ASSESSMENT OF UPPER ST. CLAIR RIVER SEDIMENTS AND BENTHIC MACROINVERTEBRATE COMMUNITIES - 1994

Report for:

Ontario Ministry of Environment and Energy
Water Resources Assessment Unit
Southwestern Region
London, Ontario

Environmental Monitoring and Reporting Branch
Surface Water Section
Etobicoke, Ontario

St. Clair River Remedial Action Plan
Implementation Committee, Sarnia, Ontario

and

Environment Canada
Great Lakes 2000 Cleanup Fund

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EXECUTIVE SUMMARY

In June 1994, the Ministry of the Environment and Energy (MOEE) conducted an integrated sediment quality study (surficial chemistry, toxicity and benthic macroinvertebrate community structure) of Study Zone 1 in the upper St. Clair River to assess the present sediment quality. Study Zone 1 is the most upstream of three areas along the Canadian shoreline between Sarnia and the mid-point of Stag Island identified as a Priority 1 area due to sediment contamination and impairment of the benthic macroinvertebrate communities based on the results of a 1990 survey.

The study was designed by the MOEE, in co-operation with the Lambton Industrial Society (LIS) and follows earlier studies which demonstrated a continuing reduction in the zone of benthic community impairment from 25 km to 6 km over the past 25 years. However, the sediment contamination over the remaining three zones is still associated with the loss of suitable benthic habitat and degradation of community structure as well as providing a source of biological uptake of these contaminants resulting in biomagnification through the food chain (Bedard and Petro, 1992).

Samples were collected from thirteen transects, with three stations along each, for a total of 39 stations. Seven of these stations coincided with transects sampled in previous surveys, with six transects added to provide additional information between these historical transects. Transects in Study Area 1 were divided into three groups, Upper, Middle and Lower, each accounting for approximately equal areas. These data served to help delineate the extent and severity of the contamination of sediment in Study Zone 1, enabling the Contaminated Sediment and Habitat Task Teams to assess remedial options for these contaminated sediments.

The MOEE retained Beak International Incorporated (BEAK) to complete the identification and enumeration of the benthic macroinvertebrates, and to examine the relationships between the benthic community structure, sediment toxicity and the sediment chemistry. The study also examined the temporal and spatial changes in sediment quality in Study Zone 1 since the last major benthic macroinvertebrate study in 1990. The MOEE was responsible for conducting the toxicity testing and examining the relationships between the toxicity results and sediment chemistry. BEAK integrated these results into this report.

Sediment Chemistry

Cluster and PCA analyses were performed on the sediment chemistry data to identify areas of similar sediment quality. The results indicated that stations in the Lower Area separated from the Upper and Middle Areas on the basis of higher concentrations of organic chemicals, including tetrachlorobenzenes, trichlorobenzenes, HCE, HCB, PCB, HCBD, PCBs, 2,3,7,8-TCDD TEQs, mercury and higher gravel content than stations in the Upper and Middle Areas. HCB and mercury were both above their respective provincial sediment quality guideline SEL values at these locations. Total PCBs and copper tended to be above their respective LEL values and TCDD-TEQs were above the draft Canadian sediment quality NOEC value. Stations in the Upper and Middle Areas were characterized by higher levels of metals, % fines, TP and TKN, with a few stations having copper or iron above the SEL value. The Middle Area also tended to have higher concentrations of solvent extractables, TOC, TP, total petroleum hydrocarbons, LOI, low and high molecular weight PAHs, and TKN. Stations in the Upper Area were distinguished from the other two areas on the basis of slightly higher sand content.

Acute and Sublethal Toxicity

Twenty-six of the thirty-nine stations demonstrated acute or chronic toxicity to one or more laboratory test species exposed to test sediment. Eleven of the thirty-nine sites demonstrated acute toxicity to one or more test species. Two of the sites demonstrated acute toxicity ($\geq$80%) to all three test species and five demonstrated acute toxicity ($\geq$80%) to both invertebrate species.

Invertebrate (*Chironomus*, *Hexagenia*) and fish (*Pimephales promelas*) mortality levels were quite variable throughout the study area, ranging from 0 to 100%, both within and among transects. For both of the benthic invertebrate species, eight of eleven sites exhibiting high toxicity ($\geq$80%) were located in the Upper and Middle Areas, with the same sites exhibiting toxicity to both species.

Sediment samples from ten stations exhibited $\geq$80% mortality to fish. Eight were located at the inner or mid-stations along a transect, with the spatial toxicity pattern far different than those observed with the invertebrate species, suggesting that the fish are responding to different contaminants than the invertebrates (e.g., water-based rather than sediment associated). Unionized ammonia levels measured in the overlying waters of the fathead minnow tests indicated that some of the observed toxicity (i.e., at IS12-I and IS12-M) was associated with waterborne unionized ammonia. This was similar to results found by Pollutech (1997). Sediments within the Lower Area were more toxic to fish than the invertebrates.

Bedard and Petro (1997) related the toxicity from the Upper and Middle Areas to a variety of petroleum-based compounds. Several of the toxic sediments from this area were characterized in the field, in the toxicity laboratory and in the benthic processing laboratory as possessing a distinct chemical odour. Total petroleum hydrocarbon sediment concentrations above 1500 μg/g (dry weight) were most frequently associated with higher organism toxicity (Bedard and Petro, 1997).

Correlation and linear regression analysis of the acute toxicity responses for both fish and benthos with the isolated Lower Area chemical data set suggested that the observed toxic responses were the result of many chlorinated benzenes, several of which share a similar mode of toxic action.

Fathead minnows which survived the acute tests were analysed for bioaccumulated compounds. Six compounds found above trace amounts in tissues included p,p´-DDE, total PCBs, HCBD, pentachlorobenzene, HCB and OCS.

Benthic Macroinvertebrates

Overall, the benthic macroinvertebrate communities at stations in the upper St. Clair River are indicative of impaired (23 stations) to degraded (16 stations) conditions. With a few exceptions, the communities were dominated by pollution-tolerant oligochaetes and chironomids, with little difference between the community assemblages characterising each of the cluster and correspondence station groups. This suggests that all areas would generally be considered to support impaired communities. A study conducted on behalf of the LIS found similar results in a parallel 1994 St. Clair River survey (Pollutech, 1997).

Results of the discriminant analysis using the benthic community cluster results to group sediment chemistry data indicated no meaningful relationships between the benthic community structure and sediment chemistry. Mantel's test results between the benthic macroinvertebrate and sediment chemistry distance matrices (matrices of similarity measures between stations) indicated that a significant association existed between the benthic community and the overall sediment matrix. This relationship was characterized by a gradient in sediment quality, with elevated fine particles and nutrient levels in the Upper Area to the Lower Area where the sediments were characterized by high loadings from chlorinated organic chemicals and mercury. Mantel's tests using smaller groupings of sediment chemistry data (i.e., nutrients, metals, chlorinated organic chemicals, PAHs and physical parameters) indicated that the highest degree of association existed between the benthic community and the physical parameter matrices. The benthic community association with the chlorinated organics was the next highest, followed by nutrient levels. These results would suggest that, while the entire study area is impaired with a variety of contaminants to which the benthos may be responding, variability between the stations is also partially attributed to habitat characteristics.

Integrating the results from the sediment chemistry, toxicity and benthic macroinvertebrate community analyses following the Sediment Quality Triad approach (Chapman, 1990 and 1996) found 14 sites classified by low Sediment Quality Scores indicative of highly contaminated sediments, acute toxicity and impaired benthic communities. Sixteen stations in the study area were classified by intermediate Sediment Quality Scores and nine stations were characterized by high Sediment Quality Scores representing areas with the best sediment quality. The Sediment Quality Scores tend to suggest a decline in sediment quality from the Upper to the Lower Area, although the pattern is patchy.

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This was a joint project designed for the St. Clair River Sediment Subcommittee by Peter Kauss, with review and suggestions provided by OMOEE, Environment Canada, Lambton Industrial Society and Pollutech Enviroquatics staff. Wendy Page, Bruce Hawkins, and Greg Hobson, Jamie Halpin, Colleen Masterson, and Mike Moody collected the samples and made field measurements, aided by Rob Belanger, Jeff Carson and Cheryl Garick. Richard Harber was vessel master of the OMOEE survey vessel Monitor VI. Thanks are also extended to the Ministry's Laboratory Services Branch staff in the Biomaterials and Sediments, Vegetation and Soils, Dioxins and Furans, Hazardous Waste, Spectroscopy and Water Quality groups for their analysis of the water, sediment and biota samples and to Donna Bedard and Steve Petro for the toxicological analysis of the sediments.

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1.0 INTRODUCTION

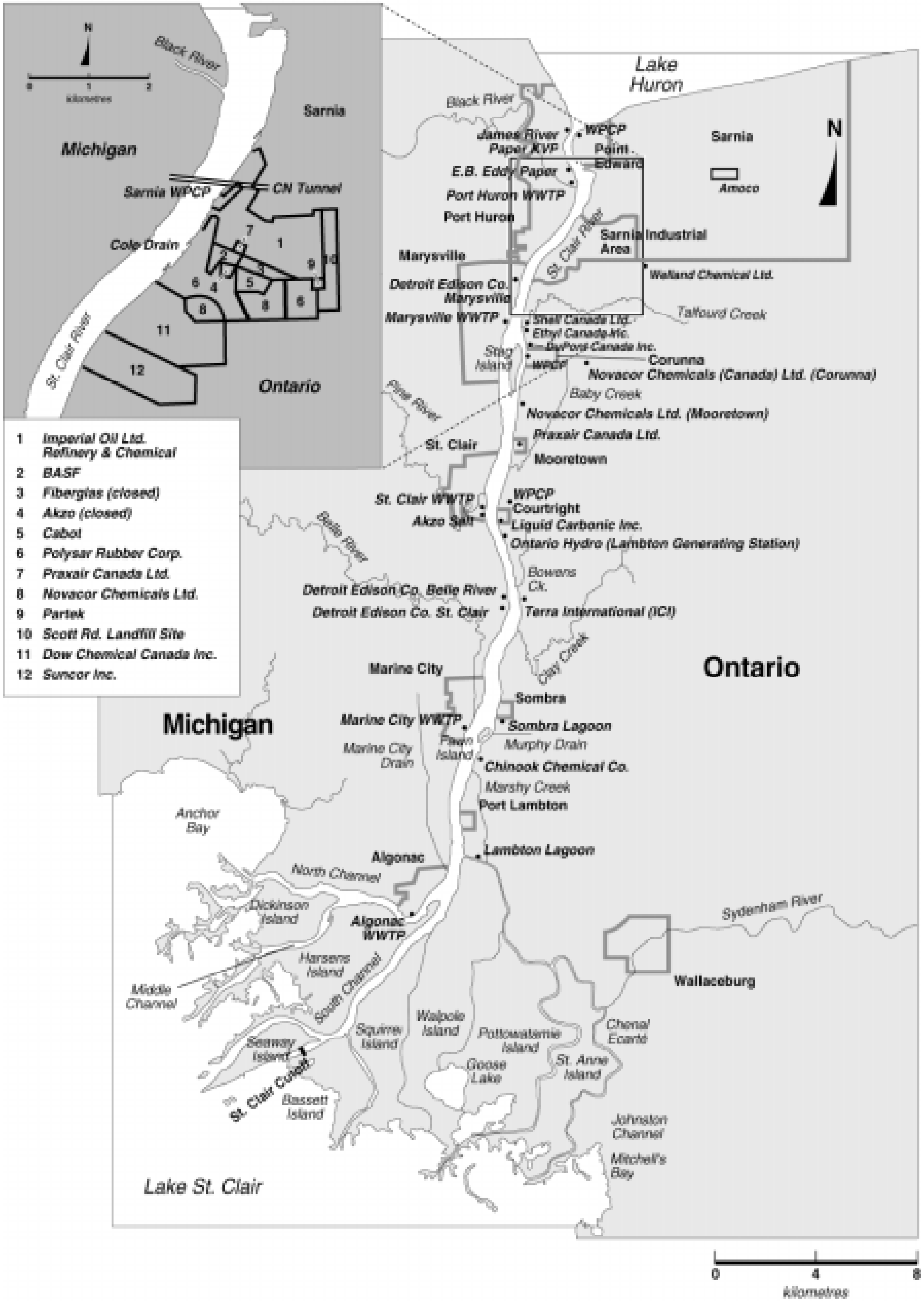
1.1 Background

For the past 40 years, contaminated sediments in the St. Clair River have been recognized as an environmental problem affecting the health of aquatic communities in the river. In 1985, the International Joint Commission (IJC) identified the St. Clair River as one of 42 “Areas of Concern” (AOC) within the Great Lakes Basin. The St. Clair River was identified as an AOC due to the impairment of beneficial uses within the river and its watershed. The Great Lakes Water Quality Board (GLWQB) defines the impairment of beneficial uses as a change in the chemical, physical or biological integrity of the Great Lakes Basin ecosystem. Of the fourteen Impairments of Beneficial Uses recognized by the GLWQB, nine categories were identified as impaired in the St. Clair River.

These impaired uses include:

- restrictions on fish and wildlife consumption;
- bird or animal deformities or reproductive problems;
- degradation of benthos;
- restrictions on dredging activities;
- restrictions on drinking water;
- beach closings;
- degradation of aesthetics;
- added cost to agriculture or industry;
- and loss of fish and wildlife habitat.

The St. Clair River serves as a channel connecting Lake Huron with Lake St. Clair. Flowing in a southerly direction from Lake Huron and prior to entering Lake St. Clair, the river divides into several channels creating an extensive delta known as the St. Clair Delta or St. Clair Flats (Figure 1.1).



Location of Major Point Source Discharges to the St. Clair River (Source: OMOEE and MDNR, 1995)

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beak international incorporated	Figure 1.1	October 1997

There is a concentration of industry in Sarnia and in the area between Sarnia and Corunna, which includes petroleum refineries, organic and inorganic chemical manufacturers and thermal electric generating facilities (Figure 1.1). There are also 23 industrial and four municipal waste sites within the watershed in Ontario, and there are six sites of environmental contamination within 4.8 kilometres of the river in the United States. In particular, there is a large number of refineries and chemical manufacturing facilities located in the industrialized area south of Sarnia (Figure 1.1, insert).

The distribution of contaminants in the sediments has been strongly related to historical industrial and municipal point sources on the Ontario side of the river. As a result, the zones of elevated contaminant levels are found along the Ontario shoreline from the Sarnia industrial area to downstream of Stag Island. The distribution of individual contaminants through this reach of the river generally reflects the effluent characteristics of present and historical individual point sources. The Stage 1 Remedial Action Plan (RAP) Report identified the sediments from the Cole Drain to Stag Island as moderately to heavily polluted with metal and organic contaminants. The sediments on the Michigan side of the river were relatively uncontaminated in comparison.

The contaminants which exceeded both the Ontario Open Water Disposal Guidelines (OMOE, 1976) and the U.S. EPA Guidelines for the Classification of Great Lakes Harbour Sediments heavily polluted criteria (U.S. EPA, 1977) included; oil and grease, mercury, iron, copper and arsenic. Contaminants which were found in concentrations associated with moderately contaminated sediment (U.S. EPA, 1977) included; total Kjeldahl nitrogen (TKN), total phosphorus, cadmium, chromium, manganese, lead, nickel and PCBs (BEAK, 1993).

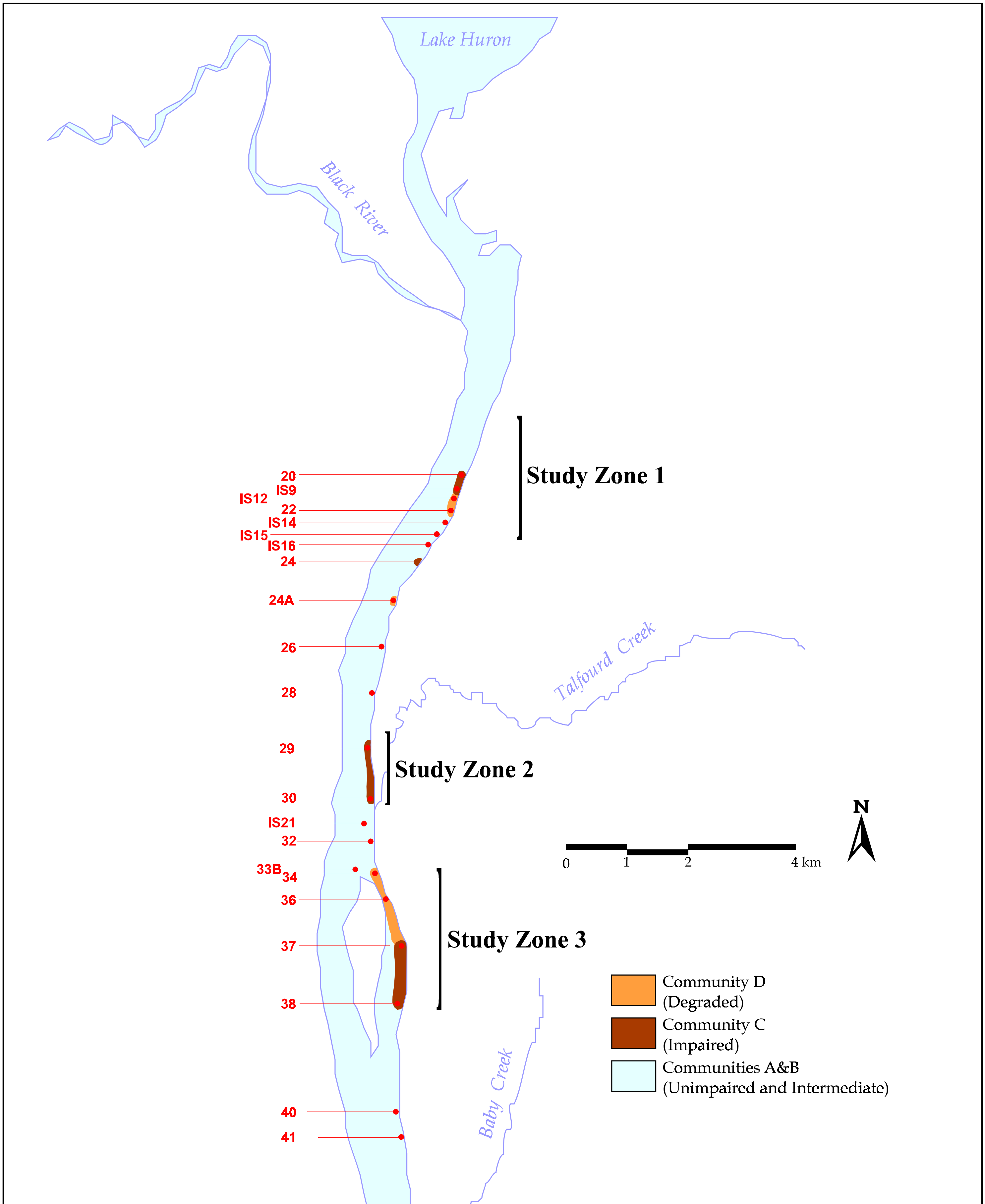
A sediment quality monitoring program in the upper section of the St. Clair River conducted by Environment Canada in 1985 (Environment Canada/OMOE 1986; Oliver, 1988) provided data on the concentrations of chlorinated organics and 16 priority polycyclic aromatic hydrocarbons (PAHs), most of which were elevated above background station levels. These contaminants included: octachlorostyrene, hexachlorobenzene, phenanthrene, hexachlorobutadiene, tri-, tetra- and pentachlorobenzenes, hexachloroethane, tetrachloroethylene, carbon tetrachloride, tetrachloroethanes, pentachloroethane, chlorobutenes, heptachlorostyrene, octachloronapthalene, alkanes, diphenyl ether, biphenyl, 4-ethyl biphenyl, diethyl biphenyl and polychlorinated dibenzofurans and dibenzo-p-dioxins.

The contaminants in the sediments of the St. Clair River have been tested for toxicity to aquatic organisms, and sediments associated with the petrochemical industries were found to be acutely lethal to young fathead minnows and mayfly nymphs (*Hexagenia limbata)* (Bedard and Petro, 1992).

In response to the identification of the St. Clair River as an AOC predominantly because of the industrial and point source discharges which resulted in sediment contamination, the Michigan and Ontario governments signed an agreement to initiate a joint Remedial Action Plan (RAP) process with Ontario to provide the lead role. In 1991, the RAP Team completed Stage 1 of a three stage RAP process. Stage 2 of the RAP process, which defines the specific goals for the AOC and describes the remedial and regulatory measures to achieve these goals, was completed in 1994 (OMOEE and MDNR, 1995).

Historically, the contaminated sediments in the St. Clair River have resulted in the impairment of the benthic invertebrate community from the Sarnia industrial area to downstream of Stag Island. In 1968, the zone of benthic impairment extended along the Ontario shoreline from the City of Sarnia to below Channel Ecarte (OMOE, 1979). This zone has been significantly reduced over the past 25 years from 25 km to 6 km as indicated by periodic benthic macroinvertebrate monitoring studies (OMOE, 1979; Hiltunen, 1980; Griffiths, 1989; Jaagumagi, 1988; Pope, 1993). However, the sediment contamination is still associated with the loss of suitable benthic habitat and degradation of community structure, as well as providing a source for biological uptake of these contaminants resulting in biomagnification through the food chain (Bedard and Petro, 1992).

A 1990 benthic macroinvertebrate survey of the river (Pope, 1993) identified four environmental quality zones based on the characteristics of the benthic community and on water and sediment chemistry data. Based on this information, areas of the river were classified as unimpaired/intermediate, impaired and degraded (Figure 1.2).



1990 Benthic Community Impact Zones and Sediment Sampling Stations in the St. Clair River (Pope, 1993)

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The study confirmed that several sites in the upper St. Clair River were contaminated with a number of inorganic (copper, mercury and zinc) and organic (chlorinated benzenes and toluenes, octachlorostyrene and hexachlorobutadiene) compounds. Several of these compounds, that were measured at concentrations in excess of the Severe Effect Level (SEL) of the Ontario Provincial Sediment Quality Guidelines (PSQG; Persaud *et al*., 1993), are persistent, bioaccumulative, have been associated with degradation of benthic macroinvertebrate communities and are lethal to benthic macroinvertebrates and forage fish in laboratory toxicity tests.

In 1990, the degraded zone was restricted to three narrow bands along the St. Clair River: adjacent to Polysar/Bayer Rubber, downstream of Suncor, and in the vicinity of DuPont and Novacor Chemicals (Corunna)(Pope, 1993). Bioassay results for sediment samples collected in the degraded zone ranged from "very highly toxic" to "moderately toxic" (Bedard and Petro, 1992).

Impaired zones were found in several areas of the river: upstream and downstream of the Cole Drain, downstream of the Dow 3rd Street sewer, near the Shell dock and intake at Corunna, and downstream of the Corunna Water Pollution Control Plant (WPCP) (Pope, 1993). Bioassay results for sediment samples collected in the impaired zone at the Cole Drain and the Shell dock indicated that the sediment was "highly toxic" (Bedard and Petro, 1992).

It should be noted that the size of the degraded and impaired zones were reported (Pope, 1993) to be substantially smaller than those noted in 1985 (Griffiths, 1989) suggesting that there were improvements in the health of the benthic community.

In conjunction with the Ontario Ministry of the Environment and Energy's (OMOEE) ongoing monitoring of the St. Clair River and the need for the RAP committee to have a clear understanding of impact zones before the implementation of remedial measures, the OMOEE, in cooperation with the Lambton Industrial Society (LIS), initiated a sediment quality assessment of the three zones of the river identified as degraded in the Stage 2 RAP report. In the spring of 1994, the LIS studied all three zones, concentrating on the two southern most zones (Zones 2 and 3), while the OMOEE concentrated efforts on the north zone (Zone 1)(Figure 1.2). The OMOEE program incorporated the collection of sediment samples for chemical, macroinvertebrate and toxicological analyses. In addition, supporting measurements (dissolved oxygen, velocity, conductivity, sediment depth, etc.), and bioaccumulation and water chemistry data were also collected for Study Zone 1.

Beak International Incorporated (BEAK) was commissioned by the OMOEE to process the macroinvertebrate samples and to provide a detailed assessment report, integrating all of the historical and recent data relevant to the sediment quality of Study Zone 1 in the upper St. Clair River.

1.2 Study Objectives

The principal objective of this study was to assess the present sediment quality of Study Zone 1 in the upper St. Clair River by focusing on surficial sediment chemistry (0 to 5 cm depth of core samples), sediment toxicity and benthic macroinvertebrate community structure. The data will serve to help delineate the extent and severity of the contamination of sediment in the St. Clair River in the vicinity of Sarnia, enabling the Contaminated Sediment and Habitat Task Teams to assess remedial options for these contaminated sediments. The study also examined the temporal and spatial changes in the sediment quality of the river in Study Zone 1 since the last major benthic invertebrate assessment in 1990.

To meet these objectives, the BEAK study report focused on the following components:

- identification and accurate enumeration of benthic macroinvertebrates in 117 Ekman grab (0.05 m^2) samples collected by the OMOEE in Study Zone 1 in the upper St. Clair River;
- tabulation and statistical analysis of the benthic macroinvertebrate, sediment chemistry and toxicity data collected by the OMOEE;
- examination of the relationships among the benthic community structure, sediment toxicity data and abiotic factors, such as sediment chemistry parameters;
- assessment of the present sediment quality status of the upper St. Clair River by comparing the 1994 data to that obtained in 1990 and 1985;

- provision of GIS output files based on information layers used in statistical analysis and environmental interpretation which are compatible with the OMOEE's Map Info software; and
- incorporation of quality control/quality assurance procedures in all components of the study to ensure data of known and high quality.

2.0 METHODS

The following sections provide a detailed account of the methods employed for all components of this study. The methods are presented in detail to ensure reproducibility of this study in future years, allowing for reliable monitoring of temporal trends in the environmental quality of Study Zone 1 in the upper St. Clair River. One of the main components of this study was the incorporation of quality control and quality assurance programs to ensure data of known and high quality.

2.1 Field Collections

The main field component was undertaken from 02 to 16 June 1994. Sediment sampling at additional downstream sites occurred on 04 October 1995. Ministry of Environment and Energy personnel from the Environmental Monitoring and Reporting Branch and Southwestern Region were responsible for the field collections.

Figure 2.1 presents the location of the sampling sites in Study Zone 1 in the upper St. Clair River that were sampled in 1994. Surficial sediment samples were collected for chemistry, benthic macroinvertebrate and toxicity testing along 13 transects extending perpendicular from the Canadian shoreline at various distances (3 different stations per transect), for a total of 39 stations.

