Ecological Standards and Toxicology Section
Standards Development Branch

Results of Laboratory Toxicity and Bioaccumulation Tests Conducted using St. Marys River Sediments, 1999

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1.0 INTRODUCTION

The St. Marys River is one of 42 identified areas of concern (AOCs) within the Great Lakes Basin where human activities have caused impairment of the area's ability to support aquatic life. Major dischargers of pollutants are the Algoma Steel Corporation and St. Marys Paper as well as waste water treatment plants and various municipal and industrial non-point sources. A remedial action plan (RAP) was developed in 1992 and activities were undertaken to restore sediment quality. Although improvements were noted in a 1995 study of the Bellevue Marine Park area (near the Algoma Steel Corporation), contamination of sediments above provincial sediment quality guidelines (PSQGs) and impairment of the benthic community were still detected. In response to the International Joint Commission's (IJC's) recommendation that monitoring be continued, the RAP Cleanup and Restoration Task Team prioritized four sites in the vicinity of the Algoma Steel Corporation for study. The objectives of the study were to:

1) To determine the extent and severity of sediment contamination in the Algoma Slag dump nearshore, Algoma Slip and Lake George Channel/East End WWTP areas;
2) To correlate toxicity and chemistry to benthic community impairment in contaminated and reference/control sites;
3) To determine the toxicity of contaminated sediments to biota and to determine whether sediment quality is still a limiting factor to improvement of the benthic communities in these areas; and
4) To determine whether sediment associated contaminants are biologically available for accumulation by aquatic organisms in the laboratory.

Details regarding the first two objectives are reported elsewhere. This report discusses the toxicity and bioaccumulation of the sediments as observed in laboratory tests conducted by the Ontario Ministry of the Environment's (MOE's) Standards Development Branch (SDB) in 1999.

2.0 MATERIALS AND METHODS

2.1 Sample Collection and Treatment

Eight sediment samples were collected according to MOE procedures (MOE, 1993) in August 1999, from Point aux Pins Bay to Little Lake George (Table 1). Approximately 10 L of composited surficial sediment (top 10 cm) were collected from several grabs using a Shipek sampler. Each composited sediment was placed into a plastic pail, lined with a food-grade polyethylene bag, and transported to the Etobicoke, Ontario laboratory. Once at the laboratory, the samples were stored at 4 ± 2°C in the dark.

Point aux Pins Bay was selected as the reference site, since it represented the sediment characteristics and background contaminant concentrations of the general area. Previously-collected sediment from Honey Harbour, Georgian Bay, Ontario served as the negative control sediment. The negative control sediment is a relatively uncontaminated sediment, known to support organism survival and

growth in the laboratory and provides a measure of organism health and test system integrity. Both the negative and reference control sediments provide a basis for comparing the biological responses in the test sediments (ASTM, 1997).

Once the sediment was received at the testing facility, it was pressed through a 2-mm stainless-steel sieve to remove existing large biota and debris. The sieved sediment was then homogenized with a spatula and stored at 4 ± 2°C without headspace.

2.2 Biological Tests

2.2.1 MOE Standard Sediment Toxicity Test Methods

Biological tests were initiated between October 27 and November 10, 1999 (Table 1). Three separate tests were performed on each homogenized sediment sample: a 10-day survival and growth test using midges (*Chironomus tentans*), a 21-day chronic survival and growth test using mayflies (*Hexagenia limbata*) and a 21 day survival and bioaccumulation test using fathead minnows (*Pimephales promelas*). All tests were performed according to the MOE's testing protocol (Bedard et al., 1992) using the same test design as described below. Details specific to each test are described in following sections.

For each test, a sediment sample was filled into three to four replicate containers in a 1: 4 ratio of sediment to water. The bottom of a 1.8L glass jar was covered with approximately 325 ml of sediment and then topped up with 1.3 L dechlorinated tap water. Vessels were then aerated overnight before test organisms were introduced. During testing, the vessels were maintained at 20 ± 2°C with constant aeration and 16 hours light / 8 hours dark photoperiod. At the start, middle and end of each test, subsamples of overlying water were collected from the test vessels and monitored for pH, conductivity, ammonia and dissolved oxygen. Each day, mortality was recorded and dead organisms were removed. Changes in the appearance of the test solutions or sediment and abnormal behaviour of the test organisms were noted, if observed. Water levels were replenished as needed.

2.2.2 Mayfly (*Hexagenia limbata*) Survival and Growth Test

Mayfly nymphs were raised from eggs obtained from the University of Windsor and were cultured in aquaria based on procedures described by Bedard *et al.* (1992) and Friesen (1981). Cultures were initiated at the MOE laboratory by transferring approximately 600 newly-hatched nymphs to a 7 L aquarium containing approximately 2 cm of autoclaved sediment and topped up with dechlorinated tap water. Animals were held at ambient room temperature (20 ± 2°C), with a 16:8 hour light:dark photoperiod and continuous aeration. Each week cultures were fed a mixed Cerophyll® and Tetra Spirulina® diet.

On the day of test initiation, five-month old mayfly nymphs were retrieved from aquaria by sieving small portions of sediment through a 500 µm mesh brass sieve. The nymphs were then washed into

an enamel tray, containing Honey Harbour sediment and dechlorinated water. From the tray, ten mayflies were counted into small glass beakers filled with dechlorinated tap water (~100ml) using the wide end of a Pasteur pipette. The contents of each beaker were then poured into each of three replicate test chambers. Since *Hexagenia* ingest sediment, no food was added to the test vessels during the 21-day exposure period.

At the end of the test, the contents of each test chamber were sieved. Surviving animals were counted and transferred to 100 ml beakers containing dechlorinated water. The nymphs were immobilized with Alka-Seltzer®, blotted dry and weighed to the nearest 0.01 mg.

2.2.3 Midge (*Chironomus tentans*) Survival and Growth Test

The MOE maintains continuous cultures of *C. tentans* larvae from egg to adult, following standard methods (Bedard *et al.*, 1992, Mosher *et al.*, 1982, Townsend *et al.*, 1981). Egg masses were originally supplied by Michigan State University and have since been cultured at the MOE laboratory.

Midge cultures were maintained under the same environmental conditions as the mayflies (16 hours light / 8 hours dark, 20 ± 2 °C, continuous aeration) in 20 L aquaria containing approximately 2 L of silica sand. The larvae were fed a mixture of Cerophyll® and Tetra Spirulina® as frequently as required to maintain a continuous supply of food.

Once an egg mass was laid, it was transferred from the aquarium to an enamel rearing tray, lined with silica sand and filled with dechlorinated tap water. Tests were initiated with 10 to 12 day old larvae (second or third instar). Larvae were transferred directly from the enamel trays to the test chambers using the wide end of a Pasteur pipette. In total, 15 animals were added to each of three replicates.

Each day of testing, midges were fed 30 mg of a Cerophyll®:Tetra Spirulina® mixture per replicate. After 10 days, the contents of the test chambers were sieved. Surviving animals were removed and placed into small beakers holding approximately 100 ml dechlorinated water and 15 ml silica sand. The larvae were counted, blotted dry and individuals were weighed to the nearest 0.01 mg.

2.2.4 Fathead Minnow (*Pimephales promelas*) Survival and Bioaccumulation Test

Minnows were cultured at the MOE laboratory based on modified U.S. EPA procedures (U.S. EPA, 1987; Bedard *et al.*, 1992). Breeding stocks were held under flow-through conditions in dechlorinated tap water at 20 ± 2°C. Eggs laid on spawning tiles were promptly removed for incubation to 25 ± 2°C hatching bowls and after hatching, larvae were transferred to holding tanks maintained under the same conditions as the breeding stocks. Each day, larval fish were fed 48-hour old live brine shrimp while juveniles and breeders were provided frozen adult brine shrimp. Light was maintained at 16 hours light to 8 hours dark.

