Assessment of Sediment Quality in the Miramichi River Estuary – A Comparison of 1993 and 2002 Survey Results

A report to:

Miramichi River Environmental Assessment Committee
Miramichi, New Brunswick

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Abstract

In 1993, Environment Canada conducted an environmental monitoring study in the Miramichi River estuary to evaluate the quality of the sediments. A sediment triad assessment approach was initiated and included benthic invertebrate community evaluation, sediment chemistry and sediment toxicity tests.

Throughout the 1990's, many environmental improvements were completed at the various industries along the Miramichi River estuary. These included the installation of secondary effluent treatment at the pulp mill, improved effluent treatment at the paper mill, improvements in water treatment at the Heath Steele Mine and expanded sewage collection and treatment for parts of the municipality.

In 2002, the Miramichi River Environmental Assessment Committee (MREAC) decided to repeat a sediment quality survey of the same stretch of the Miramichi River estuary to assess whether the improvements in effluent quality would be reflected in improved sediment quality in the estuary. MREAC conducted a sediment sampling survey in October 2002 and again had the samples evaluated for benthic community structure, sediment chemistry and sediment toxicity.

This report summarizes the results of the 1993 and 2002 surveys and evaluates the changes in sediment quality occurred.

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1.0 Introduction

Previous environmental quality assessments conducted on Miramichi River sediments (MREAC, 1992) indicated some areas with elevated levels of heavy metals and an isolated sample with elevated PAH concentrations. Benthic community assessments indicated that the stretch of estuary between Chatham and Newcastle was "impoverished" biologically (Albin, 1990(a, b); Beak, 1990). Several factors can naturally influence benthic community structure including flow regimes, salinity, water depth, substrate type, temperature and season. The identified impoverished zone may well be as a result of a combination of these natural factors but given the history of industrial and municipal development in this area of the estuary, there is reason to suspect that the observed impacts may be due in part to some anthropogenic input or activities that have occurred or are still occurring. Those influences include base metal mining, pulp and paper production, wood preservation and the discharge of domestic sewage.

As a result of these findings, a sediment quality study was initiated by Environment Canada in 1993 to further evaluate the quality of the sediments in the Miramichi River estuary. A sediment triad assessment approach (Chapman, 1992) was initiated and included benthic invertebrate community evaluation, sediment chemistry and sediment toxicity tests.

Throughout the 1990's, many environmental improvements were completed at the various industries along the Miramichi River estuary. These included the installation of secondary effluent treatment at the pulp mill , improved effluent treatment at the kraft mill, improvements in water treatment at the Heath Steele Mine and expanded sewage collection and treatment for parts of the municipality.

In 2002, the Miramichi River Environmental Assessment Committee (MREAC) decided to repeat a sediment quality survey of the same stretch of the Miramichi River estuary to assess whether the improvements in effluent quality would be reflected in improved sediment quality in the estuary. MREAC conducted a sediment sampling survey in October 2002 and again had the samples evaluated for benthic community structure, sediment chemistry and sediment toxicity.

This report summarizes the results of the 1993 and 2002 surveys and compares the results to determine if changes in sediment quality have occurred.

2.0 MATERIAL AND METHODS

2.1 1993 SURVEY

2.1.1 Sample Collection

On June 14, 1993, Environment Canada collected a series of eight sediment samples from the Miramichi River in the vicinity of the city of Miramichi. The sampling stations were labelled 1 to 8 inclusive starting at the most downriver site and proceeding up river. The geographical location of each sampling station was verified at the time of sampling using a Magellan Nav 5000 Global Positioning System (GPS). The geographical coordinates for the sampling locations are provided in Table 2.1-1 and are shown on Figure 2.1-1.

At each sampling location, the boat was anchored and eight grab samples of sediment were collected using a 0.0625 m^2 Van Veen dredge. The entire contents of three grab samples were placed in individual 4-litre plastic pails for benthic invertebrate community assessment. For the remaining five grab samples, the top 5 centimetres were removed and placed in a large stainless steel bowl. The five aliquots were mixed together by stirring with a hand trowel and sub-samples of the homogenate were taken as follows:

- One 1-litre glass jar with aluminum foil cap liner for organic analyses by RPC, Fredericton, NB
- One 1-litre polyethylene bottle for metal and grain size analyses by RPC, Fredericton, NB
- One 250-mililitre polyethylene bottle for lignin analyses by Seatech Ltd., Halifax, NS
- One 4-litre plastic pail for toxicity testing by the Environment Canada bioassay laboratory, Dartmouth, NS.

2.1.2 Benthic Invertebrate Community Evaluation

The samples for benthic invertebrate evaluation were sieved in the field immediately following collection through a 0.5-millemetre-mesh sieve, placed in 1-litre polyethylene jars and preserved with a10 % buffered formalin solution. The preserved samples were transported to Arenicola Marine in Dartmouth, NS. In the laboratory, invertebrates were picked from the residual sediment using a magnifying lamp and a binocular microscope. All invertebrates were identified to the lowest possible taxonomic level, using Bousfield (1973), Lubinsky (1980), and Pocklington (1989) as guides.

2.1.3 Physical and Chemical Analyses

The grain size distribution of each of the sediment samples was determined and the samples were analysed for a variety of chemical constituents. Specifically, the sediments were measured to determine the concentrations of:

- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)
- Chlorophenols
- Extractable organic halides (EOX)
- Lignin
- Total organic carbon (TOC)

- Trace metals

All of the analyses were performed by the RPC laboratory in Fredericton, NB with the exception of the lignin analyses that were completed by Seatech Ltd. in Halifax, NS. The laboratory methods used for these measurements were described in Parker et al, 1994.

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

Year of Survey	Location	Sample Identification	Latitude	Longitude
1993	Douglastown	EC-1993-01	47 01 42 N	65 29 20 W
1993	Chatham Head	EC-1993-02	47 00 29 N	65 33 14 W
1993	Wharf Inn	EC-1993-03	46 59 38 N	65 33 45 W
1993	Groundwood Mill	EC-1993-04	46 58 39 N	65 33 32 W
1993	Flett's Cove	EC-1993-05	46 58 06 N	65 33 49 W
1993	NW Branch north of Beaubear's Island	EC-1993-06	46 58 43 N	65 34 46 W
1993	NW Corner of Beaubear's Island	EC-1993-07	46 58 07 N	65 34 56 W
1993	NW Branch upstream of Highway # 8 Bridge	EC-1993-08	46 57 58 N	65 36 09 W
2002	Douglastown Marina	MREAC-2002-01	47° 01 18 N	65° 29 54 W
2002	Morrison's Cove	MREAC-2002-02	47° 00 57 N	65° 29 54W
2002	Wharf Inn	MREAC-2002-03	46° 59 38 N	65° 33 44 W
2002	Groundwood Mill	MREAC-2002-04	46° 58 26 N	65° 33 30 W
2002	Vye's Beach	MREAC-2002-05	46° 58 24 N	65° 35 05 W

2.1.4 Sediment Toxicity Tests

The Miramichi River estuary sediment samples underwent four types of toxicity testing:

- A ten-day survival test using the marine amphipod, *Corophium volutator,* as the test organism (Environment Canada, 1992a)
- Sediment pore water toxicity to the marine bacterium, *Photobacterium phosphoreum*, was assessed using the Microtox® Toxicity Assessment System (Environment Canada, 1992b, Microbics, 1992)
- Solid-phase sediment toxicity to the marine bacterium, *Photobacterium phosphoreum*, was assessed using the Microtox® Toxicity Assessment System (Environment Canada, 1992b, Microbics, 1992)
- The toxic effects of the sediment pore water on fertilization of the eggs of the white sea urchins (*Lytechinus pictus*) (Environment Canada, 1992c).

2.2 2002 SURVEY

2.2.1 Sample Collection

On October 8, 2002, the Miramichi River Environmental Assessment Committee (MREAC) collected sediment samples from five locations along the Miramichi River estuary using a 0.0625 m2 Van Veen grab sampler. Information on the sample locations is provided in Table 2.1-1 and in Figure 2.1-1.

The samples for invertebrate evaluation were placed in 5-litre pails and preserved in their entirety in 70-80% isopropanol. The samples were stored by MREAC prior to being transported to Envirosphere Consultants Limited in Windsor, NS in May 2003 for sorting and identification. A triplicate sample was collected at the location MREAC-2002-05 (Vye's Beach). All other samples were single samples with no replicates.

The samples for chemical analyses and toxicity tests were kept refrigerated at 4^{o}C and transported to the Environment Canada laboratory in Moncton, NB.

2.2.2 Physical and Chemical Measurements

The sediment samples were analysed at the Environment Canada laboratory in Moncton, NB for the following parameters:

- Ammonia
- Sulphide
- Oxidation reduction potential (redox)
- Trace metals
- Polychlorinated biphenyls (PCB)
- Polycyclic aromatic hydrocarbons (PAH)

The measurement of sulphide and redox is more accurate if conducted in the field on undisturbed sediment samples. The transfer of sediment from the sampling dredge to the sample containers can introduce oxygen to the sediments and result in a reduction of the sulphide concentrations and an increase in the redox readings.

The RPC laboratory in Fredericton, NB also determined the grain size and total organic carbon (TOC) content of these samples.

2.2.3 Sediment Toxicity Testing

The five sediment samples were received at the Environment Canada Environmental Quality Laboratory (EQL) in Moncton, NB on October 16, 2002. The samples were frozen upon receipt and were placed in a 4°C cooler to thaw. Once thawed, the pore water salinity was measured (Jackman and Doe, 2003).

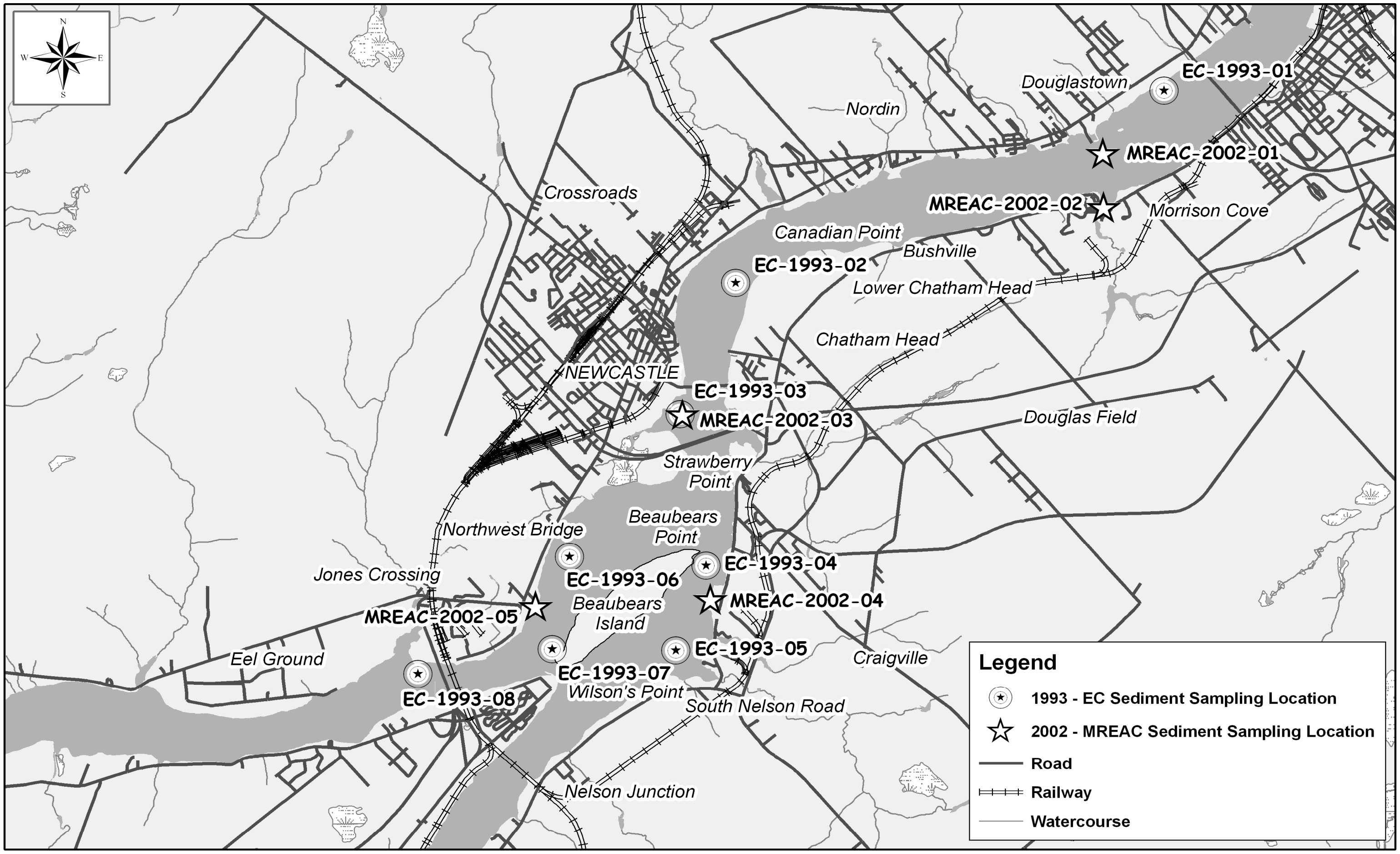
Samples were stored at 4 ± 2°C prior to testing. Each of the sediment samples was stirred thoroughly to homogenize the contents of the pails. A different set of sediment toxicity tests were used for these samples than had been used for the 1993 samples. The sediments were analysed for toxicity to the estuarine amphipod, *Eohaustorius* *estuarius*, and to the luminescent bacterium, *Vibrio fischeri,* following the Environment Canada standard testing procedures (Environment Canada, 1998 and 2002).