Exact placement of the 39 stations was not random, with each location dependent in part on the visual characterization of the substrate, with fine-grained material indicative of depositional areas being a key selection criterion. This increased the likelihood of testing areas of higher contamination and increased comparability among sites. The location of the outermost station along each transect was based on the presence of soft substrate and the absence of zebra mussels. Consequently, these outer stations were situated further out into the river than had been sampled in previous surveys. Stations along a transect were labelled as inner (I), middle (M) and outer (O). The geographic coordinates and descriptions of the station locations are presented in Table A1.1, Appendix 1.

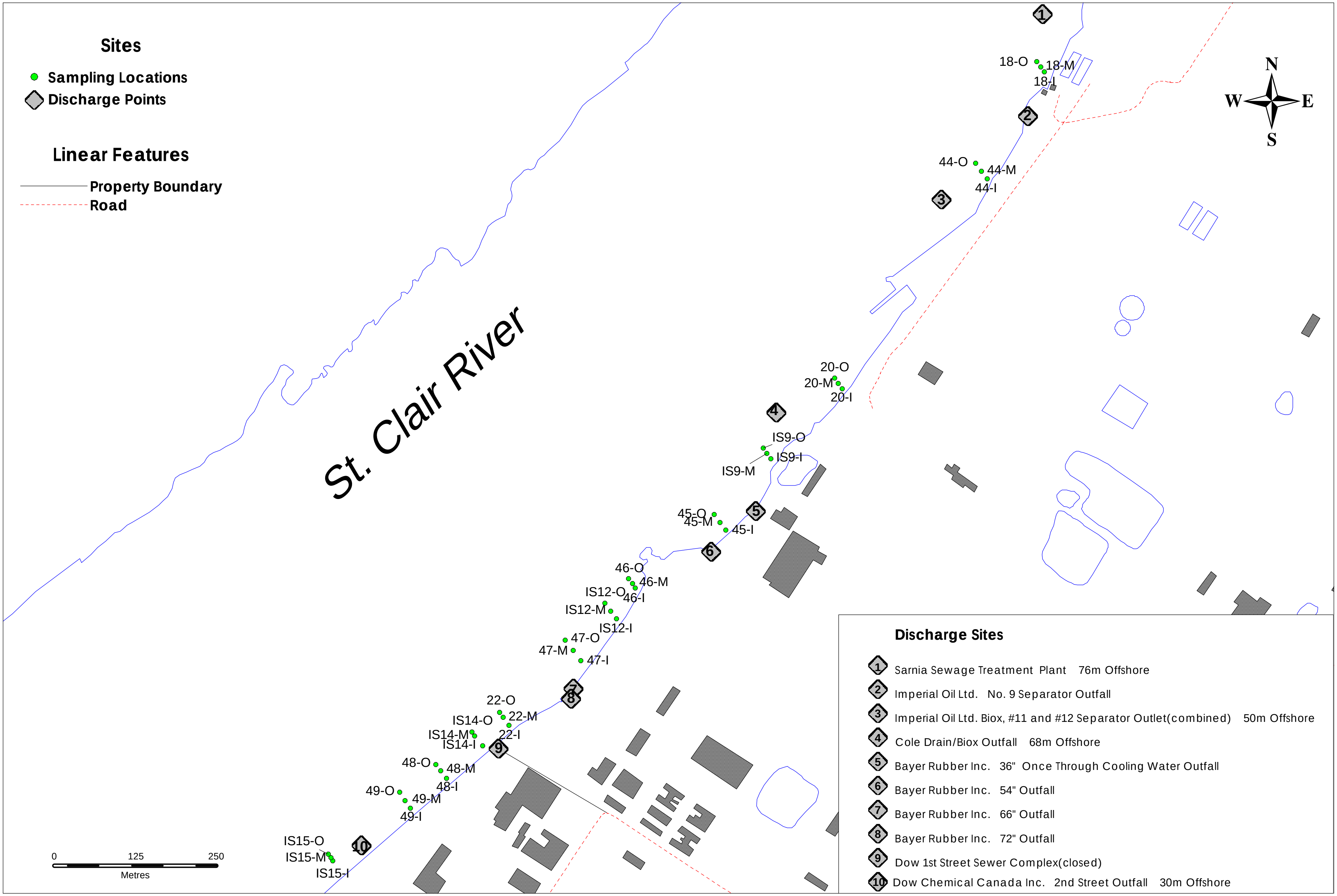


Figure 2.1 Sampling Locations and Discharge Points in the Upper St.Clair River - 1994

To provide additional information on the downstream extent of contamination, in 1995, sediment samples were obtained at 15 stations (3 per transect) located downstream of the 1994 sampling locations (Figure 3.1). The five transects were located downstream of known discharges.

2.1.1 Physical Measurements

Water velocity was measured at approximately 0.15 m above the substrate with a Marsh-McBirney velocity meter. The vessel was anchored and stationary while velocity readings were recorded over a 30 minute period with a minimum of three data points recorded per station.

Water depth, water temperature, conductivity, turbidity, pH and dissolved oxygen were also measured at 0.15 m above the substrate at all sites. Water temperature and dissolved oxygen were recorded with a YSI Model 54 dissolved oxygen meter. Conductivity was recorded with a YSI Model 300 conductivity meter and pH was measured with an Orion pH meter. Depth was determined by sonar. As a quality control measure, all meters were calibrated daily.

2.1.2 Sediment Chemistry

In 1994, samples for sediment chemistry analysis were collected at each of the 39 stations by diver using three 6.7 cm diameter acrylic core tubes, each approximately 0.5 m long. Individual cores were sectioned at pre-determined intervals (0-5cm, 5-15cm, 15-25cm, etc.). Replicate sections from three cores were composited in a hexane-rinsed stainless steel container and homogenized with a clean, solvent-rinsed stainless steel spatula. A known subsample at each core depth increment was weighed to obtain the field (wet) weight. Samples allocated for analysis of metals and conventional pollutants were placed in properly labelled 500 mL plastic PET containers. Samples collected for analysis of organic contaminants were placed in labelled hexane-rinsed amber glass jars (OMOEE, 1989).

At eight sites (IS12-I, IS12-M, IS12-O, IS14-M, 18-I, 20-M, 46-M and 47-I) three replicate composite samples (three cores per sample) were analysed individually, while for the other sites, single composite samples were analysed.

The 1995 sediment samples were obtained by Shipek dredge (hexane rinsed) and the surface layer processed as noted above for sediment core sections.

All samples were submitted to the Ontario Ministry of Environment and Energy Laboratory Services Branch, Etobicoke, Ontario for analysis of the following parameters, with the exception of particle size which was measured by the Ontario Ministry of Transportation, London, Ontario.

The 1994 sediment samples were analysed for:

- metals (As, Al, Ca, Cd, Cr, Co, Cu, Fe, Pb, Hg, Mg, Mn, Ni, Zn),
- chloride, cyanide,
- moisture, wet density, loss on ignition (LOI), total organic carbon (TOC),
- total Kjeldahl nitrogen (TKN), total phosphorus (TP), nitrates, ammonium,
- particle size,
- solvent extractables,
- polyaromatic hydrocarbons (PAHs)
- polychlorinated biphenyls (PCBs),
- volatile organohalides
- total petroleum hydrocarbons,
- chlorinated industrial organics,
- organochlorine pesticides, and
- polychlorinated dibenzo-p-dioxins and dibenzofurans

The 1995 sediment samples were analyzed for all of the above, except for volatile organohalides, total petroleum hydrocarbons and polychlorinated dibenzo-p-dioxins and dibenzofurans. A list of the individual parameters measured is provided in Appendix 1, Table A1.2.

Field Quality Control Measures

The following quality control measures were incorporated into the sediment chemistry monitoring program:

- at eight of the sampling stations (mentioned previously) the surface 5 cm from three replicate core samples were analysed individually to determine spatial and sampling method variability;

- extra sediment from each depth increment at each station were put in amber solvent-rinsed glass jars, frozen (-20°C) and archived until completion of the laboratory analysis.

The impact of different holding times on some sediment chemistry results would principally affect the organic contaminant results. However, with the posssible exception of volatile organohalides and petroleum hydrocarbons, the samples were extracted and analyzed within an acceptable time period. The results for the latter two groups should, therefore, be considered as minimum (i.e., conservative) concentrations (P. Kauss, OMOEE, pers. comm., 1997).

2.1.3 Benthic Macroinvertebrates

At each of the 39 stations sampled for sediment and toxicity, three replicate Ekman stainless steel grab samples (0.052 m^2/grab) were collected by diver for macroinvertebrate analysis. Each grab sample was gently sieved with a 600 μm (No. 30 mesh) Nitex® mesh bag. The remaining sediments and debris were preserved to a minimum level of 10% formalin (4% formaldehyde) buffered to pH 7. Samples with high organic content received additional preservative.

The Ekman sampler and sieve bag were carefully washed between grabs and stations to prevent the transfer of macroinvertebrates between samples. All samples were preserved in 4 L plastic, wide-mouth jars and labelled both inside and on the jar with the station and replicate number.

The presence of algae at any of the sampling sites was noted. In addition, water depth, Ekman fullness, presence of odour and sediment characteristics were recorded for each grab sample (Appendix 1, Table A1.3).

2.1.4 Sediment Bioassays

At all stations, additional sediments were collected for toxicological assessment. Lethal and sublethal toxicity tests were conducted using midge larvae (*Chironomus tentans),* burrowing mayfly nymphs (*Hexagenia limbata*) and juvenile fathead minnows (*Pimephales promelas*). At each station, approximately six to ten litres of surficial sediment (top 5 cm) was composited from several Ekman grabs. The composited sediment was placed into food grade polyethylene bags, tied so that most of the airspace was removed and placed into 20 L plastic pails for transport to the MOEE Toxicity Laboratory in Etobicoke, where they were stored at 4°C until tested. Samples were refrigerated for approximately one month prior to the *Hexagenia*, *Chironomus* and half of the fathead minnow tests and for three months for the remainder of the fathead minnow bioassays. This delay in conducting the remainder of the fathead minnows does not appear to have had an effect on the results since there was no obvious discontinuity between the two data sets (D. Bedard, OMOEE, pers. comm., 1997). Samples were collected in June at all stations and as a quality control check, samples were collected again in December 1994 at three stations along two of the transects.

2.1.5 Water Chemistry

At thirteen stations, located at the mid-point along each transect, water samples were collected from 0.15 m above the sediments. Water samples were collected using a March Model 5C MD submersible pump equipped with Teflon® tubing. The Teflon® hoses were hexane-rinsed each day. The system was flushed at each station for approximately three minutes prior to sample collection. Water samples were collected before the collection of sediments and macroinvertebrate samples in order to prevent resuspended sediments from contaminating the samples.

Three replicate samples were collected at each station, transferred to the appropriate type of container and preserved, where necessary (MOE, 1989). These water samples were submitted to the MOEE Laboratory, Etobicoke, Ontario for analysis of the following parameters:

- metals (As, Ca, Al, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Ni, Zn, Hg),
- chloride, cyanide,
- TKN, TP, nitrates, ammonium, alkalinity,
- total phenol, total suspended solids (TSS), and conductivity.

In addition, one large volume sample (18 litres) was collected at each of the 13 stations and submitted to Novamann, under contract to the OMOEE, for the analysis of:

- PAHs, PCBs, organochlorine pesticides, and
- chlorinated aliphatic and aromatic organic compounds.

The results of water chemistry analysis have not been discussed in detail in this report. Water quality results are available from the Ontario Ministry of Environment and Energy (EMRB, SWS).

Field Quality Control Measures

The following quality control measures were incorporated into the water sampling program:

- At five randomly selected stations (18-M, 9-O, IS14-M, 49-I and IS15-I) triplicate split samples were submitted for analysis;
- two sets of sampler blanks, each composed of three replicates, were obtained on separate days by pouring distilled water through the collection system; and
- one distilled water travel blank was submitted for analysis.

2.2 Analytical Methods

The OMOEE Laboratory Services Branch, Etobicoke, Ontario was responsible for the analysis of sediments and most water samples. Laboratory analytical and quality control methods followed documented procedures (OMOE 1989b, OMOEE 1990, OMOEE 1994a-d, OMOEE 1995a-d, OMOEE 1996, OMOEE 1997a-c). The Ontario Ministry of Transportation conducted the particle size analysis employing the Wentworth sieve and hydrometer methods.

2.3 Toxicological Methods

Sediment toxicity tests were conducted by the MOEE, Toxicity Laboratory according to the MOEE sediment biological testing protocols using fathead minnow fry and invertebrates (Bedard *et al.*, 1992). Due to the large number of stations, toxicity tests on the June samples were conducted as single tests on all three test organisms, with no replication. For QA/QC purposes, triplicate tests using *Hexagenia limbata* and *Chironomus tentans* were conducted on samples collected in December 1994 from each of three stations located along two of the transects (Transects IS9 and IS14).

2.4 Macroinvertebrate Analysis

The following subsections provide a detailed account of the benthic macroinvertebrate processing techniques employed for this study and the quality control measures taken to ensure data of known quality and to allow for reproducibility of the study in future years.

2.4.1 Sample Processing

When the samples arrived at BEAK, while being logged, they were inspected to ensure that all samples were adequately preserved in 10% buffered formalin and correctly labelled.

The samples were stained with a combination of two biological stains. This stain, developed in-house, has proven itself to be extremely effective in increasing the sorting recovery and efficiency of removing benthic macroinvertebrates from the associated debris.

Prior to detailed sorting, the samples were washed free of formalin in a 600 μm sieve (No. 30 mesh) under ventilated conditions. The benthic fauna and associated debris were then elutriated to remove any sand and gravel in the samples. Our elutriation process has been demonstrated, in most cases, to remove greater than 98% of the benthic fauna from the sand and gravel fraction (BEAK, 1992). The remaining sand and gravel fraction was still closely inspected for any of the heavier organisms such as Pelecypoda, Gastropoda, or Trichoptera with stone cases which may not have all been washed from the sample. If there was a substantial number (greater than 1% of the total count) of these invertebrates in the sample, which often occurs when the sample contains high densities of *Dreissena polymorpha* (zebra mussels), then the sand and gravel fraction was also sorted.

Senior taxonomists (benthic ecologists) with six to thirteen years of experience were assigned the task of sorting and detailed identification of invertebrates. The qualifications and experience of the taxonomic staff are presented in Appendix 2. All benthic samples were processed with the aid of stereomicroscopes. A minimum magnification of 10X was applied for the sorting of macrobenthos. The sorted debris was subsequently represerved in 10% buffered formalin and archived.

The benthos were sorted from the debris, enumerated and transferred to 80% ethanol in small fermentation vials. The fermentation vials were then placed in larger 1 ounce jars with 80% ethanol and 3% glycerol. Each replicate sample was preserved separately.

2.4.2 Detailed Identifications

The benthic invertebrates were identified to the lowest practical level, which for most groups was genus or species. Table 2.1 presents the level to which each group was identified and the major taxonomic key on which the identifications were based. Section 7.1 presents a comprehensive list of alternative taxonomic references that were sometimes used to confirm identifications or to identify individuals which were not adequately described in the principal references provided in Table 2.1. In a few instances where individuals were immature or only first instars, identification to the genus or species level was not possible. Consequently, these animals were enumerated as immature individuals under the next higher level of identification. All of the benthic fauna have been returned to the Southwestern Region MOEE and will be archived at least until the next macroinvertebrate assessment of the upper St. Clair River.

2.4.3 Quality Assurance and Quality Control Measures

There has been growing concern regarding the quality of benthic invertebrate assessment data. To ensure a high level of technical quality, for this project, the following QA/QC measures were incorporated into the study:

- A voucher collection of all taxa identified was compiled and preserved in such a manner that it will remain intact for many years. Chironomids and oligochaetes remain on the initial slides and representatives of each species or genus are circled with a permanent marker and labelled. All other taxa are preserved in 80% ethanol in separately labelled vials. Each vial contains a 3% solution of glycerol which will prevent spoilage of the fauna if the vial accidentally dries out;
- Samples were immediately checked for adequate preservation and proper
- labelling before being logged and kept secure;

Table 2.1

- The samples were stained to facilitate accurate sorting;
- The most updated and widely used taxonomic keys were used for all taxonomy and are listed in Table 2.1 so that any advances in taxonomy can be accounted for in future studies;
- Sorting recovery checks have been performed and documented for all taxonomic staff involved in this study (Appendix 2);
- The laboratory maintains a well-labelled master reference collection of over 1,000 identified and catalogued species which was accessed to confirm species identifications for this study;
- Both sorted and any unsorted sample fractions were represerved in 10% buffered formalin and were maintained for six months after the submission of this report;
- All tabulated benthic data were cross-checked against bench sheets to ensure there were no data entry errors or incorrect spelling of scientific nomenclature;
- Laboratory bench sheets will be archived for ten years.
- The qualifications of the taxonomic staff have been documented in this report;
- Details of benthic samples processed applying subsampling techniques are provided in Appendix 1, Table A1.4

The Beak Bioassessment Services Standard Operating Procedures (BEAK, 1992) were applied to this study and can be viewed on request.

2.5 Data Evaluation

2.5.1 Summary Statistics

A standard sample-by-taxa spreadsheet format in Microsoft Excel was used for electronic storage of benthic survey data. This format was conducive to subsequent univariate and multivariate statistical analysis. SPSS for Windows Release 5.0, Advanced Statistics (Norusis, 1992) and NTSYS-PC V1.8 (Rohlf, 1994) packages were employed for multivariate analysis, while simple descriptive statistics were completed in Excel. A range of diversity indices were calculated using in-house Fortran programs and Excel functions.

The following biotic indices were calculated for each replicate sample and for the mean station data:

S	=	number of taxa present
N	=	total number of organisms
H'	=	Shannon-Wiener diversity index

J' = Evenness index

The H' index (Shannon and Weaver, 1949) was estimated as follows:

$$H' = - \Sigma (n_i/N) \log_2 (n_i/N)$$

where: n_i = number of individuals of taxon i, and
N = total number of individuals.

In general, relatively high diversity reflects moderate population numbers of a large number of taxa in the community, and may indicate good water quality, while low values reflect high population numbers of a few taxa, and may indicate impaired communities (Wihlm and Dorris, 1968). It must be cautioned, however, that a low diversity may also result from natural habitat deficiencies or high densities of a single taxon (e.g. zebra mussels). Likewise, it is possible to get a high Shannon-Wiener diversity (> 3), based on the presence of numerous pollution-tolerant taxa, which does not necessarily indicate good water quality.

It is important to note that this estimate is a biased estimate of community diversity when the sample size is small and the number of taxa in the sample is less than the total number in the sampled community (Ludwig and Reynolds, 1988). However, it still can be used as a long-term trend index, as long as sampling and processing methods remain constant.

Other diversity indices that were calculated are Simpson's D, Hurlbert's PIE, Keefe's TU and McIntosh's M. Simpson's D is calculated to decrease as diversity increases and is the complement to Hurlbert's PIE (Washington, 1984). These diversity indices were calculated to provide a comprehensive database with which to compare future surveys and are only briefly discussed in this report. A comparison of these indices is available in Washington (1984). These indices were calculated according to the following formulae:

Simpson's D

$$d = \frac{\sum_{i=1}^{s} N_i (N_i - 1)}{N(N - 1)}$$

McIntosh’s M

$$D' = \frac{N - (\sum_{i=1}^{s} N_i^2)^{0.5}}{N - (N)^{0.5}}$$

Hurlbert's PIE

$$PIE = \left(\frac{N}{N-1}\right)\left(1 - \sum_{i=1}^{s} p_i^2\right)$$

Keefe’s TU

$$TU = 1 - \left(\frac{N}{N-1}\right)\left(\sum_{i=1}^{s}\right)$$

where: s = number of taxa in sample
N = number individuals in a sample
p_i = n_i/n = fraction of sample of individuals belonging to taxon i

Evenness, or equitability, is a measure of the distribution of individuals among sampled taxa. A more equitable distribution of individuals over the taxa sampled indicates a more stable community which is not dominated by one particular taxon. The measure of evenness employed in this study was (Pielou, 1966):

$$J' = H'/\log_2 S$$

where: H' = Shannon-Wiener diversity value, and
S = number of different taxa in the sample.

It is simply the Shannon-Wiener value (H)' expressed as a fraction of the maximum value H' could attain in the sample if all taxa had equal density. Evenness, like Shannon-Wiener diversity, is sensitive to sampling and processing effects (Ludwig and Reynolds, 1988).

Other indices included in the analysis of the upper St. Clair River benthic macroinvertebrate communities included:

- Number of EPT Taxa (assessed at genus level),
- Ratio of EPT Abundance to Chironomidae,
- Functional Feeding Groups, and
- Hilsenhoff Biotic Index

The EPT index is the number of taxa belonging to the relatively pollution-sensitive insect groups (**E**phemeroptera-**P**lecoptera-**T**richoptera), while the EPT/C index is the abundance of these "mostly pollution-sensitive" EPT organisms relative to the abundance of generally more pollution-tolerant **c**hironomids.

Functional feeding-group designations for individual taxa were obtained from Dr. R.W. Bode (Stream Biomonitoring Unit, New York State Department of Environmental Conservation, pers. comm., 1996).

The Hilsenhoff Biotic Index was calculated as:

$$HBI = TV * n_i / \Sigma n_i$$

where: TV = tolerance value of the i^{th} taxa
n_i = abundance of i^{th} taxa

Taxon tolerance values, generally related to organic pollution, have also been found to be applicable to other contaminants, including metals (i.e., zinc; Hoiland and Rabe, 1992). While there may some taxon specific exceptions, these tolerance values may apply to a broad range of contaminants, and overall, the calculated index value should be reflective of the habitat quality. Values of this index run from 0 to 10, with value ranges indicative of the following:

Biotic Index	Water Quality
0.00 to 3.50	Excellent
3.51 to 4.50	Very Good
4.51 to 5.50	Good
5.51 to 6.50	Fair
6.51 to 7.50	Fairly Poor
7.51 to 8.50	Poor
8.51 to 10.00	Very Poor

Specific tolerance values were obtained from Dr. R. W. Bode (Stream Biomonitoring Unit, New York State Department of Environmental Conservation, pers. comm., 1996).

Taxon counts and biotic indices were summarised for each station by computing the following statistics (across replicates):

Xa	= arithmetic mean,
SDa	= standard deviation,
Xg	= geometric mean = antilog (mean of $\log_{10}$),
SDg	= standard deviation of logs,
CVa	= coefficient of variation = SDa/Xa,
CVg	= SDg/mean of logs,
minimum	= the lowest taxa count
maximum	= the highest taxa count
range	= maximum - minimum.
occurrence	= number of replicates with the taxon

These summary statistics were tabulated in a separate summary spreadsheet and are only available in electronic format from the OMOEE (EMRB or SWR).

Four similarity indices were calculated to aid in the characterization of similar benthic macroinvertebrate community structures among stations and were used in the cluster analysis. The first of these, the Coefficient of Community (CC), was calculated from the presence-absence database (Whittaker and Fairbanks, 1958). The CC measures the percentage of taxa shared by two stations:

$$CC = \frac{c}{a+b-c} \times 100$$

where:

a	=	number of taxa in the first sample,
b	=	number of taxa in the second sample, and
c	=	number of taxa common to both.

This CC is also referred to as the Jaccard Coefficient that has been traditionally used in cluster analysis.

The second index, the Percentage Similarity of Community (PSc), uses quantitative data:

$$PSc = 1 - 0.5\, \Sigma_i\, (p_{ij} - p_{ik})$$

where: p_{ij} = average proportional abundance of taxon (i) in sample (j), and
p_{ik} = average proportional abundance of taxon (i) in sample (k).

The third index was Bray-Curtis. The Bray-Curtis coefficient (Bray and Curtis, 1957) is defined by:

$$d_{ji} = \frac{\sum_k X_{kj} - X_{kj}}{\sum_{kj} (X_{ki} = X_{kj})}$$

where: X_{ki} = average abundance of taxon k at station i
X_{kj} = average abundance of taxon k at station j

The Bray-Curtis similarity coefficient is robust to non-linearities in taxon response along environmental gradients (e.g. Gauch, 1973; Gauch and Whittaker, 1972; Beals, 1973 and 1984; Faith *et al.*, 1987; van Groenwoud, 1976). Bloom (1981) found that the coefficient responds linearly rather than exponentially to changes in the number of taxa and total organism abundance, which tends to minimize the 'size' effect (Boecklen and Price, 1989; Jackson *et al.*, 1989).

The fourth similarity index was the Morisita-Horn which has been found to be even less responsive to differences in abundance and numbers of taxa (size) effects than the Bray-Curtis index.

The Morisita-Horn coefficient (Horn, 1966) is defined by:

$$c_{ij} = \frac{2 \sum_k X_{ki} X_{kj}}{\left(\sum_k \frac{X_{ki}^2}{N_i^2} + \frac{\sum_k^2 X_{kj}}{N_j^2} \right) N_i N_j}$$

where: X_{ki} = average abundance of taxon k at station i
X_{kj} = average abundance of taxon k at station j
N_i = total abundance at station i
N_j = total abundance at station j

These similarity coefficients were summarised in a station-by-station matrix format and stored in a database file for use in cluster analysis.

2.5.2 Statistical Analysis

Raw and $\log_{10}(x+1)$-transformed mean abundance data were compared among stations in univariate ANOVA with the Student-Newman-Keuls (SNK) multiple range test. Logarithmic transformations were always to base 10, unless indicated otherwise. A non-parametric comparison was also conducted using the Kruskal-Wallis ANOVA approach.

2.5.3 Cluster Analysis

Cluster analysis techniques were used to group stations into clusters based on the similarity of the benthic invertebrate communities among stations. In cases where pollution is an important factor in structuring the benthic macroinvertebrate community, these communities (clusters) tend to be found near the pollution sources. The benthic macroinvertebrate data were $\log_{10}(x+1)$-transformed prior to clustering.

Cluster analysis was also employed to group similar stations based on sediment chemistry data to identify spatial patterns for comparison to benthic macroinvertebrate community patterns. The sediment chemistry data were $\log_{10}$-transformed, standardized and rescaled to a minimum of zero prior to cluster analysis.

Several cluster analysis techniques were applied, with each of the similarity indices, to identify robust spatial patterns which could be supported by several techniques. The techniques used included:

- Ward's method (sum of squares agglomeration),
- group average link agglomeration (UPGMA), and
- non-hierarchical method (K-means).

The Ward's method merges clusters to minimize the sum of squared distances between pairs of stations in opposite clusters within a taxa coordinate system.

The average link method (also called UPGMA) merges clusters to minimize the average distance between pairs of stations in opposite clusters within a taxa coordinate system.