Juvenile minnows with an average wet weight of 0.26 ± 0.08 g (n=30) were used in testing. The minnows were first sorted into 250 ml glass beakers before being transferred by net into the test chambers. A total of ten fish were placed in each of three replicate containers. Each day, the 21 day exposure period, minnows were fed a NutraFin Staple® in an amount equivalent to 1% of the average starting wet weight. After 21 days the surviving fathead minnows from each sediment were counted and pooled. Each treatment group was then immobilized with Alka-Seltzer®, rinsed thoroughly with distilled water and placed into 30 ml glass vials. Vials were frozen before submission for chemical analysis.

2.3 Physical/ Chemical Analysis of Sediment

Sieved and homogenized sediment samples were analysed for particle size, and nutrient content (total Kjeldahl nitrogen (TKN), total phosphorus, total organic carbon and loss on ignition), as well as metals, PCBs and organochlorines and chlorobenzenes, polynuclear aromatic hydrocarbons (PAHs) and volatile organics. All analyses were performed according to MOE standard methods (MOE, 1997 a,d,e,f,g; 1999 a,b,c,d,e,f,g,h) and concentrations were compared to the lowest effect levels (LELs) and severe effect levels (SELs) of the MOE's provincial sediment quality guidelines (PSQGs) (Persaud et al., 1993). LELs and SELs represent the levels of a contaminant that are expected to be tolerated by most organisms or impair most organisms, respectively (Persaud et al., 1993).

No chemical analyses were performed on the Honey Harbour sediment used in the toxicity tests.

2.4 Organic Contaminants in Fathead Minnows

Frozen whole fish samples were thawed and analysed for lipid content as well as PCBs, organo-chlorine pesticides and PAHs according to MOE standard methods (MOE, 1997 b,c). Contaminant concentrations measured in fish tissue were corrected for background concentrations (measured in pre-exposed and control fish), if detected, and were used in the calculations of biota-sediment accumulation factors (BSAFs). The BSAF is a ratio of a substance's concentration in tissue to that in sediment. Because non-polar organics tend to associate with lipids in tissue and TOC in sediment, both tissue and sediment concentrations were corrected for lipid and TOC content, respectively, according to the following formula:

$$BSAF = \frac{Ct / L}{Cs / TOC}$$

where Ct = concentration in tissue (ng/g wet weight)
L = lipid in tissue (g/g wet weight)
Cs = concentration in sediment (ng/g dry weight)
TOC = concentration of sediment total organic carbon (g/g dry weight)

2.5 Data Analysis

Statistical analyses of survival and growth data were performed using TOXSTAT 3.5 software package (West Inc. and Gulley, 1996). Normality and homogeneity were tested using Shapiro-Wilks and Bartlett's tests, respectively. Because groups with no mortality have zero variance, they were omitted from test of homogeneity but included in the subsequent analysis of variance. Differences in survival and growth among all exposures were assessed using Tukey's Test. Survival data were arc-sine transformed prior to data analysis.

The results of all tests were tabulated and sediment toxicity was ranked based on the combined results of all three tests.

Sediment chemical analyses were compared to mortality and growth effects observed in the midge and mayfly tests through Pearson correlations to determine which substances or sediment characteristics correlated with effects. Correlations were also carried out using the bioaccumulation data. However, for these, concentrations of individual contaminants were correlated with tissue concentrations to determine whether there was a relationship between sediment contamination and accumulation of a particular substance.

3.0 RESULTS AND DISCUSSION

3.1 Toxicity

3.1.1 Test Validity and Control Group Comparisons

Each species met the validity criterion for its particular test. That is, control mortality (i.e., in the reference and Honey Harbour sediments) did not exceed 25% in the midge test or 15% in the mayfly and fathead minnow tests. In fact, survival exceeded 90% in both controls of all three tests. Midge and mayfly growth was lower in Honey Harbour sediment than in the reference, with 21% and 28% reduction, respectively. However, only midge growth was found to be statistically reduced according to Tukey's test, most likely due to greater within- treatment variability in the mayfly test. Reduced growth in the Honey Harbour sediment may have been influenced by the increased storage time of this sediment relative to the reference (12 months versus 12 weeks). As reported by Boese et al. (1996), prolonged storage may affect the nutritive value of the sediment, thereby affecting organism feeding/growth rates.

3.1.2 Mayfly *(Hexagenia limbata)* Survival and Growth Effects

Results of the 21-day test using *Hexagenia limbata* are presented in Table 2. Organism survival was significantly reduced relative to the reference sediment in sediments 182 and 183, with 37% and 17% mortality, respectively. Organisms exposed to these sediments also exhibited the poorest growth, with 29% and 35% less weight, respectively, at the end of the test than in the reference sediment. However, only the reduced growth in sediment 183 was found to be statistically significant. No

exposure showed reduced growth relative to that of the Honey Harbour sediment.

Test solutions were monitored for dissolved oxygen, pH conductivity and ammonia at the beginning, middle and end of testing and indicated that conditions were acceptable for organism survival and growth. Oxygen levels remained at or near saturation and pH drifts were within 1 unit during the 21 day exposure period. Ammonia levels remained below 0.5 mg/L as unionized ammonia.

3.1.3 Midge *(Chironomus tentans)* Survival and Growth Effects

Results of the 10-day midge tests are presented in Table 3. As observed above in the mayfly tests, midge survival was significantly reduced in sediments 182 and 183, with 56% and 38% mortality, respectively. However, midges showed more sublethal impairment than the mayflies with growth significantly reduced in all sediments (including Honey Harbour) relative to the reference and in four sediments relative to the Honey Harbour control. Organisms exposed to sediment 34 exhibited the poorest growth, with 80% less weight at the end of the test than the reference group. Weights of the organisms exposed to Stations 182 and 183 were, respectively, 67% and 63% reduced from the reference group.

Test solutions were monitored for dissolved oxygen, pH conductivity and ammonia at the beginning, middle and end of testing. As observed in the mayfly exposures, oxygen, pH and conductivity were maintained at acceptable levels for organism survival and growth. However, in the midge exposures, unionized ammonia concentrations rose to greater than 1 mg/L in most sediments by the 6th day of testing. Ammonia was not measured in sediment 34 due to safety concerns regarding the proximity of the site to the wastewater treatment plant discharge but it is likely that ammonia levels would have been elevated in this exposure as well. However, it is unlikely that the elevated ammonia concentrations were major factors in observed toxicity since the greatest impairment was not observed in the vessels with highest ammonia concentrations, the maximum concentration of ammonia was less than half a published 96-hr LC50 of 5.6 mg/L (Besser et al., 1998) and since higher ammonia concentrations did not cause impairment in fathead minnows, a more sensitive species to ammonia (See below).

As noted above, greater within-treatment variability in the mayfly test reduced the sensitivity of the statistical analysis to detect effects and may also have contributed to the apparent greater sensitivity of the midges over mayflies.

3.1.4 Fathead Minnow *(Pimephales promelas)* Survival Effects

Fathead minnow survival data are presented in Table 4. No significant mortality was observed in any of the tests. In fact, only a single mortality was observed in all exposures despite elevations in overlying water ammonia concentrations to levels near published LC50 values (1-2 mg/L unionized ammonia at 20°C as per Thurston et al., 1983).

Bioaccumulation of organic contaminants by fathead minnows is discussed in Section 3.4.