2.2.4 Benthic Invertebrate Community Evaluation

All of the samples were provided to Envirosphere as the whole samples collected and removed from the grab samplers in the field. At the laboratory, the samples were emptied onto a 0.5 mm sieve and washed in freshwater to remove fine sediment and the preservative. The sediments and organisms retained by the sieve were stored in 70% isopropyl alcohol.

Prior to sorting in the laboratory, the samples were rinsed again on a 0.5 mm sieve to remove preservative and organisms were removed by sorting at 6.4x magnification on a stereomicroscope, with a final brief check at 16x. Sorting efficiency for lab personnel was checked periodically by resorting samples, to ensure sorting efficiency levels of 95% or better. Wet weight biomass (g/sample) was estimated by weighing animals to the nearest milligram at the time of sorting after blotting to remove surface water.

Organisms were identified to an appropriate taxonomic level, typically to species, using conventional taxonomic literature for the groups involved and verified reference specimens (Envirosphere, 2003).



January 9, 2007
Projection: NAD83 N.B. Double Stereographic
Data Sources: Service New Brunswick

Figure 2.1-1
Sediment Sampling Locations
Along the Miramichi River Estuary

1:60,000
0 0.5 1 1.5 2 km

3.0 RESULTS

3.1 1993 SURVEY

3.1.1 Physical and Chemical Measurements

The sediment sampling began at 0800 on June 14, 1993 at Station EC-1993-01, the most down river location sampled. The tide was low at the time and was rising. High tide occurred at 1400 when Station EC-1993-06 was being sampled. The final sample was collected at EC-1993-08 at 1530 hours with the tide ebbing. A description of the sediment collected at each location is provided in Table 3.1-1 and the results of the grain size and moisture content measurements are provided in Table 3.1-2. Most of the samples were described as soft, fine mud and some contained traces of wood bark. All of the samples were predominantly sand with the percentage ranging from 45.95 % in sample EC-1993-07 up to 95.68 % in sample EC-1993-06. Most of the samples had 20 to 30 percent silt and all of the samples, except EC-1993-07 had low gravel contents. All samples had low levels of clay.

A summary of the analytical results for total polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), extractable organo-halogens (EOX), spruce wood lignin and total organic carbon (TOC) are presented in Table 3.1-3. The PAH data has been summed to give just the total PAH values and ranged from < 0.05 up to 1.89 mg/kg (parts per million). Analytical results for individual PAH's are provided in Appendix Table A-1. Trace amounts of PCB were found in the sediments from Stations 1, 2 and 3 and no PCB were detected in any of the other samples. The results indicate that the amount of lignin found in the sediments was highest at EC-1993-02 (19.0 mg/g) and lowest at EC-1993-04 ((0.29 mg/g). Total organic carbon ranged from 0.31 % at Station 4 up to 6.82 % at Station 8. Extractable organo-halogens and chlorophenols were not detected in any of the sediment samples.

The results of the analyses for total trace metal content in the sediment samples are presented in Table 3.1-4. All five metals that were analysed for were detected in all eight samples. The concentrations of mercury were the lowest with values ranging from 0.02 to 0.16 mg/kg. Cadmium was the next lowest in terms of concentration with values ranging from 0.33 to 1.47 mg/kg. Copper concentrations ranged from 4.3 mg/kg up to 36.6 mg/kg and lead values ranged from 10.2 mg/kg to 57.9 mg/kg. Zinc was present in the highest concentrations with values ranging up to 331 mg/kg at EC-1993-03.

3.1.2 Sediment Toxicity Tests

Sediment toxicity tests were conducted with the amphipod *Corophium volutator* , the white sea urchin, *Lytechinus pictus* and with the Microtox system. The results of these tests are summarized in Table 3.1-5.

After 10 days exposure to the sediments, the amphipods had 90% survival in the control sediment and between 87% and 94% survival in the eight test sediments. Therefore, none of the test sediments was considered to be toxic to *Corophium volutator*.

The results of the Microtox pore water assays indicated that all of the Miramichi River samples were toxic except EC-1993-04 and EC-1993-06. The most toxic samples

(those with the lowest IC50 values) were from EC-1993-03, EC-1993-05 and EC-1993-07.
In the Microtox solid phase assay, samples with an IC50 of <1000 ppm are considered toxic while samples with an IC50 of > 5000 ppm are considered to be of low toxicity. Using these criteria, samples from EC-1993-01, EC-1993-02 and EC-1993-08 are considered to be toxic in the solid phase assay. Samples from EC-1993-04 and EC-1993-06 and the reference sediment were non-toxic. The results of the Microtox pore water assays indicated that three other samples, EC-1993-03, EC-1993-05 and EC-1993-07, were the most toxic. The two Microtox assays are intended to compliment one another. The pore water assay is designed to detect soluble contaminants while the solid phase assay measures the toxicity associated with hydrophobic contaminants bound to the sediment particles.

The results of the pore water assays using the sea urchin *Lytechinus pictus* identified that the pore water of all eight Miramichi River estuary sediment samples were toxic. EC-1993-03, EC-1993-05 and EC-1993-07 were the most toxic while the reference sediment pore water was non-toxic.

3.1.3 Benthic Invertebrate Community Evaluation

A summary of the results of the benthic invertebrate survey and analyses are presented in Tables 3.1-6 and 3.1-7. The complete data on species abundance for all of the samples are provided in Appendix Table A-2. The total numbers of individual organisms per square metre were quite low except at sample stations 1 and 2 and decreased as the sampling locations moved upstream. The number of organisms per square metre for the 24 samples (8 stations with 3 replicates per station) ranged from 5792 down to 16 (mean = 760; standard deviation = 1367). All of the sediment samples showed low numbers of species diversity (richness) ranging from 1 to 6 species present in any one sample. For the 24 samples, the overall average number of species per sample was 3 (standard deviation = 2). The animals recovered were species that can tolerate very low salinities suggesting that the samples were taken quite far up in the estuary. For example, the species recovered from stations 1 to 5 were dominated by species which are found in coastal marine environments but are also typical of the upper reaches of estuaries e.g. the mollusc *Macoma balthica*, the polychaetes *Nereis diversicolor* and *Marenzellaria viridis*, a marine oligochaete and two amphipod crustaceans *Marinogammarus finmarchicus* and *Gammarus oceanicus*. The fauna of stations 6, 7 and 8 were very scarce and were comprised of only a few specimens of polychaetes known to be able to tolerate low salinities.

Table 3.1-1 Description of sediment conditions for samples collected on the Miramichi River on June 14, 1993

Sample Identification	Sample Location	Water Depth (m)	Description of Sediment Collected
EC-1993-01	Douglastown	3.5	Soft, fine mud
EC-1993-02	Chatham Head	4.5	Soft, fine mud
EC-1993-03	Wharf Inn	<1.0	Soft mud with vegetation and some gravel material
EC-1993-04	Groundwood Mill	5.5	Fine, dark sand with some pieces of bark
EC-1993-05	Flett's Cove	1.8	Soft, fine mud with some pieces of bark
EC-1993-06	NW Branch north of Beaubear's Island	4.2	Fine, dark sand with some pieces of bark
EC-1993-07	NW Corner of Beaubear's Island	3.0	Muddy material with gravel
EC-1993-08	NW Branch upstream of Highway # 8 Bridge	4.9	Soft, fine, black mud

Table 3.1-2 Results of grain size analysis and moisture content determination on sediment samples collected from the Miramichi River estuary on June 14, 1993.

Sample Identification	Percent Gravel	Percent Sand	Percent Silt	Percent Clay	Percent Moisture
EC-1993-01	< 0.05	76.56	23.40	< 0.05	54.3
EC-1993-02	1.79	63.24	31.01	3.96	65.0
EC-1993-03	6.94	69.9	21.89	1.27	49.2
EC-1993-04	2.18	94.7	3.11	< 0.05	23.0
EC-1993-05	0.46	81.92	16.27	1.35	48.7
EC-1993-06	1.90	95.68	2.42	< 0.05	23.1
EC-1993-07	32.6	45.95	20.47	1.03	46.6
EC-1993-08	0.68	63.82	32.16	3.34	71.0

Table 3.1-3 Results for PAH, PCB, EOX, lignan and TOC measurements on sediment samples collected from the Miramichi River estuary on June 14, 1993.

Sample Identification	Total PAH (mg/kg)	PCB (as Arochlor 1254) (mg/kg)	EOX (mg/kg)	Spruce Wood Lignin (mg/g)	TOC (%)
EC-1993-01	0.51	0.17	< 2.5	6.69	3.57
EC-1993-02	0.70	0.06	< 2.5	19.0	5.62
EC-1993-03	1.80	0.04	< 2.5	13.7	3.88
EC-1993-04	0.06	n.d. (< 0.02)	< 2.5	0.29	0.31
EC-1993-05	0.32	n.d. (< 0.02)	< 2.5	8.93	2.70
EC-1993-06	n.d. (< 0.05)	n.d. (< 0.02)	< 2.5	0.68	0.23
EC-1993-07	0.18	n.d. (< 0.02)	< 2.5	3.56	2.22
EC-1993-08	0.59	n.d. (< 0.02)	< 2.5	10.8	6.82

Table 3.1-4 Results for trace metal analyses on sediment samples collected from the Miramichi River estuary on June 14, 1993.

Sample Identification	Cadmium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Mercury (mg/kg)
EC-1993-01	0.88	19.6	28.1	163	0.11
EC-1993-02	1.45	28.3	43.5	236	0.14
EC-1993-03	1.47	36.6	57.9	331	0.16
EC-1993-04	0.54	4.7	10.2	48.7	0.02
EC-1993-05	0.40	11.4	18.9	94.9	0.04
EC-1993-06	0.33	4.3	10.2	45.5	0.02
EC-1993-07	1.06	14.6	31.1	101	0.06
EC-1993-08	1.23	24.3	36.7	241	0.12

Table 3.1-5 Results of toxicity tests conducted on sediment samples collected from the Miramichi River estuary on June 14, 1993.

Sample Identification	Amphipod Survival (%)	Microtox Pore Water Test IC50 (%)	Microtox Solid Phase IC50 (mg/L)	Sea Urchin Percent Fertilization in 100 % Pore water
EC-1993-01	88	52 (17 – 160)	673	2
EC-1993-02	94	47 (38 - 59)	358	2
EC-1993-03	87	13 (12 – 15)	2005	0
EC-1993-04	90	> 100	> 76085	38
EC-1993-05	90	23 (20 – 26)	5217	0
EC-1993-06	89	> 100	> 75493	3
EC-1993-07	89	9.2 (6.4 – 13)	5197	0
EC-1993-08	89	75 (44 – 128)	550	3
Control	90	> 100	18565	86

Table 3.1-6 Total number of benthic organisms per square metre (abundance) in sediment samples collected from the Miramichi River estuary on June 14, 1993.

Station	Replicate #1	Replicate #2	Replicate #3	Mean	Standard Deviation
EC-1993-01	2144	5792	3166	3701	1536
EC-1993-02	1664	656	2192	1504	637
EC-1993-03	304	304	208	272	45
EC-1993-04	144	496	112	251	174
EC-1993-05	144	224	160	176	35
EC-1993-06	64	64	48	50	8
EC-1993-07	48	160	80	96	47
EC-1993-08	16	16	48	27	15

Table 3.1-7 Total number of benthic invertebrate species (richness) in sediment samples collected from the Miramichi River estuary on June 14, 1993.

Station	Replicate #1	Replicate #2	Replicate #3	Mean	Standard Deviation
EC-1993-01	5	3	4	4	1
EC-1993-02	6	6	4	5	1
EC-1993-03	4	5	4	4	0
EC-1993-04	4	6	4	5	1
EC-1993-05	4	4	3	4	0
EC-1993-06	1	3	2	2	1
EC-1993-07	2	4	2	3	1
EC-1993-08	1	1	1	1	0

3.2 2002 SURVEY

3.2.1 Physical and Chemical Measurements

The results for the grain size distribution and the total organic carbon content of the 2002 sediment samples are summarized in Table 3.2-1. There appears to be a gradient from finer grade sediments downstream to larger grain sediments upriver. The samples from the Douglastown Marina and Morrison's Cove were predominantly finer grain material with almost 80 % clay and silt. The other 3 samples were predominantly sand with some clay and silt contents. The sample from Vye's Beach was predominantly sand (52.9 %) with similar proportions of gravel, clay and silt. The total organic carbon content was generally similar for all stations (2.6 to 4.6 %) with the noticeable exception of the groundwood mill site that had a TOC of 21 %.

All five samples had detectable concentrations of total polycyclic aromatic hydrocarbons (PAH) and four of the five samples had detectable concentrations of polychlorinated biphenyls (Table 3.2-2). The concentrations of the individual PAH measured are provided in Appendix Table A-3. The complete results for the trace metal in sediment analyses are provided in Appendix Table A-4. Table 3.2.3 provides a summary of the more important metal results that will be discussed further in the report.