The K-means cluster analysis (non-hierarchical method) is based on nearest centroid sorting (Anderberg, 1973). That is, a case is assigned to the cluster with the smallest distance between the case and the centre of the cluster. The cluster centres were iteratively estimated from the data. Unlike hierarchical cluster analysis, the number of clusters in the solution are pre-selected.

The cluster solution that produced the greatest structure and was best supported by correspondence and principal component analyses, sediment quality and other clustering techniques was chosen to represent the upper St. Clair River benthic communities. Structure is indicated by well-defined station clusters that are internally homogeneous and dissimilar from each other. Solutions of this type tend to be the most interpretable.

Cluster results were confirmed with correspondence analysis using a chi-square distance matrix with log (x+1) transformed data and principal components analysis of the correlation matrix for $\log_{10}$ (x+1) transformed abundance data (Pearson's and Spearman's rank correlation).

2.5.4 Community Ordination

While cluster analysis serves to identify natural groupings of stations based on their biological similarities (i.e., sample classification), it provides very little information on the nature of those similarities (i.e., which taxa are characteristic of each group). It is this information that defines the community represented by a cluster of stations.

Ordination methods aid in providing an ecological interpretation for the observed pattern. Principal components analysis (PCA) was used to plot stations in three dimensional space, where each axis is defined as a linear algebraic combination of the $\log_{10}$ abundance data for each taxon. The axes were sequentially derived to explain as much of the remaining variability in macroinvertebrate composition as possible. Stations were plotted on these axes and biologically similar station groups were arbitrarily assigned to clusters. These clusters were compared to those arising from cluster analysis.

In addition, correspondence analysis (CA) was employed to support the results of other clustering techniques. This approach is similar to PCA except for a double (row and column) normalisation of the chi-square distances derived from $\log_{10}$ (x+1) abundance data. Proximities

are then estimated for both row (taxa) and column (station) variables (Greenacre, 1984). This allows plotting of both stations and taxa in the same system of three dimensions.
The starting point of PCA is a taxon-by-taxon correlation matrix. Both parametric (Pearson's r) and non-parametric (Spearman's r_s) correlation matrices were used. The results were subsequently evaluated with MANOVA and discriminant analysis. The number of axes from the PCA/CA that were included in subsequent analysis were those that were shown in a broken-stick analysis to account for more variance than would be explained by random chance.

2.5.5 Community Comparisons

Biological communities revealed by cluster analysis of stations were characterised by various community indices that summarise different aspects of the community structure, as well as by individual macroinvertebrate counts at member stations. Clusters were compared using the following metrics to determine whether they were statistically distinct. Univariate analysis of variance (ANOVA) was used for specific comparisons based on a single measure.

The metrics that were used to compare clusters included:

- total number of taxa
- total organism density
- diversity indices
- species richness
- species evenness
- % tubificids
- % chironomids
- EPT Index
- Hilsenhoff Biotic Index

All indices were appropriately transformed to meet the parametric assumptions (normality, homogeneity of variance) of ANOVA. Log transformation was applied prior to statistical analysis of macroinvertebrate abundance data and total density data (Elliott, 1971). Transformation improved the distributional and variance properties of the data, reducing the dependence of variance and mean, which permitted the use of parametric statistical techniques.

2.5.6 Relationships of Benthic Communities to Sediment Quality Variables

Multiple-group discriminant analysis (Cooley and Lohnes, 1971) was employed to model the groupings of the 1994 benthic communities in terms of sediment chemistry and physical factors.

This technique requires a full set of physico-chemical variables for all stations included in the analysis. The measured environmental variables were reduced to a smaller set of orthogonal discriminant functions potentially representing environmental gradients (axes). Individual stations and cluster centroids were plotted against these axes as a graphic presentation of community structure.

The number of discriminant functions used for interpretation of community structure depended on each function's relative contribution to overall cluster separation in discriminant space (i.e., the ability of an axis to separate groups based on a MANOVA). Only discriminant functions which made a statistically significant contribution were used for interpretation. The chi-square test based on Wilk's Lambda was used as a test for significance of cluster (community) separation on environmental discriminant functions.

Interpretation of each discriminant axis was based on the sign and magnitude of the standardized coefficients for the environmental variables. Variables with large coefficients on a particular discriminant function were considered important in interpretation of the environmental gradient represented by that function.

Discriminant analysis assumes multivariate normality and homogeneity of variance and covariance matrices. The probability that one of these assumptions will be violated increases with the number of variables, and violations are generally the rule rather than the exception. Heterogeneity of variance and covariance matrices is probably the most serious type of violation, although multivariate methods are generally quite robust. Heterogeneity must be large and obvious before significance tests assuming homogeneity break down (Marriott, 1974). Box's test for homogeneity of variance/covariance was performed with the discriminant analysis as a check on this assumption.

An alternative approach involved the use of the CA coordinate file created for the benthic macroinvertebrate data and similar files created from the PCA analysis of the sediment data. Separate PCA coordinate files were created for the sediment data as a whole, as well as for individual data files which included physical data from each station (i.e., particle size, water depth, water velocity), nutrient data, metals, organochlorine contaminants, and PAHs. Each of the sediment quality files and the benthic data file were converted to similarity matrices

(Euclidean distance). The similarity between the benthic similarity matrix and each of the sediment quality matrices was then measured using Mantel's test.

2.5.7 Temporal Changes in the Sediment Quality Status of the Upper St. Clair River

Considerable differences exist between the sampling protocols used in the 1985, 1990 and 1994 surveys. In 1985 and 1990, a Shipek sampler was used to collect sediment samples for chemical analysis, compared to a diver using a core tube in 1994. In 1985, the surficial 0 to 3 cm were collected from one station along the transect, with the station location ranging from the closest to shore to the furthest offshore. In 1990, surficial samples (0 to 3 cm) samples were collected as composites from Transects 18 and IS9 and as three individual samples from Transects 20, IS12, 22, IS14 and IS15. In 1994, three individual (0 to 5 cm) samples, each consisting of a composite of 3 three replicate core samples, were collected from each transect. In addition, in 1985 and 1990, station locations offshore were determined using radar, whereas in 1994 distances offshore were determined by diver using measured rope anchored to the bottom.

Benthic macroinvertebrate samples were collected with a Ponar at each of the three stations along a transect (single grab at each station) and analyzed as a composite in 1985. In 1990, the samples were processed individually and the results composited for interpretation. In 1994, three replicate samples were collected from each station along the transect by diver assisted Ekman and analyzed separately. In addition, there was considerable variablity in the distances offshore where stations were situated along each transect between the three surveys. In 1985, stations tended to be much closer to shore (in particular IS9, IS12, IS14 and IS15) than the later surveys. As already noted, the outer stations along each transect were located much further offshore in 1994. Earlier samples were also collected without the aid of divers to identify areas of sediment accumulation. Macroinvertebrate processing techniques also differed between surveys, with samples collected in 1985 sorted live at a field laboratory, while those in 1990 and 1994 were preserved prior to sorting under a stereomicroscope.

The 1994 benthic community data were compared to those of previous surveys conducted in 1985 and 1990. However, due to differences in sample processing, which would have a profound effect on diversity and density, direct comparisons of biotic indices, such as number of taxa and total density at each station were not feasible. Some general comparisons (e.g., %

tubificids and % chironomids, presence/absence of indicator taxa, water quality zones) were made among the three surveys, although it can be argued that even these comparisons are spurious given the changes in diversity and density that are attributable to greater accuracy in sorting and identification of invertebrates for this study.

Sediment chemistry parameters for the same transects from the 1985, 1990 and 1994 surveys were $\log_{10}$-transformed and tested for significant differences using a two-tailed paired sample t-test. The data were tested to ensure that assumptions of homogeneity of variance and normal distribution were met. Appropriate alternate transformations were applied where necessary.

In 1985, only one station along each transect was sampled for sediment quality and this location was matched as closely as possible with the corresponding station sampled in 1994.

Given the differences in sampling design between the 1990 and 1994 surveys, the arithmetic mean of the inner and middle sample stations along each transect from the 1994 survey were compared to the composite results from the 1990 study. These two locations were more closely related to the stations sampled in 1990 and the arithmetic mean mimics the compositing of the three samples collected along each transect in the 1990 survey.

2.6 GIS Data Presentation

At the request of the OMOEE, selected sediment chemistry parameters, toxicity and Sediment Quality Index (see section 5.0) results were presented using GIS linear interpolation techniques. For the sediment chemistry and toxicity results, the Triangular Irregular Network (TIN) approach, whereby points are connected based on a nearest neighbour relationship (Delaunay criterion), was applied. One of the advantages of this approach is that anistrophy (i.e., gives more weight to the direction of streamflow than to the direction of the transects) is preserved.

The GIS presentation for the Sediment Quality Index values was derived as the best method from a variety of approaches in order to provide an accurate estimate of the zones of contaminated sediment in the St. Clair River (Tomczak, 1997). Priority areas arbitrarily defined in the past (Pope, 1993, St. Clair River RAP Team, 1991) were not precise enough for modelling and estimation of the volume of contaminated sediments (M. Tomczak, 1997). In this evaluation, the interpolation methods were evaluated via cross-validation. The anisotropic inverse distance to a power method (IWD) with an exponent of 2 and anisotrophy ratio of 5.5 in the NE-SW direction was selected as the most representative (Tomczak, 1997). This approach takes into account the effects of the direction of river flow and subsequent pattern of sediment transport and deposition. The result of this analysis was characterized by a low root-mean-squared error (RMSE) and preserved the local patterns in sediment priority class.

3.0 SEDIMENT QUALITY

The results of the sediment chemistry analyses were compared to the most recent Ontario aquatic sediment quality guidelines (Persaud *et al.*, 1993). The guideline contaminant concentrations are based on the known responses of aquatic organisms to three levels of the contaminant. The levels are as follows:

- No Effect Level (**NEL**) - *this is a level at which no toxic effects have been observed on aquatic organisms. This is the level at which no biomagnification through the foodchain is expected*. Sediments with contaminants below these levels can be considered as clean (Persaud *et al.*, 1993).

- Lowest Effect Level (**LEL**) - *this is a level of contamination that can be tolerated by the majority of benthic organisms*. Sediments with contaminants above these levels may support benthic communities that are indicative of a slightly to moderately impacted environment. Sediments with contaminants above these levels can be considered marginally to significantly polluted (Persaud *et al*., 1993) or moderately contaminated.

- Severe Effect Level (**SEL**) - *this is a contaminant level at which the pronounced disturbance of the sediment-dwelling community can be expected.* This is the sediment concentration of a compound that would be detrimental to the majority of benthic species. Sediments with contaminants above this level are considered heavily or grossly polluted (Persaud *et al.*, 1993).

3.1 Current Levels of Sediment Contamination

The contaminant concentrations were calculated as the mean of three replicate composite samples in the cases where stations were selected for QA/QC analysis or are the values for one composite sample of three grabs. For the QA/QC sites, where three replicate samples were collected, if contaminants were below the detection limit (i.e., “< W” or “<”, a value of 0 was used for calculating the geometric mean concentration (P. Kauss, OMOEE, pers. comm., 1996). Only the contaminants which were above the detection limit have been presented in this section.

A complete list of sediment quality results is available from the OMOEE, EMRB Surface Water Section, Toronto, Ontario.

For ease of comparison of the spatial distribution of contaminants, Study Zone 1 was divided into three distinct areas, referred to as the Upper Area, Middle Area and Lower Area. Elevated levels of contaminants in any of these areas are not necessarily originating from the companies mentioned since there are numerous other discharges in the upper St. Clair River watershed, all of which may be potential contributors of specific contaminants.

Physical and Nutrient Parameters

Sediments in the upper St. Clair River were characterised by % loss on ignition (%LOI), total organic carbon (TOC), total phosphorus (TP) and total Kjeldahl nitrogen (TKN), calcium, chloride, potassium, sodium, ammonium and particle size (% sand (2 mm to 62μm), %silt (62 to 3.7μm), %clay (3.7 to 0.1μm)) (Table 3.1).

TOC values were less than the SEL (100 g/kg, 10%) at all stations, with values ranging from 2 to 97 g/kg. However, 67% of the stations had TOC levels above the LEL (10 g/kg, 1%). Values tended to be lowest in the Lower Area and highest opposite the Middle Area of Study Zone 1.

Total phosphorus levels are not a problem in the study area. Levels were below the LEL level (0.6 g/kg) with the exception of one site (Station 45-O) where concentrations slightly exceeded the LEL.

Surficial sediments within the study area appeared to be characteristic of a high energy riverine system, with about 90% of the stations containing at least 50% sand-sized particles or larger. This was particularly evident along the Middle Area. Loose sediments were restricted to the nearshore area throughout the St. Clair River, with the dominant substrate beyond the outer stations consisting of glacial hard-packed clay and rock.

TKN values ranged from 0.28 to 2.02 g/kg. Twenty-five of the 39 stations (64%) exceeded the LEL value (0.55 g/kg); however, no stations had levels exceeding the SEL. Elevated

TABLE 3.1: SEDIMENT QUALITY DATA FOR SAMPLES FROM STATIONS IN THE UPPER ST. CLAIR RIVER - JUNE 1994

							Upper Area													Middle Area																			Lower Area										
		Station	18-I	18-M5	18-O	44-I	44-M	44-O	20-I	20-M5	20-O	IS9-I	IS9-M	IS9-O	45-I	45-M	45-O	46-I	46-M5	46-O	IS12-I5	S12-M5	IS12-O5	47-I5	47-M	47-O	22-I	22-M	22-O	IS14-I	IS14-M5	IS14-O	48-I	48-M	48-O	49-I	49-M	49-O	IS15-I	IS15-M	IS15-O	PSQG LEL[1]	PSQG SEL[1]	OWDG[2]	EC9
Parameters[3]	MDL4	Units																																											
Distance from Canadian Shore		m	15	25	35	15	30	45	10	20	30	10	20	30	5	20	35	7	15	25	10	25	40	15	35	55	5	20	30	10	30	37	10	25	37	10	25	40	22	28	35	-	-	-	-
Water Velocity		m/sec	0.18	0.09	0.24	0.25	0.38	0.49	0.13	0.05	0.07	0.05	0.22	0.37	0.03	0.06	0.23	0.13	0.07	0.34	0.07	0.025	0.13	0.04	0.12	0.25	0.05	0.14	0.16	0.2	0.42	0.7	0.07	0.36	0.7	0.36	0.6	0.68	0.58	0.6	0.6	-	-	-	-
Water Depth		m	1.6	3.0	5.8	1.3	2.1	5.2	1.3	1.6	3.0	2.4	3.9	5.2	0.5	1.0	5.2	2.6	3.3	6.7	3.0	5.5	8.5	1.8	3.0	6.1	1.5	3.9	7.0	1.6	6.1	6.7	2.7	5.5	6.7	2.0	5.8	7.0	5.2	5.8	6.1	-	-	-	-
Wet Density		g/cm^3	1.79	1.74	1.63	1.73	1.65	1.82	1.79	1.88	1.73	1.77	1.71	1.68	1.87	1.48	1.40	1.61	1.67	1.71	1.74	1.45	1.86	1.83	1.48	1.77	1.88	1.30	1.67	2.01	1.78	1.83	1.75	1.51	1.84	1.93	1.93	1.98	1.93	2.03	1.90	-	-	-	-
LOI	1	g/kg	14.0	17.7	16.0	13.0	17.0	16.0	14.0	22.3	24.0	19.0	18.0	24.0	9.0	56.0	64.0	62.0	55.7	68.0	39.9	37.3	15.0	15.7	26.0	13.0	7.9	53.0	26.0	4.3	13.3	19.0	65.0	34.0	18.0	8.4	15.0	13.0	11.0	9.7	30.0	-	-	-	-
TOC	0.2	g/kg	**10.8**	**12.0**	9.9	8.8	**10.4**	**13.3**	2.4	**13.6**	**15.1**	**17.5**	**12.4**	**10.3**	9.0	**81.1**	**97.3**	**46.9**	**42.9**	**48.3**	**33.6**	**30.4**	**12.8**	**19.1**	**25.4**	**18.8**	3.8	**28.4**	**20.6**	3.7	9.6	**15.8**	8.3	**25.1**	**13.6**	4.7	9.4	8.5	4.3	8.1	**23.9**	10	100	-	-
Calcium	-	mg/kg	52000	50658	42000	49000	51000	45000	36000	56831	60000	37000	52000	49000	32000	23000	50000	47000	45993	47000	62932	55976	39613	49324	57000	44000	43000	58000	53000	55000	60983	38000	58000	56000	40000	63000	75000	42000	53000	72000	48000	-	-	-	-
Chloride	-	mg/kg	38.0	31.3	4.5	45.0	6.9	5.4	17.0	4.7	4.6	21.0	41.0	22.0	27.0	15.0	8.2	36.0	22.1	10.0	33.3	110.4	43.9	22.6	32.0	41.0	34.0	22.0	35.0	39.0	186.6	97.0	29.0	50.0	39.0	28.0	33.0	35.0	34.0	33.0	42.0	-	-	-	-
Potassium	-	mg/kg	710	991	2100	680	690	1200	740	1631	3700	1200	1000	1000	1000	1200	1500	1300	824	1300	877	1469	691	980	1300	930	600	2000	960	330	777	730	720	1600	580	430	840	550	550	590	690	-	-	-	-
Sodium	-	mg/kg	120	126	130	130	100	150	150	130	190	330	170	170	140	210	220	180	170	240	147	233	127	160	170	180	120	190	250	120	196	170	160	210	150	130	210	150	130	160	130	-	-	-	-
Ammonium	-	mg/kg	1.0	1.3	1.3	1.8	7.3	1.0	1.0	2.4	6.5	1.8	50.0	2.0	3.5	1.3	0.3	13.3	1.0	1.3	1.3	18.4	2.0	1.0	3.5	1.0	6.3	28.8	3.0	1.8	2.2	0.8	1.5	5.5	0.8	2.0	2.8	1.5	2.0	0.5	0.5	-	-	100	-
TKN	0.025	g/kg	**0.56**	**0.76**	**0.74**	**0.63**	**0.88**	**0.62**	0.33	**0.58**	**0.81**	0.48	**0.65**	**0.68**	0.47	**0.70**	**1.04**	**1.05**	**0.66**	**0.91**	**0.88**	**1.49**	0.48	**0.68**	**1.27**	0.53	0.41	**2.02**	**0.68**	0.36	0.46	0.40	**0.59**	**1.30**	**0.55**	0.28	0.52	0.31	0.38	0.50	**0.61**	0.550	4.800	-	-
Nitrates	0.000	g/kg	<0.001	******	******	******	******	******	******	<0.0002	<0.0002	0.00750	******	0.00025	******	0.00025	******	******	******	<0.0002	******	******	******	******	******	******	******	******	******	******	0.00017	<0.00025	******	******	******	******	******	******	******	******	<0.0002	-	-	-	-
Total Phosphorus	-	g/kg	0.19	0.20	0.25	0.16	0.21	0.16	0.13	0.26	0.39	0.27	0.22	0.23	0.43	0.34	**0.75**	0.35	0.37	0.32	0.37	0.44	0.24	0.18	0.28	0.15	0.16	0.47	0.33	0.11	0.23	0.17	0.12	0.28	0.13	0.12	0.26	0.17	0.14	0.20	0.17	0.600	2.000	-	-
Solvent Extractables	-	mg/kg	674	972	498	727	967	678	591	1326	**4222**	1118	1058	**2920**	365	533	**5272**	1335	931	**1585**	**1898**	**1842**	377	1091	1431	488	522	**3034**	**6374**	348	898	**2603**	921	**2278**	**5168**	619	1258	1200	634	452	**2526**	-	-	1500	-
Aluminum	-	mg/kg	3100	3956	8100	3100	3300	4900	3300	6358	13000	9600	3700	4400	4800	6400	8000	4600	3499	5600	3930	5732	3064	3998	5000	3400	2600	7600	4200	1900	3231	3100	2800	5200	2800	2200	3600	2700	2500	3200	3600	-	-	-	-
Arsenic	-	mg/kg	3.80	4.33	**7.60**	3.20	3.60	4.20	4.10	5.59	**6.00**	**7.40**	3.30	3.90	5.80	**8.10**	**9.20**	4.10	3.93	**7.50**	4.89	4.85	3.88	4.10	5.30	4.60	2.70	**6.80**	3.60	3.50	3.46	3.60	3.40	4.90	3.90	2.70	4.60	3.70	1.90	3.90	4.60	6	33	-	-
Cadmium	0.20	mg/kg	0.44	0.52	0.39	0.47	0.28	0.34	0.28	0.47	**0.62**	**0.83**	0.52	**0.81**	**0.79**	**0.99**	**1.10**	0.36	0.31	0.35	0.45	0.46	0.21	**1.46**	**0.61**	0.47	<0.20	**0.68**	0.37	0.54	0.25	0.50	<0.20	0.54	0.29	0.23	0.33	0.26	0.24	0.24	0.21	0.6	10	-	-
Chromium	1	mg/kg	7.4	11	16	8.0	9.0	12	7.3	12	23	15	8.6	12	14	20	18	11	10	15	13	13	10	11	12	9.3	22	17	15	11	10	12	7.8	12	12	18	9.2	12	7.9	9.7	11	26	110	-	-
Cobalt	-	mg/kg	3.4	3.4	6.5	2.3	3.5	3.9	3.0	5.9	8.7	8.7	3.8	3.9	6.9	10.0	7.1	3.8	3.8	4.8	4.2	5.2	3.1	4.4	5.2	3.4	6.1	7.3	4.9	3.0	3.9	3.6	3.6	5.0	3.2	2.9	3.7	3.4	2.9	3.5	3.8	-	-	50	-
Copper	0.5	mg/kg	**44**	**130**	**57**	**21**	**38**	**29**	**23**	**37**	**36**	**37**	**23**	**84**	**20**	**45**	**67**	**20**	**21**	**46**	**28**	**29**	15	**35**	**25**	**19**	15	**34**	**58**	**24**	**25**	**41**	**16**	**29**	**30**	13	**30**	**30**	11	**21**	**58**	16	110	-	-
Cyanide	0.010	mg/kg	<0.010	<0.010	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	-	-	0.1	-
Iron	200	mg/kg	7400	8727	16000	6800	7600	10000	9200	14659	19000	**67000**	7600	10000	**41000**	**55000**	**31000**	12000	12000	**21000**	10656	13658	11000	13325	12000	10000	6400	13000	9900	10000	10000	12000	6900	9900	13000	6500	11000	14000	7200	9800	12000	20000	40000	-	-
Lead	1.25	mg/kg	15.0	**33.2**	25.0	11.0	16.0	**32.0**	18.0	28.3	**55.0**	27.0	11.0	**37.0**	26.0	30.0	**85.0**	17.0	19.6	**53.0**	27.8	18.5	24.5	20.1	16.0	15.0	**62.0**	22.0	23.0	8.8	15.3	**33.0**	7.3	15.0	17.0	9.6	17.0	17.0	7.9	6.2	26.0	31	250	-	-
Magnesium	-	mg/kg	14000	13658	12000	14000	15000	12000	8800	15000	21000	10000	14000	14000	9300	7200	15000	13000	12000	11000	12974	17946	8527	13658	18000	11000	9300	19000	14000	8100	12658	9200	11000	15000	7600	9300	12000	7700	11000	12000	9700	-	-	-	-
Manganese	-	mg/kg	170	183	280	160	170	180	160	300	360	180	180	180	200	170	220	170	153	180	193	206	143	170	210	170	140	250	190	130	187	160	140	200	150	130	180	150	150	170	150	460	1100	-	-
Mercury	0.01	mg/kg	0.07	0.05	0.02	0.12	0.09	0.06	0.03	0.06	0.10	**0.27**	0.10	0.13	**0.27**	**0.23**	**0.29**	**0.29**	**0.40**	**0.99**	**0.57**	**0.21**	0.18	**0.26**	0.07	0.13	**0.77**	**0.36**	**0.66**	**5.20**	**6.20**	**1.60**	**60**	**29**	**3**	**163**	**84**	**44**	**13**	**24**	**24**	0.2	2	-	-
Nickel	0.2	mg/kg	7.4	9.2	**19**	6.6	8.4	9.5	8.0	**17**	**25**	**24**	9.2	13	**21**	**37**	**24**	13	11	**16**	**31**	**16**	11	11	14	9.3	6.8	**19.0**	12	12	10	11	8.0	13	7.8	12	10	8.6	5.8	8.1	**22**	16	75	-	-
Zinc	2	mg/kg	**150**	**349**	**200**	58	100	110	78	65	91	59	64	110	37	49	56	52	53	110	69	70	45	66	72	62	46	**180**	93	70	76	**120**	46	91	76	42	56	91	33	51	72	120	820	-	-
TCDD-TEQ	-	ng/kg	0.149	1.19	0.646	1.99	0.853	0.137	0.463	0.350	0.096	**20.31**	0.635	**16.775**	0.305	15.855	44.51	1.864	0.446	2.61	0.402	1.26	0.504	1.13	1.09	0.548	1.462	3.202	3.488	**20.923**	**39.77**	**100.29**	**56.2**	**64.01**	**162.25**	**20.55**	**243.72**	**75.57**	**3.639**	**31.52**	**160.52**	-	-	-	7.9
Hexachloroethane	1	µg/kg	<1	1	<1	<1	<1	<1	<1	<1	<1 1	<1	<1	<1	<1	<1	1	1	8	20	4	<1	2	6	6	4	1	1	1	225	371	3100	411	120	1600	154	552	727	30	280	2400	-	-	-	-
Hexachlorobutadiene	1	µg/kg	11	2	<1	94	33	<1	3	7	5	380	1800	875	210	3500	900	435	996	912	156	347	655	256	338	1300	3480	4000	2000	3400	24507	114000	16600	6700	243000	4400	4940	55000	1430	4000	13250	-	-	-	-
2,3,6-Trichlorotoluene	1	µg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	5	<1	<1	<1	<1	20	8	27	5	5	108	<1	<1	4	<1	30	<1	-	-	-	-
2,4,5-Trichlorotoluene	1	µg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	10	<1	12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	34	<1	75	<1	4	<1	6	3	19	13	<1	54	<1	88	<1	-	-	-	-
2,6,a-Trichlorotoluene	1	µg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	62	<1	<1	<1	<1	<1	<1	-	-	-	-
1,2,3-Trichlorobenzene	2	µg/kg	<2	<2	<2	<2	<2	<2	<2	<2	3	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	40	2	17	11	9	118	<2	<2	11	<2	<2	12	-	-	-	-
1,2,4-Trichlorobenzene	2	µg/kg	20	24	<2	28	23	25	<2	1	<2	130	118	167	41	300	230	11	35	170	<2	56	71	<2	2	2	1400	590	2800	1300	1889	6600	1270	480	7000	83	136	1680	62	253	572	-	-	-	-
1,3,5-Trichlorobenzene	2	µg/kg	<2	<2	<2	15	<2	<2	9	15	<2	140	91	167	17	190	215	67	98	436	28	65	40	32	45	37	<2	89	<2	83	68	1600	323	172	427	200	532	177	86	307	130	-	-	-	-
1,2,3,4-Tetrachlorobenzene	1	µg/kg	<1	<1	1	<1	<1	<1	<1	<1	<1	8	<1	<1	<1	15	15	<1	<1	9	<1	<1	<1	<1	<1	3	48	65	<1	120	150	300	<1	124	1640	22	35	152	<1	62	110	-	-	-	-
1,2,3,5-Tetrachlorobenzene	1	µg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	30	14	28	<1	20	20	5	4	32	3	7	10	6	11	14	62	<1	30	180	88	206	227	138	1276	67	127	380	25	102	130	-	-	-	-
1,2,4,5-Tetrachlorobenzene	1	µg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	28	<1	20	20	12	7	69	7	21	13	12	27	19	62	<1	66	140	258	360	323	264	1565	157	344	295	100	335	327	-	-	-	-
Pentachlorobenzene	1	µg/kg	<1	1	<1	<1	<1	<1	<1	<1	<1	67	35	103	10	200	83	15	30	55	11	21	28	17	33	69	95	280	95	270	2832	2450	750	580	6500	290	267	1590	61	325	560	-	-	-	-
Hexachlorobenzene	1	µg/kg	<1	**20**	<1	**20**	5	5	6	6	12	**260**	**120**	**1100**	**20**	**400**	**200**	**47**	**129**	**121**	**86**	**190**	**75**	**74**	**205**	**196**	**450**	**2000**	**750**	**1950**	**151168**	**160000**	**14000**	**7400**	**105000**	**8750**	**4570**	**41000**	**800**	**6300**	**5900**	20	24000	-	-
Octachlorostyrene	1	µg/kg	<1	2	<1	<1	<1	<1	6	4	<1	1130	110	5300	24	660	3400	110	203	1444	84	213	121	483	160	190	110	800	750	180	6761	13000	1300	2600	8600	371	485	2750	160	254	215	-	-	-	-
Total PCBs	20	µg/kg	<20	<20	<40	**340**	<20	<20	120	80	120	<20	<20	<20	<20	<20	<20	3	**140**	**142**	<20	<20	<20	**133**	**100**	<20	**360**	<20	<20	**1380**	**1171**	**2340**	**3500**	**1680**	**1900**	**680**	**920**	**1200**	**100**	**520**	**1980**	70	5300006	-	-
Total Petroleum Hydrocarb	100	mg/kg	<100	270	<100	400	300	450	200	800	4000	470	220	1700	<100	200	2214	270	200	1500	530	500	<100	600	300	<100	<100	700	4100	<100	<100	1000	<100	957	1200	<100	220	<100	<100	230	1100	-	-	-	-
Chloroform	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	80	960	790	10	-	30	<10	1500	20	<10	350	350	-	-	-	-
1,1,1-Trichloroethane	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	30	180	130	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
Trichloroethene	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	20	-	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	460	3100	11000	100	-	540	30	80	210	<10	60	160	-	-	-	-
1,1,2-Trichloroethane	10	µg/kg	<10	10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	240	<10	<10	250	60	-	-	-	-
Tetrachloroethene ("Perc")	10	µg/kg	<10	<10	140	<10	<10	40	10	40	40	-	40	30	40	30	-	<10	<10	20	30	20	<10	20	<10	<10	10	10	<10	1700	80000	300000	250	-	5200	250	270	1900	40	140	270	-	-	-	-
Carbon Tetrachloride	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	320	<10	<10	<10	<10	-	-	-	-
Benzene	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	40	-	<10	600	<10	<10	-	<10	<10	20	<10	<10	<10	<10	<10	<10	<10	<10	<10	30	40	470	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
Toluene	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	270	-	<10	960	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
meta- & para-Xylenes	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	1800	<10	<10	-	<10	<10	110	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
ortho-Xylene	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	350	-	<10	1300	<10	<10	<10	<10	<10	310	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
Ethylbenzene	10	µg/kg	<10	<10	<10	<10	<10	<10	<10	<10	210	-	<10	2300	<10	<10	-	<10	<10	470	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	-	-	-	-
Acenaphthene	20	µg/kg	<20	33	<20	<20	40	<20	340	139	60	140	<20	200	<20	<20	440	<20	16	240	25	124	3	157	4300	60	<20	60	600	<20	<20	<20	<20	40	140	<20	<20	<20	<20	40	<20	-	-	-	-
Acenaphthylene	20	µg/kg	<20	<20	<20	<20	<20	<20	80	<20	40	60	<20	40	<20	<20	280	<20	2	200	14	66	<20	73	100	40	<20	100	180	<20	<20	<20	<20	<20	80	<20	<20	40	<20	<20	100	-	-	-	-
Anthracene	20	µg/kg	<20	11	<20	<20	<20	<20	140	46	60	180	60	**360**	<20	<20	**420**	40	119	**640**	11	<20	<20	109	**11000**	60	<20	80	**1140**	<20	<20	80	<20	<20	**220**	<20	40	60	<20	<20	60	220	3700006	-	-
Benzo(a)anthracene	20	µg/kg	80	262	40	60	200	140	**400**	**526**	**680**	220	140	**580**	<20	<20	**580**	200	**533**	**1100**	**322**	173	26	**472**	**32000**	280	40	200	**1740**	40	105	**700**	160	260	**2200**	40	240	220	50	80	**780**	320	4800006	-	-
Benzo(b)fluoranthene	20	µg/kg	40	155	20	20	120	80	**280**	**305**	**500**	100	120	**340**	<20	<20	**380**	140	**410**	**460**	209	209	124	186	**22000**	140	<20	**240**	**1340**	60	73	**680**	100	160	**760**	<20	120	220	<20	60	**720**	240	3400006	-	-
Benzo(k)fluoranthene	20	µg/kg	30	78	<20	20	40	40	120	104	360	60	60	160	<20	<20	380	80	260	240	174	146	26	139	21000	100	<20	240	1040	40	17	540	60	120	480	<20	60	80	<20	40	500	-	-	-	-
Benzo(g,h,I)perylene	40	µg/kg	<40	5	<40	<40	80	<40	**240**	**213**	**320**	80	<40	**320**	<40	<40	**320**	80	**231**	**360**	**186**	100	18	115	**12000**	80	<40	120	**760**	<40	<40	**360**	<40	<40	**560**	<40	<40	160	<40	<40	**640**	170	3200006	-	-
Benzo(a)pyrene	40	µg/kg	<40	21	<40	<40	80	<40	200	127	200	120	80	**440**	<40	<40	**380**	120	342	**440**	3	<40	<40	20	**22000**	120	<40	200	**1440**	<40	18	**440**	<40	<40	280	<40	120	160	<40	<40	280	370	4400006	-	-
Chrysene	20	µg/kg	120	300	80	100	**480**	220	**600**	**825**	**1100**	**380**	240	**860**	<20	<20	**940**	240	**582**	**1400**	431	**423**	173	**559**	**29000**	280	60	320	**2140**	60	135	**800**	180	**400**	**2700**	60	260	300	70	140	**960**	340	4600006	-	-
Dibenzo(a,h)anthracene	40	µg/kg	<40	5	<40	<40	<40	<40	**80**	**120**	**240**	<40	<40	**160**	<40	<40	**240**	<40	3	**120**	3	3	<40	<40	**3600**	<40	<40	<40	**440**	<40	<40	**240**	<40	<40	**360**	<40	<40	<40	<40	<40	<40	60	1300006	-	-
Fluoranthene	20	µg/kg	120	219	40	60	140	100	540	373	200	500	480	**1140**	60	60	**1260**	360	**1051**	**1500**	709	739	338	**779**	**99000**	500	160	**1060**	**6460**	60	186	**1080**	260	400	**1800**	80	300	280	120	280	**1440**	750	10200006	-	-
Fluorene	20	µg/kg	40	36	100	40	<20	40	**280**	166	140	160	100	**360**	<20	<20	**320**	<20	68	**720**	18	104	2	172	**9700**	60	40	100	**740**	<20	2	60	<20	60	160	40	<20	60	<20	40	<20	190	1600006	-	-
Indeno(1,2,3-cd)pyrene	40	µg/kg	<40	<40	<40	<40	<40	<40	120	80	120	<40	<40	100	<40	<40	80	80	**226**	160	145	110	21	4	**15000**	80	<40	120	**800**	<40	4	**320**	<40	<40	**360**	<40	<40	<40	<40	<40	**480**	200	3200006	-	-
Naphthalene	20	µg/kg	<20	10	<20	<20	40	<20	60	84	60	120	100	<20	<20	<20	120	<20	27	<20	56	300	5	46	1200	280	80	240	2880	<20	14	<20	<20	140	1800	<20	<20	60	<20	40	<20	-	-	-	-
Phenanthrene	-	µg/kg	120	273	120	80	160	100	**1100**	**880**	**560**	**880**	**560**	**2060**	80	160	**2320**	260	**859**	**4200**	**682**	**718**	130	**919**	**85000**	**560**	220	**1060**	**6840**	80	226	500	180	340	**2200**	100	180	160	140	340	420	560	9500006	-	-
Pyrene	-	µg/kg	100	259	40	80	260	180	**800**	**540**	**560**	**800**	440	**1520**	60	60	**3000**	440	**982**	**3000**	**786**	**805**	329	**1232**	**70000**	480	160	**860**	**6000**	40	134	**1100**	220	380	**3100**	80	340	320	160	360	**2140**	490	8500006	-	-
Total PAHs	40	µg/kg	650	1980	420	420	1640	900	**5380**	**4545**	**5200**	3800	2380	**8600**	200	280	**11460**	2040	**5899**	**14780**	**4153**	**4060**	1547	**5077**	**436900**	3120	760	**5000**	**34540**	380	1053	**6900**	1160	2300	**17200**	400	1660	2120	540	1420	**8520**	4000	0000000	-	-
Gravel	0.1	%	0	4.8	7.8	4.1	12.2	20.5	0.8	29.4	2.9	20	1.1	26.7	0.2	6	0	1.3	0.9	16.9	2.6	0	2.3	0.2	0	1.3	25.1	0	5.2	22.1	17.2	34	6.8	7	28.9	17.9	34.1	41.7	40	45.2	42.9	-	-	-	-
Coarse Sand	0.1	%	1.1	2.5	5.8	10	3.7	7.1	10.8	26.2	2.5	11.7	1.9	4.1	4.8	10	0	6.3	3.7	13.6	32.5	2.5	22.3	12.3	4.1	3.7	24.4	1.8	4.8	36.1	8.9	19.1	22.6	1.1	17.1	25.9	14.4	8	26.4	25.5	23.8	-	-	-	-
Fine Sand	0.1	%	78.2	75.8	61.2	73.6	68.2	49.9	63.3	21.6	26.6	49.8	76.6	58.1	88	69.2	48.5	75.3	77.7	37.6	54.1	44.1	65.3	55.4	54.3	81.9	45.4	44.6	75.9	37.5	58.5	45.2	60.7	73.7	48.7	46.6	39.9	49.1	19.3	24.3	31.6	-	-	-	-
Silt+Clay	0.1	%	20.7	16.9	25.2	12.3	15.9	22.5	25.1	22.8	68	18.5	20.4	11.1	7	14.8	51.5	17.1	17.7	31.9	10.8	53.8	10.1	32.1	41.6	13.1	5.1	53.6	14.1	4.3	15.4	1.7	9.9	18.2	5.3	9.6	11.6	1.2	4.3	5	1.7	-	-	-	-