3.1.5 Sediment Scoring Based on Toxicity

Results of toxicity tests using all three species are summarized in Table 5. Organism responses in Column 2 sediments were compared to those in sediments along Row 1. Significant reduction was indicated by a red square (dark grey on non-colour copy) and lack of significant reduction was indicated by a green square (light grey on non-colour copy). For example, midge growth in Honey Harbour sediment was significantly reduced relative to midge growth in the reference sediment (red or dark grey square), but was not significantly lower than any other sediment (green or light grey squares). In contrast, midge survival and growth in sediment 182 was significantly lower than in both Honey Harbour and the reference sediments, as well as sediments 196, 179 and 176. As reported above, mayfly growth in sediment 182 was 29% lower than the reference sediment but was not found to be statistically significant. Sediments were ranked according to impairment detected by all tests and are, from greatest to least toxicity:

182 > 183 >	**34 > 170 >**	**179, 176, HH, 196 >**	**REFERENCE**
survival and growth effects	***growth effects***	***growth effects***	
reduced relative to both controls (HH and reference)		***reduced relative to reference only***	

Since growth in sediments 179, 176 and 196 was not significantly different from the Honey Harbour (HH) control group, and since this control passed the validity criterion for the test, only sediments 182, 183, 34 and 170 could be considered impacted.

3.2 Sediment Analyses

3.2.1 Sediment Characterization

General sediment characteristics are presented in Table 6a. Most sediments were similar to the reference in terms of particle size, TOC and nutrient content, with some exceptions as described below.

Particles were divided into three size classes: 1) less than 63 μm (clay/silt), 2) 63 to 1000 μm (sand) and 3) >1000 - 2000 μm (coarse sand). As shown in Figure 1, sediments in the Algoma Slip to just downstream of wastewater treatment plant (stations 182, 183, 170 and 34) contained lower percentages of silt/clay (18 to 43 %) than those sediments upstream or downstream (57 to 67 %). Contaminants are most often associated with fine sediments (silts and clays) because higher surface to volume ratios of smaller particles increase the sorptive capacity for contaminants (Power and Chapman, 1992 as cited in Ingersoll, 1995). Sediment particle size is also important for habitat selection since certain sizes may impede tube building or burrowing (Environment Canada, 1999).

Bioavailability of contaminants in sediment is heavily influenced by natural organic material, which

is represented by total organic carbon (TOC) measurements. TOC may bind to contaminants, rendering them unavailable for uptake by benthic organisms or fish (Spacie et al., 1995). As shown in Table 6a, most sediments contained similar concentrations of TOC (4 to 6%) with the exception of sediments 182 and 183, which contained 24 and 25%, respectively. In contrast, sediments 182 and 183 contained the lowest concentrations of total phosphorus. The highest concentration of phosphorus was measured in sediment 34, over three times that of the reference.

3.2.2 Metals

As shown in Table 6b, concentrations of most metals, including cadmium, copper, zinc, lead, arsenic, chromium and iron, exceeded their respective PSQG LEL in most sediments. Of note is that background copper and cadmium sediment concentrations measured in the reference also exceeded the LEL. Sediment 34 contained noticeably higher concentrations of mercury and copper than all other sediments, with 100 µg/g copper approaching the SEL of 110 µg/L. The SEL for manganese was exceeded in sediment 183 and the SEL for iron was exceeded in sediments 179 and 170.

3.2.3 Organic Chemicals in Sediment

Concentrations of organic contaminants are presented in Table 6c. Only sediment 34 contained PCBs (100 ppb) at a concentration above the LEL (70 ppb). Oxy-chlordane was detected in all sediments except the reference and was at least six times higher in concentration in 182 and 183 than in other sediments. Sediments 182 and 183 also had the highest concentration of endrin and endosulphan sulphate. Volatile organics were not detected in any samples. However, PAHs were above the LEL in almost every sediment. The highest concentrations of PAHs were found in sediments 182 and 183, which contained total PAH concentrations at least one order of magnitude higher than the other sediments (Table 6d).

3.3 Toxicity versus Sediment Concentrations

Toxicity observed in the midge and mayfly tests was compared to sediment chemistry by Pearson correlations. Correlations with p values ≤ 0.05 were qualitiatively described by designating correlation coefficients of 0.8 and above, <0.8 to 0.6 and <0.6 to 0.4 as "strong", "moderate" and "weak" correlations, respectively. As shown in Table 7, endosulphan II, oxy-chlordane, PAHs and TOC strongly correlated with mortality in both tests. Endosulphan sulphate was strongly correlated to mayfly mortality and moderately correlated with midge mortality. The similarity of the correlations is consistent with observed toxicity, since sediments 182 and 183 caused the greatest mortality in both the midge and mayfly tests. The greater sensitivity of midges to growth effects is reflected by more correlations with metal concentrations. In contrast, mortality and growth effects in both tests were negatively correlated (coefficients of 0.4 to 0.7) with % fine particles (silts and clays). This may suggest that sediments containing higher proportions of fine sediments are more suitable habitats for the two species than those with higher sand content, in spite of the greater binding affinity of contaminants to fine sediments. Alternatively, it could simply mirror the pattern of contaminant deposition.

Regardless of the strength of the coefficient or the p value, correlations of physical or chemical characteristics with organism response do not, in themselves, prove causality. As outlined above for particle sizes, although a correlation may be evident, the characteristic of interest could simply co-vary or may interact with another to cause the observed response. Another example is TOC which was strongly linked with mortality in the midge and mayfly tests. It is unlikely that high TOC per se caused the effects. Rather, contaminants making up part of, or covarying with, TOC were more likely the causal agents. Therefore, correlations are best used to direct subsequent investigations or to confirm a toxicant identified during a toxicity identification evaluation (TIE).

3.4 Organics in Fish Tissue

Tissue concentrations of PCBs, PAHs and other organic contaminants in non-depurated fish are presented in Tables 8a and 8b. Non-depurated whole tissue concentrations include both the contaminant absorbed to tissue and adsorbed to food in the gut. However, according to Boese et al. (1996) depuration often does not significantly change estimates of accumulation and the use of non-depurated organisms is a valid approach since a predator is exposed to the non-depurated prey.

Comparisons of mean PCB tissue concentrations (ng PCB/g tissue ww) for each exposure group indicated that most accumulation was within approximately 30% of the background (pre-exposure group). Only sediment 34 showed high accumulation (twice the background concentration) (Table 8a). However, because lipid content of an organism affects the amount of lipophilic chemical it accumulates, normalization for lipid content affords a better comparison between different exposure groups. When lipid normalized (ng/g lipid), accumulation of PCBs in sediment 34, 179, 176 and the reference remained close to their non-normalized concentrations (relative to the background) but increased in all other groups including Honey Harbour.

Pearson correlations were carried out to determine whether tissue concentrations of PCBs were related to sediment concentrations. Mean PCB concentrations were correlated against concentrations measured in each sediment with and without lipid and TOC normalization. The best correlation was observed between lipid normalized tissue concentrations and sediment concentrations without TOC normalization (coefficient of 0.80) (Table 9).

PAHs were only detected in sediments 182 and 183, with phenanthrene and fluoranthene present in the highest concentrations. For each sediment, concentrations of each lipid normalized PAH were correlated against their respective sediment concentration. As shown in Table 10, PAHs in fish tissue were strongly correlated to their respective concentration in both sediments. In this case, mean tissue concentrations represented two replicate samples, normalized for their lipid content. However, sediment concentrations were not normalized for TOC since each sediment was reviewed separately and normalizations within one sediment would not have influenced the correlation analysis.

3.4.1 BSAFs

BSAFs were calculated for those contaminants measured above background. For PCBs, sediment

183 had the highest BSAF of 8.93, followed by 182, 170, 196, and 34 with BSAFs of 4.93, 1.31, 1.24 and 1.19, respectively (Table 11).