Prior to starting to toxicity tests, the salinity of the pore water was measured. In addition, triplicate measurements were made on each sample for ammonia, sulphide and oxidation–reduction potential (redox) were made. The results of these measurements are summarized in Table 3.2-4. The salinity in the samples ranged from 7 to 12 parts per thousand (ppt) with the higher values being observed in the more downriver stations. Sediment ammonia concentrations ranged from 38.4 ug/g at the Wharf Inn location up to 85.8 ug/g at Morrison's Cove. Sulphide was the highest at the Groundwood Mill location and the lowest concentrations were measured at the Douglastown Marina site. Redox was similar at all stations with values ranging from 189 to 220 mV. Due to sample handling and storage, the results of sulphide and redox on the samples on the samples in the laboratory would not accurately reflect the conditions in the river.

3.2.2 Sediment Toxicity

The toxicity tests conducted on the 2002 sediment samples were:

- The 10-day amphipod survival assay with *Eohaustorius estuarius*
- The Microtox Solid Phase Assay with the bacterium *Vibrio ficheri*

The mean survival rates for the amphipod tests ranged from 92 % up to 100 % and were not significantly different from the control results (Table 3.2-5). For the Microtox solid phase assay, the IC50 values ranged from 882 mg/L for sample MREAC-2002-02 up to 5640 mg/L for sample MREAC-2002-05.

One of the only guidelines in Canada for interpreting Microtox results is "The Interim Guideline for the Environment Canada Ocean Disposal Program" (Environment Canada, 1996 and 2002). This guideline states that a sample is considered toxic in the Microtox Solid Phase Test if the EC50 is less than 1,000 mg /L corrected for dry weight of solids. Sample MREAC-2002-02 (Morrison's Cove) would be considered toxic using these criteria. Sample MREAC-2002 05 (Groundwood Mill) had the next lowest IC50 value, and while not judged toxic would be considered borderline with an IC50 of 1120 mg /L. The other three samples would not be considered toxic to the bacterium, *Vibrio fischeri*, according to these criteria.

3.2.3 Benthic Invertebrate Community Evaluation

The results of the sorting and identification of the benthic samples are provided in Appendix Table A-5 and are summarized in Table 3.2-6. Polychaete worms, principally *Nereis diversicolor* and *Marenzellaria viridis,* and the clam *Macoma balthica*, dominated bottom communities surveyed. Other species which were occasionally dominant included the gastropod *Hydrobia totteni* at Vye's Beach and Groundwood Mill; aquatic oligochaetes at Wharf Inn, Morrison's Cove and Douglastown Marina; and softshell clams (*Mya arenaria*) at Wharf Inn and Douglastown Marina. The mud crab, *Rhithropanopeus harrisii,* was only observed at Vye's Beach. Abundance and biomass were moderate to high at most stations while the overall number of species (richness) was low. The number of organisms per square metre (abundance) ranged from 1072 at MREAC-2002-02 up to 4640 at MREAC-2002-05 (mean = 2454, standard deviation = 1432). Richness ranged from 4 to 7 with a mean of 6 (S.D. = 1).

Table 3.2-1 – Results of the grain size and total organic carbon measurements on the 2002 Miramichi River sediment samples

Sample Identification	Sample Location	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	TOC (%)
MREAC-2002-01	Douglastown Marina	0	17.1	58.6	24.3	4.2
MREAC-2002-02	Morrison's Cove	0.5	14.7	58.2	26.7	4.6
MREAC-2002-03	Wharf Inn	4.6	43.6	32.9	18.8	3.2
MREAC-2002-04	Groundwood Mill	7.7	54.3	17.4	20.6	21.0
MREAC-2002-05	Vye's Beach	16.0	52.9	19.2	11.9	2.6

Table 3.2-2 PAH and PCB concentrations in the 2002 Miramichi River sediment samples

Sample Identification	Sample Location	Total PAH (mg/kg)	Total PCB (mg/kg)
MREAC-2002-01	Douglastown Marina	0.76	0.076
MREAC-2002-02	Morrison's Cove	0.65	0.060
MREAC-2002-03	Wharf Inn	1.35	0.022
MREAC-2002-04	Groundwood Mill	0.44	< 0.010
MREAC-2002-05	Vye's Beach	0.28	0.021

Table 3.2-3 – Trace metal analyses for the 2002 Miramichi River sediment samples

Sample Identification	Sample Location	Arsenic (mg/kg)	Cadmium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
MREAC-2002-01	Douglastown Marina	10.7	1	16.9	27.9	133.5
MREAC-2002-02	Morrison's Cove	11.2	1	18.5	31.1	125
MREAC-2002-03	Wharf Inn	8.7	1	18.8	35.9	172.9
MREAC-2002-04	Groundwood Mill	7.2	1.5	15.2	27.5	129
MREAC-2002-05	Vye's Beach	5.8	< 1.0	12.4	16.3	82.3

Table 3.2-4 Results of salinity, ammonia, sulphide and redox measurement on the 2002 Miramichi River sediment samples. Results for ammonia, sulphide and redox are the means of three measurements on each sample.

Sample Identification	Sample Location	Salinity (ppt)	Ammonia-Nitrogen (ug/g)	Sulphide (ug/g)	Redox (mV)
MREAC-2002-01	Douglastown Marina	12	61.3	18.6	200
MREAC-2002-02	Morrison's Cove	10	85.8	63.4	189
MREAC-2002-03	Wharf Inn	10	38.4	31.1	220
MREAC-2002-04	Groundwood Mill	8	52.9	77.8	207
MREAC-2002-05	Vye's Beach	7	48.5	38.5	192

Table 3.2-5 Results of amphipod survival and Microtox Solid Phase assays with the 2002 sediment samples from the Miramichi River estuary. The concentration that causes 50 % inhibition in the test bacteria (IC50) is expressed as mg dry sediment/litre of diluent solution.

Sample Identification	Sample Location	Amphipod Tests Mean % Survival and Standard Deviation	Microtox Solid Phase Tests IC50 with 95% Confidence Limits (mg/L)
Laboratory Control	n/a	100 ± 0	n/a
MREAC-2002-01	Douglastown Marina	92 ± 4.5	3830 (3260 – 4500)
MREAC-2002-02	Morrison's Cove	93 ± 5.7	882 (834 – 932)
MREAC-2002-03	Wharf Inn	98 ± 2.7	2850 (2220 – 3650)
MREAC-2002-04	Groundwood Mill	98 ± 2.7	1120 (1120 – 1130)
MREAC-2002-05	Vye's Beach	100 ± 0	5640 (5310 – 6010)

Table 3.2-6 Summary of the benthic community results for the 2002 sediment samples from the Miramichi River estuary.

Sample Identification	Sample Location	Number of Organisms per m^2 (Abundance)	Number of Individual Taxa (Richness)
MREAC-2002-01	Douglastown Marina	2464	7
MREAC-2002-02	Morrison's Cove	1072	4
MREAC-2002-03	Wharf Inn	2816	5
MREAC-2002-04	Groundwood Mill	1280	7
MREAC-2002-05	Vye's Beach	4640	6

4.0 DISCUSSION

The discussion will first examine the results of each survey in terms of environmental quality of the sediments from this section of the Miramichi River estuary. Since the two surveys were similar in terms of sampling locations and parameters measured, the discussion will then focus on a comparison of the results and evaluate how environmental conditions may have changed over the nine-year period between the surveys.

4.1 1993 Survey

The 1993 survey collected sediment samples that consisted primarily of sand and silt and would be indicative of depositional areas. Total organic carbon content was generally low with values ranging from 0.23 % up to 6.82 %. The lowest value was from sample EC-1993-06 that consisted almost entirely of sand. The next lowest TOC was 0.31 % for sample EC-1993-04 and again this sample was 95 % sand. This inverse relationship between sand content and TOC was consistent for most of the samples (Figure 4.1-1). The highest TOC value was for EC-1993-08 and this sample was 64 % sand and 32 % silt. The other sample with a higher TOC value (5.62 %) was EC-1993-02 and again, this sample consisted of 63 % sand and 31.01 % silt. Samples with lower silt content had lower levels of TOC (Figure 4.1-2).

Extractable organo-halogens (EOX) were not detected in any of the samples. These compounds can originate from pulp and paper mills that use elemental chlorine in their bleaching process. PAH were detected in 7 of the 8 samples. The highest concentration of total PAH was measured in sample EC-1993-03 at 1.80 mg/kg (ppm) and that sample exceeded the CCME interim sediment quality guidelines (ISQG) for the protection of marine aquatic organisms for 10 individual PAH (Appendix Table A-1)). None of the samples exceeded the Probable Effects Level (PEL) for total PCB (CCME 2002).

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 collected at EC-1993-01 exceeded that recommended value 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 exceeded that value as well.

The CCME has established ISQG and PEL for trace metals (CCME, 2002) in marine sediments for the protection of aquatic life (Table 4.1-1). Several of the samples had metal concentrations that exceeded the ISQG (Table 4.1-2) but only one sample (EC-1993-03) exceeded the PEL for the metals measured. This sample exceeded the PEL for zinc. There was a positive relationship between the silt content of the samples and the metal concentrations (Figure 4.1-3). The samples with the higher amounts of silt had the higher metal concentrations. This is due in part to dissolved metals in the river attaching to fine particulate material and then the particulates settle out in the depositional areas of the estuary. The Heath Steele Mine operated in the headwaters of the Northwest Miramichi River from the mid 1950’s until the late 1990’s and was known to have discharged elevated levels of zinc and copper to the Tomogonops River throughout that period. Pollution control efforts at the mine have greatly reduced these discharges but the elevated concentrations observed in some of the 1993 samples from the estuary could be reflecting historic discharges from the mine.

Figure 4.1-1 Comparison of sand content to total organic carbon content for 1993 Miramichi River estuary sediment samples.

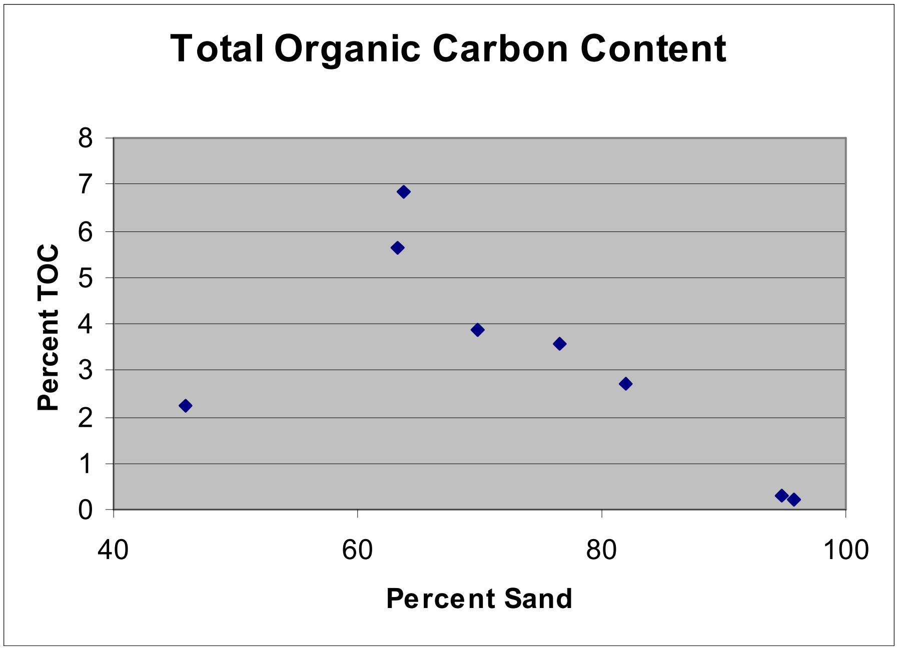


Figure 4.1-2 Comparison of silt content to total organic carbon content for 1993 Miramichi River estuary sediment samples.