[1] Ontario Ministry of the Environment Provincial Sediment Quality Guidelines (Persaud et al., 1993) - LEL = Lowest Effect Level; SEL = Severe Effect Level
[2] Open Water Disposal Guideline (Persaud et al., 1993)
[3] Parameters expressed on a dry weight basis
4 MDL - Method Detection Limit (Values less than MDL considered = 0)
5 Value is mean of three replicate samples
6 SEL value adjusted by site-specific TOC value for organic contaminants
7 Exceeds Draft Canadian Environmental Quality Guideline for 2,3,7,8-TCDD and PCDD/PCDF TEQ - Direct Toxicity NOEC Value (7.9 ng/kg) adjusted for site-specific TOC value (EC, 1994)
- parameter not measured or no applicable score
Flow/concentration not measured - estimated value
Equal to or exceeds LEL or open water disposal guideline - fails guideline and may have an adverse effect on some benthic organisms
Equal to or exceeds SEL - highly contaminated and likely will have an adverse effect on benthic organisms

levels of ammonium were present along the Middle Area waterfront (Stations IS9-M, 46-I and IS12-M) and tended to be associated with the highest values of TKN (Table 3.1). Effluent from the Polysar/Bayer outfalls are historically associated with elevated levels of ammonia nitrogen, however, these have decreased steadily since 1984 (St. Clair River RAP, 1991).

Chloride values were elevated relative to background concentrations at Station 12-M (Middle Area) and at Stations IS14-M and IS14-O (Lower Area). Both Polysar/Bayer and Dow have had effluent characterised by elevated chloride levels (OMOE, 1979; EC/OMOE, 1986) although Dow Chemical no longer discharges significant levels of chloride.

Trace Metals

Fourteen trace metals (aluminium, arsenic, cadmium, chromium, cobalt, copper, cyanide, iron, lead, magnesium, manganese, mercury, nickel and zinc) were analyzed in the sediments from the upper St. Clair River. Of these, only three (copper, iron and mercury) were found to exceed their respective PSQG SEL values (Table 3.1).

Elevated mercury levels were found in the Lower Area (Stations IS14-I, IS14-M, 48-I, 48-M, 48-O, 49-I, 49-M, 49-O, IS15-I, IS15-M and IS15-O). The highest concentrations were recorded at Stations 49-I, 48-I and 49-M, where the concentrations were 81, 30 and 21 times the SEL value (2 mg/kg), respectively. This area was also characterised historically by elevated mercury levels, with maximum values of 1,470 mg/kg recorded in 1968 (OMOE, 1979), 58 mg/kg recorded in 1977 (OMOE, 1979), 51 mg/kg in 1985 (OMOE, unpubl. data) and 15 mg/kg in 1990 (Pope, 1993). The spatial distribution patterns of mercury contamination in the study area and extending downstream to Suncor, are presented in Figure 3.1 and Appendix 3 (Table A3.1). In general, mercury concentrations decreased below the SEL level downstream of the Lower Area, but remained above the LEL level.

Elevated copper levels (130 mg/kg) above the SEL (110 mg/kg) were only associated with the mid-station along Transect 18 (Station 18-M). Copper concentrations at most stations exceeded the LEL (16 mg/kg), but were lower than concentrations measured along transect 18 (Table 3.1).

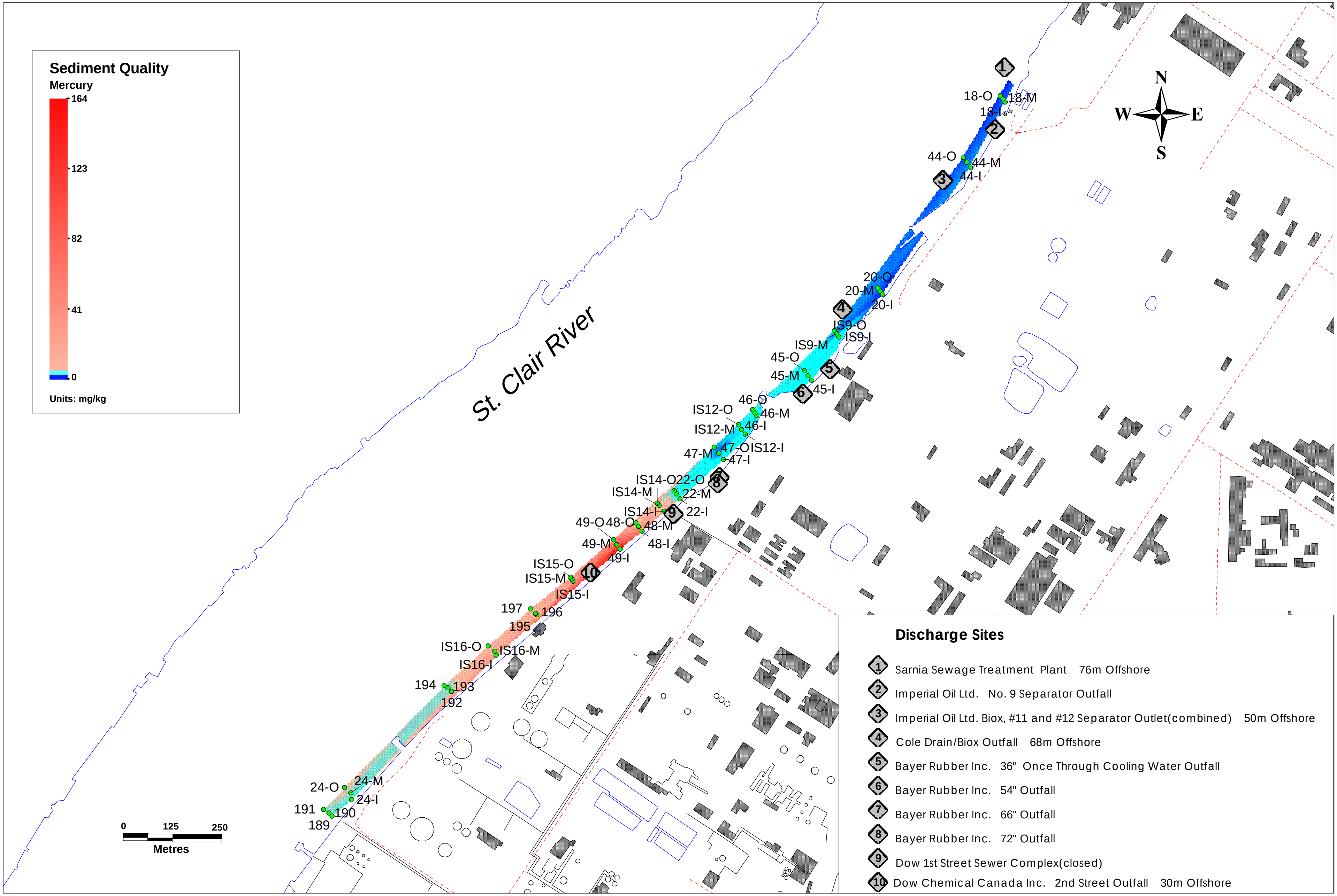


Figure 3.1 Spatial Distribution of Mercury in Sediments in the Upper St.Clair River - 1994/95

Elevated iron levels were recorded at Stations IS9-I, 45-I, 45-M, 45-O and 46-O. However, the levels exceeded the SEL only at Stations IS9-I, 45I and 45-M.

Most of the concentrations of the other metals (arsenic, cadmium, lead, nickel and zinc), were only marginally above or below the LEL and were not much different from levels recorded at the upstream transect.

Organic Chemicals

Sediment concentrations of 15 chlorinated organic compounds, total PCBs, 16 individual PAHs and total PAHs, solvent extractables, polychlorinated dibenzo-p-dioxins and dibenzofurans, total petroleum hydrocarbons and volatile organohalides were measured at each station. For dioxins and furans, only the Toxic Equivalent (TEQ) values (relative to 2,3,7,8-TCDD) are presented in Table 3.1. Detailed results of individual isomers are provided in Appendix 3 (Table A3.2). Of these parameters, PSQG values are available only for hexachlorobenzene (HCB), PCBs and PAHs (individual and total PAHs). Concentrations of 20 organochlorine pesticides were below their respective method detection limits in all samples (Table 3.2).

Exceedances of the PSQG SEL for hexachlorobenzene occurred at 16 of the 39 sites: 4 stations in the Middle Area (Stations IS9-O, 22-I, 22-M and 22-O) and 12 stations in the Lower Area (Transects IS14, 48, 49 and IS15). The elevated levels of HCB in the nearshore along the Middle Area were identified in earlier surveys (EC/OMOE, 1986). These likely reflect input from the Cole Drain **(**St. Clair River RAP Team, 1991; Oliver and Pugsley, 1986). In 1994, the highest levels of HCB were measured in the Lower Area (151,168 μg/kg and 160,000 μg/kg at Stations IS14-I and IS14-O, respectively). Dow discharges in this area, particularly the now-closed 1st Street sewer complex, have been associated with HCB, OCS and other chlorinated organics (OMOE, 1992). Concentrations of HCB downstream of Transect IS14 decreased to a range of 800 to 105,000 μg/kg. The concentrations at Transect IS14 are slightly higher than have been measured in previous surveys (i.e., 5,000 μg/kg in 1984, (EC/OMOE, 1986); 110,000 μg/kg in 1986, (OMOE, 1991); 97,000 μg/kg in 1990 (Pope, 1993), suggesting there were continued inputs prior to the 1994 survey. The spatial distribution patterns of HCB contamination in the study area and extending downstream to

**TABLE 3.2: ORGANOCHLORINE PESTICIDES AND VOLATI
NOT DETECTED (BELOW DETECTION LIMITS)
SEDIMENTS FROM THE UPPER ST. CLAIR RIVE**

Parameter[1]	All Stations
Heptachlor	<1
Aldrin	<1
Mirex	<5
a-BHC	<1
b-BHC	<1
g-BHC	<1
a-Chlordane	<2
g-Chlordane	<2
Oxychlordane	<2
o,p-DDT	<5
p,p-DDD	<5
p,p-DDT	<5
p,p-DDE	<1
Methoxychlor	<5
Heptachlor Epoxide	<1
Endosulphan I	<2
Endosulphan II	<4
Endosulphan Sulphate	<4
Dieldrin	<2
Endrin	<4
Dichloromethane	<20
1,1-Dichloromethane	<20
Trans-2-Dichloroethene	<20
Bromodichloromethane	<10
Dibromochloromethane	<10
Bromoform	<10
Chlorobenzene	<10
1,2-Dichlorobenzene	<10
1,3-Dichlorobenzene	<10
1,4-Dichlorobenzene	<10

[1] All concentrations expressed as µg/kg

Suncor, are presented in Figure 3.2 and Appendix 3 (Table A3.1). In general, HCB concentrations decreased downstream of the Lower Area but remained above the SEL.

Elevated levels of the other chlorinated organic chemicals, including HCBD, OCS, trichlorobenzenes and pentachlorobenzene were also associated with existing or historical loadings to the study area. Elevated levels of HCBD, trichlorobenzenes, pentachlorobenzene, and OCS above those at the upstream transect (18) first occur downstream of the Cole Drain (Transect 9). The Cole Drain (Township Ditch) serves as a collector of process discharges, treated and untreated runoff, leachate and runoff from several landfills. Some of the highest net loadings of chlorobenzenes, HCBD, hexachloroethane, and OCS were reported at this source (St. Clair River RAP, 1991; OMOE, 1992; OMOEE/MDNR, 1995). Another area showing elevated levels of organic contaminants was located downstream of the Polysar/Bayer 66" and 72" sewers. Along Transect 22, elevated sediment levels of HCBD and 1,2,4-trichlorobenzene were recorded. The highest sediment concentrations of HCBD, OCS, trichlorobenzenes, tetrachlorobenzenes and pentachlorobenzene were also recorded in the Lower Area (Dow Chemical waterfront). Spatial patterns of HCBD contamination are illustrated in Figure 3.3 and Appendix 3 (Table A3.1). In general, HCBD concentrations were the highest of the chlorinated organics measured. HCBD levels decreased downstream of the Lower Area but remained above levels recorded in the Upper Area. Loadings from the Dow Chemical sewers indicated elevated levels of HCB, OCS and other chlorinated organics (OMOE, 1992). Dow Chemical was a major manufacturer of chlorinated solvents until mid 1993 when the chlorine plant was closed and the discharge source (1st Street sewer complex) sealed permanently in late 1994.

Total PCBs were below the SEL value at all locations in the study area (Table 3.1). Five locations in the Middle Area (46-O, IS12-I, 47-I, 47-M, 22-I) and twelve locations in the Lower Area (IS14-I, IS14-M, IS14-O, 48-I, 48-M, 48-O, 49-I, 49-M, 49-O, IS15-I, IS15-M, IS15-O) had concentrations above the LEL value (70 μg/kg), and were greater than concentrations measured at reference Transect 18. Concentrations ranged from 100 to 3,500 μg/kg.