PAHs were not detected in the pre-exposed or the Honey Harbour control groups and were only detected in fish exposed to sediments 182 and 183. BSAFs for individual PAH compounds ranged from 0.02 to 0.10 in sediment 182 and from 0.03 to 0.06 in sediment 183 (Table 12).

Two other organic contaminants were detected in fish tissue: pp-DDE and a-chlordane. Fish exposed to sediment 34 were the only ones to contain pp-DDE above background and a BSAF was calculated as 5.66. Fish from the sediment 34 exposure were also the only ones to contain detectable levels of a-chlordane even though this substance was not detected in the sediment. If ½ the detection limit is used as the sediment concentration, then a BSAF can be estimated as approximately 8 but could be much higher if the true concentration of a-chlordane was lower than ½ the detection limit.

BSAFs provide an estimate of an organism's maximum uptake of a contaminant assuming steady state conditions. Values greater than 1 reflect that the contaminant has a higher affinity for the organism lipid than the sediment TOC. In such cases, contaminants are more likely to build up to a concentration that would cause adverse effects. Additionally, contaminants that are readily accumulated could potentially be biomagnified in the food chain. However, biomagnification is dependent on many factors such as persistence and metabolism within the organism and cannot be estimated from laboratory tests that do not include contaminant exposure via food.

A potentially important application of BSAFs would be in the prediction of toxicity. If the critical body concentration (i.e., the tissue concentration (C_T) that is associated with an adverse effect) is known, then the BSAF and sediment concentration could be used to predict whether enough contaminant would be taken up by an organism to cause an adverse effect. A limited number of critical body concentrations have been determined for individual chemicals and species but work has generally focussed on invertebrates.

The BSAFs calculated above account for the influence sediment TOC and body lipid concentrations have on bioavailability and accumulation, respectively. If BSAFs, calculated for one contaminant accumulated from different sediments, are approximately the same, then lipids and TOC probably account for the majority of factors influencing uptake. A constant BSAF allows prediction of uptake at different sites using the equation in Section 2.4 if the sediment concentration, TOC and body lipids are known. Since BSAFs are relatively similar for all the individual PAHs in 182 and 183, tissue concentrations of a PAH in one sediment could be approximated based on knowledge of another's BSAF. However, the predictability of PAH uptake at other sites is uncertain since BSAFs were only calculated for two fairly similar sediments. PCB BSAFs were similar for all sediments except 182 and 183, both of which had elevated TOC concentrations. For these two sediments there may be other factors influencing uptake of these compounds. In such cases carbon normalization might not significantly improve the prediction of toxicity over the total contaminant concentration (Environment Canada, 1999).

It is important to remember that bioaccumulation measured in the 21 day test may underestimate accumulation in the field since the test does not include uptake from contaminated food and since steady state may not be reached by all contaminants in the test medium by 21 days (US EPA, 2000).

4.0 SUMMARY / CONCLUSIONS

1) Toxicity tests suggest that contaminants are bioavailable and that sediment quality in the Algoma Slip (sediments 182 and 183) and downstream of the wastewater treatment plant (sediment 34) is still a limiting factor to improvement of the benthic community. Contaminants in these sediments are sufficiently high in concentration to cause lethal effects (182 and 183) and/or sublethal effects (182, 183, 34) in laboratory exposures of invertebrates.

2) Strong correlations of biological responses to sediment contaminant concentrations suggest that invertebrate mortality is related to organic contaminants such as PAHs, oxychlordane, and endosulphan II. Moderate correlations of biological response to sediment contaminants suggest that midge growth impairment may be linked with metals such as copper, mercury, lead, as well as organic contaminants such as PCBs, ppDDE and b-BHC. However, it is important to remember that correlations do not, in themselves, prove cause-effect relationships.

3) Toxicity test results are supported by bioaccumulation data showing highest accumulation of PCBs, pp-DDE and a-chlordane in fish exposed to sediment 34 and highest PAHs accumulated by fish exposed to sediment 182 and 183. In addition, lipid-normalized tissue concentrations of PAHs and PCBs are strongly correlated with sediment concentrations.

4) Based on sediment concentrations, tissue concentrations and BSAFs (normalized for lipid and TOC), the sediments of greatest concern for accumulation of contaminants is sediment 34 for PCBs, pp-DDE and a-chlordane and 182 and 183 for PCBs. BSAFs for contaminants in these sediments are 1 or greater, indicating that contaminants are as likely or more likely to partition to tissue lipids from the sediment.

5) BSAFs for PAHs in sediments 182 and 183 are less than 1, indicating that PAHs have higher affinity for the sediment TOC than organism lipid. Future determination of critical body residues for fish will allow estimation of effects due to accumulation.

6) Growth effects observed in the midge test suggest that sediment 170 may be impaired by chemical contamination.

7) Results of laboratory tests should be compared to field monitoring to develop a "weight of evidence" for assessing effects of sediment contaminants on the environment.

5.0 REFERENCES

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Figure 1: Particle Size Distributions in St. Marys River Sediments