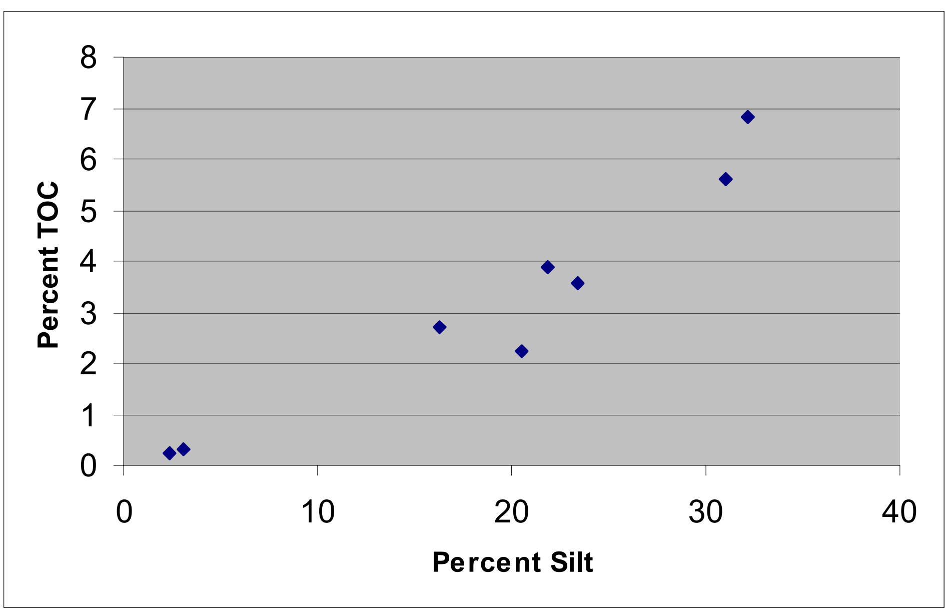


Table 4.1-1 CCME Guidelines for the Protection of Marine Aquatic Life

Metal	Interim Sediment Quality Guideline (ISQG) (mg/kg)	Probable Effects Level (PEL) (mg/kg)
Cadmium	0.7	4.2
Copper	18.7	108
Lead	30.2	112
Zinc	124	271
Mercury	0.13 mg/kg	0.70

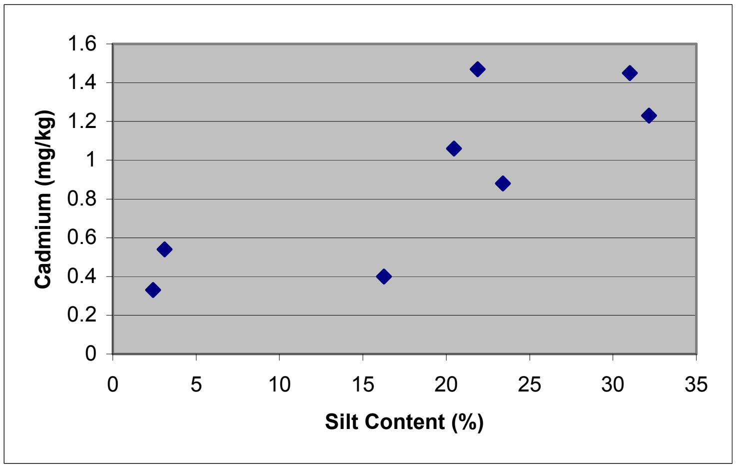
(CCME, 2002)

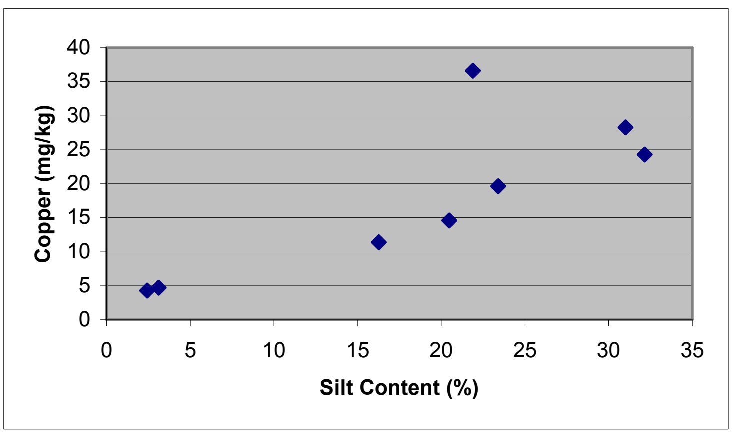
Table 4.1-2 Sediment samples that had metal concentrations that exceeded the CCME ISQG.

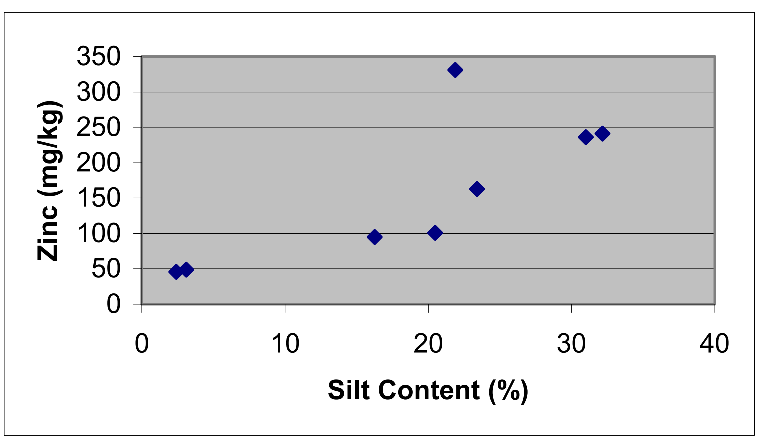
Cadmium	Copper	Lead	Zinc	Mercury
EC-1993-01	EC-1993-01	EC-1993-02	EC-1993-01	EC-1993-02
EC-1993-02	EC-1993-02	EC-1993-03	EC-1993-02	EC-1993-03
EC-1993-03	EC-1993-03	EC-1993-07	EC-1993-03*	
EC-1993-07	EC-1993-08	EC-1993-08	EC-1993-08	
EC-1993-08				

* Also exceeded the PEL for zinc

Figure 4.1-3 Relationship between silt content and metal concentrations in the 1993 Miramichi River estuary sediment samples.







Sediment Toxicity Tests

The sediments samples did not cause significant mortality to the amphipod, *Corophium volutator*, in the 10-day exposures.

In the Microtox tests, 6 of the 8 samples were toxic in the pore water test and only EC-1993-04 and EC-1993-06 were not toxic. For the solid phase Microtox test, samples EC-1993-01, EC-1993-02 and EC-1993-08 were determined to be toxic and EC-1993-04 and EC-1993-06 were rated as non-toxic. The toxicity results are similar for the two Microtox tests. The same two samples were non-toxic in either assay and these samples were primarily made up of sand so the toxicity could be related to some of the contaminants associated with the finer grain sediments.

When the pore water was tested using the sea urchin fertilization test, all of the samples caused toxicity. This assay is known to be very sensitive, particularly to ammonia and sulphide, which can be elevated in fine grain sediments that may have low dissolved oxygen concentrations.

Benthic Invertebrate Community Survey

In terms of abundance, there is an obvious gradient response from the furthest downriver station up to the most upriver station (Figure 4.1-4) with much higher numbers of organisms in the more seaward stations. The same trend can be seen for the species richness data but the gradient is not as strong (Figure 4.1-5). Overall, abundance and species richness are low, particularly in the stations further upstream. This reflects, in part, the fact that the area of the river sampled is in the transition zone between fresh water and salt water and only a few species can tolerate the fluctuating salinity conditions as the tide changes twice every day. The salinity is too low for many marine species and too high for freshwater invertebrates.

However, the abundance and richness are very low and may well be reflecting environmental impacts from some of the contaminants found in these sediments.

Overall Evaluation of 1993 Results

The eight sediment samples collected consisted primarily of sand and silt. Total organic carbon was higher in samples with less sand and more silt and two samples that were mostly sand had very low TOC. PAH were detected in most samples and the sample collected near the Wharf Inn (EC-1993-03) had the highest amount and exceeded the CCME guideline. PCB was detected in three of the sample and the most downriver sample, EC-1993-01, had a concentration that exceeded the CCME ISQG and PEL.

For metals, most samples exceeded the CCME ISQG for cadmium, copper, lead and zinc. The Wharf Inn sample had a zinc concentration that exceeded the CCME PEL. Samples EC-1993-04 and EC-1993-06, which were primarily sand, had lower levels of metals.

None of the samples was toxic to the amphipod, *Corophium volutator*. Samples EC-1993-04 and EC-1993-06 were not toxic in either the Microtox solid phase or pore water tests. The most toxic samples using the Microtox pore water test were EC-1993-03, EC-1993-05 and EC-1993-07. EC-1993-01 and EC-1993-02 were rated as the most toxic to the Microtox solid phase test. All samples were toxic in the sea urchin fertilization test.

The benthic community in this section is impoverished with both low abundance and low species richness. There was a gradient of higher abundance and richness to lower abundance and richness as the sample locations proceeded upriver. Although samples EC-1993-04 and EC-1993-06 had low levels of contaminants and were not very toxic, they still exhibited low abundance and species richness. The two samples that were most toxic in the Microtox Solid Phase test had the highest abundance.

Figure 4.1-4 Abundance of benthic invertebrates in 1993 sediment samples from the Miramichi River.

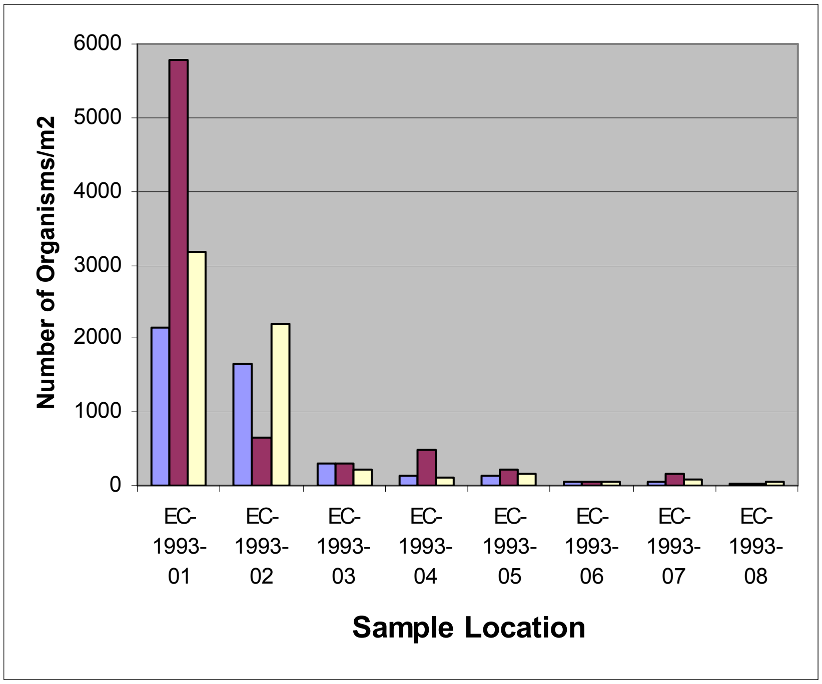
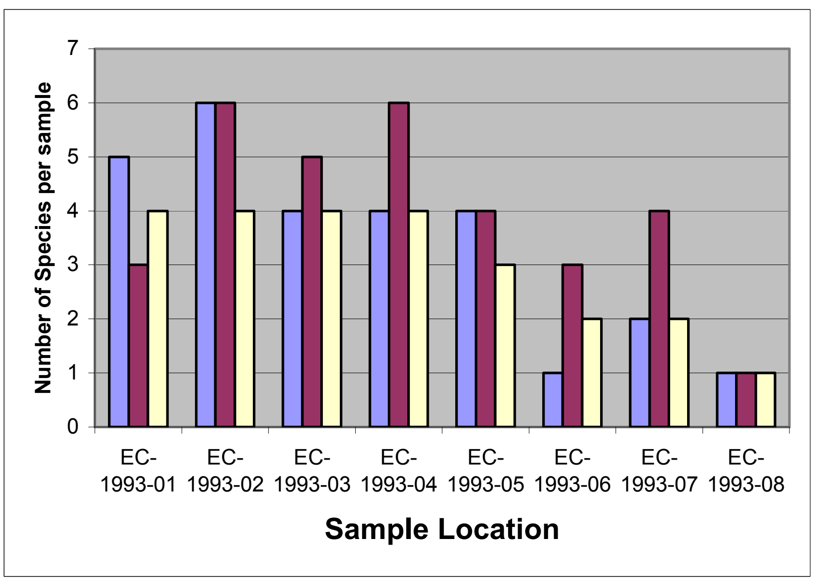


Figure 4.1-5 Species richness for benthic invertebrates in 1993 sediment samples from the Miramichi River.



4.2 2002 Survey

The sediments collected for the 2002 survey consisted primarily of silt and clay (fine material) and three samples were about 50 % sand (Table 3.2-1). One sample had a high total organic carbon content of 21 %. There was no apparent relationship between sand content and total organic carbon (Figure 4.2-1) and silt content (Figure 4.2-2).

Total PAH were detected in all five samples (Table 3.2-1). The highest concentration of total PAH was measured in sample MREAC-2003-03 at 1.35 mg/kg (ppm) and that sample had concentrations of eight (8) individual PAH that exceeded the CCME interim sediment quality guidelines (ISQG) for the protection of marine aquatic organisms (Appendix Table A-3). No samples exceeded the Probable Effects Level (PEL)>

Four of the five samples had detectable concentrations of polychlorinated biphenyls (Table 3.2-2). The CCME ISQG for total PCB is set at 0.022 mg/kg and two of the samples exceeded that value and two other were equal to that value. None of the samples exceeded the PEL for total PCB.

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.

There are no apparent relationships between the metal concentrations and the grain size distributions (Figure 4.2-3) with the exception of arsenic that appears to have a direct relationship to the silt content.

Sediment Toxicity Tests

The 2002 sediment samples did not cause any mortality to the estuarine amphipod *Eohaustorius estuarius* during the 10-day exposure.