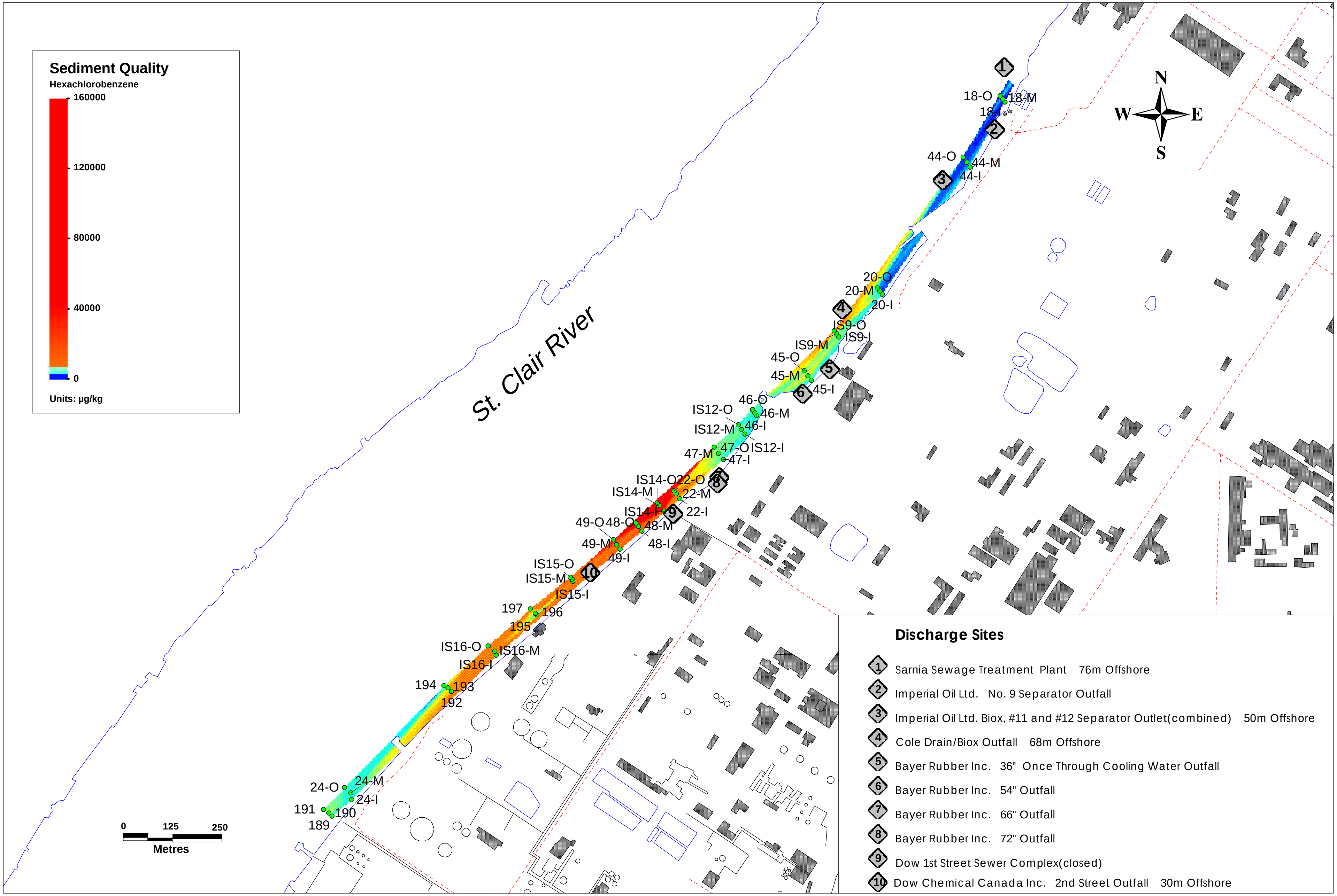


Figure 3.2 Spatial Distribution of Hexachlorobenzene in Sediments in the Upper St.Clair River - 1994/95

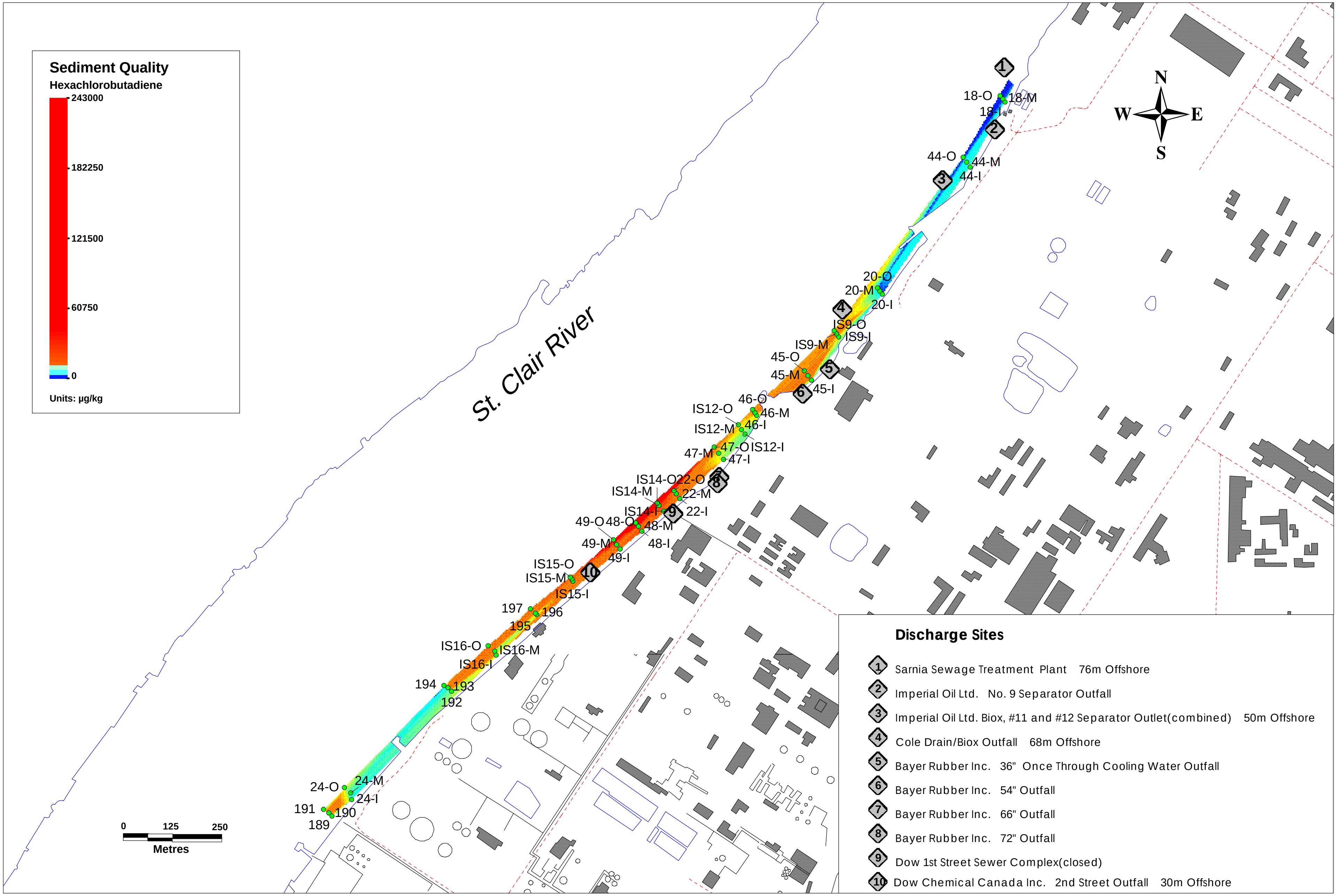


Figure 3.3 Spatial Distribution of Hexachlorobutadiene in Sediments in the Upper St.Clair River - 1994/95

Polycyclic aromatic hydrocarbons (PAHs) and solvent extractables were fairly widespread throughout the study area, with higher levels of both parameters first occurring downstream of Transect 44 when compared to levels at the reference transect. Higher sediment concentrations in this area appear to be associated with municipal and industrial discharges upstream of and in the Upper Area. These effluents were previously characterised by low concentrations of some PAHs and solvent extractables (King and Sherbin, 1986). Total PAH concentrations ranged from 200 to 34,540 μg/kg at all but one site (Station 47-M) where a concentration of 436,900 μg/kg was recorded. In general, the highest sediment concentrations of PAHs and solvent extractables were associated with the Middle Area. These accumulations are suspected to be associated with spills of petroleum products from Esso Petroleum, Esso Chemical and Novacor/Polysar, in addition to whatever material has been contributed from the Cole Drain (St. Clair River RAP, 1991). The elevated PAH and solvent extractable levels also appeared to be associated with the presence of oil globules and/or coal chunks noted in the substrates during sample collection (Appendix 1, Table A1.3a).

Total Petroleum Hydrocarbons (TPH), measured in frozen archived samples in early 1997, are likely a conservative estimate of the actual concentrations, given the volatile nature of some of these compounds. No values were available for stations IS9-I, 45-O and 48-M due to the unavailability of material. Values for these stations used in the cluster and PCA analyses were derived by the OMOEE (P. Kauss, OMOEE, pers. comm., 1997) using neighbouring concentrations and known sources. Elevated levels of these compounds, relative to the background concentrations at transects 18 and 44 (<100 to 450 mg/kg) were measured throughout the study area at 20-M, 20-O, IS9-O, 46-O, IS12-I, IS12-M, 47-I, 22-M, 22-M, IS14-O, 48-O and IS15-O. The highest values (>1000 mg/kg) were associated with the outermost stations. TPH were highly correlated with solvent extractable concentrations (R^2=0.722, p=<0.0001).

Volatile organohalides, also measured in frozen archived samples in early 1997, are also likely a conservative estimate of the actual concentrations. No values were available for stations IS9-I, 45-O and 48-M due to a lack of sediment sample. It was not considered possible to derive estimates for the missing values and therefore, these parameters were not included in the statistical analyses. Elevated concentrations of 1,1,1-trichloroethane, trichloroethene, 1,1,2-trichloroethane and tetrachloroethene (perchloroethylene), were measured in the Lower Area associated with the Dow 1st Street sewer, which was closed prior to the 1994 survey. Elevated levels of tetrachloroethene, benzene, toluene, meta- and para-xylenes, ortho-xylene and ethylbenzene (relative to the background transects) were measured at Stations 20-O, IS9-O and 46-O. These concentrations are likely associated with the Cole Drain and spills from Esso (P. Kauss, MOEE, pers. comm., 1997).

Calculated total 2,3,7,8-TCDD toxicity equivalent concentrations (TEQ) were higher in sediments in the Lower Area. Total TEQs ranged from 3.6 to 243 ng/kg, with a geometric mean of 39 ng/kg, compared to a geometric mean of 3.2 ng/kg (range of 0.09 to 45 ng/kg) in the Upper and Middle Areas. TEQ values from Stations IS9-I and IS9-O in the Upper Area, and all twelve stations in the Lower area were above the draft "recommended interim" Canadian Environmental Quality Guideline No Observed Effect Concentration (NOEC) for direct toxicity (7.9 ng/kg, assuming a TOC of 1%)(Environment Canada, 1994). This guideline was derived from the water quality guideline using the equilibrium partitioning approach.

3.2 Cluster Analysis

A total of 64 parameters were used in the cluster analysis (Table 3.3). Figure 3.4 illustrates the results of cluster analysis of sediment chemistry data which were super-imposed on a study area map using GIS (Figure 3.5). All of the clustering approaches used illustrated very similar results (Appendix 2). Based on Ward's clustering technique, the stations cluster into 3 major groups. Cluster Group 1 was represented by 16 of the 39 stations including seven stations located in the Upper Area (Transects 18 and 44; Station 20-I), and nine stations located in the Middle Area (IS9-M, 45-I, 45-M, 46-I, 46-M, IS12-I, IS12-O, 47-I and 47-O). Stations that were grouped in Cluster 1 were characterised by sediments that were the least contaminated in the study area, with only TOC, TKN and copper marginally in excess of their respective PSQG-LEL levels (Table 3.3).

Cluster 2 was comprised of ten stations, including the remainder of the stations located in the Upper Area (Stations 20-M, 20-O), and Middle Area (Stations IS9-I, IS9-O, 45-O, 46-O,

TABLE 3.3: MEAN SEDIMENT QUALITY DATA IN UPPER ST. CLAIR RIVER CLUSTER GROUPS- JUNE 1994

Cluster Number			1	2	3				
Number of Stations			N=16	N=10	N=13	PSQG	PSQG		
Parameters³	MDL4	Units				LEL¹	SEL¹	OWDG²	EC
Water Velocity		m/sec	0.12	0.12		-	-	-	-
Water Depth		m	3.4	4.1	4.2	-	-	-	-
Wet Density		g/cm³	1.72	1.58	1.86	-	-	-	-
LOI	1	g/kg	20.7	33.9	14.9	-	-	-	-
TOC	0.2	g/kg	**15.6**	**25.9**	8.8	10	100	-	-
Calcium		mg/kg	44842	51098	52976	-	-	-	-
Chloride		mg/kg	21.7	19.9	43.6	-	-	-	-
Potassium		mg/kg	1019	1341	645	-	-	-	-
Sodium		mg/kg	149	208	154	-	-	-	-
Ammonium		mg/kg	2.4	3.0	1.6	-	-	-	-
TKN	0.03	g/kg	**0.65**	**0.92**	**0.47**	0.550	4.800	-	-
Nitrates	0.00	g/kg	******	******	******	-	-	-	-
Total Phosphorus		g/kg	0.24	0.35	0.17	0.600	2.000	-	-
Solvent Extractables		mg/kg	835	**2306**	1091	-	-	1500	-
Aluminum		mg/kg	4288	6059	2943	-	-	-	-
Arsenic		mg/kg	4.53	5.76	3.50	6	33	-	-
Cadmium	0.20	mg/kg	0.47	0.59	0.31	0.6	10	-	-
Chromium	1	mg/kg	11.2	14.3	11.4	26	110	-	-
Cobalt		mg/kg	4.3	5.7	3.7	-	-	50	-
Copper	0.5	mg/kg	**30**	**43**	**24**	16	110	-	-
Cyanide	****	mg/kg	<0.010	<0.010	<0.010	-	-	0.1	-
Iron	200	mg/kg	12510	17245	9587	*****	40000	-	-
Lead	1.25	mg/kg	20.8	29.9	14.9	31	250	-	-
Magnesium		mg/kg	12119	14580	10148	-	-	-	-
Manganese		mg/kg	184	210	155	460	1100	-	-
Mercury	0.01	mg/kg	0.13	**0.23**	**14**	0.2	2	-	-
Nickel	0.2	mg/kg	12.8	**16.8**	9.8	16	75	-	-
Zinc	2	mg/kg	77.6	87.4	62.9	120	820	-	-
2,3,7,8-TCDD-TEQ		pg/g	0.69	3.91	**39.08**	-	-	-	7.9
Hexachloroethane	1	µg/kg	<1	2	260	-	-	-	-
Hexachlorobutadiene	1	µg/kg	122	492	11745	-	-	-	-
2,3,6-Trichlorotoluene	1	µg/kg	<1	<1	4	-	-	-	-
2,4,5-Trichlorotoluene	1	µg/kg	<1	2	5	-	-	-	-
2,6,a-Trichlorotoluene	1	µg/kg	<1	<1	<1	-	-	-	-
1,2,3-Trichlorobenzene	2	µg/kg	<2	<2	5	-	-	-	-
1,2,4-Trichlorobenzene	2	µg/kg	10	77	729	-	-	-	-
1,3,5-Trichlorobenzene	2	µg/kg	12	59	221	-	-	-	-
1,2,3,4-Tetrachloroben	1	µg/kg	<1	3	114	-	-	-	-
1,2,3,5-Tetrachloroben	1	µg/kg	2	10	141	-	-	-	-
1,2,4,5-Tetrachloroben	1	µg/kg	2	10	255	-	-	-	-
Pentachlorobenzene	1	µg/kg	6	9	571	-	-	-	-
Hexachlorobenzene	1	µg/kg	27	238	**10091**	20	240006	-	-
Octachlorostyrene	1	µg/kg	19	505	890	-	-	-	-
Total PCBs	20	µg/kg	<20	3	**1013**	70	5300006	-	-
Total Petroleum Hydro	100	mg/kg	50	1137	19	-	-	-	-
Acenaphthene	20	µg/kg	<20	271	2	-	-	-	-
Acenaphthylene	20	µg/kg	<20	63	2	-	-	-	-
Anthracene	20	µg/kg	<20	210	4	220	3700006	-	-
Benzo(a)anthracene	20	µg/kg	95	**758**	166	320	14800006	-	-
Benzo(b)fluoranthene	20	µg/kg	67	**518**	54	240	13400006	-	-
Benzo(k)fluoranthene	20	µg/kg	35	345	34	-	-	-	-
Benzo(g,h,I)perylene	40	µg/kg	<40	**345**	5	170	3200006	-	-
Benzo(a)pyrene	40	µg/kg	<40	268	9	370	14400006	-	-
Chrysene	20	µg/kg	144	**1129**	223	340	4600006	-	-
Dibenzo(a,h)anthracen	40	µg/kg	<40	52	1	60	1300006	-	-
Fluoranthene	20	µg/kg	228	**1803**	293	750	10200006	-	-
Fluorene	20	µg/kg	20	**380**	9	190	1600006	-	-
Indeno(1,2,3-cd)pyrene	40	µg/kg	<40	136	3	200	3200006	-	-
Naphthalene	20	µg/kg	<20	87	7	-	-	-	-
Phenanthrene		µg/kg	288	**2669**	251	560	9500006	-	-
Pyrene		µg/kg	274	**2288**	312	490	8500006	-	-
Total PAHs		µg/kg	1592	**12547**	1685	4000	100000006	-	-
Gravel		%	2.2	0.0	24.0	-	-	-	-
Coarse Sand		%	5.7	1.0	15.5	-	-	-	-
Fine Sand		%	66.1	46.0	42.2	-	-	-	-
Silt+Clay		%	17.6	28.7	5.3	-	-	-	-

¹ Ontario Ministry of the Environment Provincial Sediment Quality Guidelines (Persaud et al., 1993) - LEL = Lowest Effect Level; SEL = Severe Effect Level

² Open Water Disposal Guideline (Persaud et al., 1993)

³ Parameters expressed on a dry weight basis

4 MDL - Method Detection Limit (Values less than MDL considered = 0)

5 Value is mean of three replicate samples

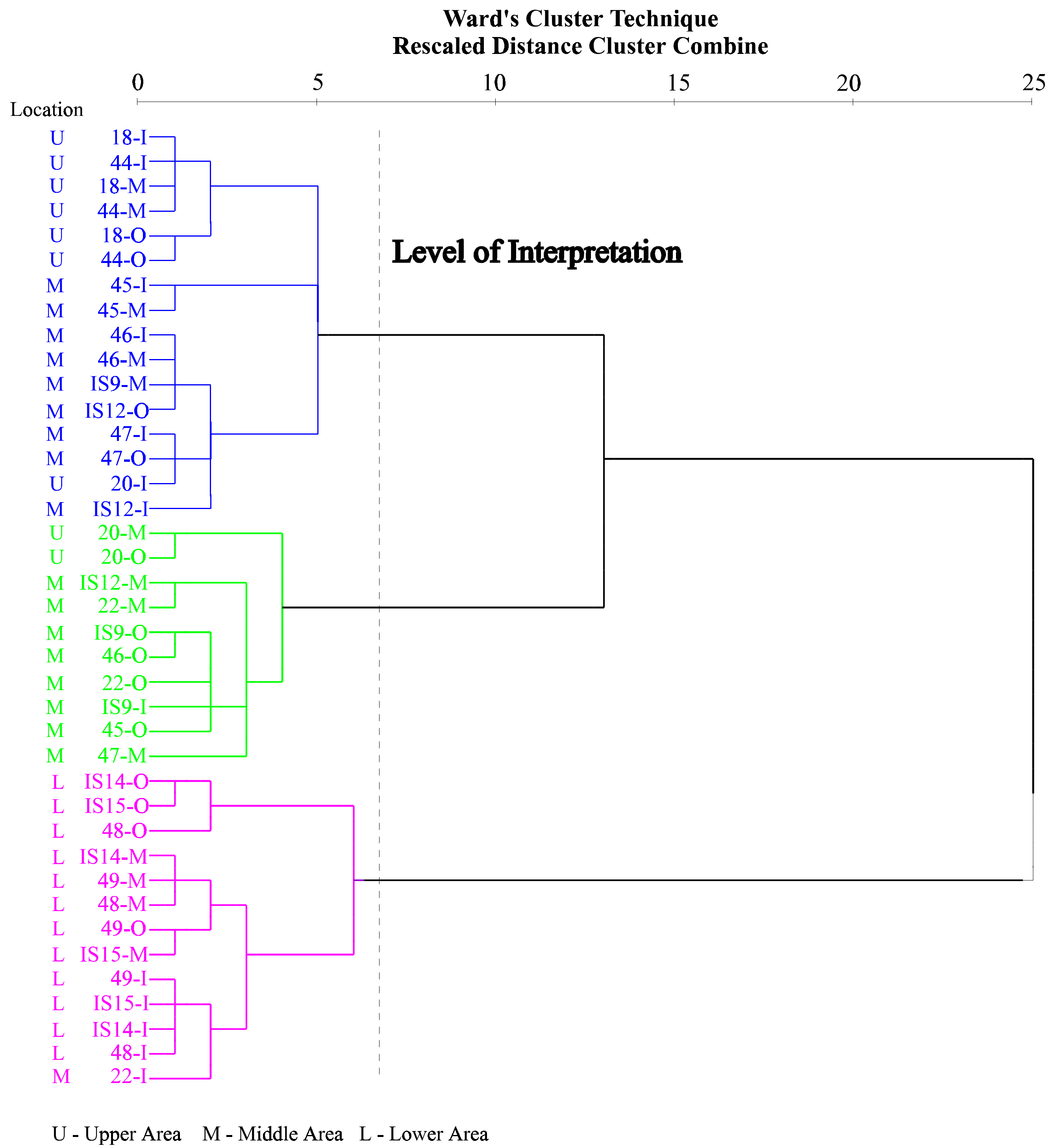
6 SEL value adjusted by site-specific TOC value for organic contaminants

- parameter not measured or no applicable score

Equal to or exceeds LEL or open water disposal guideline - fails guideline and may have an adverse effect on some benthic organisms

Equal to or exceeds SEL - highly contaminated and likely will have an adverse effect on benthic organisms

Exceeds Draft Canadian Environmental Quality Guideline for 2,3,7,8-TCDD and PCDD/PCDF TEQ - Direct Toxicity NOEC Value (7.9 ng/ kg) adjusted for site-specific TOC value (EC, 1994)



1994 Upper St. Clair River Sediment Quality Cluster Analysis Results Ontario Ministry of the Environment and Energy		
beak international incorporated	Figure 3.4	October 1997

Figure 3.5 Sediment Quality of Upper St. Clair River based on Cluster Analysis Results - 1994

IS12-M, 47-M, 22-M and 22-O). These stations were more contaminated than those from Cluster 1, with mean levels of TOC, TKN, solvent extractables, copper, mercury, nickel, eight individual PAHs and total PAHs in excess of their respective PSQG-LEL levels or open water disposal guidelines (Table 3.3). In addition, the mean concentrations for virtually all parameters were higher compared to mean contaminant concentrations for Cluster 1 stations.

Cluster 3 was comprised of the thirteen stations located in the Lower Area (Transects IS14, 48, 49, and IS15) and Station 22-I, located at the downstream end of the Middle Area. This cluster group was characterised by stations with the most heavily contaminated sediments in the study area, with levels of mercury and hexachlorobenzene generally in excess of their respective PSQG-SEL values. An additional three parameters, TKN, copper and total PCBs, were in excess of their respective PSQG-LEL levels (Table 3.3). Elevated levels of several other parameters for which there are no sediment quality guidelines also occurred at these stations. These parameters included 2,3,7,8-TCDD TEQs, hexachloroethane, hexachlorobutadiene, trichlorobenzenes, tetrachlorobenzenes and octachlorostyrene. However, the mean concentrations of most PAHs and metals were lower than the mean concentrations characteristic of Cluster 2 stations.

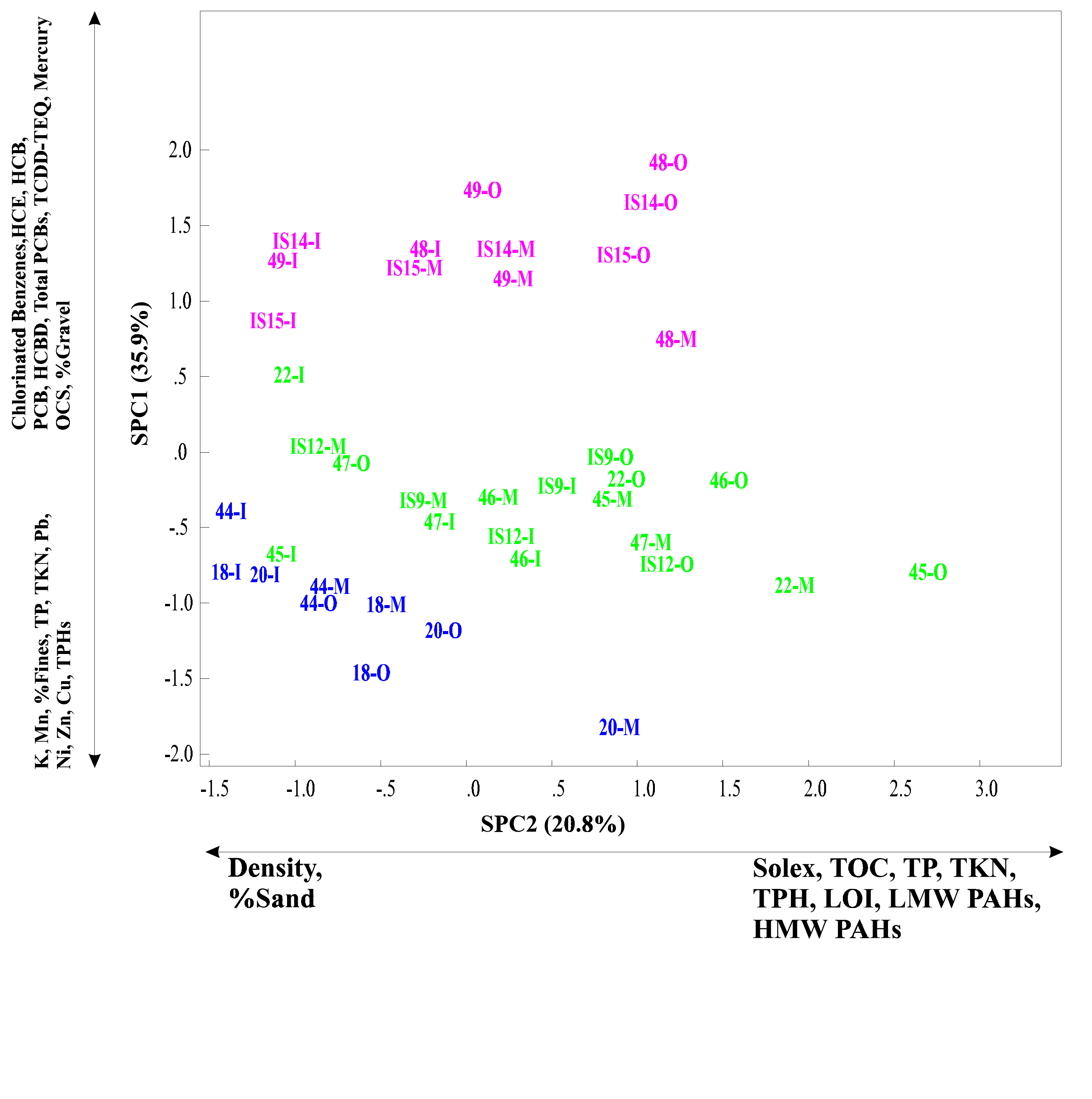
3.3 Principal Components Analysis (PCA)

Sediment parameters included in the PCA analysis of the sediment data differed slightly from those included in the cluster analysis due to degrees of freedom restrictions. The PAHs were collapsed to low molecular weight PAHs (LMW - acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, phenanthrene) and high molecular weight (HMW) PAHs. Low molecular weight PAHs are generally regarded as the more bioavailable forms. In addition, parameters which either demonstrated very little variation among stations or were very low in concentration were also eliminated from the database. The 36 parameters used in the analysis are presented in Table 3.4, along with the loadings for each parameter on the first three axes.