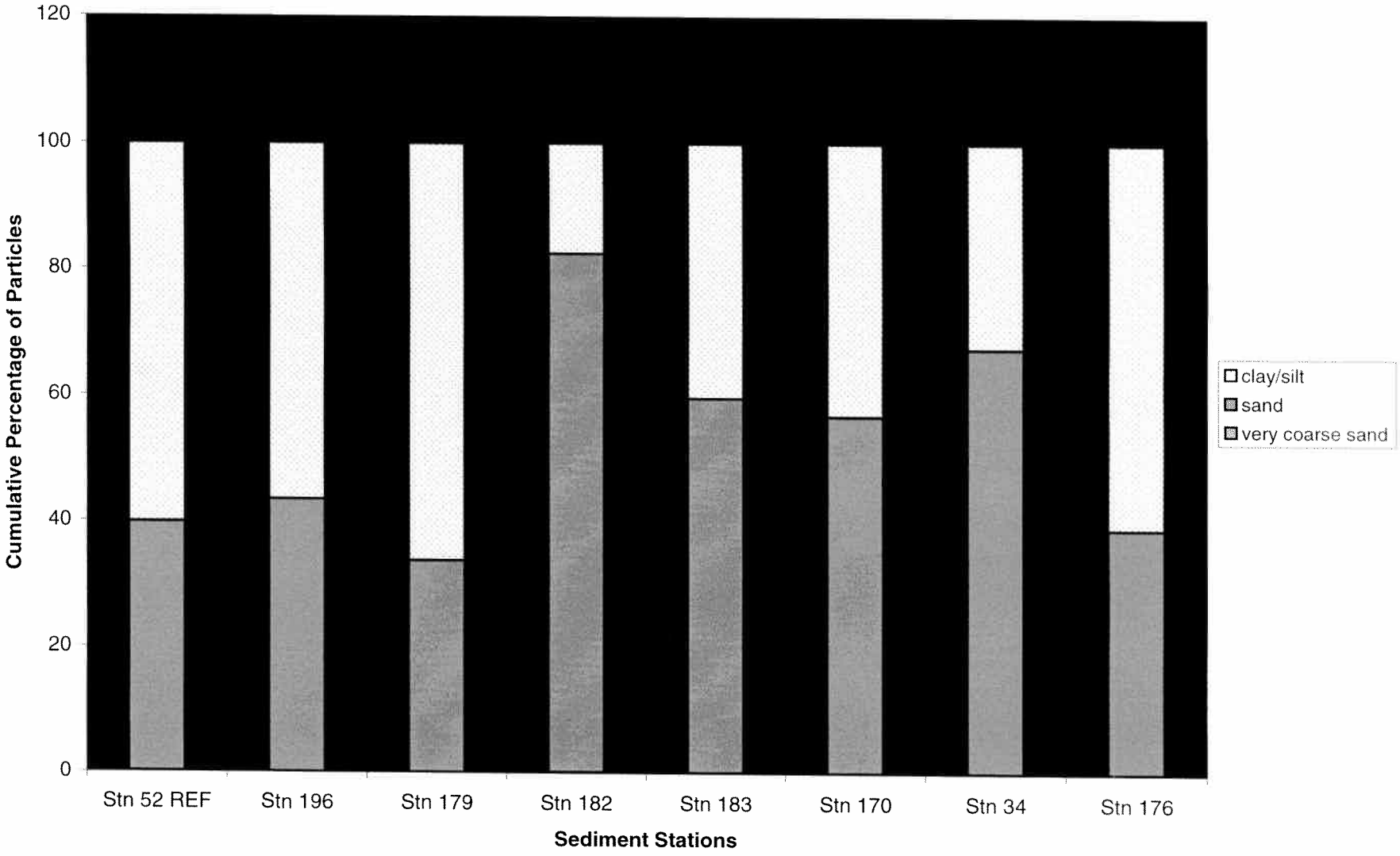

Table 1: Summary of St. Marys Sediment Samples Tested for Toxicity, 1999

Table 1a: Sediment Locations and Characteristics

Sediment	Location	Observations Made During Sample Preparation
52	reference: Point aux Pins Bay	brown clay, fibrous material, sticks
196	Algoma Slag Dump	dark brown clay, slight oily sheen and odour, very little grit
179	Algoma Slip	medium brown clay, slight oily sheen and odour
182	Algoma Slip	dark, gritty, spongy, slight oily sheen and odour
183	Algoma Slip	dark brown clay, gritty, rocks, oily sheen
170	WWTP 100 m up stream	dark brown, peaty, spongy, silt/clay, slight oily sheen and odour, vegetation
34	WWTP 150 m down stream	dark brown/black, peaty, spongy, silt/clay, vegetation, mod. oily odour
176	WWTP 2300 m downstream	med brown, vegetation, silt/clay

Table 1b: Sediment Collection and Toxicity Test Dates

Sediment	Date Collected	Date Tests Intitiated		
		Mayfly	Midge	Fathead Minnow
52	21-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
196	24-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
179	24-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
182	30-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
183	30-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
170	29-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
34	29-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99
176	26-Aug-99	27-Oct-99	02-Nov-99	10-Nov-99

Table 2: St. Marys River Sediment Toxicity: 21-day Test using Mayflies (*Hexagenia limbata*)

Table 2a: Survival Effects

Sediment	Percentage Mortality			Significant Reduction	
	replicate A	replicate B	replicate C	from HH	from Reference (52)
Honey Harbour (HH)	10	0	10	-	n
Reference (52)	0	0	0	n	n
196	0	0	10	n	n
179	10	0	0	n	n
182	30	40	40	y	y
183	20	20	10	n	y
170	0	0	0	n	n
34	0	10	0	n	n
176	0	0	0	n	n

y = yes
n = no

Table 2b: Growth Effects

Sediment	mean weight per replicate (mg)			mean weight per sediment (mg)	Significant Reduction	
	replicate A	replicate B	replicate C		from HH	from Reference (52)
Honey Harbour (HH)	7.984	9.272	7.078	8.111	-	n
Reference (52)	14.237	8.755	10.722	11.238	n	-
196	10.38	12.05	12.038	11.489	n	n
179	8.42	8.328	8.953	8.567	n	n
182	9.487	6.094	8.368	7.983	n	n
183	8.099	6.37	7.542	7.337	n	y
170	7.89	8.756	8.886	8.511	n	n
34	8.138	7.847	8.41	8.132	n	n
176	8.173	8.81	8.1	8.361	n	n

Table 3: St. Marys River Sediment Toxicity: 10-day Test using Midges (*Chironomus tentans*)

Table 3a: Survival Effects

Sediment	Percentage Mortality			Significant Reduction	
	replicate A	replicate B	replicate C	from HH	from Reference (52)
Honey Harbour (HH)	6.7	13.3	6.7	-	n
Reference (52)	0	6.7	0	n	-
196	0	6.7	0	n	n
179	20	20	13.3	n	n
182	53.3	66.7	46.7	y	y
183	40	26.7	46.7	y	y
170	20	0	0	n	n
34	13.3	33.3	6.7	n	n
176	0	6.7	26.7	n	n

y = yes
n = no

Table 3b: Growth Effects

Sediment	mean weight per replicate (mg)			mean weight per sediment	Significant Reduction	
	replicate A	replicate B	replicate C	(mg)	from HH	from Reference (52)
Honey Harbour (HH)	10.158	10.375	10.681	10.405	-	y
Reference (52)	12.707	13.733	13.332	13.257	n	-
196	9.775	8.734	9.038	9.182	n	y
179	6.531	9.331	7.916	7.926	n	y
182	5.273	4.612	3.376	4.42	y	y
183	3.874	4.693	6.011	4.859	y	y
170	6.11	6.645	7.419	6.725	y	n
34	2.644	2.316	2.792	2.584	y	y
176	6.117	9.248	8.796	8.054	n	y

Table 4: St. Marys River Sediment Toxicity: 21-day Test using Fathead Minnows (*Pimephales promelas*)

Sediment	Percentage Mortality			Significant Reduction	
	replicate A	replicate B	replicate C	from HH	from Reference (52)
Honey Harbour (HH)	0	0	0	-	n
Reference (52)	0	0	0	n	-
196	0	0	0	n	n
179	0	0	0	n	n
182	0	0	0	n	n
183	0	0	0	n	n
170	0	0	0	n	n
34	10	0	0	n	n
176	0	0	0	n	n

No survival effects

y = yes
n = no

Table 5: Comparison of Sediments Based on Toxicity Test Results

Species	Sediment	HH		52 REF		196		179		182		183		170		34		176	
		S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G
midge	**HH**																		
mayfly																			
minnow																			
midge	**ref**																		
mayfly																			
minnow																			
midge	**196**																		
mayfly																			
minnow																			
midge	**179**																		
mayfly																			
minnow																			
midge	**182**																		
mayfly																			
minnow																			
midge	**183**																		
mayfly																			
minnow																			
midge	**170**																		
mayfly																			
minnow																			
midge	**34**																		
mayfly																			
minnow																			
midge	**176**																		
mayfly																			
minnow																			

S: survival
G: growth

Colour of square based on comparison of sediment toxicity in column 2 to sediments listed in row 1.
red (dark grey on non-colour copy): significant reduction compared to row 1 sediment
green (light grey on non-colour copy): no significant reduction

Table 6a: Characteristics of St. Marys River Sediments

Parameter	LEL	SEL	Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
TOC(%)	1	10	5.2	7.4	7.5	24	25	5	4.7	5
TOC (mg/g dw)			52	74	75	240	250	50	47	50
TKN (mg/g dw)	550	4800	1.5	1.7	1.3	1.8	2.2	1.3	1.7	1.8
TP (mg/g dw)	600	2000	0.32	0.52	0.52	0.24	0.4	0.52	1.1	0.56
moisture (%)			56	58	56	44	51	57	62	63
solids total (%)			44	42	44	56	49	43	38	37
solids total, ash (%)			87	93	94	83	80	93	92	93
solids, total, LOI (mg/g dw)			100	66	64	170	200	71	81	69
particles (%)										
<2000 >1000 um very coarse sand			0.07	0.03	0.06	0.13	0.07	0.07	0.07	0.1
<1000 >63 um sand			39.74	43.42	33.71	82.28	59.5	56.63	67.34	38.76
<63 clay/silt			60.19	56.55	66.22	17.59	40.43	43.3	32.59	61.14