The results of the Microtox Solid Phase tests indicated that MREAC-2002-02 (Morrison's Cove) was rated as being toxic with a EC50 of less than 1000 mg/L and the sample from MREAC-2002-04 (Groundwood Mill) was rated as being marginally toxic. The other three samples were rated as being non-toxic using the Canada Ocean Disposal Program criteria. The sediment sample from Morrison's Cove had the highest concentration of arsenic and ammonia-nitrogen and these compounds may have contributed to the observed toxicity. The sample from the groundwood mill had the highest amount of total organic carbon, total PCB and sulphide. Environment Canada conducted a Pearson Product Moment Correlation and did not detect any significant correlations between the Microtox results and the results of the grain size and chemical analyses (Jackman & Doe, 2003). Therefore, the causes of the observed toxicity could not be identified.

Benthic Invertebrate Community Survey

The benthic invertebrate assessment indicated moderately to high numbers of organisms per square metre. The lowest abundance was observed at MREAC-2002-02

(Morrison's Cove) with a total of 1072 organisms. The highest abundance was observed at MREAC-2002-05 (Vye's Beach) with a mean value of 4640 organisms/m^2.

The number of different species in each sample was overall quite low and ranged from 4 species (taxa) at MREAC-2002-02 (Morrison's Cove) up to 7 taxa at MREAC-2002-01, MREAC-2002-04 and MREAC-2002-05. Most of the species observed are tolerant to variable salinity levels typically found in an estuary; low salinity values at low tide and increasing salinity at high tide.

The results of the sorting and identification, organized from lowest to highest values, are provided in Figures 4.2-4 and 4.2-5. The sediment sample from Morrison's Cove had the lowest abundance and the lowest species richness. Other than that, the stations do not follow the same gradient for abundance and richness. The resulting gradients also do not follow a geographic pattern such as sorting out from up river to down river or vice versa. The sample from Morrison's Cove was also the most toxic in the Microtox solid phase test and had the highest concentration of arsenic and ammonia-nitrogen.

Overall Evaluation of 2002 Results

The sediment samples collected in 2002 were primarily silt and clay. One sample, MREAC-2002-04, had a very high total organic carbon content. PAH were detected in all samples and the highest concentration was at MREAC-2002-03, the Wharf Inn sampling location. This sample also exceeded the CCME ISQG. Four of the five samples had detectable PCB concentrations that were equal to or exceeded the CCME ISQG.

Arsenic, cadmium and zinc concentrations exceeded the CCME ISQG for most samples and MREAC-2002-03 had the highest concentration of lead, copper and zinc.

None of the samples was toxic to the amphipod, *Eohaustorius estuarius*. In the Microtox Solid Phase test, only MREAC-2002-02 from Morrison's Cove was rated as being toxic.

The Morrison's Cove sample also had the lowest abundance and species richness in the benthic invertebrate analysis.

There were no apparent relationships between sediment toxicity and the benthic community with any of the physical and chemical parameters measured.

Figure 4.2-1 Total organic carbon content compared to sand content of sediment samples collected from the Miramichi River estuary on October 2002.

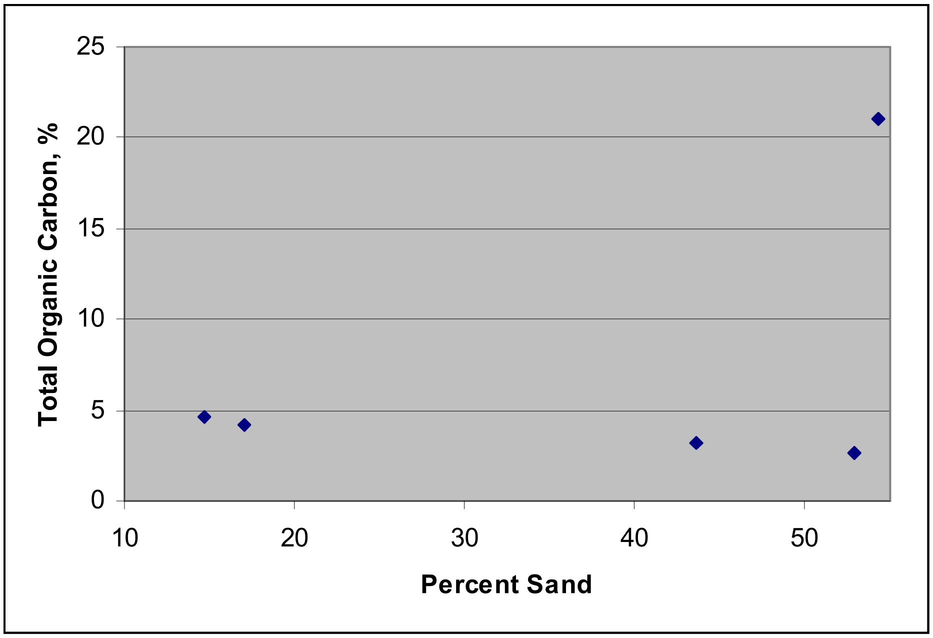


Figure 4.2-2 Total organic carbon content compared to silt content of sediment samples collected from the Miramichi River estuary on October 2002.

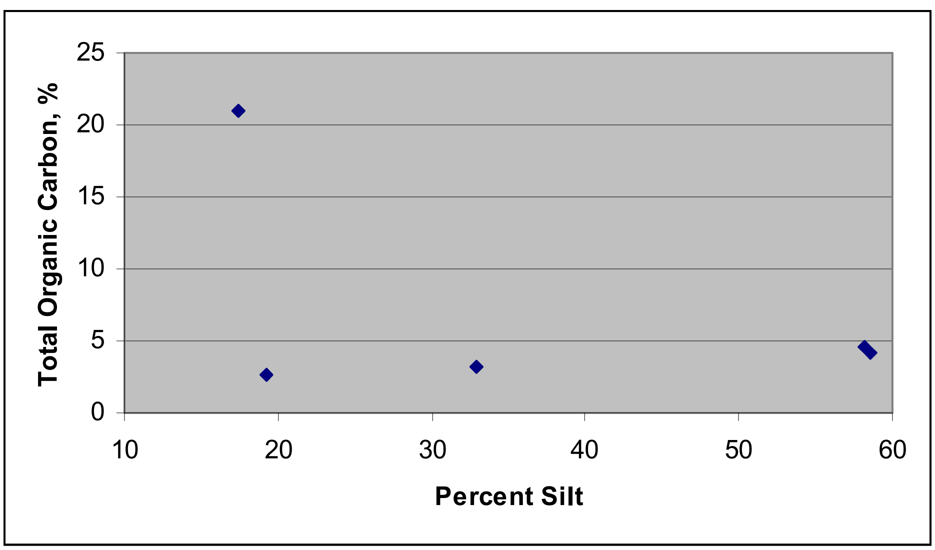
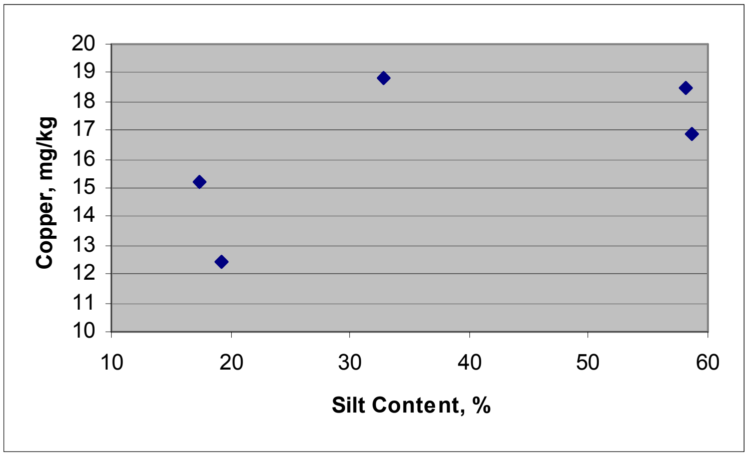
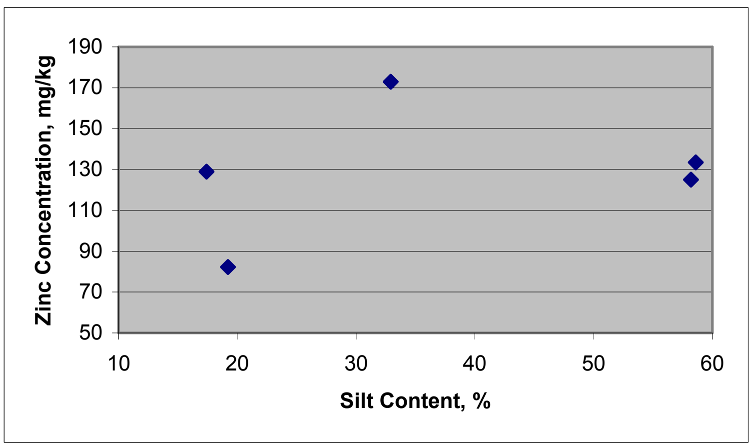


Figure 4.2-3 Relationship of metal concentrations to silt content of sediments





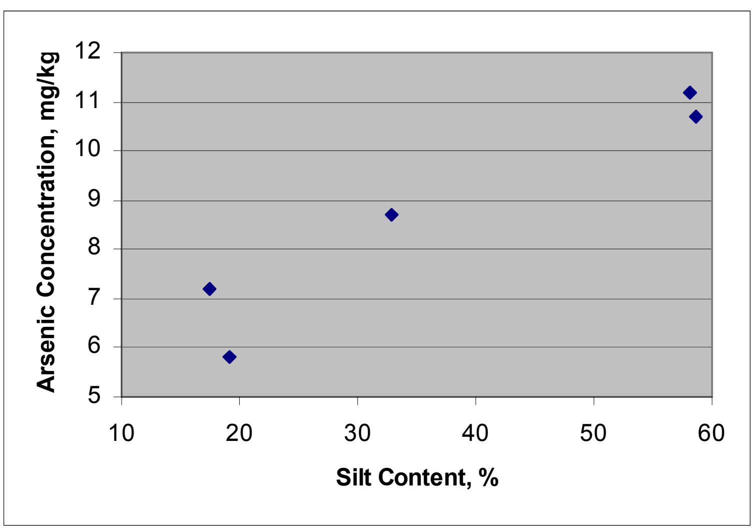


Figure 4.2-4 Abundance of benthic invertebrates for each of the 2002 sampling stations

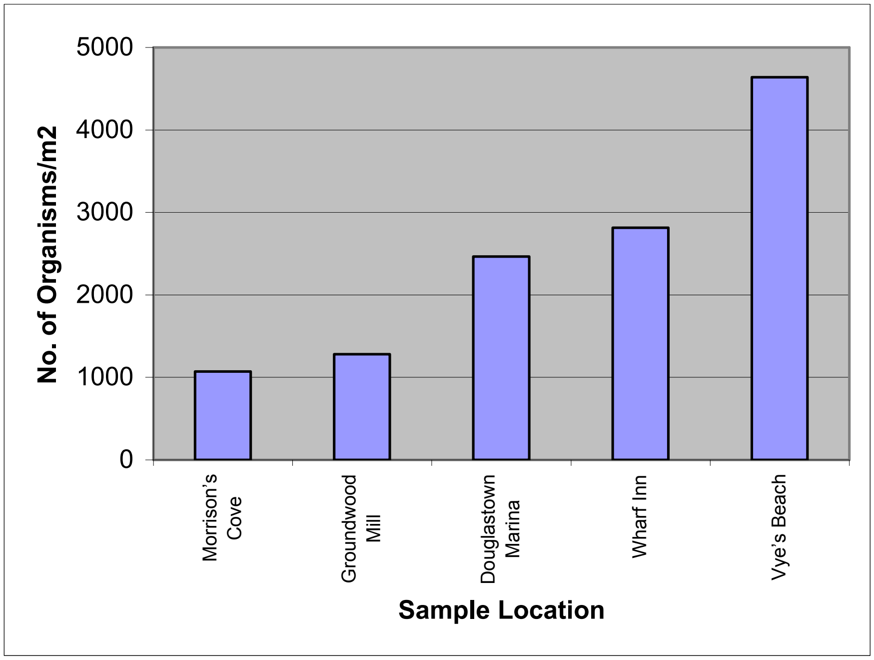
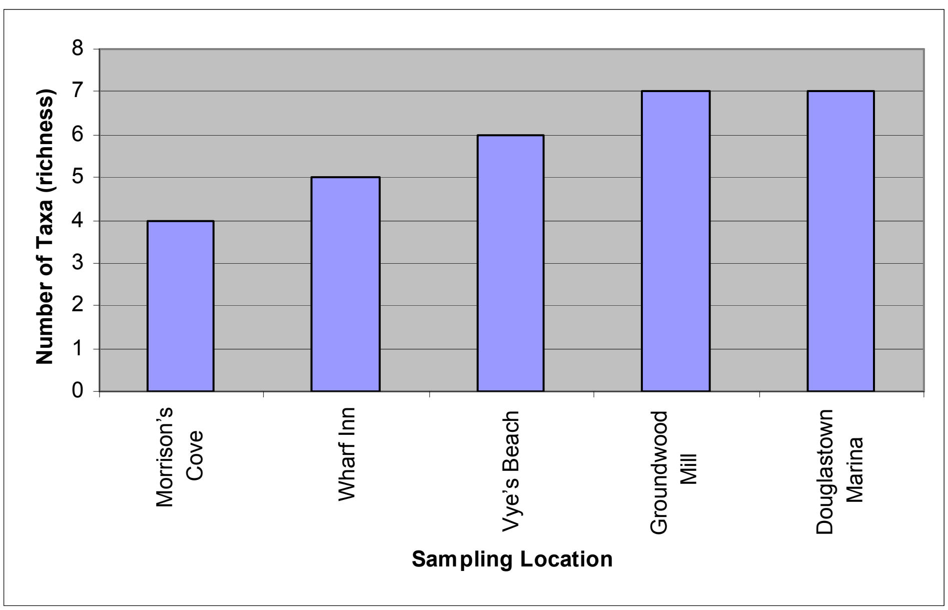