The first two PCA factors explained 57% of the total variance in the sediment data (Table 3.4; Figure 3.6). PCA Axis 1 (SPC1) explained 35.9% of the variance in the data, with station scores on SPC1 positively correlated with tetrachlorobenzenes, HCE, HCB, PCB, HCBD,

TABLE 3.4: COMPONENT LOADINGS AND PERCENT OF TOTAL VARIANCE FOR THE PCA OF THE UPPER ST. CLAIR RIVER SEDIMENT DATA

Parameter	PC1	PC2	PC3
1,2,3,5-Tetrachlorobenzene	0.9097	0.2881	-0.0226
Hexachloroethane	0.9059	0.1519	0.1737
Hexachlorobenzene	0.8967	0.3490	-0.0374
1,2,4,5-Tetrachlorobenzene	0.8868	0.2781	-0.0010
Pentachlorobenzene	0.8563	0.4269	-0.1655
Hexachlorobutadiene	0.8496	0.3645	-0.2702
Total PCBs	0.8337	0.0179	0.1073
2,3,4,8-TCDD TEQ	0.8050	0.3945	0.0927
Mercury	0.7742	-0.0385	0.0237
1,2,3,4-Tetrachlorobenzene	0.7313	0.3423	0.1274
1,2,4-Trichlorobenzene	0.7271	0.2965	-0.0692
Octachlorostyrene	0.6682	0.5879	-0.2536
%Gravel	0.6621	-0.0367	0.4694
1,2,3-Trichlorobenzene	0.6541	0.1911	0.2412
1,3,5-Trichlorobenzene	0.6407	0.4380	-0.3245
Chloride	0.5951	-0.0204	-0.2716
Wet Sediment Density	0.5100	-0.6177	0.3262
Water Depth	0.3401	0.4329	0.3384
%Sand	0.0397	-0.4555	-0.4878
Solvent Extractables	-0.0265	0.8140	0.3060
High Molecular Weight PAHs	-0.0653	0.6278	0.3239
Low Molecular Weight PAHs	-0.1670	0.6386	0.2042
LOI	-0.1948	0.6453	-0.4229
Iron	-0.2489	0.4479	-0.2574
TOC	-0.2561	0.6586	-0.4405
Ammonium	-0.2737	0.1149	-0.2675
Total Petroleum Hydrocarbons	-0.2957	0.6457	0.2763
Copper	-0.3178	0.4613	0.4768
Zinc	-0.3354	0.2247	0.5846
Nickel	-0.3719	0.5472	-0.2266
Lead	-0.4340	0.4559	0.1810
TKN	-0.4765	0.6189	-0.1518
TP	-0.4964	0.6465	-0.3468
%Fines	-0.6612	0.4830	0.0264
Manganese	-0.6678	0.3863	0.2606
Potassium	-0.7059	0.5176	0.0660
Percent of Total Variance Explained	35.9	20.8	7.9



Bivariate Plot of Sediment PCA Results from the 1994 Upper St. Clair River, Study Zone 1

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OCS, PCBs, 2,3,7,8-TCDD TEQ, mercury, %Gravel and trichlorobenzenes. Potassium, manganese, %Fines, TP, TKN, lead, nickel, zinc and copper were negatively correlated with SPC1.

PCA Axis 2 (SPC2) explained an additional 20.8% of the variance (Table 3.4). Station scores on SPC2 were positively correlated with solvent extractables, TOC, TP, TPH, LOI, LMW PAHs, HMW PAHs and TKN; and negatively correlated with sediment density and %Sand.

In general, the pattern of station similarities and the predominant parameters associated with the stations from the PCA agrees with those provided by the cluster analysis, with some deviations likely associated with differences in the datasets, primarily due to the collapse of the individual PAHs to two summary parameters. Stations in the Lower Area separated from the other two areas along SPC1 on the basis of higher concentrations of organic chemicals, including tetrachlorobenzenes, trichlorobenzenes, HCE, HCB, PCB, HCBD, PCBs, 2,3,7,8-TCDD TEQ, mercury and %gravel. Stations in the Upper and Middle Areas were characterized by higher levels of metals, %Fines, TP and TKN. There was separation of the Upper and Middle Areas along SPC2, with the Middle Area tending to exhibit higher concentrations of solvent extractables, TOC, TP, TPH, LOI, LMW PAHs, HMW PAHs and TKN. Stations in the Upper Area tended to be characterized by slightly higher levels of %Sand.

3.4 Laboratory Sediment Bioassays

Mortality of chironomid larvae, mayfly nymphs and juvenile fathead minnows exposed to reference sediments from Honey Harbour, Ontario and the upstream reference (Transect 18) averaged less than the acceptable maximum control mortality of 25%, 15% and 10%, respectively (Bedard *et al.*, 1992), indicating that the cultures were suitable for use in testing.

Chironomid, mayfly and fathead minnow mortality levels were quite variable throughout the study area, ranging from 0 to 100%, both within and among transects (Table 3.5).

TABLE 3.5: SEDIMENT TOXICITY RESULTS FOR SAMPLES FROM STATIONS IN THE UPPER ST. CLAIR RIVER - JUNE AND DECEMBER 1994

Upper Area Station	18-I	18-M5	18-O	44-I	44-M	44-O	20-I	20-M5	20-O
Acute Toxicity (% Mortality)									
June									
Chironomus tentans	0	7	7	7	60	**100**	0	**93**	**100**
Hexagenia limbata	0	10	0	0	60	**80**	40	0	**100**
Pimephales promelas	0	0	10	**100**	**100**	**90**	0	10	20
December1									
Chironomus tentans	-	-	-	-	-	-	-	-	-
Hexagenia limbata	-	-	-	-	-	-	-	-	-
Chronic Toxicity - Change in Growth (%)2									
June									
Chironomus tentans	57	-27	-5	34	-84	-100	-63	-100	-100
Hexagenia limbata	221	-10	145	37	-16	-100	-19	-20	-100
December1									
Chironomus tentans	-	-	-	-	-	-	-	-	-
Hexagenia limbata	-	-	-	-	-	-	-	-	-

Middle Area Station	IS9-I	IS9-M	IS9-O	45-I	45-M	45-O	46-I	46-M5	46-O	IS12-I5	IS12-M5	12-O5	47-I5	47-M	47-O	22-I	22-M	22-O
Acute Toxicity (% Mortality)																		
June																		
Chironomus tentans	**100**	20	**93**	0	0	**100**	7	7	**87**	0	0	0	27	20	13	0	13	47
Hexagenia limbata	**100**	0	**90**	10	0	**100**	0	0	40	10	0	0	70	10	0	0	10	**80**
Pimephales promelas	**100**	20	60	0	10	20	20	10	10	**80**	**100**	0	0	**90**	0	**80**	**100**	0
December1																		
Chironomus tentans	**100/100/100**	0/0/7	**100/100/100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hexagenia limbata	**100/100/100**	0/0/0	**100/100/90**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chronic Toxicity - Change in Growth (%)2																		
June																		
Chironomus tentans	-100	-6	-100	24	-58	-100	39	-5	-100	32	9	21	-83	-32	15	47	17	-81
Hexagenia limbata	-100	88	-100	-15	1	-100	123	39	-15	76	235	35	-100	59	115	-8	121	-100
December1																		
Chironomus tentans	-100	-2	-100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hexagenia limbata	-100	-13	-100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Lower Area Station	IS14-I	IS14-M5	IS14-O	48-I	48-M	48-O	49-I	49-M	49-O	IS15-I	IS15-M	S15-O
Acute Toxicity (% Mortality)												
June												
Chironomus tentans	0	7	**100**	13	0	33	0	7	33	0	7	0
Hexagenia limbata	10	0	**80**	0	0	**100**	0	30	**100**	10	10	50
Pimephales promelas	30	**100**	60	**100**	10	20	40	30	**100**	10	0	0
December1												
Chironomus tentans	7/13/0	7/13/13	**93/100/100**	-	-	-	-	-	-	-	-	-
Hexagenia limbata	10/20/20	**90/90/80**	**100/100/100**	-	-	-	-	-	-	-	-	-
Chronic Toxicity - Change in Growth (%)2												
June												
Chironomus tentans	59	34	-100	23	30	-45	31	-26	22	44	-4	-49
Hexagenia limbata	5	244	-100	174	168	-100	127	-20	-100	222	6	-29
December1												
Chironomus tentans	14	30.8	-100	-	-	-	-	-	-	-	-	-
Hexagenia limbata	-48	-100	-100	-	-	-	-	-	-	-	-	-

1 Samples tested in triplicate
2 Growth at exposure stations expressed as % difference from reference station (Honey Harbour)
- parameter not measured or no applicable score
Acute toxicity level ³80%

3.4.1 *Chironomus tentans* - 10-Day Midge Larvae Lethality and Growth

Nine of the stations were characterised as highly toxic (>50% mortality) and three stations were considered moderately toxic (33 to 50%). Of the eight stations characterised by >80% mortality, six were located at the outer stations of transects (Transects 44, 20, IS9, 45, 46 and IS14). Figure 3.7 illustrates the various levels of toxicity to *Chironomus tentans* using GIS contour mapping. The most toxic sediments to *Chironomus tentans* were located in the Upper and Middle Areas.

Statistical analysis of the growth results at stations which had a sufficient number of surviving larvae indicated significantly lower growth rates ($p<0.0001$) at seven stations relative to the Honey Harbour Reference results (Bedard and Petro, 1997). These included Stations 44-M, 20-I, 45-M, 47-I, 22-I, 48-O and IS15-O, where the minimum decrease in fresh body weight was 45% and the maximum was 84%. The 100% or almost total mortality at Stations 44-O, 20-M, 20-O, IS9-I, IS9-O, 45-O, 46-O and IS14-O precluded inclusion of these stations in the analysis.

QA/QC testing of sediments collected from Transects IS9 and IS14 in December 1994 indicated similar acute toxicity results to those for samples collected at the same sites in June (Table 3.5).

3.4.2 *Hexagenia limbata* - 21-Day Mayfly Nymph Lethality and Growth

Eleven of the stations were characterised as highly toxic (>50% mortality) and three stations were moderately toxic (33 to 50%)(Bedard and Petro, 1997). Of the six stations characterised by >80% mortality, five were located at the outer stations along a transect (Transects 20, IS9, 45, 48 and 49). Figure 3.8 illustrates the areas of toxicity to *Hexagenia limbata* using GIS contour mapping. As seen with the *Chironomus* results, the largest area of sediment toxicity is located in the Upper and Middle Areas. The spatial toxicity patterns for both of these benthic invertebrate species were very similar.

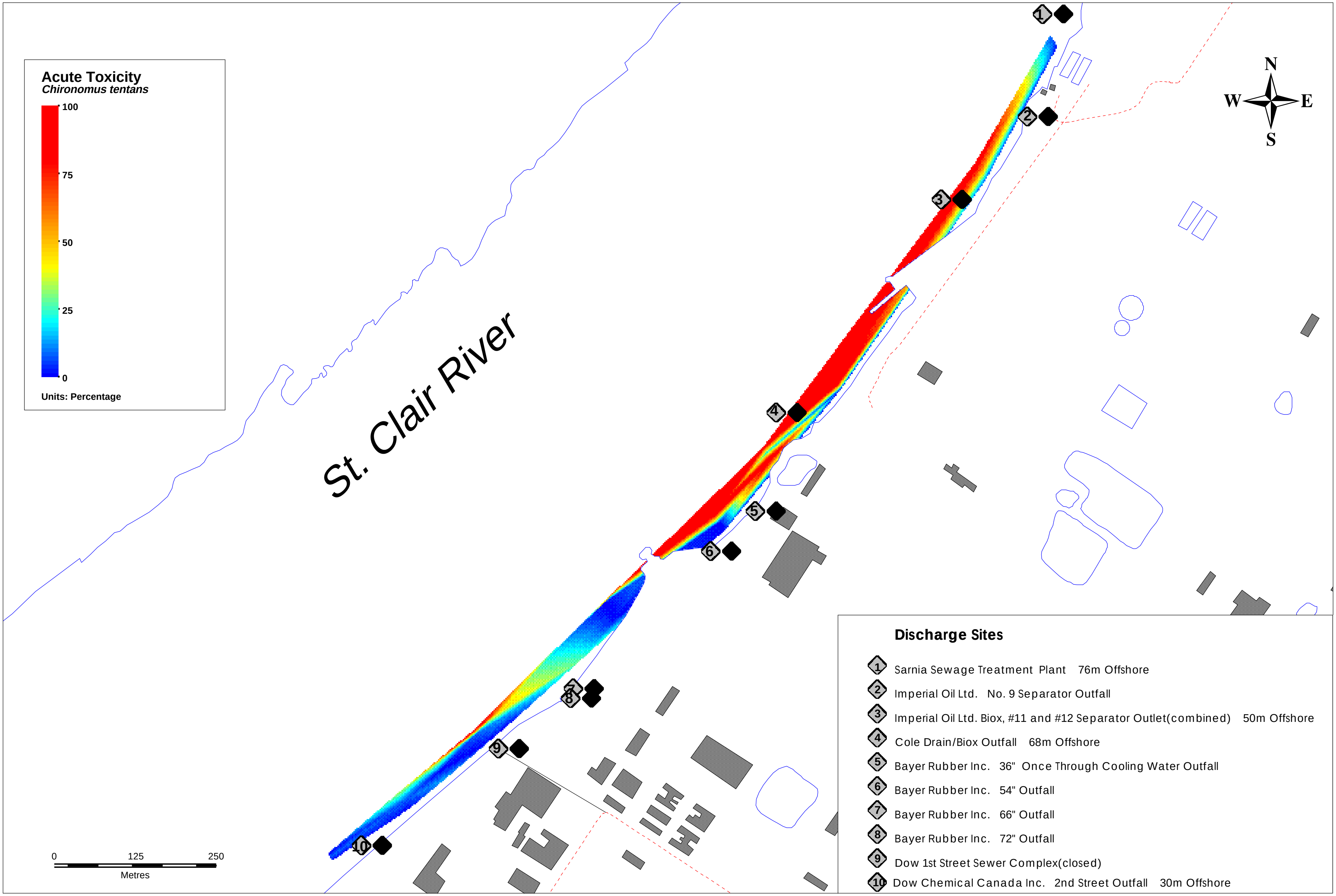


Figure 3.7 Acute Toxicity Results for *Chironomus tentans* - 1994

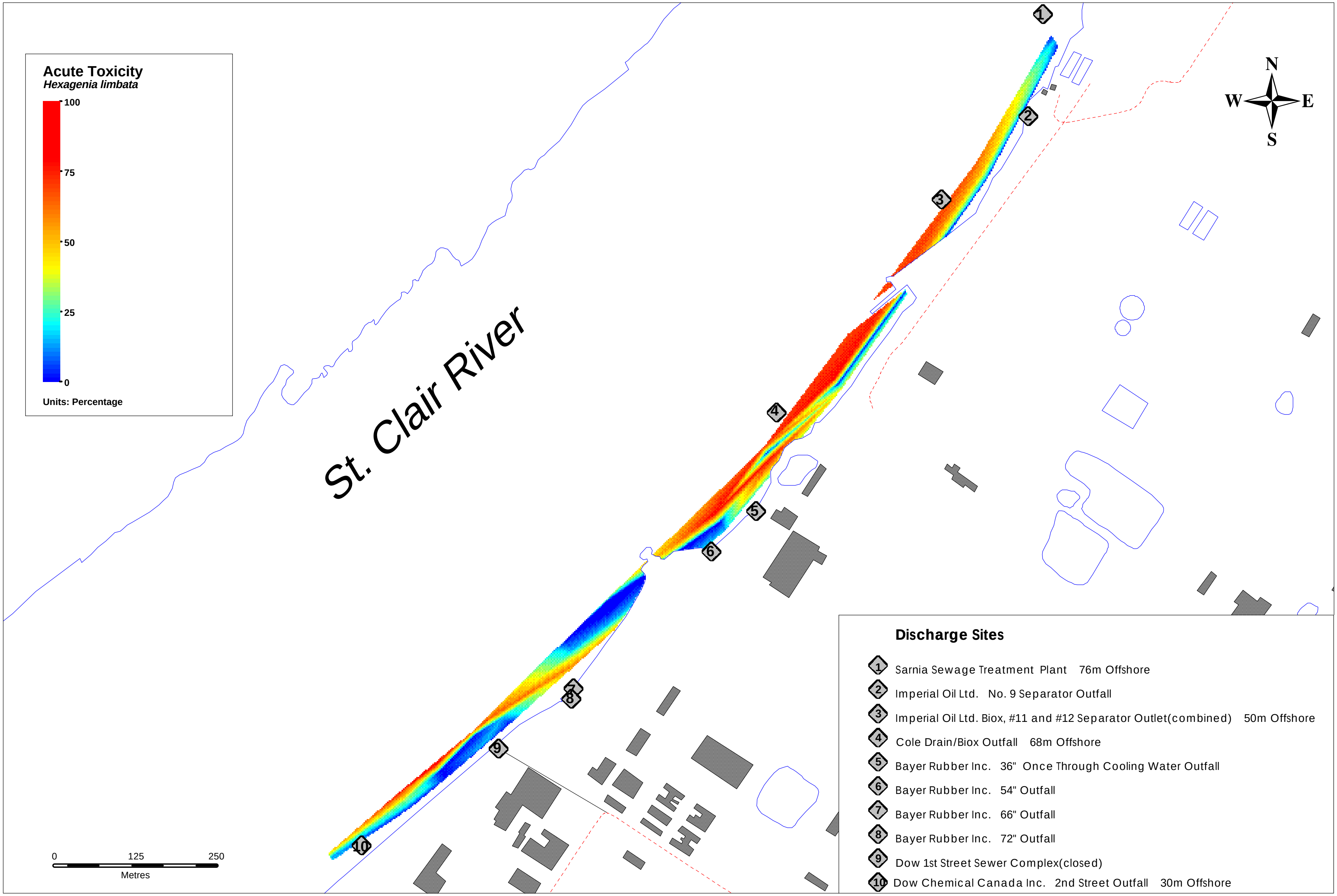


Figure 3.8 Acute Toxicity Results for *Hexagenia limbata* - 1994

Statistical analysis of the growth results at stations which had a sufficient number of surviving nymphs indicated significantly lower growth rates ($p<0.0001$) at five stations relative to the Honey Harbour Reference results (Bedard and Petro, 1997). These included Stations 20-I, 20-M, 45-I, 49-M and IS15-O, where the minimum decrease in fresh body weight was 15% and the maximum was 29%. The 100% or almost total mortality at Stations 44-O, 20-O, IS9-I, IS9-O, 45-O, 47-I, 22-0, IS14-O, 48-O and 49-O precluded inclusion of these stations in the analysis.

QA/QC testing of sediments collected from Transects IS9 and IS14 in December 1994 indicated similar acute toxicity results to those for samples collected at the same sites in June. The only notably difference occurred at Station IS14-M, where toxicity increased from 0% in June to >80% in the December sediment sample (Table 3.5).

It was observed during the bioassays that the majority of toxic sediments resulted in an immediate avoidance response (i.e., no burrowing, remained on surface), which is characteristic of a chemical stress (Bedard and Petro, 1997).

3.4.3 *Pimephales promelas* - 21-Day Fathead Minnow Lethality

Fourteen of the stations (44-I, 44-M, 44-O, IS9-I, IS9-O, IS12-I, IS12-M, 47-M, 22-I, 22-M, IS14-M, IS14-O, 48-I and 49-O) were characterised as highly toxic (≥60% mortality) and three stations were moderately toxic (20 to 60% mortality) and the remaining 22 stations were non-toxic(≤20% mortality)(Bedard and Petro, 1977). Of the ten stations characterised by >80% mortality, eight were located at the inner or mid-stations along a transect (Transects 44, IS9, IS12, 47, 22, IS14 and 48). Figure 3.9 illustrates the areas of sediment toxicity to fathead minnows, using GIS contour mapping. The spatial toxicity patterns for minnows are different than those observed with the invertebrate species, suggesting that the fish are responding to different contaminants than the invertebrates (e.g., water-based rather than sediment-associated). Unionized ammonia levels measured in the overlying waters indicated that some of the observed toxicity (i.e., at IS12-I and IS12-M) was associated with waterborne unionized ammonia. There also appears to be more toxic sediments within the Lower Area based on the minnow tests than observed with the invertebrate tests.

Figure 3.9 Acute Toxicity Results for *Pimephales promelas* - 1994

3.4.4 Fathead Minnow Tissue Contaminant Levels

Surviving fathead minnows were analysed for bioaccumulated compounds. In order to provide sufficient tissue material, surviving minnows were pooled along transects (i.e., fish from the 3 stations combined). Six compounds which were found above trace amounts in tissues included p,p´-DDE, total PCBs, HCBD, pentachlorobenzene, HCB and OCS (Table 3.6; Bedard and Petro, 1997).

Levels of p,p´-DDE were similar in the upstream (Transect 18) and downstream areas, reflecting some level of background contamination. Elevated levels of HCBD, relative to background levels, were measured at transects IS14 (10,676 μg/kg) and 48 (3,202 μg/kg), both downstream of the Dow 1st street discharge. Elevated levels of PCBs, pentachlorobenzene and hexachlorobenzene were also found downstream of the Dow 1st street discharge (Transects IS14, 48, 49 and IS15). OCS tissue concentrations were generally elevated downstream of the Cole Drain discharge (Transect IS9) as far downstream as Transect IS15, with concentrations ranging from 942 μg/kg to 16,956 μg/kg. The highest value was measured in fish exposed to sediments collected at Transect 48, located approximately 200 m downstream of the Dow 1st street discharge (Bedard and Petro, 1997).

3.5 Relationships Between Sediment Toxicity Endpoints and Sediment Chemistry

Initial investigations utilising the entire sediment chemistry data set indicated that midge and mayfly mortality and growth, and fathead minnow mortality were not clearly related to any of the measured parameters on an individual basis (Bedard and Petro, 1997). Bedard and Petro (1997) concluded, based on significant correlations of toxicity results with concentrations of solvent extractables, that the toxicity was probably indicative of a number of compounds that co-occur with solvent extractables rather than a direct consequence of any single chemical.

In an attempt to clarify the relationships between mortality and sediment chemistry, the study area was broken into two areas: Upper and Middle Areas and the Lower Area, and the

Table 3.6

correlations were again calculated. This separation of stations was similar to that suggested by the cluster analysis of sediment chemistry data (Section 3.2).

Results from the combined Upper and Middle Areas were similar to those for the combined data set. Several of the toxic sediments from this area were characterized in the field, in the toxicity laboratory and in the benthic processing laboratory as possessing a distinct chemical odour (Appendix 1. Table A1.3a). Petroleum-based substances were inferred as the principle toxicants in sediments in the Upper and Middle Areas. Total petroleum hydrocarbon sediment concentrations above 1500 μg/g (dry weight) were most frequently associated with higher organism toxicity (Bedard and Petro, 1997).

Correlation and linear regression analysis with the isolated Lower Area chemical data set substantially improved correlation factors and included several new parameters (Bedard and Petro, 1997). These included HCBD, HCE, trichlorobenzenes, tetrachlorobenzenes, total PCBs, HCB and OCS. These parameters were generally found at higher concentrations in the Lower Area. HCB concentrations were found to exceed the respective PSQG-SEL value (24 mg/kg; TOC-based), however, there was no significant correlation between HCB sediment concentrations and the toxic response of any of the test species. It was suggested that the observed toxic responses were the result of many chlorinated benzenes, several of which share a similar mode of toxic action (McCarty *et al.*, 1992).

3.6 Temporal Trends in Sediment Quality

Comparisons between the 1985 and 1994 upper St. Clair River sediment quality results required the matching of specific stations to those sampled in 1985, by matching the distance from shore along each transect (Table 3.7). These stations were 18-I, 20-M, IS9-I, IS12-I, 22-M, IS14-I and IS15-I. In most cases, these matches were within 2 m, however, in 2 cases, the differences were 5 m (IS14-I) and 9 m (IS15-I). Three parameters were found to differ significantly ($p<0.05$) between the two surveys: water depth, copper and zinc, all of which were lower in 1994. With the exception of TKN, HCB, octachlorostyrene and gravel, most parameters either remained unchanged overall or decreased slightly between the two surveys. The former four parameters increased overall from 1985 to 1994.

Table 3.7

Comparisons in sediment quality were also made between the 1990 and 1994 studies at coincident stations (Table 3.8). In order to compare between the two surveys, arithmetic means of the results from the inner and middle stations in 1994 were compared to the results from single composite samples at the same transects. The outer stations sampled in 1994 were well beyond (i.e., further offshore) the areas sampled in 1990 and therefore the data from the outer stations were not used for temporal comparisons.

Mean concentrations of metals, TKN, TP, solvent extractables and particle size distribution (Table 3.8) indicated that over the entire study area, contaminant levels have remained relatively unchanged since 1990. Levels of hexachlorobenzene increased slightly from 1990 to 1994, with higher levels recorded, particularly at Transect IS14. PAH concentrations generally decreased substantially compared to 1990 levels. Overall, statistical analysis (paired T-tests using results from Transects 18, 20, IS9, IS12, 22, IS14 and IS15) indicated that none of the parameters changed significantly ($p>0.05$) between the two surveys. These results were due, at least in part, to the trends at some transects (generally Transects 18 and 20) which were opposite to those observed at the other transects (Table 3.8). However, this comparison does not include the additional (i.e., new) stations sampled in 1994, some of which had much higher sediment contaminant levels (e.g., mercury along Transects 48 and 49).