Table 6b: Metals in St. Marys River Sediments

Table 6b: Metals in St. Marys River Sediments Used in Toxicity Testing

Parameter	LEL	SEL	Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
µg/g dw										
cyanide (total)	0.1 (free)		0.87	0.28	0.88	0.69	1.35	1.28	0.8	0.82
mercury	0.2	2	0.02	0.06	0.09	0.11	0.1	0.15	0.75	0.08
beryllium			W	0.6	0.6	0.6	0.8	W	W	W
magnesium			2000	5700	5400	5200	6600	2600	2100	4400
aluminum			5100	10000	11000	7000	9200	6300	5900	10000
calcium			3700	7400	5600	14000	18000	3400	3700	4500
vanadium			21	42	44	28	35	29	22	41
chromium	26	110	14	36	39	27	36	65	35	48
manganese	460	1100	96	680	680	860	1100	360	200	370
iron	20000	40000	7500	36000	40000	33000	38000	40000	20000	35000
cobalt			2.4	6.7	6.9	5.4	7	5.1	3.3	6.1
nickel	16	75	7.5	17	18	13	16	18	12	19
copper	16	110	22	34	36	33	41	45	100	47
zinc	120	820	41	230	270	130	200	180	210	140
molybdenum			W	0.7	0.9	1.4	2.1	1.2	1.3	1.4
cadmium	0.6	10	0.7	0.7	1	0.4	0.3	0.6	0.8	0.8
barium			27	66	65	57	75	32	51	52
lead	31	250	14	47	57	31	39	60	76	37
strontium			14	25	24	36	42	16	16	20
titanium			610	770	760	550	570	560	450	770
arsenic	6	33	3.9	9.9	10	9	12	11	5.5	9
selenium			0.5	0.9	0.9	1.3	1.5	0.7	0.6	0.9

W = not detected

Parameter	LEL	SEL	Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
chlorinated organics (ng/g dw)										
PCB, total	70	530000	W	60	40	40	40	60	100	40
HCB	20	24000	W	W	W	W	W	W	17	W
heptachlor			W	W	W	W	W	W	W	W
aldrin	2	8000	W	W	W	W	W	W	W	W
pp-DDE			W	W	W	4	W	2	4	W
mirex	7	130000	W	W	W	W	W	W	W	W
a-BHC	6	10000	W	W	W	W	2	W	W	W
b-BHC	5	21000	W	W	W	5	4	W	5	W
g-BHC	3	1000	W	W	W	W	W	W	W	W
a-chlordane	7	6000(chlordane	W	W	W	W	4	W	W	W
g-chlordane			W	8	12	8	8	4	W	4
oxychlorane			W	12	16	120	92	8	4	8
op-DDT	7	12000 (total)	W	W	W	W	W	W	W	W
pp-DDD	8	6000	W	W	W	W	W	W	W	W
pp-DDT			W	W	W	W	W	W	W	W
methoxychlor			W	W	W	W	W	W	W	W
heptachlor epoxide	5	5000	W	W	W	W	W	W	6	W
endosulphan I			4	W	W	W	W	W	4	W
dieldrin	2	91000	W	W	4	W	4	W	W	W
endrin	3	130000	W	8	8	24	20	W	W	W
endosulphan II			W	W	W	W	W	W	W	W
endosulphan sulphate			8	W	W	20	16	W	W	W
octachlorostyrene	190		W	W	W	W	W	W	W	W
hexachlorobutadiene			W	4	W	W	W	W	62	W
1,2,3-TCB			W	W	W	W	W	W	W	W
1,2,3,4-TCB			W	W	W	W	W	W	W	W
1,2,3,5-TCB			W	W	W	W	W	W	W	W
1,2,4-TCB			W	W	W	W	W	W	14	W
1,2,4,5-TCB			W	W	W	W	W	W	W	W
1,3,5-TCB			W	W	W	W	W	W	W	W
hexachlorethane			W	W	W	W	W	W	18	W
pentachlorobenzene			W	W	W	W	W	W	W	W
2,3,6-TCT			W	W	W	W	W	W	W	W
2,4,5-TCT			W	W	W	W	W	W	W	W
2,6-bichlorobenzyl chloride			W	W	W	W	W	W	W	W

Parameter	LEL	SEL	Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
PAHs (ng/g dw)										
naphthalene			40	1400	1200	15000	17000	600	260	420
acenapthylene			W	100	120	860	820	80	80	40
acenapthene			W	260	260	4100	4600	40	40	40
fluorene	190	160000	W	440	460	7100	7100	80	80	60
phenanthrene	560	950000	60	2400	2700	46000	46000	640	860	500
anthracene	220	370000	W	640	780	8400	7400	200	380	120
fluoranthene	750	1020000	80	3700	4600	51000	56000	1600	2100	940
pyrene	490	850000	60	2700	3300	34000	38000	1400	1700	720
benzo (a) anthracene	320	1480000	W	1800	2300	15000	16000	1100	1200	500
chrysene	340	460000	40	2000	2600	16000	16000	1200	1300	600
benzo (b) fluoranthene			40	1900	2400	9800	11000	1200	1200	560
benzo (k) fluoranthene	240	1340000	W	1500	1900	8300	9100	1100	1000	460
benzo (a) pyrene	370	1440000	W	1700	2100	8600	9600	1000	1100	480
indeno (1,2,3-c,d) pyrene	200	320000	W	1300	1600	6200	6400	880	960	400
dibenzo (a,h) anthracene	60	130000	W	280	320	1100	1200	160	200	80
benzo (g,h,I) perylene	170	320000	W	1100	1300	4900	5200	720	720	360
total PAHs	4000	10000000	600	23220	27940	236360	251420	12000	13180	6280
TPH (mg/kg)			130	950	500	2500	2000	1000	1000	880

Table 6c: PCBs and Chlorinated Organics in St. Marys River Sediments

Parameter	LEL	SEL*		Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
(ng/g dw)											
PCB, total	70	530000		W	60	40	40	40	60	100	40
HCB	20	24000		W	W	W	W	W	W	17	W
heptachlor				W	W	W	W	W	W	W	W
aldrin	2	8000		W	W	W	W	W	W	W	W
pp-DDE				W	W	W	4	W	2	4	W
mirex	7	130000		W	W	W	W	W	W	W	W
a-BHC	6	10000		W	W	W	W	2	W	W	W
b-BHC	5	21000		W	W	W	5	4	W	5	W
g-BHC	3	1000		W	W	W	W	W	W	W	W
a-chlordane	7	6000	chlordane	W	W	W	W	4	W	W	W
g-chlordane				W	8	12	8	8	4	W	4
oxychlordane				W	12	16	120	92	8	4	8
op-DDT	7	12000	total	W	W	W	W	W	W	W	W
pp-DDD	8	6000		W	W	W	W	W	W	W	W
pp-DDT				W	W	W	W	W	W	W	W
methoxychlor				W	W	W	W	W	W	W	W
heptachlor epoxide	5	5000		W	W	W	W	W	W	6	W
endosulphan I				4	W	W	W	W	W	4	W
dieldrin	2	91000		W	W	4	W	4	W	W	W
endrin	3	130000		W	8	8	24	20	W	W	W
endosulphan II				W	W	W	W	W	W	W	W
endosulphan sulphate				8	W	W	20	16	W	W	W
octachlorostyrene	190			W	W	W	W	W	W	W	W
hexachlorobutadiene				W	4	W	W	W	W	62	W
1,2,3-TCB				W	W	W	W	W	W	W	W
1,2,3,4-TCB				W	W	W	W	W	W	W	W
1,2,3,5-TCB				W	W	W	W	W	W	W	W
1,2,4-TCB				W	W	W	W	W	W	14	W
1,2,4,5-TCB				W	W	W	W	W	W	W	W
1,3,5-TCB				W	W	W	W	W	W	W	W
hexachlorethane				W	W	W	W	W	W	18	W
pentachlorobenzene				W	W	W	W	W	W	W	W
2,3,6-TCT				W	W	W	W	W	W	W	W
2,4,5-TCT				W	W	W	W	W	W	W	W
2,6-bichlorobenzyl chloride				W	W	W	W	W	W	W	W