Figure 4.2-5 Species richness (number of taxa) of benthic invertebrates for each of the 2002 sampling stations



4.3 Comparison of 1993 and 2002 Survey Results

The two sediment surveys were similar in several ways:

- The sampling took place in the same section of the Miramichi River estuary extending from the Chatham Bridge up stream to the Highway # 8 Bridge over the Northwest Miramichi
- The samples were collected with a 0.0625 m^2 Van Veen grab sampler
- Sediment samples from both surveys were analyzed for trace metals, grain size, TOC, PAH and PCB
- Sediment samples from both surveys underwent toxicity testing
- Benthic invertebrate community evaluations were conducted on both sets of samples

Despite all of these similarities, the two surveys also differed in a number of factors:

- The 1993 samples were collected in June, the 2002 samples were collected in October
- The sampling locations for the two surveys were not exactly the same
- The 1993 samples were analyzed for PCB as Arochlor 1254; the 2002 samples were analyzed for total PCB
- The same metals were not measured on both sets of samples
- For the toxicity tests, a different species of amphipod was used for each set of samples and the sea urchin test was not used in 2002

4.3.1 Sampling Locations

The sampling locations for the two surveys are provided in Table 2.1-1 and Figure 2.1-1. Table 4.3-1 provides an estimate of the distances between the closer sampling locations for the two surveys. The sample from the area of the Douglastown Marina (MREAC-2002-01) was about one kilometer upstream from EC-1993-01 and the Morrison's Cove sample (MREAC-2002-02) was on the opposite shore of the river and 1.5 kilometres from EC-1993-01. Direct comparison of these samples is not possible. The sample from the area of the Wharf Inn (MREAC-2002-03) was within 25 metres to the location of EC-1993-03 so these two samples could possibly be compared. The two samples from near the groundwood mill were within half a kilometre of each other and can be compared. None of the 1993 samples were close to the Vye's Beach sample (MREAC-2002-05) but EC-1993-07 and EC-1993-06 were both within a kilometre of the 2002 sample location.

Table 4.3-1 Distances between sampling locations for the 1993 and 2002 sediment surveys.

Year of Survey	Location	Sample Identification	Nearest 1993 Survey Location	Distance Between Locations (m)
2002	Douglastown Marina	MREAC-2002-01	EC-1993-01	1032
2002	Morrison’s Cove	MREAC-2002-02	EC-1993-01	1564
2002	Wharf Inn	MREAC-2002-03	EC-1993-03	21
2002	Groundwood Mill	MREAC-2002-04	EC-1993-04	404
2002	Vye’s Beach	MREAC-2002-05	EC-1993-07	558
2002	Vye’s Beach	MREAC-2002-05	EC-1993-06	711

4.3.2 Grain Size

The samples from the two surveys were similar in that they consisted primarily of sand and silt (Figure 4.3-2). Gravel content was low in all samples and a couple of the 2002 samples had more than 20 % clay. For the two samples from near the Wharf Inn (EC-1993-03 and MREAC-2002-03), there is an apparent shift towards finer grain sediments over the 9-year period (Figure 4.3-3). The 1993 sample was about 70 % sand and 20 % silt while the 2002 sample consisted of about 40 % sand, more than 30 % silt and nearly 20 % clay. This difference in physical characteristics may also be an indication that the sediments are quite patchy in that area. Direct comparison of the grain size distributions for the other sampling locations would not be meaningful because of the distance between the locations used for the two surveys but there is a general trend for finer grain sediments in the 2002 samples.

4.3.3 Total Organic Carbon (TOC)

The total organic carbon content of the sediment samples from the two surveys was provided in Tables 3.1-3 and 3.2-1. In general, the TOC content were low and in the expected normal range but there were a few anomalies (Figure 4.3-4). A couple of the 1993 samples that had the highest sand content had low levels of TOC (EC-1993-04 and EC-1993-06). The sample collected near the groundwood mill in 2002 (MREAC-2002-04) had the highest TOC level with a measurement of 21 %. This is a very high value and indicates an area that is clearly organically enriched. Even though this sample had such a high TOC content, the ammonia, sulphide and redox measurements do not indicate anoxic conditions in the sediment (Table 3.2-4).

Figure 4.3-1 Grain size distribution of sediment samples from the Miramichi River estuary

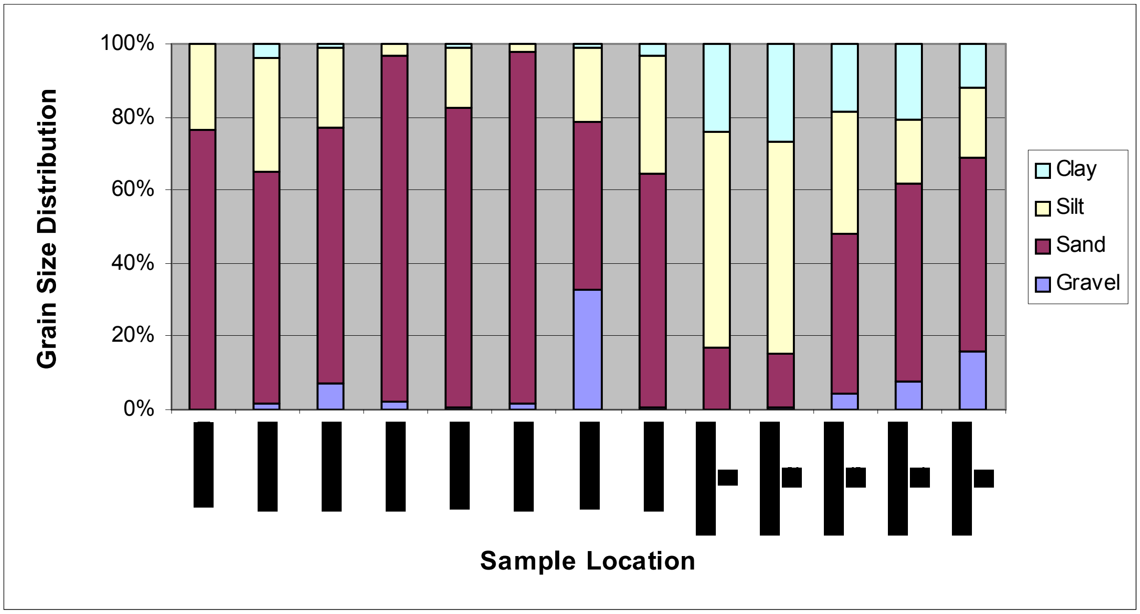


Figure 4.3-2 Comparison of grain size distribution for two samples collected near the Wharf Inn.

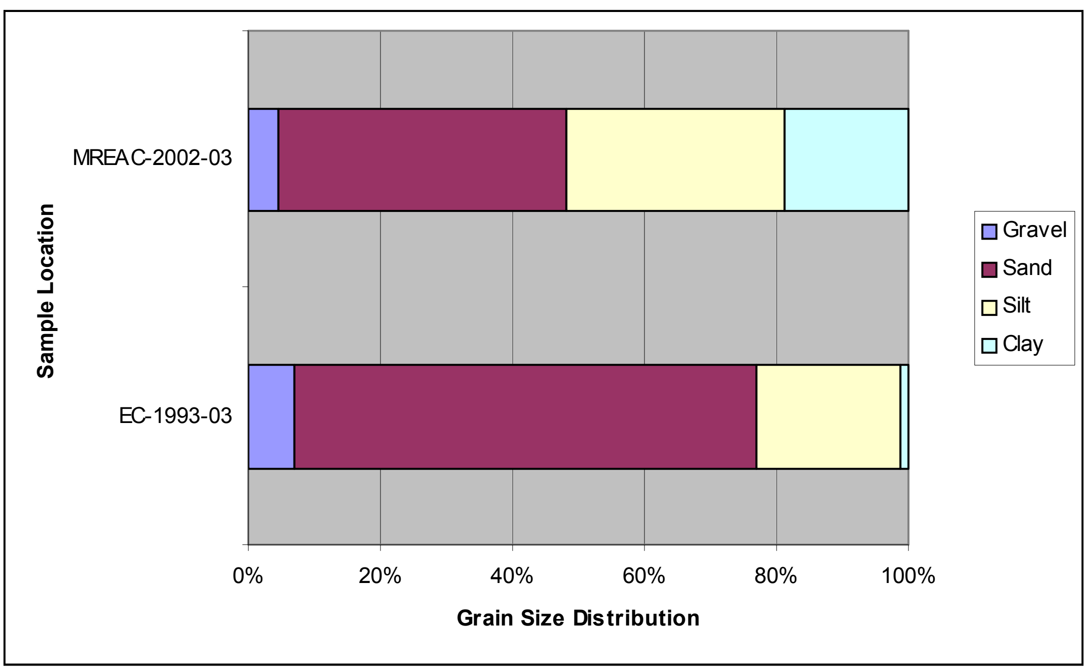
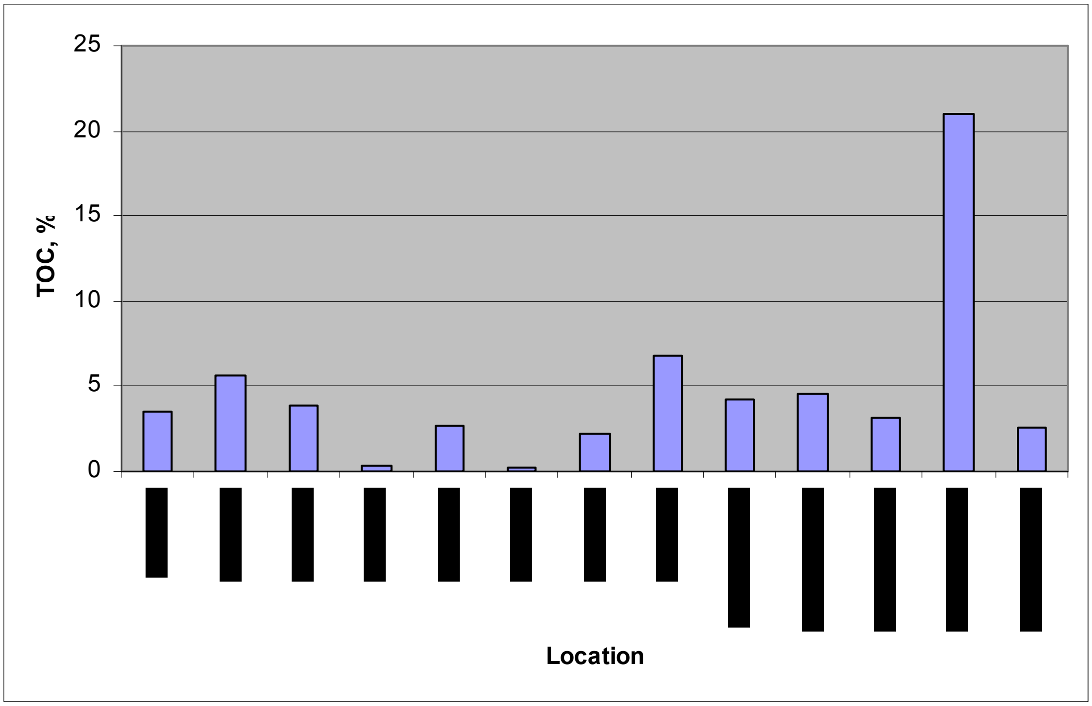


Figure 4.3-3 Total Organic Carbon Content of sediment samples from the Miramichi River estuary



Polycyclic Aromatic Hydrocarbons (PAH)

Overall, the concentrations of total PAH in the sediment samples were low. The one exception was the Wharf Inn location, which had the highest concentration of total PAH in both surveys (Figure 4.3-5). The PAH concentration in these samples were similar and both samples had concentrations of individual PAH that exceeded the CCME interim sediment quality guidelines for the protection of marine aquatic life (Appendix Tables A-1 and A-3). The elevated levels of PAH is this area could be attributed to a former wood preserving plant that operated in Newcastle. Runoff from that plant entered a small brook and flowed into the Miramichi River near the Wharf Inn location.

Polychlorinated Biphenyls (PCB)

The two surveys measured PCB in a different manner so the results are not directly comparable. In 1993, the samples were analyzed by RPC using GC-ECD and the results were reported as concentrations of Arochlor 1254 with a detection limit of 0.02 mg/kg. In 2002, the samples were analyzed by Environment Canada, also using capillary column GC-ECD and reported as concentrations as Total PCB with a detection limit of 0.01 mg/kg. These values are not directly comparable to each other. In 1993, PCB were only detected in two samples: EC-1993-01 and EC-1993-02. In the 2002 samples, PCB were detected in all samples except MREAC-2002-04. A common pattern for the two surveys was that the highest concentrations of PCB were detected in the most downriver stations for both surveys (Figure 4.3-6).