TABLE 3.8: COMPARISON OF CONTAMINANTS IN SURFICIAL SEDIMENTS FROM STATIONS IN THE UPPER ST. CLAIR RIVER - 1990 AND 1994

		Transect															
		18		20		IS9		IS12		22		IS14		IS15		Mean	
		1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994	1990	1994
Copper	mg/kg	80	86.9	26.3	29.8	31	30.0	28.3	28.0	46.3	24.5	35.5	24.5	19.7	16.0	38.2	34.2
Nickel	mg/kg	22	8.3	14	12.7	12	16.6	24	23.5	21	12.9	22.7	11.2	16	7.0	18.8	13.1
Lead	mg/kg	26	24.1	18	23.2	16	19.0	25.3	23.1	20.3	42.0	17.7	12.1	13	7.1	19.5	21.5
Zinc	mg/kg	250	250	89.7	71.7	81	61.5	77.7	69.5	84	113.0	97	72.8	50	42.0	104.2	97.2
Arsenic	mg/kg	3.9	4.1	3.8	4.8	4.3	5.4	5.2	4.9	3.5	4.8	4.5	3.5	3.4	2.9	4.1	4.3
Chromium	mg/kg	9.8	9.1	9.7	9.8	11	11.8	17.3	13.3	14	19.5	14.3	10.7	11.3	8.8	12.5	11.9
Mercury	mg/kg	0.05	0.1	0.05	0.0	0.11	0.2	0.22	0.4	1.4	0.6	3.6	5.7	10.8	18.5	2.3	3.6
Iron	mg/kg	8100	8064	7200	11929	8700	37300	12667	12157	8467	9700	9667	10000	8600	8500	9057	13950
Cadmium	mg/kg	0.25	0.5	0.05	0.4	0.76	0.7	0.1	0.5	0.27	0.7	0.22	0.4	0.15	0.2	0.3	0.5
LOI	mg/kg	15	15.8	16.3	18.2	17	18.5	45	38.6	30.3	30.5	32.7	8.8	13.5	10.4	24.3	20.1
Total Phosphorus	g/kg	0.15	0.2	0.2	0.2	0.19	0.2	0.45	0.4	0.31	0.3	0.33	0.2	0.22	0.2	0.26	0.24
TKN	mg/kg	0.67	0.7	0.68	0.5	0.78	0.6	1.69	1.2	0.85	1.2	1.08	0.4	0.47	0.4	0.89	0.70
Calcium	mg/kg	50000	51329	50500	46415	54000	44500	57300	59454	57833	50500	62783	57992	53867	62500	55183	53241
Chloride	mg/kg	18	34.6	27.3	10.8	15	31.0	45	71.8	21	28.0	135	112.8	28	33.5	41.3	46.1
TOC	mg/kg	11	11.4	8.8	8.0	13	15.0	28.3	32.0	17.2	16.1	19.5	6.7	7.3	6.2	15.0	13.6
Gravel	%	42.2	2.4	6.1	15.1	1.6	10.6	1.9	1.3	22	12.6	4.2	19.7	33.7	42.6	16.0	14.9
Sand	%	47.6	78.8	75.8	61.0	66.1	70.0	72.1	66.6	29.8	58.1	62.6	70.5	55.1	47.8	58.4	64.7
Silt+Clay	%	10.2	18.8	18.1	24.0	32.3	19.5	5.9	32.3	68.3	29.4	33.2	9.9	11.2	4.7	25.6	19.8
Solvent Extractables	mg/kg	735	823	626	958	891	1088	1272	1870	1870	1778	1650	623	1475	543	1217	1098
Hexachlorobenzene	µg/kg	0	9.9	12	6.0	1020	190	322	138	876	1225	29039	76559	1473	3550	4677	11668
Octachlorobenzene	µg/kg	0	0.9	17	4.8	3020	620.0	123	148.3	1263	455	2145	3471	512	207	1011	701
Octachlorostyrene	µg/kg	-	1.0	-	5	-	620	-	149	-	455	-	3471	-	207	-	701
Total PCBs	µg/kg	-	<20	-	<20	-	<20	-	71	-	180	-	1276	-	310	-	459
Phenanthrene	µg/kg	250	197	550	990	880	720	1470	700	2460	640	625	153	12550	240	2684	520
Anthracene	µg/kg	40	5.4	90	92.9	340	120.0	290	5.4	397	40.0	77.5	0.0	1570	0.0	400.6	37.7
Fluoranthene	µg/kg	160	170	570	457	440	490	1140	724	1990	610	610	123	9530	200	2063	396
Pyrene	µg/kg	180	180	560	670	720	620	1230	795	1790	510	647.5	87	7570	260	1814	446
Benzo(a)anthracene	µg/kg	70	171	240	463	250	180	450	247	650	120	347.5	72	2640	65	664	188
Chrysene	µg/kg	120	210	360	713	480	310	560	427	760	190	287.5	98	3170	105	820	293
Benzo(k)Fluoranthene	µg/kg	0	54	60	112	30	60	230	160	440	120	255	28	1240	20	322	79
Benzo(b)Fluoranthene	µg/kg	0	97	190	292	130	110	510	209	910	120	547.5	66	2720	30	715	132
Benzo(a)Pyrene	µg/kg	70	11	140	164	160	100	390	2	480	100	292.5	9	1990	0	503	55

Values present at the detection limit were considered equal to 0

4.0 BENTHIC MACROINVERTEBRATE COMMUNITY STRUCTURE

Benthic macroinvertebrate data for individual replicate samples are provided in Appendix 1 (Table A1.5) and the mean community assemblage for each station, expressed per m^2, is provided in Table A1.6. Summary statistics for individual invertebrate taxa at each station across replicates are available only in electronic format from the OMOEE (Environmental Monitoring and Reporting Branch, Surface Water Section, Etobicoke or Southwestern Region, London). An example of the format is presented in Table A1.7.

4.1 Taxa Composition and Occurrence

A total of 111 macroinvertebrate taxa were identified in the 1994 upper St. Clair River samples, not including immature oligochaetes and pupae (Table 4.1). The dominant groups were oligochaetes, which were represented by 29 species, and chironomids, which were represented by 33 genera.

Table 4.1 lists the taxa found in the 1994 survey in conjunction with their respective frequency of occurrence among stations and replicates. The most commonly encountered taxon in the study area was nematodes, which occurred in 113 of the 117 samples and at all 39 stations. This taxon is considered to be moderately tolerant of anthropogenic impacts (Golini, 1979). Other common taxa occurring at more than 85% of the stations were the chironomids *Polypedilum* and *Phaenopsectra*, the oligochaetes *Limnodrilus hoffmeisteri*, *L. udekemianus* and immature tubificids without hair chaetae, the snail *Amnicola limosa* and the zebra mussel *Dreissena polymorpha*.

Chironomid pupae were recorded at 35 (92%) of the 39 stations, indicating that chironomids and possibly other emergent insects were emerging during the sampling period. Since the sampling period extended from 02 to 16 June, the density and diversity of some of the insect taxa may be underestimated and somewhat biased among the stations depending on the elapsed collection time among stations.

E 4.1: OCCURRENCE OF MACROINVERTEBRATES IN THE ST. CLAIR RIVER, 1994

Taxon	Occurrence[1] Replicates	Stations	Taxon No.	Taxon	Occurrence[1] Replicates	Stations
Hydra	64	30	59	*Hydroptila*	2	1
Nematoda	113	39	60	Leptoceridae - indeterminate	1	1
Tardigrada	5	3	61	*Ceraclea*	1	1
Turbellaria	16	10	62	*Mystacides*	1	1
Prostoma	31	22	63	*Oecetis*	1	1
Enchytraeidae	11	9	64	*Neureclipsis*	4	3
Nais barbata	36	21	65	Pyralidae - indeterminate	20	11
Nais behningi	1	1	66	Chrysomelidae - indeterminate	1	1
Nais bretscheri	21	13	67	Circulionidae - indeterminate	2	2
Nais elinguis	1	1	68	*Probezzia*	2	2
Nais pardalis	11	7	69	Chironomidae pupae	81	35
Nais simplex	2	2	70	*Axarus*	1	1
Nais variabilis	20	16	71	*Chironomus*	6	5
Ophidonais serpentina	22	12	72	*Cladotanytarsus*	4	4
Paranais frici	4	3	73	*Cryptochironomus*	57	28
Vejdovskyella intermedia	1	1	74	*Cryptotendipes*	1	1
Aulodrilus americanus	1	1	75	*Demicryptochironomus*	38	24
Bothrioneurum vejdovskyanum	4	3	76	*Dicrotendipes*	41	22
Ilyodrilus templetoni	35	20	77	*Harnischia*	2	2
Isochaetides freyi	2	2	78	*Glyptotendipes*	4	4
Limnodrilus claparedianus	37	25	79	*Parachironomus*	2	2
Limnodrilus hoffmeisteri	106	38	80	*Paracladopelma*	9	7
Limnodrilus maumeensis	4	4	81	*Paralauterborniella*	18	17
Limnodrilus udekemianus	90	37	82	*Paratanytarsus*	2	2
Potamothrix moldaviensis	61	28	83	*Paratendipes*	59	26
Potamothrix vejdovskyi	15	12	84	*Phaenopsectra*	74	33
Quistadrilus multisetosus	32	19	85	*Polypedilum*	110	39
Spirosperma ferox	51	26	86	*Pseudochironomus*	2	2
Tubifex ignotus	4	4	87	*Stempellina*	7	6
Tubifex tubifex	4	4	88	*Stempellinella*	3	2
immatures with hair chaetae	17	12	89	*Stictochironomus*	37	22
immatures without hair chaetae	111	39	90	*Tanytarsus*	67	32
Stylodrilus heringianus	36	20	91	*Tribelos*	71	28
Manayunkia speciosa	3	2	92	*Pagastia*	1	1
Mooreobdella microstoma	9	6	93	*Cricotopus*	26	16
Harpacticoida	20	14	94	*Epoicocladius*	4	4
Ostracoda	2	2	95	*Heterotrissocladius*	7	7
Hydracarina	72	33	96	*Hydrobaenis*	2	2
Crangonyx	1	1	97	*Paracladius*	4	3
Gammarus	25	18	98	*Psectrocladius*	12	8
Hyallela azteca	2	2	99	*Monodiamesa*	31	18
Caecidotea	7	6	100	*Ablabesmyia*	30	17
Baetidae - indeterminate	1	1	101	*Procladius*	79	32
Baetisca	4	4	102	*Thienemannimyia complex*	44	25
Caenis	4	4	103	*Hemerodromia*	7	7
Ephemera	4	4	104	*Pericoma*	3	2
Hexagenia	30	20	105	*Psychoda*	1	1
Ephemerella	7	6	106	*Ferrissia*	3	2
Stenonema	1	1	107	*Amnicola limosa*	93	37
Stenonema femoratum	2	2	108	*Stagnicola catascopium*	1	1
Stenonema terminatum	7	6	109	*Gyraulus*	15	10
Isoperla	1	1	110	*Elimia livescens*	37	18
Trichoptera pupae	2	1	111	*Physella*	12	8
Protoptila	2	2	112	*Dreissena polymorpha*	89	35
Cheumatopsyche	38	24	113	*Dreissena bugensis*	5	3
Hydropsyche dicantha	1	1	114	*Pisidium*	52	25
Hydropsyche scalaris	38	20	115	*Sphaerium striatinum*	4	3
Agraylea	5	3				

number of replicates = 117, stations = 39

4.2 Biotic Indices

The biotic indices, including the breakdown of functional feeding groups calculated for each station, are provided at the end of the taxa densities in Appendix 1 (Table A1.6). A summary of the key biotic indices are provided in Table 4.2.

The total number of taxa at stations ranged from 17 at Station 45-O to 46 at Stations 44-M, 45-M and 14-M (Table 4.2). Total macroinvertebrate densities ranged from 843 to 124,126 individuals/m^2, at Stations 45-O and IS12-M, respectively. Zebra mussels comprised 54% of the community at Station IS12-M; however, they did not account for greater than 15% of the community at any other station. Zebra mussels were not found in the 1990 St. Clair River study. Tubificids and chironomids comprised 3.9% to 90% and 1.8% to 62.3%, respectively of the community.

Shannon-Wiener diversity index values for Study Zone 1 in the upper St. Clair River indicated that 22 stations had a diversity value $\geq$3.5, suggestive of healthy, diverse communities. Indices at another eight stations ranged from 3.1 to 3.4, suggestive of slight to no impact. Nine stations had Shannon-Wiener diversity values in the range of 2.0 to 3.0, indicative of slight to moderate impact (Wilhm and Dorris, 1968). Station IS12-M, one of the stations with a Shannon-Wiener diversity value less than 3, had high densities of zebra mussels, which comprised 54% of the community. In general, a benthic macroinvertebrate community with relatively high diversity reflects moderate densities of a large number of taxa in the community and may reflect good water and sediment quality. In contrast, low diversity values reflect high abundance of a few taxa and may indicate an impaired community. It must be cautioned, however, that a low diversity may also result from natural habitat deficiencies or high densities of particular taxa (e.g., zebra mussels) and may not be related to impaired water or sediment quality. Likewise, a high diversity can result from low-level toxic effects which can reduce invertebrate densities evenly within the benthic community. It is also common that under some anthropogenic effects the diversity and density of pollution-tolerant taxa increase, resulting in higher diversity values. This is the case for the 1994 data where stations are characterised by highly diverse communities of pollution-tolerant taxa and consequently have high Shannon-Wiener diversity values (i.e., suggestive of good water and sediment quality) representing degraded and impaired

TABLE 4.2: MACROINVERTEBRATE BIOTIC INDICES FOR STATIONS IN THE UPPER ST. CLAIR RIVER, JUNE 1994

		Total																	
	Number	Density		Diversity Indices			Evenness			Hilsenhoff				% Relative Density					
Station	of Taxa	(no./m²)	Shannon	Brillouin's	Hurlbert's PIE	McIntosh's M	(J)	Richness	EPT Index	Biotic Index	Nematoda	Naididae	Tubificidae	Lumbriculidae	Trichoptera	Chironomidae	Gastropoda	Sphaeriidae	Zebra mussels
18-I	45	26921	3.704	2.560	0.893	0.678	0.674	4.493	7	8.2	5.3	0.0	54.8	0.0	0.6	20.5	12.0	0.4	1.0
18-M	45	29480	3.452	2.386	0.868	0.641	0.629	4.453	8	8.5	1.6	0.0	61.6	0.0	0.3	19.8	4.9	0.1	1.0
18-O	25	945	3.754	2.521	0.901	0.713	0.808	3.736	4	8.2	0.6	0.0	44.8	0.0	2.7	22.2	12.9	0.6	12.9
44-I	34	32712	3.698	2.558	0.881	0.659	0.727	3.304	1	8.8	3.3	2.6	61.3	0.0	0.0	27.5	2.8	1.6	0.5
44-M	46	47228	3.465	2.397	0.832	0.594	0.627	4.346	5	8.9	11.9	0.0	64.3	0.9	0.6	9.0	7.8	0.8	0.3
44-O	34	11808	3.701	2.553	0.892	0.679	0.728	3.680	5	7.8	6.5	0.0	41.9	0.0	2.3	11.8	22.3	4.4	9.1
20-I	18	2724	2.922	2.002	0.829	0.600	0.701	2.267	0	8.7	6.3	0.0	61.2	0.0	0.0	32.0	0.0	0.0	0.0
20-M	24	12416	2.171	1.497	0.689	0.447	0.473	2.550	3	9.8	2.3	0.0	90.0	0.0	0.0	6.0	0.6	0.0	0.2
20-O	27	893	3.910	2.618	0.909	0.727	0.822	4.078	5	8.1	16.4	0.7	29.2	2.9	1.3	27.3	5.0	1.5	7.2
IS9-I	39	10877	3.765	2.595	0.859	0.632	0.712	4.278	4	9.0	3.0	10.3	64.6	0.8	0.1	15.4	1.7	0.0	0.4
IS9-M	44	33945	3.897	2.695	0.896	0.682	0.714	4.290	3	8.7	2.0	4.9	61.5	0.0	0.3	18.9	6.3	0.2	0.9
IS9-O	35	12841	3.593	2.478	0.855	0.626	0.700	3.759	4	8.8	2.8	2.8	65.4	0.7	2.8	17.5	1.6	0.6	1.8
45-I	25	2447	2.695	1.833	0.668	0.434	0.580	3.248	0	7.0	5.2	14.5	12.3	0.0	0.0	62.3	0.0	0.0	0.0
45-M	46	8135	4.278	2.943	0.927	0.739	0.775	5.235	5	8.2	16.1	7.3	38.0	2.2	1.6	20.9	4.8	0.3	0.6
45-O	17	843	2.453	1.643	0.690	0.463	0.600	2.526	0	9.5	3.0	0.7	85.8	0.0	0.0	2.1	4.6	1.6	0.0
46-I	23	12888	3.358	2.320	0.870	0.646	0.742	2.429	2	9.1	2.3	0.5	73.3	0.0	0.2	21.8	0.8	0.0	0.0
46-M	28	25476	2.930	2.026	0.757	0.511	0.609	2.772	1	9.1	1.3	6.9	76.2	1.5	0.1	12.3	0.7	0.0	0.1
46-O	25	886	3.608	2.416	0.874	0.671	0.777	3.769	1	7.1	25.2	2.9	23.8	17.3	4.4	16.4	2.2	0.0	2.2
IS12-I	36	22487	3.495	2.415	0.867	0.641	0.676	3.640	2	8.7	3.0	0.7	62.0	0.0	0.0	31.6	1.2	0.1	0.4
IS12-M	32	1E+05	2.603	1.803	0.686	0.442	0.521	2.738	1	8.1	1.1	3.9	24.7	0.0	0.0	1.8	12.5	0.1	53.5
IS12-O	27	2308	3.401	2.316	0.832	0.605	0.715	3.548	1	8.2	3.1	0.0	48.0	1.4	0.0	32.0	4.7	0.8	7.5
47-I	33	3367	3.041	2.075	0.778	0.540	0.603	4.154	2	7.8	5.1	1.5	38.6	0.9	0.2	48.9	0.6	0.2	0.4
47-M	38	44343	3.590	2.484	0.876	0.651	0.684	3.595	4	8.0	3.8	25.5	44.5	0.0	0.7	10.8	7.9	0.3	4.2
47-O	36	4176	3.395	2.323	0.827	0.595	0.657	4.414	3	7.9	1.1	0.0	40.9	0.6	0.3	47.1	5.7	1.8	0.1
22-I	28	6741	3.000	2.064	0.813	0.576	0.624	3.213	1	9.0	1.4	0.5	71.1	0.0	0.3	24.1	1.1	0.3	0.4
22-M	37	44881	3.018	2.089	0.838	0.601	0.579	3.493	2	8.9	0.2	14.5	73.8	0.0	0.0	2.0	7.0	0.2	0.4
22-O	39	3687	3.809	2.602	0.863	0.642	0.721	4.884	3	8.8	4.4	5.5	57.5	1.1	0.3	22.6	1.5	0.9	2.4
IS14-I	22	855	3.511	2.353	0.882	0.684	0.787	3.337	0	7.7	6.7	52.4	9.6	0.7	0.0	21.7	1.4	0.0	1.6
IS14-M	46	9994	3.941	2.713	0.889	0.675	0.714	5.116	3	8.8	1.8	9.8	58.9	0.6	0.4	21.0	1.4	0.2	3.6
IS14-O	34	2997	3.841	2.621	0.887	0.679	0.755	4.351	3	6.6	4.3	38.5	3.9	3.9	0.7	9.8	4.5	0.0	9.0
48-I	30	7347	3.126	2.151	0.817	0.580	0.637	3.415	1	8.5	1.7	1.3	57.4	0.0	0.0	37.9	0.4	0.0	0.3
48-M	31	16776	3.517	2.429	0.862	0.634	0.710	3.218	3	9.3	1.2	3.0	77.1	0.0	1.1	13.0	1.5	0.2	0.5
48-O	31	4435	4.101	2.815	0.921	0.732	0.828	3.756	3	7.4	5.1	23.1	20.8	17.0	4.5	15.0	0.4	0.0	11.4
49-I	38	6685	3.847	2.644	0.891	0.680	0.733	4.414	2	8.5	14.6	38.2	24.5	0.0	0.2	18.0	1.1	0.2	0.9
49-M	40	8916	3.738	2.573	0.866	0.642	0.702	4.493	3	7.8	3.7	14.5	30.6	0.3	0.0	48.1	0.4	0.0	0.4
49-O	36	2144	3.588	2.433	0.856	0.637	0.694	4.832	5	6.6	3.3	1.5	8.7	26.5	2.1	15.4	16.1	1.5	19.7
IS15-I	32	6596	3.392	2.333	0.853	0.627	0.678	3.698	3	9.1	1.5	1.5	74.2	1.9	0.5	12.5	6.9	0.0	0.2
IS15-M	33	2169	3.877	2.636	0.893	0.690	0.769	4.409	3	6.9	2.4	10.7	20.3	24.8	0.9	19.8	10.4	0.6	3.5
IS15-O	26	2612	3.456	2.360	0.868	0.652	0.735	3.353	2	6.5	2.5	0.0	14.0	23.5	3.4	13.5	20.6	1.0	12.5

benthic communities (Table 4.2). For these reasons biotic indices are not used as sole descriptors of the benthic community at a particular site without taking into account the macroinvertebrate assemblages, exposure to contaminants and natural habitat characteristics.

The Brillouin's, Hurlbert's PIE, and McIntosh's M indices followed a similar pattern to the Shannon-Wiener diversity index. Evenness values were closely associated with the diversity values, with the lowest values occurring at the stations with the lowest diversity.

Hilsenhoff Biotic Index (HBI) values were all greater than 6, with the majority greater than 7.5, suggestive of poor to very poor water quality (Hilsenhoff, 1987). Only Station IS15-O was characterized by a HBI value indicative of fair water quality.

It should be noted that the pollution-tolerance evaluation used the HBI and discussed further in this section relates primarily to organic enrichment. In general, these tolerances are similar to those exhibited for metals, however there are some differences. Relative tolerances of benthic macroinvertebrates to organic chemicals is not well known and, consequently, are not discussed in this report.

4.3 Summary Statistics

The summary statistics (available in electronic format only) indicated that the level of variation (coefficient of variation or CV) among replicates at each station was generally high for individual taxa. The coefficient of variation for untransformed total density data exceeded the generally accepted level of 30% at 26 of the 39 stations and was less than 20% at only seven stations. Log_{10} transformation of the density data (log(x+1)) resulted in an overall improvement of the CVs relative to the untransformed data. The coefficient of variation for log-transformed data exceeded the generally accepted level of 30% at only 1 of the 39 stations and was generally less than 20% at most stations.

Tests for homogeneity of variance and normality using the replicate total density data indicated that neither the untransformed or $\log_{10}$ (x+1)-transformed data generally satisfied these requirements ($p<0.05$). ANOVAs performed on the untransformed, $\log_{10}$-transformed data and ranked data (Kruskal-Wallis non-parametric ANOVA) indicated that there were significant ($p<0.001$) differences in the number of individuals among stations (Table A1.8).

4.4 Quantitative Cluster Analysis

Analyses of the quantitative data were performed using $\log_{10}(x+1)$ transformations of the station data presented in Table A1.6, Appendix 1. The various clustering methods employed produced different patterns of station similarities, with little overlap. Table 4.3 demonstrates the concordance of station groupings among the different clustering techniques. The highest level of similarity was between the Bray-Curtis average link agglomeration technique and the non-hierarchical technique (K-means).

An alternative approach involved dividing the stations into shallow water (<4 m depth) and deep water (>4 m) groups (Appendix 4). The separation of stations based on water depth did not appreciably improve the results and, therefore, the complete data set was used. Overall, the different cluster analyses indicated that there was very little difference in benthic macroinvertebrate community structures among all of the stations, including the reference stations at Transect 18. All of the stations in the study were characterised by benthic macroinvertebrate communities reflecting impaired to degraded environmental conditions.

In order to determine if the measured sediment chemistry had any influence on the quality of the benthic macroinvertebrate community, the benthic cluster solution that provided the greatest concordance with at least one other benthic cluster solution and which demonstrated significant differences in some of the benthic metrics characterizing each cluster group was selected for further evaluation. The solution which satisfied these requirements was the non-hierarchical (K-means) approach which also appeared to produce discrete benthic clusters which were also similar to station groupings revealed by correspondence and principal components analyses. Consequently, results of the non-hierarchical method are presented and discussed in detail. The non-hierarchical method was also used for the 1985 and 1990 studies. Results of all of the cluster techniques evaluated for this study are provided in Appendix 4.

TABLE 4.3: LEVEL OF SIMILARITY BETWEEN DIFFERENT CLUSTERING TECHNIQUES FOR UPPER ST. CLAIR RIVER BENTHIC MACROINVERTEBRATE COMMUNITY DATA

	5-Cluster Solution Clustering Technique						6-Cluster Solution Clustering Technique					
	B-C	M-H	Ward's	K-Means	PSC	Jaccard	B-C	M-H	Ward's	K-Means	PSC	Jaccard
B-C	1	72	62	21	51	56						
M-H	28	1	67	28	51	72						
Ward's	24	26	1	51	31	38						
K-Mean	8	11	20	1	18	23						
PSC	20	20	12	7	1	51						
Jaccard	22	28	15	9	20	1						
B-C							1	59	56	38	18	38
M-H							23	1	62	51	41	49
Ward's							22	24	1	79	31	46
K-Means							15	20	**31**	1	28	44
PSC							7	16	12	11	1	31
Jaccard							15	19	18	17	12	1

Note: Values below diagonal are number of stations found in same cluster between techniques
Values above diagonal are percent of total
B-C = Bray-Curtis and UPGMA
M-H = Morisita Horn and UPGMA
PSC = Percent Similarity Coefficient and UPGMA

Six cluster groups were identified in the analysis of the 1994 survey data. The physical, chemical and biological characteristics of the station clusters are provided in Table 4.4. Biological characteristics include mean values for number of taxa, total density, diversity indices and the relative densities of major taxonomic groups. The pollution tolerance levels of invertebrate taxa referred to in the following sections generally follow Klemm *et al*., 1990; Hilsenhoff, 1988 and Dr. R.W. Bode (Stream Biomonitoring Unit, NY State Dept. of Environmental Conservation, pers. comm., 1996).

Cluster 1

The eight stations that were grouped in this cluster (IS9-I, IS9-M, IS9-O, IS14-M, IS18-M, 44-O, 45-M, 49-M) were located along the entire length of the 1994 St. Clair River study zone. Sediments at stations in Cluster Group 1 were predominantly silty fine sand and gravel, with mean contaminant concentrations slightly exceeding the LEL values for TKN, TOC, copper and mercury and the SEL value for hexachlorobenzene (Table 4.4). Sediments from three of the six stations located in the Upper and Middle Areas were characterized as toxic to one of the laboratory test species. The toxicity did not appear to be associated with the measured sediment chemistry (Bedard and Petro, 1997), and was assumed to be due to either elevated ammonia levels in the test water or to unmeasured water soluble petroleum products in the sediment. The toxicity did appear to be associated with the presence of an obvious petrochemical odour in the sediments (Table 4.5). Toxicity at Station IS14-M was believed to be associated with elevated levels of chlorinated benzenes and mercury (Bedard and Petro, 1996). Most of the stations in Cluster Group 1 were characterised by a high percentage of tubificid oligochaetes (53%) ranging from 31% to 65% of the assemblages and characterized by species that are considered highly pollution tolerant. Chironomids comprised another 22% of the community, represented primarily by pollution-tolerant taxa (e.g. *Phaenopsectra*, *Polypedilum*, *Cryptochironomus*, *Demicryptochironomus*, *Tribelos*, *Procladius* and *Thienemannimyia* complex). Overall, the macroinvertebrate occurrences at stations within Cluster Group 1 would be considered indicative of a moderately impaired environment. Mean density was 13,637 organisms/m^2.