W= not detected

*for SEL, multiply value by TOC of sediment

Table 6d: PAHs in St. Marys River Sediments

Parameter	LEL	SEL*	Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
PAHs (ng/g dw)										
naphthalene			40	1400	1200	15000	17000	600	260	420
acenapthylene			W	100	120	860	820	80	80	40
acenapthene			W	260	260	4100	4600	40	40	40
fluorene	190	160000	W	440	460	7100	7100	80	80	60
phenanthrene	560	950000	60	2400	2700	46000	46000	640	860	500
anthracene	220	370000	W	640	780	8400	7400	200	380	120
fluoranthene	750	1020000	80	3700	4600	51000	56000	1600	2100	940
pyrene	490	850000	60	2700	3300	34000	38000	1400	1700	720
benzo (a) anthracene	320	1480000	W	1800	2300	15000	16000	1100	1200	500
chrysene	340	460000	40	2000	2600	16000	16000	1200	1300	600
benzo (b) fluoranthene			40	1900	2400	9800	11000	1200	1200	560
benzo (k) fluoranthene	240	1340000	W	1500	1900	8300	9100	1100	1000	460
benzo (a) pyrene	370	1440000	W	1700	2100	8600	9600	1000	1100	480
indeno (1,2,3-c,d) pyrene	200	320000	W	1300	1600	6200	6400	880	960	400
dibenzo (a,h) anthracene	60	130000	W	280	320	1100	1200	160	200	80
benzo (g,h,I) perylene	170	320000	W	1100	1300	4900	5200	720	720	360
total PAHs	4000	10000000	600	23220	27940	236360	251420	12000	13180	6280
TPH (mg/kg)			130	950	500	2500	2000	1000	1000	880

W= not detected

*for SEL, multiply value by TOC of sediment

Table 6c: PCBs and Chlorinated Organics in St. Marys River Sediments

Parameter	LEL	SEL*		Stn 52 REF	Stn 196	Stn 179	Stn 182	Stn 183	Stn 170	Stn 34	Stn 176
(ng/g dw)											
PCB, total	70	530000		W	60	40	40	40	60	100	40
HCB	20	24000		W	W	W	W	W	W	17	W
heptachlor				W	W	W	W	W	W	W	W
aldrin	2	8000		W	W	W	W	W	W	W	W
pp-DDE				W	W	W	4	W	2	4	W
mirex	7	130000		W	W	W	W	W	W	W	W
a-BHC	6	10000		W	W	W	W	2	W	W	W
b-BHC	5	21000		W	W	W	5	4	W	5	W
g-BHC	3	1000		W	W	W	W	W	W	W	W
a-chlordane	7	6000	chlordane	W	W	W	W	4	W	W	W
g-chlordane				W	8	12	8	8	4	W	4
oxychlordane				W	12	16	120	92	8	4	8
op-DDT	7	12000	total	W	W	W	W	W	W	W	W
pp-DDD	8	6000		W	W	W	W	W	W	W	W
pp-DDT				W	W	W	W	W	W	W	W
methoxychlor				W	W	W	W	W	W	W	W
heptachlor epoxide	5	5000		W	W	W	W	W	W	6	W
endosulphan I				4	W	W	W	W	W	4	W
dieldrin	2	91000		W	W	4	W	4	W	W	W
endrin	3	130000		W	8	8	24	20	W	W	W
endosulphan II				W	W	W	W	W	W	W	W
endosulphan sulphate				8	W	W	20	16	W	W	W
octachlorostyrene	190			W	W	W	W	W	W	W	W
hexachlorobutadiene				W	4	W	W	W	W	62	W
1,2,3-TCB				W	W	W	W	W	W	W	W
1,2,3,4-TCB				W	W	W	W	W	W	W	W
1,2,3,5-TCB				W	W	W	W	W	W	W	W
1,2,4-TCB				W	W	W	W	W	W	14	W
1,2,4,5-TCB				W	W	W	W	W	W	W	W
1,3,5-TCB				W	W	W	W	W	W	W	W
hexachlorethane				W	W	W	W	W	W	18	W
pentachlorobenzene				W	W	W	W	W	W	W	W
2,3,6-TCT				W	W	W	W	W	W	W	W
2,4,5-TCT				W	W	W	W	W	W	W	W
2,6-bichlorobenzyl chloride				W	W	W	W	W	W	W	W

W= not detected

*for SEL, multiply value by TOC of sediment

Table 7: Statistically Significant Correlations of Sediment Chemistry and Toxicity (p=/< 0.05)

correlation coefficient	0.8 - 1.0 (Strong)	0.6 - <0.8 (Moderate)	0.4 - <0.6 (Weak)
Midge Mortality	endosulphan II, oxychlordane, PAHs, TOC	Ca, endosulphan sulphate, Mn, Sr	Ba, Be, Mg, Mo, pp-DDE
Mayfly Mortality	endosulphan II, endosulphan sulphate, oxychlordane, PAHs, TOC	Ca, Mn, Sr, b-BHC	Be, Mg, Mo, pp-DDE
Midge Growth Impairment		Cu, Hg, Mo, Pb, PCBs, pp-DDE, b-BHC	Ba, heptachlor epoxide, hexachlorobenzene, hexachlorobutadiene, oxychlordane, Ti, TOC, 1,2,4-trichlorobenzene, PAHs
Mayfly Growth Impairment		Mo	b-BHC, oxychlordane, PAHs

Table 8a: St. Mary's River Sediment: Concentrations of PCBs and ppDDE in Fathead Minnow Tissue

	PRE-EXPOSED		HH		52-REF		196		179		182		183		170		34		176	
Parameter	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Lipids (%)	2.5	3	1.6	2	2.9	3	2.6	2	2.5	2.5	2.4	1.9	1.8	2.3	2	2.5	2.5	2.2	2.5	2.5
Lipids g/g tissue	0.025	0.03	0.016	0.02	0.029	0.03	0.026	0.02	0.025	0.025	0.024	0.019	0.018	0.023	0.02	0.025	0.025	0.022	0.025	0.025
PCBs																				
tissue (ng/g ww)	60	80	100	40	100	60	80	80	60	60	60	80	80	80	100	80	140	100	60	60
ng/g lipid	2400	2666.67	6250	2000	3448	2000	3077	4000	2400	2400	2500	4211	4444	3478	5000	3200	5600	4545	2400	2400
mean / sample ng/g lipid	2533.33		4125		2724		3538		2400		3355		3961		4100		5073		2400	
pp-DDE																				
tissue (ng/g ww)	5.0	7.0	6.0	6.0	9.0	5.0	4.0	2.0	4.0	4.0	3.0	4.0	4.0	5.0	5.0	5.0	9	8	4.0	6.0
ng/g lipid	200.0	233.3	375.0	300.0	310.3	166.7	153.8	100.0	160.0	160.0	125.0	210.5	222.2	217.4	250.0	200.0	360.0	363.6	160.0	240.0
mean / sample ng/g lipid	216.7		337.5		238.5		126.9		160.0		167.8		219.8		225.0		361.8		200.0	

