PAH have been closed down or mitigated to reduce the further release of PAH to the river. One can assume that during the 5 years between the last 2 surveys, PAH discharges to the estuary have been reduced thus resulting in the reduced concentrations of PAH in the sediments in 2007.

4.6.3.2 Polychlorinated Biphenyls (PCB)

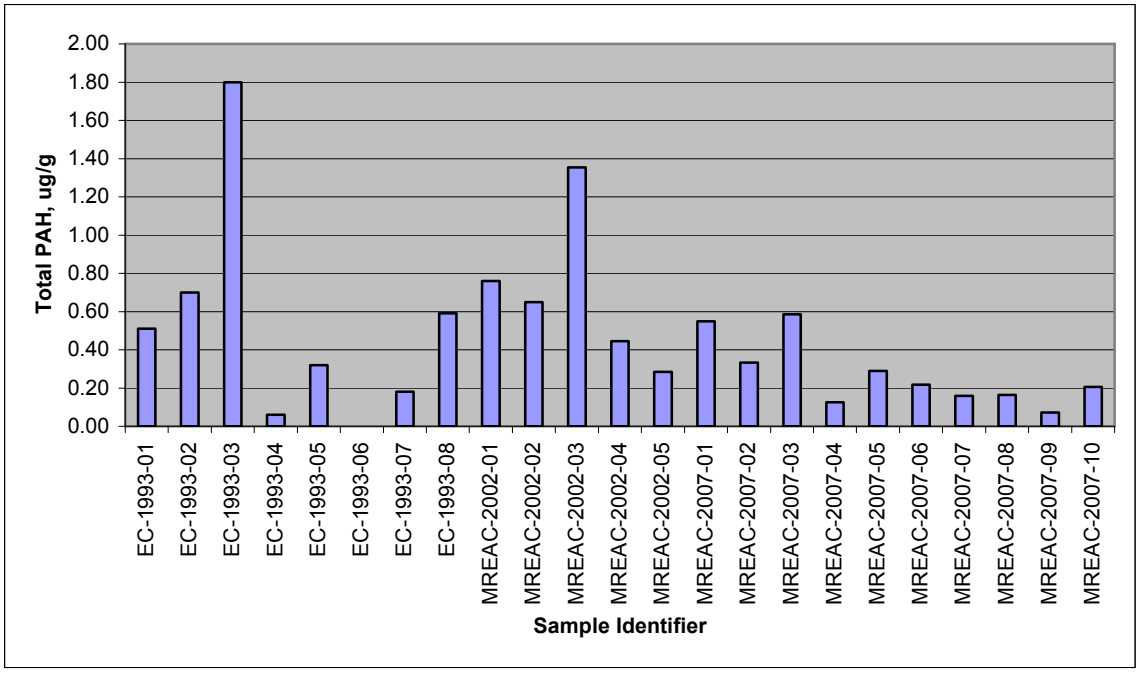
In the 1993 survey, PCB (measured as Arochlor 1254) was detected in 3 of the 8 samples. The CCME ISQG for Arochlor 1254 is set at 0.063 mg/kg (CCME, 2002). Only the sediment sample, EC-1993-01, exceeded the ISQG with a concentration of 1.70 mg/kg. The CCME has established a concentration of 0.709 mg/kg at a probable effects level (PEL) for Arochlor 1254 and sample EC-1993-01 also exceeded that value.

In 2002, the sediment samples were analyzed for total PCB and 4 of the 5 samples had detectable concentrations of TPCB. Two of the samples exceeded the CCME ISQG for TPCB (0.022 mg/kg) and two other samples had concentrations equal to that value. None of the samples exceeded the PEL for total PCB (0.189 mg/kg).

TPCB was not detected (< 0.01 mg/kg) in any of the sediment samples collected for the 2007 survey.

Overall, there appears to be less total PCB in the sediments collected from the lower estuary and the bay in 2007 compared to the sediments collected farther upriver in the earlier surveys.

Figure 4.6-2 Total PAH concentrations for all of the sediment samples from surveys conducted in 1993, 2002 and 2007.