Figure 4.3-4 Total polycyclic aromatic hydrocarbon concentrations in sediment samples from the Miramichi River estuary

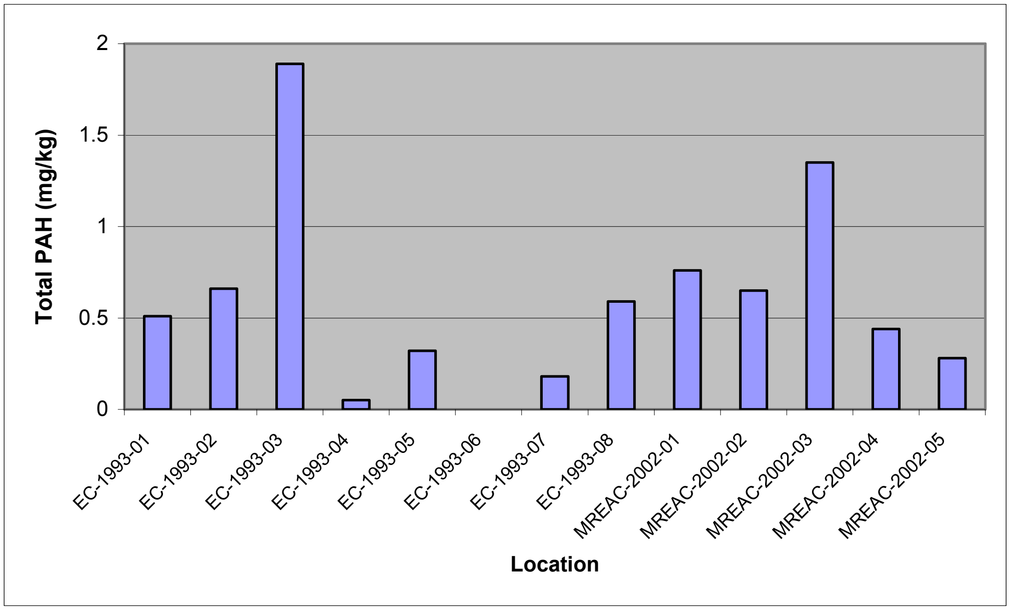
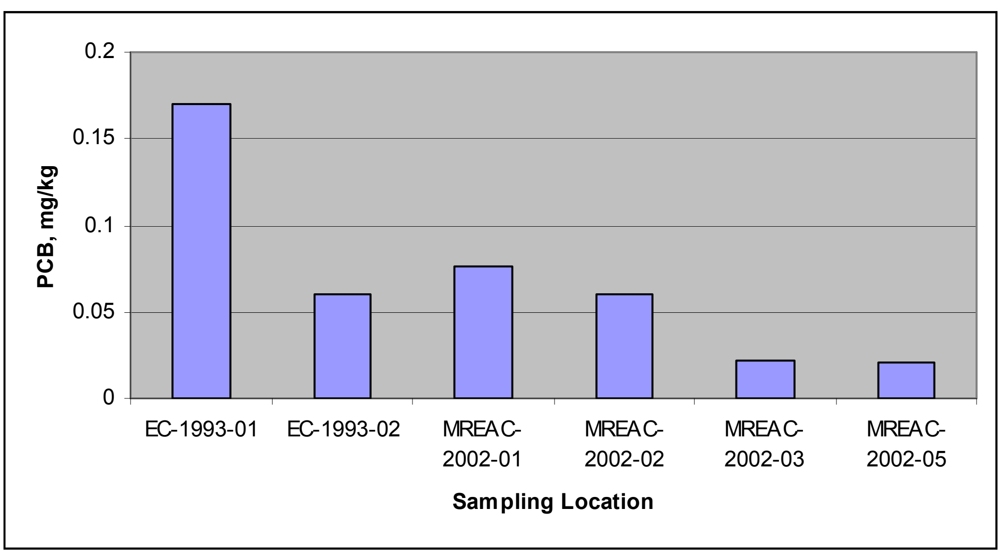


Figure 4.3-5 PCB concentrations in sediment samples from the Miramichi River estuary.



Metals

The two surveys did not measure the exact same group of metals but cadmium, copper, lead and zinc were measured on both sets of samples. Overall, metal concentrations were elevated in most of the samples and many values exceeded the CCME guidelines for the protection of marine aquatic life. Mean concentrations for the two surveys are provided in Table 4.1-4.

Cadmium was detected in all samples except MREAC-2002-05 (Figure 4.3-7). The CCME ISQG for cadmium in marine sediments is 0.7 mg/kg and five of the eight samples from 1993 exceeded that value. All of the 2002 samples with detectable concentrations of cadmium exceeded the CCME guideline. In 1993, there was a direct relationship between silt content and cadmium concentration (Figure 4.1-2) with high cadmium concentrations occurring in the samples with higher silt content. This same pattern was not observed with the 2002 samples. There are no apparent upriver-downriver gradients in cadmium concentrations. The mean cadmium concentration for the eight samples in 1993 was 0.9 mg/kg and was the same as the mean concentration for the five samples collected in 2002.

Copper was detected in all of the samples from both surveys. The mean concentration for the 1993 samples was 18 mg/kg compared to a mean of 16 mg/kg for the 2002 samples. There was not a significant difference in the copper concentrations between the two surveys ($p = 0.05$). The CCME ISQG for copper has been established at 18.7 mg/kg and four of the eight samples from 1993 exceeded that value. For the 2002 samples, only one sample (MREAC-2002-03) exceeded that value. There were no apparent concentration gradients upstream or downstream for copper in either set of samples.

Lead was detected in all samples from both surveys. The mean lead concentration from the 1993 survey was 29.6 mg/kg and the 2002 samples had a mean lead concentration of 27.7 mg/kg. There was no significant difference ($p=0.05$) in the lead concentrations from the two surveys. The CCME ISQG for lead is 30.2 mg/kg and five of the 1993 samples and two of the 2002 samples exceeded that value. There are no apparent geographical gradients for lead concentrations from either survey.

Zinc was detected in all samples from both surveys. The mean zinc concentration for the 1993 and 2002 surveys were 157.6 mg/kg and 128.5 mg/kg respectively. There was no significant difference ($p=0.05$) in the zinc concentrations from the two surveys. The CCME ISQG for zinc is 124 mg/kg and four of the 1993 samples and four of the 2002 samples exceeded that value. There are no apparent concentration gradients upstream or downstream for zinc from either survey.

The Wharf Inn sampling locations for the two surveys were close together (within 25 metres). A direct comparison of the metal results for this station indicates that the concentrations of all the metals have decreased from 30 % to 50 % from 1993 to 2002 (Figure 4.3-8). For all of the samples, there is a slight decrease in the mean values for copper, lead and zinc (Table 4.3-2) from 1993 to 2002 but the decreases are not statistically significant.

Table 4.3-2 Mean metal concentrations for Miramichi River sediment samples

Survey	Cadmium (mg/kg	Copper (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)
1993	0.9	18	29.6	157.6
2002	0.9	16.4	27.7	128.5

Figure 4.3-6 Cadmium concentrations in sediment samples from the Miramichi River estuary.

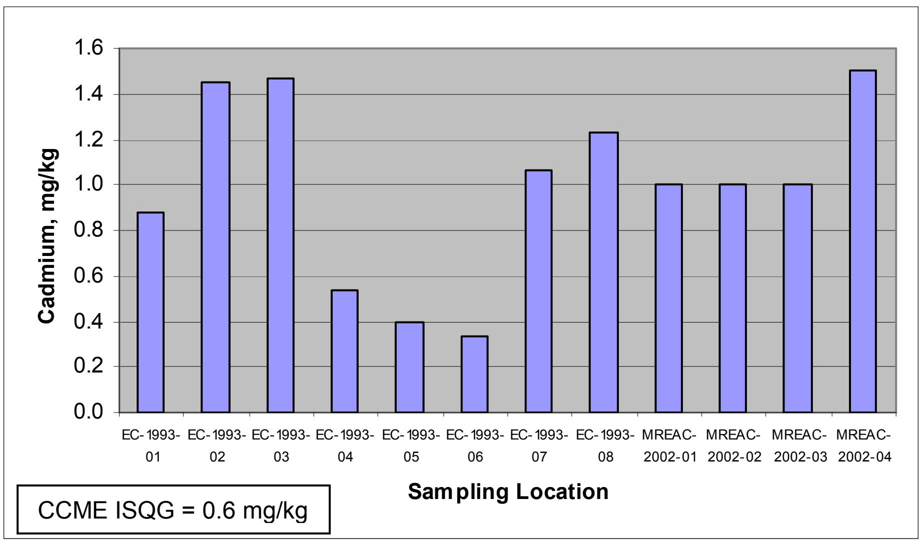
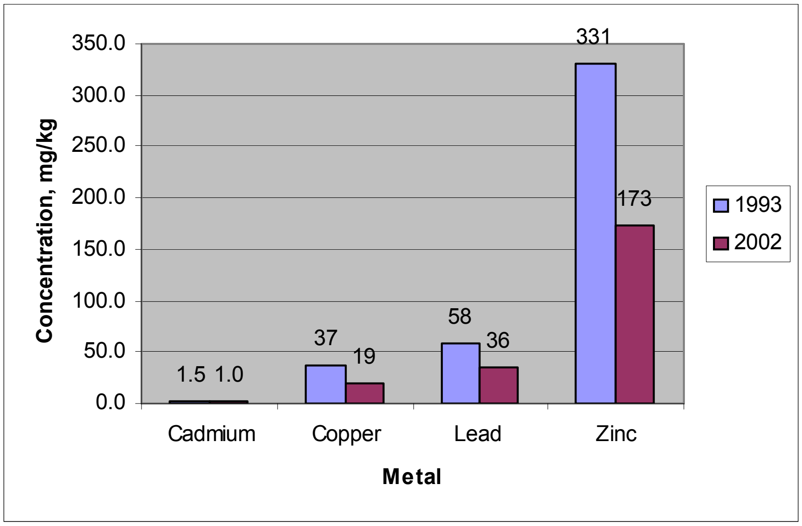


Figure 4.3-7 Metal concentrations in sediments collected from the Miramichi River estuary in the vicinity of the Wharf Inn



Sediment Toxicity

In 1993, the amphipod survival test was conducted with *Corophium volutator* and the eight sediment samples were determined to be not significantly toxic to this species in a 10-day exposure. The 2002 sediment samples were tested with a different amphipod species, *Eohaustorius estuarius,* but the results were similar; the five sediment samples did not cause any mortality during the 10-day exposure. So although different species were used, the sediments from the Miramichi River estuary were consistently non-toxic to amphipods.

The other toxicity test that was conducted on both sets of sediment samples was the Microtox Solid Phase test (Table 4.3-3). The Environment Canada criterion for determining if sediment is significantly toxic with this test is an IC50 of less than 1000 mg/l. Using this criterion, three samples for 1993 and one sample from 2002 were rated to be toxic. In 1993, the two most downstream samples (EC-1993-01 and EC-1993-01) and the most upstream sample (EC-1993-08) were toxic. These three samples also had the highest concentration of silt and the results of the chemical analyses have indicated that there was a direct relationship between silt content and the concentrations of some of the metals and contaminants. For the 2002 results, sample MREAC-2002-02 was determined to be toxic. This sample was not located in close proximity to any of the 1993 sample locations so direct comparison cannot be made but it is one of the most downstream sample from the 2002 series. This sample also had one of the highest proportions of fine grain sediments (silt and clay) of the 2002 samples but none of the levels of measured contaminants was particularly high.

For the Wharf Inn samples (EC-1993-03 and MREAC-2002-03), the Microtox Solid Phase test results were similar for the 1993 and 2002 samples. Both samples were rated as being non-toxic and they had comparable IC50 values – 2005 mg/L for the 1993 sample and 2580 mg/L for the 2002 sample.

Table 4.3-3 Results of Microtox Solid Phase toxicity tests

Sample Identification	Microtox Solid Phase IC50 and 95 % C.L. (mg/L)
EC-1993-01	673 (607 – 747)
EC-1993-02	358 (302 – 425 0
EC-1993-03	2005 (1735 – 2317)
EC-1993-04	> 76085
EC-1993-05	5217 (4937 – 5599)
EC-1993-06	> 75493
EC-1993-07	5197 (4715 – 5729 0
EC-1993-08	550 (515 – 588)
MREAC-2002-01	3830 (3260 – 4500)
MREAC-2002-02	882 (834 – 932)
MREAC-2002-03	2850 (2220 – 3650)
MREAC-2002-04	1120 (1120 – 1130)
MREAC-2002-05	5640 (5310 – 6010)

Benthic Invertebrate Community

Both benthic community surveys indicated that the Miramichi River estuary supported a low number of invertebrate species. There are few species that can tolerate the fluctuating salinity concentrations. The 2002 results had higher abundance and species richness than the 1993 survey results (Table 4.3-4) but the results are not significantly different ($p = 0.05$). In the 1993 survey, there was an apparent gradient response from the most downstream sampling locations to the most upstream location (Figure 4.1-4 and 4.1-5). The more downstream locations had higher levels of both abundance and species richness compared to the more upstream stations. A similar pattern was not observed in the 2002 survey results (Figures 4.1-9 and 4.1-10). In fact, the 2002 results indicated that the station with the highest abundance was MREAC-2002-05 (Vye's Beach) which was the most upriver station sampled.