W = not detected

Table 8b: St. Mary's River Sediment: Concentrations of PAHs in Fathead Minnow Tissue

	Sediment 183					Sediment 183				
	Measured Concentrations		Lipid Normalized			Measured Concentrations		Lipid Normalized		
Parameter	A	B	A	B	Mean	A	B	A	B	Mean
Lipids (%)	2.4	1.9				1.8	2.3			
Lipids g/g tissue	0.024	0.019				0.018	0.023			
naphthalene	80	80	3333	4211	3772	60	80	3333	3478	3406
phenanthrene	80	120	3333	6316	4825	120	100	6667	4348	5507
anthracene	20	40	833	2105	1469	W	W	W	W	W
fluoranthene	100	100	4167	5263	4715	220	100	12222	4348	8285
pyrene	60	80	2500	4211	3355	160	60	8889	2609	5749
benzo-a-anthracene	10	40	417	2105	1261	60	40	3333	1739	2536
chrysene	40	40	1667	2105	1886	60	60	3333	2609	2971
benzo-b-fluoranthene	40	10	1667	526	1096	60	40	3333	1739	2536
benzo-k-fluoranthene	W	W	W	W	W	40	10	2222	435	2222
indeno-1,2,3-c,d-pyrene	80	20	3333	1053	2193	W	W	W	W	W
benzo-g,h,i-perylene	80	20	3333	1053	2193	W	W	W	W	W

W = not detected

NB: if chemical was not detected in one replicate, 1/2 detection limit was used for calculation of mean

Table 9: Pearson Correlations of PCB Concentrations in Tissue and Sediment

PCB Concentration in...	PCB Concentration in...	
Tissue (ng PCB/g ww)	**Sediment (ng/g dw)**	**Correlation Coefficient**
80	10	
80	60	
60	40	**0.68**
70	40	
80	40	
90	60	
120	100	
60	40	
Lipid normalized tissue (ng PCB/g lipid ww)	**Sediment (ng/g dw)**	
2724	10	
3538	60	
2400	40	**0.80**
3355	40	
3961	40	
4100	60	
5073	100	
2400	40	
Lipid normalized tissue (ng PCB/g lipid ww)	**TOC normalized sediment (ng PCB /g TOC dw)**	
2724	192	
3538	811	**0.66**
2400	533	
3355	167	
3961	160	
4100	1200	
5073	2128	
2400	800	

NB: 1/2 detection limit used for concentrations below detection

	Column 1	*Column 2*
Column 1	1	
Column 2	0.681037	1

	Column 1	*Column 2*
Column 1	1	
Column 2	0.796712	1

	Column 1	*Column 2*
Column 1	1	
Column 2	0.655675	1

Table 10: Pearson Correlations for PAHs in Tissue and Sediment

	Station 182		Station 183	
	tissue ng/g lipid	sediment ng/g dw	tissue ng/g lipid	sediment ng/g dw
naphthalene	3772	15000	3406	17000
phenanthrene	4825	46000	5507	46000
anthracene	1469	8400	10	7400
fluoranthene	4715	51000	8285	56000
pyrene	3355	34000	5749	38000
benzo-a-anthracene	1261	15000	2536	16000
chrysene	1886	16000	2971	16000
benzo-b-fluoranthene	1096	9800	2536	11000
benzo-k-fluoranthene	10	8300	2222	9100
indeno-1,2,3-c,d-pyrene	2193	6200	20	6400
benzo--g,h,i-perylene	2193	4900	20	5200
Correlation Coefficients	**0.82**		**0.95**	

NB: 1/2 detection limit used for concentrations below detection

Table 11: St. Marys River Sediments: BSAFs for PCBs Detected in Fish Tissue

Station	PCB ng/g Lipid	exposure - background	PCB-sediment ng/g dw	TOC g/g
BACKGROUND:				
Control (pre-exposure)	2533			
52 (reference)	2724	191	10	0.052
196	3538	1005	60	0.074
179	2400	-133	40	0.075
182	3355	822	40	0.24
183	3961	1428	40	0.25
170	4100	1567	60	0.05
34	5073	2540	100	0.047
176	2400	-133	40	0.05
BSAFs				
Reference	0.99			
196	1.24			
179				
182	4.93			
183	8.93			
170	1.31			
34	1.19			
176				

NB: PCBs were not detected in the reference sediment; 1/2 detection limit used for calculation of BSAF

Table 12: St. Marys River Sediments: BSAFs for PAHs Detected in Fish Tissue

	Station 182		Station 183	
	Lipid Normalized ng/g lipid	sediment ng/g dw	Lipid Normalized ng/g lipid	sediment ng/g dw
			(mean, n=2)	
naphthalene	3772	15000	3406	17000
phenanthrene	4825	46000	5507	46000
anthracene	1469	8400	W	7400
fluoranthene	4715	51000	8285	56000
pyrene	3355	34000	5749	38000
benzo-a-anthracene	1261	15000	2536	16000
chrysene	1886	16000	2971	16000
benzo-b-fluoranthene	1096	9800	2536	11000
benzo-k-fluoranthene	W	8300	2222	9100
indeno-1,2,3-c,d-pyrene	2193	6200	W	6400
benzo--g,h,i-perylene	2193	4900	W	5200
TOC (%)		24		25
TOC (g/g)		0.24		0.25

BSAFs	182	183
naphthalene	0.060350877	0.050085251
phenanthrene	0.025171625	0.029930687
anthracene	0.04197995	
fluoranthene	0.022187822	0.036986715
pyrene	0.023684211	0.037821002
benzo-a-anthracene	0.020175439	0.039628623
chrysene	0.028289474	0.046422101
benzo-b-fluoranthene	0.026852846	0.057641634
benzo-k-fluoranthene		0.061050061
indeno-1,2,3-c,d-pyrene	0.084889643	
benzo--g,h,i-perylene	0.107411386	

PCB ng/g Lipid	exposure - background	PCB-sediment ng/g dw	TOC g/g
2724	191	10	0.052
3538	1005	60	0.074
2400	-133	40	0.075
3355	822	40	0.24
3961	1428	40	0.25
4100	1567	60	0.05
5073	2540	100	0.047
2400	-133	40	0.05
	LN PCB-BKGND		
2724	191	10	0.052
3538	1005	60	0.074
2400	0	40	0.075
3355	822	40	0.24
3961	1428	40	0.25
4100	1567	60	0.05
5073	2540	100	0.047
2400	0	40	0.05

	Column 1	*Column 2*
Column 1	1	
Column 2	0.819439	1

	sed/toc
191	192.3076923
1005	810.8108108
0	533.3333333
822	166.6666667
1428	160
1567	1200
2540	2127.659574
0	800

	Column 1	*Column 2*
Column 1	1	
Column 2	0.681037	1

2724	10
3538	60
2400	40
3355	40
3961	40
4100	60
5073	100
2400	40

	Column 1	*Column 2*
Column 1	1	
Column 2	0.796712	1

2724	192.3076923
3538	810.8108108
2400	533.3333333
3355	166.6666667
3961	160

	Column 1	*Column 2*
Column 1	1	
Column 2	0.655675	1

		4100	1200
		5073	2127.659574
		2400	800
REF		2724	192.3076923
	196	3538	810.8108108
	179	2400	533.3333333
	182	3355	166.6666667
	34	5073	2127.659574
	176	2400	800
		191	192.3076923
		1005	810.8108108
		0	533.3333333
		1567	166.6666667
		2540	2127.659574
		0	800

	Column 1	*Column 2*
Column 1	1	
Column 2	0.794249	1

	Column 1	*Column 2*
Column 1	1	
Column 2	0.655165	1