4.6.4 Trace Metals and Mercury

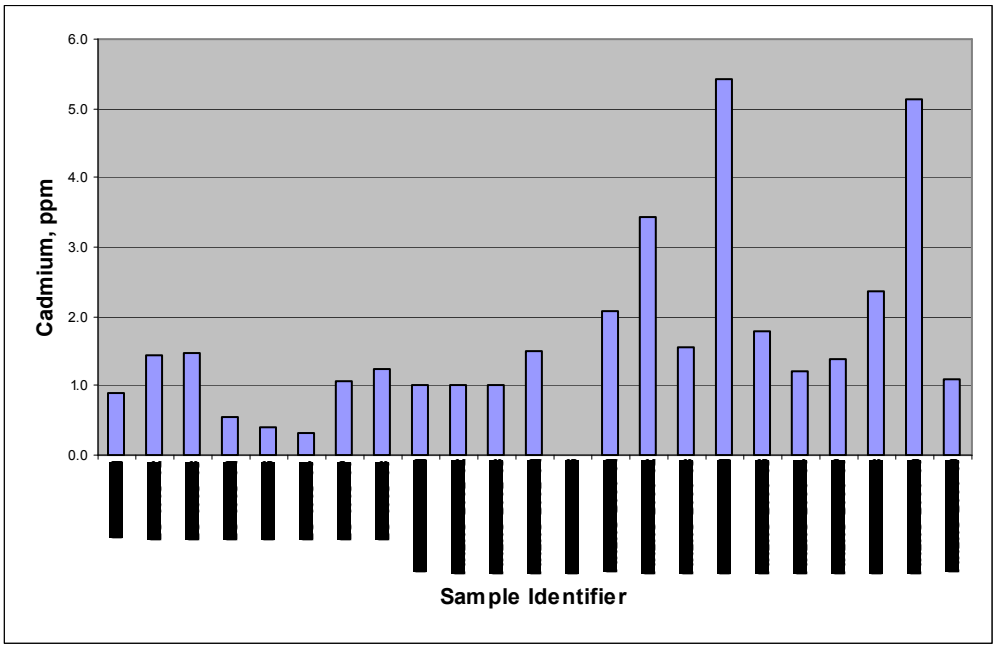
The 1993 survey measured and detected cadmium, copper, lead, zinc and mercury in all of the 8 samples collected. Five of the samples exceeded the CCME ISQG for cadmium with the highest concentration measured being 1.47 mg/kg. Four of the samples exceeded the ISQG for copper, lead and zinc while 2 samples exceeded the mercury ISQG. One sample (EC-1993003) exceeded the PEL for zinc.

In 2002, the sediment samples were analyzed for 15 different trace metals. All of the sediment samples exceeded the ISQG for cadmium and four of the five samples exceeded the ISQG for zinc. The ISQG for arsenic is set at 5.9 mg/kg and all of the samples exceeded or were equal to that level. Only one of the samples exceeded the ISQG for copper but all samples were close to the recommended level for protection of marine aquatic life. Two of the five samples exceeded the ISQG for lead and two other samples had lead concentrations close to the guideline. None of the metal concentrations exceeded the PEL concentrations.

For the 2007 survey, all ten samples had concentrations of cadmium that exceeded the CCME ISQG and 2 samples exceeded the PEL. Chromium, copper and zinc were detected in all samples but none of the samples had concentrations that exceeded the ISQG or the PEL. Lead was detected in 8 of the 10 samples but concentrations measured did not exceed the ISQG or the PEL. Arsenic was detected in all of the samples but one and the concentrations of arsenic measured in seven of the samples exceeded the ISQG. Finally, mercury was detected in all but one of the samples. None of the samples exceeded the ISQG values.

Cadmium concentrations in the sediments of the Miramichi estuary and Miramichi Bay, as measured during the 3 surveys, always exceeded the CCME ISQG of 0.7 ppm and two samples had concentrations greater than the PEL. The highest concentrations of cadmium are observed in the lower estuary and in the bay (Figure 4.6-3). This may be an indication that the sediments in the lower estuary and the bay have a higher natural background level of cadmium or that this area is acting as a sink for cadmium being transported down the river.

Figure 4.6-3 Cadmium concentrations in sediment samples collected from the Miramichi River estuary and Miramichi Bay in 1993, 2002 and 2007.



Copper was found in all 23 samples from the 3 surveys. Copper concentrations are similar between sampling years (Table 4.6-2) but the results are not significantly different (Student's t-test, p = 0.5). The concentrations from the 2007 survey of the lower estuary and the bay appear lower and none of the values from this latest survey exceed the ISQG.

Table 4.6-2 Comparison of results for copper in sediment between surveys conducted in 1993, 2002 and 2007.

Year of Survey	# of Samples	Mean Copper Concentration	Minimum	Maximum
1993	8	18	4.3	36.6
2002	5	16	12.4	18.8
2007	10	12.2	3.1	17.6

Lead was measured in all but 2 of the 23 sediment samples (MREAC-2007-09 and MREAC-2007-10). Lead concentrations as measured in 2007 from the lower estuary and the bay are lower than the results obtained from the upstream locations during the earlier surveys (Table 4.6-3). Almost half of the samples in the 1993 and 2002 surveys had lead concentration above the ISQG of 30.2 ug/g but none of the samples from 2007 exceeded this value.