A direct comparison of the benthic invertebrate results for the Wharf Inn sampling location (EC-1993-03 and MREAC-2002-03) indicates that abundance was ten times higher in 2002 (2816 organisms/m^2 compared to 272 organisms/m^2). Species richness was the same with 5 species detected in both surveys. Four of those species were found in both surveys: *Macoma balthica, Marine oligochaetes, Marenzellaria viridis and Nereis diversicolor*. The 1993 surveys identified the amphipod *Marinogammarus finmarchicus* while in 2002, the bivalve Mya arenaria was found at this location.

One factor that must be considered when comparing the results of the two surveys is timing. The 1993 survey was conducted in late spring (June 14) and the 2002 sampling occurred in the fall (October 8). Generally, benthic invertebrate communities are more diverse and biologically active in the late summer to early fall period because water temperatures are warmer and food in more abundant. As well, some marine invertebrate species have juvenile stages that exist as plankton and those species may not have settled to the bottom and established themselves on the sediments until later in the summer. The 2002 samples, collected in the fall, had the higher values for abundance and richness. This may reflect improved environmental quality in the estuary but the results are confounded by the different sampling season for the two surveys.

Table 4.3-4 Mean abundance and species richness for two surveys of the benthic invertebrate community in the Miramichi River estuary

Year of Survey	Number of Stations	Mean Abundance (Organisms/m^2)	Mean Species Richness
1993	8	760 (S.D. = 1367)	3 (S.D. = 2)
2002	5	2454 (S.D. = 1432)	6 (S.D. = 1)

5.0 Conclusions

1) The sediments in the Miramichi River estuary have concentrations of metals and organic contaminants that exceed the Interim Sediment Quality Guidelines established by the Canadian Council of Ministers of the Environment.

2) Due to differences in sampling locations between the two surveys, direct comparison of the results is not possible. Although the sampling stations near the Wharf Inn (EC-1993-03 and MREAC-2002-02) were close in proximity, the two samples showed quite different physical characteristics that makes direct comparison of these samples questionable.

3) The most contaminated site for polycyclic aromatic hydrocarbons (PAH) in both surveys was the site near the Wharf Inn – EC-1993-03 AND MREAC-2002-03.

4) Both surveys indicated that concentrations of polychlorinated biphenyls (PCB) were higher in the more downstream locations.

5) Both surveys determined that metal levels are elevated in the estuary and many concentrations in sediments exceed the Interim Sediment Quality Guidelines established by the Canadian Council of Ministers of the Environment. The samples collected from near the Wharf Inn (EC-1993-03 and MREAC-2002-03) consistently had higher concentrations of metals.

6) The concentrations of metals have decreased slightly from 1993 to 2002 but the change is not statistically significant. At the Wharf Inn location, metal concentrations in 2002 were 30 % to 50 % lower than in 1993.

7) The sediments collected for both surveys were not toxic to estuarine amphipods.

8) Some of the samples were toxic when tested using the Microtox Solid Phase test. The two samples from near the Wharf Inn (EC-1993-03 and MREAC-2002-03) had similar toxicity results using this test.

9) The benthic invertebrate surveys indicated that the Miramichi River estuary supports an impoverished benthic community with low numbers of species. There were higher values for abundance and species richness in the 2002 survey compared to the 1993 results. This may reflect improved environmental quality in the estuary but the results are confounded by the different sampling season for the two surveys.

6.0 RECOMMENDATIONS

It would be beneficial to the ongoing assessment of the environmental quality of the Miramichi River estuary to repeat the sediment surveys from time to time – perhaps every 5 to 10 years. These surveys should be conducted in the fall and use the same sampling locations as the 1993 survey. The sediment quality analyses should include the key toxicity, chemical and benthic invertebrate components in order to have a sound basis for comparing the results over time.

7.0 ACKNOWLEDGEMENTS

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APPENDICES

Appendix Table A-1

Results for individual PAH congener measurements on sediment samples collected from the Miramichi River estuary on June 14, 1993. Shaded values exceed the Interim Sediment Quality Guideline (ISQG) (CCME 2002)

PAH	1	2	3	4	5	6	7	8	ISQG	PEL
Naphthalene	0.04	0.06	0.01	0.03	0.02	nd	nd	0.03	0.0346	0.391
Acenaphthylene	nd	nd	0.02	nd	nd	nd	nd	nd	0.00587	0.128
Acenaphthene	nd	nd	0.04	nd	nd	nd	nd	nd	0.00671	0.0889
Fluorene	nd	nd	0.04	nd	nd	nd	nd	nd	0.0212	0.144
Phenanthrene	0.04	0.06	0.14	0.01	0.02	nd	0.02	0.07	0.0867	0.544
Anthracene	0.02	0.03	0.08		nd	nd	nd	nd	0.0469	0.245
Fluoranthene	0.11	0.14	0.39	0.01	0.06	nd	0.04	0.13	0.113	1.494
Pyrene	0.09	0.11	0.32	0.01	0.06	nd	0.04	0.03	0.153	1.398
Benz(a)anthracene	0.02	0.03	0.1	nd	0.02	nd	0.02	0.03	0.0748	0.693
Chrysene/triphenylene	0.04	0.06	0.12	nd	0.02	nd	0.02	0.07	0.108	0.846
Benzo(b+k)fluoranthene	0.07	0.09	0.2	nd	0.04	nd	0.02	0.07	na	na
Benzo(e)pyrene	0.02	0.03	0.08	nd	0.02	nd	nd	0.03	na	na
Benzo(a)pyrene	0.02	0.03	0.12	nd	0.02	nd	nd	0.03	0.0888	0.763
Indenopyrene	0.02	0.03	0.08	nd	0.02	nd	0.02	0.07	na	na
Benzo(g,h,i)perylene	0.02	0.03	0.06	nd	0.02	nd	nd	0.03	na	na
Dibenz(a,h)anthracene	nd	nd	nd	nd	nd	nd	nd	nd	0.00622	0.135
Total PAH	0.51	0.7	1.80	0.06	0.32	nd	0.18	0.59	0.7458	6.8699

nd = non-detectable
na = not available

Appendix Table A-2

Results of the analyses of 24 benthic samples from 8 stations along the Miramichi Estuary, taken June 14, 1993.

	STATION								
SPECIES	1A	1B	1C	2A	2B	2C	3A	3B	3C
Macoma balthica	10	15	23	8	6	9	-	1	1
Mar. Oligochaete	106	325	166	87	21	121	8	1	5
Marenzelleria viridis	15	22	7	6	7	5	5	10	2
Nereis diversicolor 2	-	2	1	-	-	5	6	5	
Crangon septimspinosa	1	-	-	-	-	-	-	-	-
Marinogammarus finmarchicus	-	-	-	1	4	2	1	1	-
Gammarus oceanicus	-	-	-	-	2	-	-	-	
Chironomid		-	-	1	1	-	-	-	-

	STATION								
SPECIES	4A	4B	4C	5A	5B	5C	6A	6B	6C
Macoma balthica	-	-	-	3	-	-	-	-	-
Mar. Oligochaete	1	9	1	1	1	-	-	1	-
Marenzelleria viridis 3	10	2	5	3	3	4	2	2	
Nereis diversicolor 2	2	2	2	9	4	-	1	1	
Crangon septimspinosa	-	-	-	-	-	-	-	-	-
Marinogammarus finmarchicus	-	3	-	-	-	-	-	-	-
Gammarus oceanicus	-	3	-	1	1	-	-	-	
Chironomid	-	-	-	-	-	-	-	-	-
Insect larvae									
Plecoptera									
Simuliidae	3	4	2	-	-	-	-	-	-

TABLE A-2 (continued)

	STATION					
	7A	7B	7C	8A	8B	8C
SPECIES						
Macoma balthica	-	-	-	-	-	-
Mar. Oligochaete	-	1	-	-	-	-
Marenzelleria viridis -	4	4	-	-	-	
Nereis diversicolor -	1	-	-	-	-	
Chironomid	1	4	1	-	1	3
Insect larvae						
Plecoptera	-	1	-	-	-	-
Simuliidae	2	-	-	-	-	-

Appendix Table A-3 – PAH concentrations in the 2002 sediments samples from the Miramichi Rive estuary. Shaded values exceed the CCME Interim Sediment Quality Guidelines (ISQG) for the protection of aquatic life.

PAH (µg/kg)	MREAC-2002-01	MREAC-2002-02	MREAC-2002-03	MREAC-2002-04	MREAC-2002-05	ISQG	PEL
Naphthalene	0.0133	0.00993	0.0218	0.0073	<0.005	0.0346	0.391
Acenaphthylene	0.00724	<0.005	0.00757	<0.005	<0.005	0.00587	0.128
Acenaphthene	<0.005	<0.005	0.01476	0.00584	<0.005	0.00671	0.0889
Fluorene	0.01131	0.01056	0.01913	0.01028	<0.005	0.0212	0.144
Phenanthrene	0.0506	0.04672	0.12154	0.03036	0.01221	0.0867	0.544
Anthracene	0.02079	0.02713	0.04116	0.01927	0.02077	0.0469	0.245
Fluoranthene	0.15295	0.12662	0.26947	0.08364	0.04593	0.113	1.494
Pyrene	0.12577	0.10653	0.2327	0.0685	0.03747	0.153	1.398
Benz(a)anthracene	0.06621	0.05233	0,12762	0.03172	0.03496	0.0748	0.693
Chrysene	0.04218	0.05048	0.03751	0.04703	0.03374	0.108	0.846
Benzo(b+k)fluoranthene	0.11789	0.09992	0.19924	0.06515	0.05317	na	na
Benzo(e)pyrene	na	na	na	na	na	na	na
Benzo(a)pyrene	0.06117	0.04819	0.11227	0.0283	0.02199	0.0888	0.763
Indenopyrene	0.04361	0.03383	0.07086	0.0216	0.01319	na	na
Benzo(g,h,i)perylene	0.03833	0.03135	0.0622	0.02009	0.01148	na	na
Dibenz(a,h)anthracene	0.00888	0.00699	0.0156	0.00547	<0.005	0.00622	0.135
Total PAH	0.75923	0.64958	1.35343	0.44455	0.28491	0.7458	6.8699

nd =non-detectable
na = not available
(CCME, 2002)

Appendix Table A-4

Results of Metal Analyses on sediment samples from the Miramichi River estuary collected on October 8, 2002

Sample Identification	Ag µg/g	As µg/g	Cd µg/g	Cr µg/g	Co µg/g	Cu µg/g	Fe %	Pb µg/g	Mn µg/g	Mo µg/g	Ni µg/g	Sb µg/g	Sn µg/g	V µg/g	Zn µg/g
MREAC-2002-05	1	5.8	< 1.0	32.2	7.8	12.4	1.8	16.3	298.3	3.8	18.5	1.5	2.9	48.7	82.3
MREAC-2002-04	3.8	7.2	1.5	36.9	9.5	15.2	1.3	27.5	365.2	4.2	23.7	2.9	6	65.8	129
MREAC-2002-03	3.1	8.7	1	35.7	9.1	18.8	2.6	35.9	374.1	2.3	20.6	2.8	3.5	60.7	172.9
MREAC-2002-02	4	11.2	1	47.6	12.7	18.5	3.3	31.1	670	1.7	29.1	1.3	3.9	84.6	125
MREAC-2002-01	3.3	10.7	1	38.9	10.7	16.9	2.8	27.9	414.2	1.6	25.7	1.3	4.2	67.3	133.5

Appendix Table A-5

Sample ID	MREAC-2002-01	MREAC-2002-02	MREAC-2002-03	MREAC-2002-04	MREAC-2002-05	MREAC-2002-05	MREAC-2002-05
Location	Douglastown Marina	Morrison's Cove	Wharf Inn	Groundwood Mill	Vye's Beach # 1	Vye's Beach # 2	Vye's Beach # 3
GASTROPODS							
Hydrobia totteni	**0**	**0**	**0**	**176**	**432**	**80**	**288**
BIVALVES							
Macoma balthica	**416**	**128**	**272**	**48**	**720**	**688**	**800**
Modiolus modiolus	**16**	**0**	**0**	**0**	**0**	**0**	**0**
Mulinia lateralis	**32**	**0**	**0**	**0**	**0**	**0**	**0**
Mya arenaria	**96**	**0**	**48**	**16**	**0**	**0**	**16**
POLYCHAETES							
Ampharetidae	**0**	**0**	**0**	**0**	**0**	**0**	**32**
Marenzellaria viridis	**576**	**160**	**832**	**128**	**144**	**96**	**144**
Nereis diversicolor	**64**	**80**	**1376**	**96**	**4192**	**2960**	**3280**
Nereis succinea	**64**	**0**	**0**	**0**	**0**	**0**	**0**
OLIGOCHAETA	**1264**	**704**	**288**	**16**	**16**	**0**	**0**
DECAPODA							
Rhithropanopeus harrisii	**0**	**0**	**0**	**0**	**0**	**16**	**16**
INSECTA							
Chironomidae	**0**	**0**	**0**	**800**	**0**	**0**	**0**
Abundance (Number/m^2)	**2464**	**1072**	**2816**	**1280**	**5504**	**3840**	**4576**
Number of Species/sample	**7**	**4**	**5**	**7**	**5**	**5**	**7**