Table 4.6-3 Comparison of results for lead in sediment between surveys conducted in 1993, 2002 and 2007.

Year of Survey	# of Samples	Mean Lead Concentration	Minimum	Maximum
1993	8	30	10.2	57.9
2002	5	28	16.3	35.9
2007	10	7.9	< 2.5	13.1

Zinc was detected in all samples from all 3 surveys. Zinc concentrations are lower in the 2007 samples than in the samples from the previous surveys (Table 4.6-4). Over half of the samples (8 of 13) from the 1993 and 2002 surveys had zinc concentration above the ISQG of 124 ug/g but none of the 2007 samples had zinc concentrations above that level.

Table 4.6-4 Comparison of results for zinc in sediment between surveys conducted in 1993, 2002 and 2007.

Year of Survey	# of Samples	Mean Zinc Concentration	Minimum	Maximum
1993	8	158	45.5	331.0
2002	5	129	82.3	172.9
2007	10	78	22.5	117.2

Mercury was measured in the sediment samples collected in 1993 and in 2007 but not in the 2002 samples. Mercury was detected in all 8 of the 1993 samples and 2 samples had concentrations in excess of the ISQG for mercury (0.13ug/g) and two other samples had concentrations very close to the ISQG. Mercury was detected in 9 of the 10 samples collected in 2007 but none of the samples had concentrations that exceeded the ISQG. Mercury concentrations were generally lower in the 2007 survey compared to the 1993 survey.

Although not conclusive, it appears that the concentrations of copper, lead, zinc and mercury are lower in the lower Miramichi River estuary and in Miramichi Bay compared to the results of earlier surveys in the upper estuary above the Highway 11 bridge. On

the other hand, cadmium concentrations appear to be higher in the lower estuary and in the bay.

4.6.5 Sediment Toxicity Tests

Sediment toxicity tests were conducted on all of the sediment samples from the three surveys. The only sediment toxicity test used for all three surveys was the Microtox Solid Phase assay. The results of these tests are summarized in Table 4.6-5.

Environment Canada uses two interim guidelines to interpret the results of the Microtox Solid Phase tests and to determine if the sediment is toxic to the luminescent bacteria. The first guideline states that sediment is considered to be toxic if the IC50 is less than 1000 mg/L regardless of its grain size. The second guideline addresses sediments that have more than 20 % fine-grained material (silt and clay combined) and have an IC50 of greater than 1000 mg/L. In this case, the results are compared to the results from testing clean reference sediment with similar fines content. The test sediment is considered to be toxic if (a) the IC50 is more than 50 % lower than the IC50 for the reference sediment and (b) the IC50's for the test sediment and the reference sediment are significantly different (Sprague and Fogels, 1977).

Based on these criteria, none of the sediment samples from the 2007 survey were considered to be toxic (Jackman and Doe, 2008). For the 2002 survey, only one sample (MREAC-2002-02) was determined to be toxic. In 1993, 3 of the 8 sediment samples were determined to be toxic, 3 other samples were determined to be marginally toxic and 2 samples were non-toxic.

Based on these results, it can be stated that the sediment samples collected from the lower estuary and the bay in 2007 were less toxic, as determined by the Microtox Solid Phase Assay, than the sediment samples collected further upriver in the earlier surveys.

Table 4.6-5 **Comparison of Microtox Solid Phase toxicity tests on sediment samples collected from the Miramichi River. Shaded values indicate samples that were determined to be toxic.**

Sample Identification	Microtox Solid Phase Assay IC50 (mg/L)
EC-1993-01	673
EC-1993-02	358
EC-1993-03	2005
EC-1993-04	> 76085
EC-1993-05	5217
EC-1993-06	> 75493
EC-1993-07	5197
EC-1993-08	550
Control	18565
MREAC-2003 –01	3830
MREAC-2003-02	882
MREAC-2003-03	2850
MREAC-2002-04	1120
MREAC-2002-05	5640
MREAC-2007-01	1980
MREAC–2007-02	> 114,000
MREAC-2007-03	1880
MREAC-2007-04	27,700
MREAC-2007-05	6830
MREAC-2007-06	1390
MREAC-2007-07	2300
MREAC-2007-08	31,900
MREAC-2007-09	21,200
MREAC-2007-10	25,300

5.0 CONCLUSIONS

1) The sediment samples collected from the lower Miramichi River estuary and Miramichi Bay in 2007 have concentrations of some metals and organic contaminants that exceed the Interim Sediment Quality Guidelines established by the Canadian Council of Ministers of the Environment.

2) Five samples had concentrations of fluorene that exceeded the ISQG.

3) Total polychlorinated biphenyls (PCB) were not detected in any of the samples.

4) All ten samples had detectable concentrations of cadmium. All samples exceeded the CCME ISQG for cadmium and 2 samples exceeded the PEL.

5) Arsenic was detected in all of the samples but one. The concentrations of arsenic measured in seven of the samples exceeded the ISQG.

6) Chromium, copper and zinc were detected in all samples but none of the samples had concentrations that exceeded the ISQG or the PEL.

7) Lead was detected in 8 of the ten samples but the concentrations measured did not exceed the ISQG or the PEL.

8) Titanium was not detected in any of the samples

9) Mercury was detected in all of the samples but one. No samples exceeded the ISQG value.

10) Metal concentrations were generally higher in samples that had a higher proportion of fine-grain sediment and the metal concentrations were lower in the samples that had a high sand content.

11) None of the samples was toxic when tested using the Microtox Solid Phase test.

12) There was a general pattern of lower levels of organic contaminants, trace metals and mercury in the 2007 samples from the lower estuary and Miramichi Bay compared to the results of the 1993 and 2002 surveys in the upper estuary.

13) Cadmium concentrations were higher in the sediment samples from the lower estuary and the bay compared to the earlier results from the upriver surveys.

6.0 ACKNOWLEDGEMENTS

The author would like to thank Harry Collins of the Miramichi River Environmental Assessment Committee for his support and guidance during the writing of this report. Hélène Dupuis, Paula Jackman and Ken Doe with Environment Canada Atlantic Region reviewed the draft manuscript and the author gratefully acknowledges their comments and constructive advice.

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APPENDICES

Appendix Table A-1

Results are expressed as ug/g dry weight. Shaded values exceed the CCME ISQG.

Sample Location	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene
	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
MREAC-2007-01	<5	<5	<5	25.2	39.9	14.6	121.4	107.8
MREAC-2007-02	<5	<5	<5	13.2	25.1	8.2	58.2	54.3
MREAC-2007-03	<5	<5	<5	37.6	44.3	15.9	81.4	70.7
MREAC-2007-04	<5	<5	<5	20.2	8.3	<5	23.4	19.1
MREAC-2007-05	<5	<5	<5	22.9	21.5	5.9	48.2	43.6
MREAC-2007-06	<5	<5	<5	26.1	18.6	5.1	36.4	28.9
MREAC-2007-07	<5	<5	<5	21.4	10.9	<5	25.2	21.4
MREAC-2007-08	<5	<5	<5	13.5	8.6	<5	22.8	20.4
MREAC-2007-09	<5	<5	<5	11.5	<5	<5	<5	<5
MREAC-2007-10	<5	<5	<5	14.6	10.8	6.1	23.9	16.7
CCME ISQG	34.6	5.87	6.71	21.2	86.7	46.9	113	153
CCME PEL	391	128	88.9	144	544	245	1494	1398

Appendix Table A-1 (continued)

Results are expressed as ug/g dry weight. Shaded values exceed the CCME ISQG.

Sample Location	Benzo(a) Anthracene	Chrysene	Benzo(b) Fluoranthene	Benzo(k) Fluoranthene	Benzo(a) Pyrene	Indeno (1,2,3-cd) Pyrene	Dibenz(a,h) Anthracene	Benzo(ghi) Perylene
	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
MREAC-2007-01	41.6	44.2	34.9	37.9	37.4	21.0	5.3	17.9
MREAC-2007-02	29.6	30.8	24.5	26.9	30.0	17.6	<5	13.8
MREAC-2007-03	37.5	45.4	59.5	57.1	63.6	36.5	9.4	27.6
MREAC-2007-04	8.3	9.4	9.4	8.7	8.1	6.2	<5	<5
MREAC-2007-05	20.7	22.8	24.3	23.2	22.4	18.4	<5	15.1
MREAC-2007-06	13.5	15.6	18.5	16.2	14.6	13.4	<5	10.9
MREAC-2007-07	10.1	12.1	14.8	12.4	11.0	10.5	<5	8.7
MREAC-2007-08	12.5	19.2	16.7	16.1	13.3	11.5	<5	9.1
MREAC-2007-09	<5	<5	<5	<5	<5	<5	<5	<5
MREAC-2007-10	20.9	26.0	23.0	22.3	20.7	12.0	<5	9.8
CCME ISQG	74.8	108	n/a	n/a	88.8	n/a	6.22	n/a
CCME PEL	693	846	n/a	n/a	763	n/a	135	n/a