An average of 41 taxa were characteristic of the Cluster 1 stations which was significantly ($p<0.05$) higher than the number of taxa found in Clusters 2, 4 and 6. The EPT index value of

TABLE 4.4: CHARACTERISTICS OF THE 1994 UPPER ST. CLAIR RIVER STATION CLUSTERS

Cluster Number 1 2 3 4 5 6 PSQG PSQG
Number of Stations Units 8 15 3 7 3 3 LEL SEL OWDG² EC

		Cluster Number 1	2	3	4	5	6	PSQG	PSQG		
Number of Stations	Units	8	15	3	7	3	3	LEL	SEL	OWDG[2]	EC
Biological Characteristics											
Total Number[1] of Organisms		13,637	3,357	62,746	2,273	34,647	21,261	-	-	-	-
Total Number of Taxa		41	27	36	31	42	32	-	-	-	-
Shannon-Wiener Diversity Index		3.796	3.192	3.070	3.767	3.622	3.314	-	-	-	-
Evenness (J)		0.709	0.673	0.595	0.763	0.676	0.665	-	-	-	-
Richness		4.413	3.434	3.275	4.124	4.048	3.210	-	-	-	-
Brillouin's Diversity Index		2.617	2.177	2.125	2.560	2.505	2.290	-	-	-	-
Hurlbert's PIE		0.881	0.814	0.800	0.886	0.869	0.829	-	-	-	-
McIntosh's M		0.664	0.590	0.565	0.682	0.644	0.595	-	-	-	-
Keefe's TU		0.881	0.813	0.800	0.885	0.869	0.828	-	-	-	-
EPT Index		4	2	2	2	4	2	-	-	-	-
EPT/Chironomide Index		0.07	0.05	0.04	0.13	0.04	0.03	-	-	-	-
Hilsenhoff Biotic Index		8.4	8.4	8.3	7.3	8.6	9.0	-	-	-	-
Hydra	%	2.6	1.0	0.7	4.6	2.2	0.3	-	-	-	-
Nematoda	%	4.7	3.8	1.7	8.8	6.9	1.9	-	-	-	-
Naidid Oligochaetes	%	6.2	1.8	14.6	23.9	0.9	3.5	-	-	-	-
Tubificid Oligochaetes	%	52.8	53.2	47.7	16.0	60.1	71.8	-	-	-	-
Lumbriculidae	%	0.6	2.2	0.0	12.9	0.3	0.5	-	-	-	-
Chironomidae	%	21.7	27.5	4.9	16.6	19.0	19.0	-	-	-	-
Gastropoda	%	5.4	4.4	9.1	5.2	7.5	1.1	-	-	-	-
zebra mussels	%	2.2	2.9	19.4	6.9	0.6	0.3	-	-	-	-
Gatherers	%	69.1	65.7	63.5	66.7	75.0	81.8	-	-	-	-
Predators	%	5.1	4.2	2.1	7.0	5.2	3.2	-	-	-	-
Scrapers	%	8.4	5.0	9.4	6.9	7.7	1.9	-	-	-	-
Shredders	%	11.1	18.5	2.1	6.3	8.3	11.5	-	-	-	-
Filterers	%	4.3	4.7	20.0	9.9	2.6	1.3	-	-	-	-
Physical and Chemical Characteristics[2]											
Water Velocity	m/s	0.20	0.12	0.07	0.47	0.26	0.12	-	-	-	-
Water Depth	m/s	3.6	3.1	4.0	4.5	1.6	3.8	-	-	-	-
Wet Density	g/cm^3	1.7	1.8	1.4	1.9	1.7	1.6	-	-	-	-
LOI	%	20.0	20.8	37.2	14.0	14.6	42.3	-	-	-	-
TOC	g/kg	**15.0**	**13.2**	**28.0**	**10.3**	**10.0**	**33.1**	10	100	-	-
Calcium	mg/kg	46696	46770	56986	49696	50651	54523	-	-	-	-
Chloride	mg/kg	27	20	43	34	23	33	-	-	-	-
Potassium	mg/kg	1014	1040	1563	592	693		-	-	-	-
Sodium	mg/kg	188	156	196	156	116	174	-	-	-	-
Ammonium	mg/kg	2.6	1.9	12.3	1.1	2.4	1.9	-	-	-	-
TKN	g/kg	**0.6**	**0.6**	**1.6**	0.4	**0.7**	**0.9**	0.550	4.800	-	-
Nitrates	g/kg	0.002	0.002	0.008	1.001	0.001	0.032	-	-	-	-
Total Phosphorus	g/kg	0.234	0.235	0.386	0.164	0.186	0.336	0.600	2.000	-	-
Solvent Extractables	mg/kg	1040	1100	**2000**	1139	780	**1591**	-	-	1500	-
Aluminum	mg/kg	4668	4399	6017	2907.3	3165	4151	-	-	-	-
Arsenic	mg/kg	4.7	4.4	5.6	3.9	3.5	4.5	6	33	-	-
Cadmium	mg/kg	0.5	0.4	**0.6**	0.3	0.4	0.4	0.6	10	-	-
Chromium	mg/kg	12	12	14	13	8	12	26	110	-	-
Cobalt	mg/kg	4.7	4.6	5.8	3.4	3.0	4.3	-	-	50	-
Copper	mg/kg	**42**	**28**	**29**	**27**	**33**	**26**	16	110	-	-
Iron	mg/kg	15090	12665	12868	11655	7259	10818	20000	40000	-	-
Lead	mg/kg	23	24	19	16.0	14	20	31	250	-	-
Magnesium	mg/kg	11701	11789	18309	9146.0	14326	13267	-	-	-	-
Manganese	mg/kg	180	188	221	151.9	167	181	460	1100	-	-
Mercury	mg/kg	**0.43**	**0.44**	**0.17**	**8.72**	0.09	**1.87**	0.2	2	-	-
Nickel	mg/kg	13	13	**16**	10	7	**17**	16	75	-	-
Zinc	mg/kg	87	64	97	75	95	69	120	820	-	-
TCDD-TEQ	ng/kg	6.9	1.9	1.6	**33.1**	0.6	2.3	-	-	-	-
Hexachloroethane	µg/kg	4.0	4.0	1.4	354.2	<1	15.1	-	-	-	-
Hexachlorobutadiene	µg/kg	407	287	777	13533	32	1014	-	-	-	-
2,3,6-Trichlorotoluene	µg/kg	0.3	0.1	0.7	9.0	<1	0.8	-	-	-	-
2,4,5-Trichlorotoluene	µg/kg	1.3	0.9	<1	6.5	<1	1.0	-	-	-	-
2,6,a-Trichlorotoluene	µg/kg	<1	<1	<1	0.8	<1	<1	-	-	-	-
1,2,3-Trichlorobenzene	µg/kg	0.1	0.5	<2	6.3	<2	1.2	-	-	-	-
1,2,4-Trichlorobenzene	µg/kg	136	17	40	864	23	25	20	24000	-	-
1,3,5-Trichlorobenzene	µg/kg	43	17	64	309	2	78	-	-	-	-
1,2,3,4-Tetrachlorobenzene	µg/kg	4.5	1.5	3.0	101	<1	4.0	70	530000	-	-
1,2,3,5-Tetrachlorobenzene	µg/kg	14.4	8.0	3.6	169	<1	11.5	-	-	-	-
1,2,4,5-Tetrachlorobenzene	µg/kg	8.3	11.3	7.5	262	<1	23.2	-	-	-	-
Pentachlorobenzene	µg/kg	53.5	20.9	58.3	621	<1	57.2	-	-	-	-
Hexachlorobenzene	µg/kg	**418**	**111**	**427**	**9844**	4.0	**434**	-	-	-	-
Octachlorostyrene	µg/kg	213	74	301	1334.3	<1	353	-	-	-	-
Total PCBs	µg/kg	5	7	4	**866**	6	**93**	-	-	-	-
Total Petroleum Hydrocarbons	mg/kg	233	29	472	45	48	467	-	-	-	-
Acenaphthene	µg/kg	5	12	318	7	40	25	-	-	-	-
Acenaphthylene	µg/kg	2	7	87	6	<20	3	-	-	-	-
Anthracene	µg/kg	14	16	95	17	<20	35	220	370000	-	-
Benzo(a)anthracene	µg/kg	106	159	**1035**	241	99	**355**	320	140000	-	-
Benzo(b)fluoranthene	µg/kg	67	75	**1033**	109	46	239	240	1340000	-	-
Benzo(k)fluoranthene	µg/kg	34	40	903	69	29	176	-	-	-	-
Benzo(g,h,I)perylene	µg/kg	3	31	**524**	26	3	**207**	170	320000	-	-
Benzo(a)pyrene	µg/kg	25	22	163	25	3	33	370	1440000	-	-
Chrysene	µg/kg	143	237	**1577**	333	179	**465**	340	460000	-	-
Dibenzo(a,h)anthracene	µg/kg	1	5	23	9	<40	2	60	130000	-	-
Fluoranthene	µg/kg	259	365	**4264**	378	100	668	750	1020000	-	-
Fluorene	µg/kg	19	22	**465**	48	11	42	190	160000	-	-
Indeno(1,2,3-cd)pyrene	µg/kg	1	19	**584**	10	<40	31	200	320000	-	-
Naphthalene	µg/kg	5	14	442	8	2	60	-	-	-	-
Phenanthrene	µg/kg	340	431	**4015**	412	115	**584**	560	950000	-	-
Pyrene	µg/kg	302	466	**3646**	451	128	**664**	490	850000	-	-
Total PAHs	µg/kg	1694	2486	**20700**	2600	765	3834	4000	10000000	-	-
Gravel	%	16.3	11.1	0.0	29.5	6.4	3.5	-	-	-	-
Coarse Sand	%	7.6	13.0	2.8	20.8	4.9	12.4	-	-	-	-
Fine Sand	%	59.7	53.7	47.7	41.3	73.3	68.5	-	-	-	-
Silt+Clay	%	16.4	19.5	49.7	8.4	16.3	15.6	-	-	-	-

[1] Density calculated as geometric mean

2 Concentrations within clusters calculated as geometric mean of station values, all concentrations exprressed as ng/g unless indicated otherwise

Equal to or exceeds LEL or open water disposal guideline - fails guideline and may have an adverse effect on some benthic organisms

Equal to or exceeds SEL (adjusted for TOC value for organic contaminants) - highly contaminated and likely will have an adverse effect on benthic organisms

Exceeds Draft Canadian Environmental Quality Guideline for 2,3,7,8-TCDD and PCDD/PCDF TEQ - Direct Toxicity NOEC Value (7.9 ng/kg) adjusted for site-specific TOC value (EC, 1994)

TABLE 4.5: FIELD OBSERVATIONS FOR SEDIMENTS SAMPLED IN THE UPPER ST. CLAIR RIVER, JUNE 19
(Source: OMOEE field observation sheets - Appendix A, Tables A1.3a and A1.3b)

	Odour	Oily Sheen	Globules	Sewage Fungus	Plants	Other	Sediment
Cluster 1							
IS9-I	petrochemical	x	x	x	S	very oily	silty sand/gravel
IS9-M	petrochemical	x	x	x	S	-	sandy silt
IS9-O	petrochemical	x	x	-	C	-	silty sand/stones
IS14-M	-	x	-	x	-	-	sandy gravel
18-M	slight petrochemical	x	-	x	S	-	silty sand
44-O	petrochemical	x	x	-	S	-	silty sand/clay
45-M	-	-	-	x	S	-	gravel/silty sand
49-M	-	x	x	-	S	-	silty sand/gravel
Cluster 2							
IS12-O	-	x	x	-	-	-	sandy gravel
IS15-I	petrochemical	x	x	-	S	-	sandy gravel
IS15-O	petrochemical	x	x	-	-	-	sandy gravel
18-O	petrochemical	x	x	-	-	greasy	sandy gravel
20-I	petrochemical	x	x	-	-	-	sandy gravel
20-M	petrochemical	x	x	-	S	-	sandy gravel
20-O	fuel	x	-	-	-	-	silty clay
22-I	-	x	-	-	-	-	sand/silt/gravel
22-O	strong petrochemical	x	tar	-	-	lots of oil	silty ooze
45-I	-	-	-	x	S	coal	silty sand
45-O	petrochemical/oily	x	-	-	-	-	silty sand/clay
46-I	organic	-	-	-	-	coal	sandy silt
47-I	petrochemical	x	-	-	-	-	silty sand/clay
47-O	-	x-lots	x	-	-	-	sand
48-I	-	-	-	x	-	gravel	silty sand/gravel
Cluster 3							
IS12-M	organic	x	-	-	A	Elodea	silty ooze
22-M	organic	-	-	x	S	Elodea	silty ooze
47-M	organic	x	x	-	S	Elodea	silty ooze
Cluster 4							
IS14-I	-	x	x	x	-	-	sandy gravel
IS14-O	strong perchloroethylene	x	x	x	-	-	sandy gravel
IS15-M	organic	x	x	x	-	-	sandy gravel
46-O	strong petrochemical	x	x	x	-	lots of coal	sandy gravel
48-O	perc/organic/petrochemical	x	x	x	-	lots of coal	sandy gravel
49-I	organic	x	x	x	-	-	sandy gravel
49-O	organic	x	x	x	-	some perc.	sandy gravel
Cluster 5							
18-I	-	x	-	-	S	root material	silty sand
44-I	organic	x	x	x	-	-	silty sand
44-M	petrochemical	x	x	-	s	-	silty sand
Cluster 6							
IS12-I	-	-	-	-	-	coal	sandy silt
46-M	-	x	-	-	S	-	sandy silt
48-M	slight petrochemical	x	x	-	-	root material	silty ooze

S = sparse, C = common, A = abundant

4 was significantly higher ($p<0.05$) than that recorded for Cluster 2 and equal to that recorded for Cluster 5. The average HBI value was 8.4, indicative of poor water quality (Hilsenhoff, 1987). Together, the species composition and HBI value reflect an impaired community, characterized predominantly by taxa tolerant of pollution.

Cluster 2

The 15 stations in this group (IS12-O, IS15-I, IS15-O, 18-O, 20-I, 20-M, 20-O, 45-I, 45-O, 46-I, 47-I, 47-O, 48-I) were also located along the entire length of the St. Clair River study zone, but situated primarily at the inner and outer stations along transects. Substrates were predominantly sand and gravel at the stations along Transects IS12, IS15, 18 and 20 and silty sand, similar to Cluster 1, along Transects 45 and 46 (Table 4.5). Mean contaminant levels exceeding their respective LELs were the same as for Cluster 1. Unlike Cluster 1, Hexachlorobenzene was below the SEL level in Cluster 2 (Table 4.4). Sediments from six of the eleven stations, which were located in the Upper and Middle Areas were characterized as toxic to one of the test species.

The most abundant taxa in this cluster were again the most pollution-tolerant oligochaetes and chironomids. Overall, the benthic community characterising this cluster group would be considered indicative of a moderate to severely impaired environment and was not much different than that of Cluster 1.

Total densities averaged 3,357 organisms/m^2, the second lowest in the study area, and significantly less than that recorded at Clusters 1, 3, 5 and 6. On average, the lowest number of taxa (27) were collected at these stations, which was significantly ($p<0.05$) less than that recorded at Clusters 1 and 5. The HBI averaged 8.4, indicative of poor water quality. Overall, the species composition and HBI value reflect a moderately impaired community.

Cluster 3

The three stations grouped in Cluster 3 were located at the mid-point of three transects in the Middle Area (IS12-M, 47-M and 22-M). The stations in Cluster 3 were characterized in the field as consisting of silty ooze (Table 4.5) with the aquatic plant *Elodea* sp. present at all stations. Analysis of the sediments confirmed silty clay as the dominant grain size, which constituted the highest percentage (50%) in the study area. Despite the increase in silt and clay, contaminant levels did not exceed the SEL value for any of the contaminants measured, but did exceed the LEL values for 18 parameters. In addition to those common to Clusters 1 and 2, these included solvent extractables, cadmium, nickel, nine individual PAHs and total PAHs. This cluster was characterised by the highest mean concentrations for most of the contaminants measured. The sediments at stations within this cluster were not associated with any strong odour (Table 4.5). Cluster analysis of sediment chemistry data (Section 3.2) grouped most of these stations in Cluster 2, which was characterised by stations considered to have marginally polluted sediments. Sediment toxicity tests indicated that all three stations were characterised as highly toxic, but only to the fish species tested, potentially due to elevated unionized ammonia levels (Section 3.4).

Similar to all cluster groups the most abundant organisms characteristic of the group were oligochaetes, which comprised 47% of the community. The cluster was also characterised by high numbers of the naidid oligochaete *Ophidonais serpentina* which is moderately pollution tolerant and may be associated with the aquatic macrophytes at the stations in this group. The other taxa representative of this cluster are facultative to tolerant of pollution and also associated with aquatic plants (e.g., *Amnicola limosa).* Mean density, at 62,746 organisms/m^2, was the highest of all clusters.

The mean HBI value was 8.3, indicative of poor water quality. Overall, the areas of the upper St. Clair River represented by the benthic macroinvertebrate communities at stations within Cluster 3 are indicative of moderately impaired habitats.

Cluster 4

The seven stations included in Cluster 4 were located in the Middle Area (46-O), and in the Lower Area (IS14-1, IS14-O, 48-O, 49-I, 49-O and IS15-M). The overall substrate texture was dominated by fine sand (41%), coarse sand (21%) and gravel (30%). Average water depth was also the deepest (4.5 m) within this cluster group. Mercury and hexachlorobenzene exceeded their respective SEL values and copper, TOC and total PCBs exceeded their respective LELs. Field notes indicated that the sediment at stations in Cluster 4 were characterized as sandy gravel, with an odour of perchloroethylene, petroleum products or organic matter (Table 4.5). Coal chunks were also present at Stations 46-O and 48-O. Cluster analysis of sediment chemistry data grouped four of these stations (IS14-1, IS14-O, 48-O, 49-I and 49-O) in with other stations, which together represented the most contaminated sites (Section 3.2). Four of the stations (46-O. IS14-O. 48-O and 49-O) exhibited toxicity to one or more of the laboratory test species (Section 3.4).

The benthic macroinvertebrate community characterising Cluster Group 4 was not dominated by any group, and consisted mainly of naidid oligochaetes, which comprised 24% of the community, tubificid oligochaetes (16%), lumbriculid oligochaetes (13%), chironomids (17%), nematodes (9%), zebra mussels (7%), snails (5%) and *Hydra* (5%).

Mean density for Cluster 4 stations was 2,273 organisms/m^2, significantly less ($p<0.05$) than average densities in Clusters 1, 6, 5 and 3, and similar to those of Cluster 2. The mean number of taxa (31) was the second lowest in the study area and significantly ($p< 0.05$) less than that recorded for Cluster 1. The Hilsenhoff Biotic Index value was 7.3, significantly lower ($p>0.05$) than that recorded at Clusters 1, 2, 3 and 6. This value reflects a benthic macroinvertebrate community that is comprised of lower densities of tolerant taxa than are present in the other clusters: oligochaetes in particular. The HBI reflects fairly poor water quality (Hilsenhoff, 1987). Overall, the area is indicative of an impaired habitat.

Cluster 5

Three stations were included in Cluster 5, with all situated in the Upper Area (18-1, 44-I and 44-M). Fine sand was the major constituent of the substrate (73%) with clay and silt comprising 16%. Field notes indicate that substrate texture in this cluster group was silty sand. Contaminant levels were notably lower than for Cluster 4, and only three sediment chemistry parameters exceeded their respective LELs (Table 4.4). Cluster analysis of sediment chemistry grouped these three stations with the least polluted group (Section 3.2). In the laboratory, sediment toxicity was observed at Stations 44-I and 44-M, with high acute toxicity to fathead minnows at 44-I and 44-M, and acute toxicity to invertebrates and fish at Station 44-M. Impaired growth of *Chironomus tentans* (84%) was observed at 44-M (Table 3.5). A petrochemical odour was apparent in Station 44-M sediment (Table 4.5), which elicited the highest toxicity.

For the stations in Cluster 5, the dominant taxa were tubificid oligochaetes, comprising 60% of the community and made up of tolerant and moderately tolerant species. Naidid oligochaetes were virtually absent from this group of stations. The other dominant group was chironomids (19%), represented primarily by pollution-tolerant taxa.

Mean total density in Cluster 5 stations was 34,647 organisms/m^2, significantly greater ($p<0.05$) than that for Clusters 2 and 4, and similar to that of the other three cluster groups. The mean number of taxa (42) was the highest but only significantly ($p<0.05$) greater than that of Cluster 2. The HBI value averaged 8.6, indicative of very poor water quality.

Overall, the benthic macroinvertebrate community is indicative of a moderately impaired community.

Cluster 6

Cluster 6 consisted of two stations located in the Middle Area (46-M, IS12-1) and one in the Lower Area (48-M). The sediment exceeded the respective LELs for TOC mercury, hexachlorobenzene, nickel, solvent extractables, copper and a number of PAHs (Table 4.4). Particle size analysis indicated that the substrate was predominantly fine sand (68%) with silt and clay together comprising another 16% of the substrate. Sediment toxicity was apparent only at Station IS12-I, where the sediments were toxic to fathead minnows.

The dominant taxa characteristic of this cluster were again tubificid oligochaetes (72%), represented by the most pollution-tolerant species. This cluster represents the highest overall percentage of oligochaetes in the study area and is indicative of an organically rich environment. The community representative of this cluster was also characterised by chironomids (19%), represented primarily by *Polypedilum* and *Procladius,* which are genera tolerant of moderate to severe impairment, respectively. Average total density within this cluster was 21,261 organisms/m^2, represented by 32 taxa. The average HBI value (9.0) was the highest of all clusters and indicative of very poor water quality with severe organic pollution (Hilsenhoff, 1987). However, none of these stations were characterized by acute toxicity to laboratory test invertebrates, suggesting that the community imbalance is primarily due to organic enrichment. Overall, the benthic community within Cluster Group 6 was indicative of moderate to severely impaired conditions.

Summary

Overall, the cluster analysis indicated that the benthic macroinvertebrate communities at stations in the upper St. Clair River are indicative of impaired to degraded conditions. With the exception of Cluster 4, all of the communities were dominated by pollution-tolerant oligochaetes and chironomids. There was little difference among the community assemblages characterising each of the cluster groups, suggesting that all sites would generally be considered to be represented by impaired communities. The LIS found similar results (i.e., very little difference in community structure between the clusters (Moran *et al.*, 1997)) in a parallel 1994 St. Clair River survey which included all three degraded zones identified in 1990.

4.5 Community Ordination Analysis

Ordination analysis included correspondence analysis (CA) using quantitative and qualitative data, as well as principal components analysis (PCA) using Pearson's and Spearman's correlation matrices. Since the results of these analyses were intended to further characterize distinct communities identified by cluster analysis, the non-hierarchical results discussed above were chosen for comparison. The qualitative results are provided in Appendix 2 and are not substantially different from the quantitative solutions to warrant any further discussion.

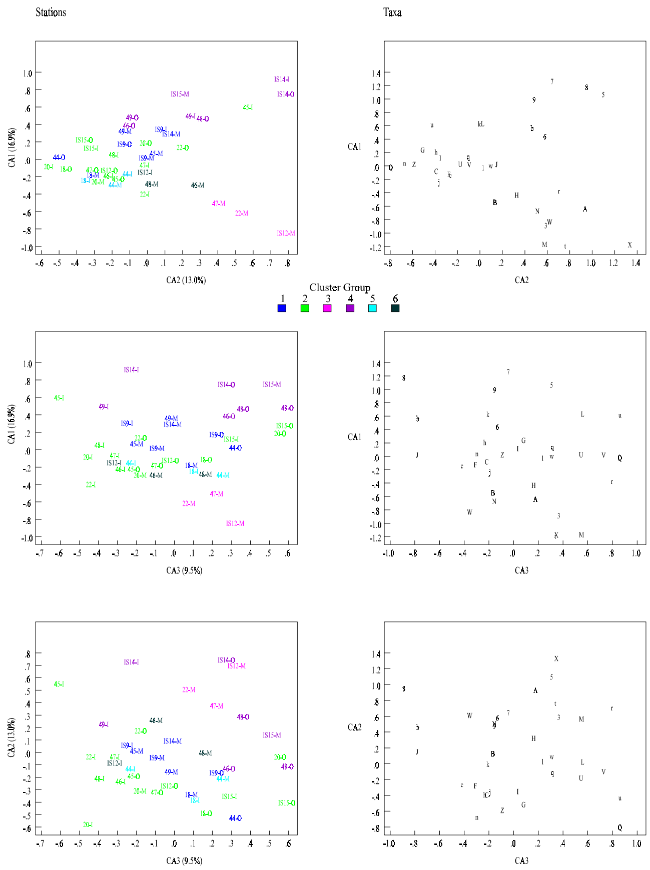
4.5.1 Correspondence Analysis

Prior to conducting the CA analysis, it is necessary to reduce the potential for computational problems associated with the data matrices comprised of many zeros (Gibbons *et al.*, 1993). This is normally done by removing the rare taxa from both the abundance and presence/absence data matrices. Therefore, taxa were excluded if they were found at less than 10% of the stations and if they accounted for less than 5% of the total macroinvertebrate density at each of the stations. The results of the correspondence analysis are illustrated in Figure 4.1 and the station (Table 4.6) and taxa (Table 4.7) factor scores are provided in the accompanying tables.

The overall variance explained by the correspondence analysis was only 39.4%, with 16.9% explained by CA Axis 1, 13.0% by CA Axis 2 and 9.5% by CA Axis 3. This indicated that the solution explains a relatively small portion of the total variance among stations. However, it is clear that the solution presented in Figure 4.1 is consistent with the pattern produced by the non-hierarchical cluster analysis showing that there is very little separation among the different communities.

In Figure 4.1, only those taxa which contributed at least 2% towards the observed variance along an axis were plotted. This accounted for greater than 50% of the total variance along each axis. This screening procedure resulted in plots which are much clearer and easier to interpret than plots which included all taxa.

As suggested by the results of the cluster analysis, the differences between the cluster groups are relatively subtle. The majority of the stations are clustered about the origin of the axis, with only a small number of the stations extending beyond this clustering. Cluster Groups 3 and 6 separated from the central portion of the plot along the negative end of CA Axis 1 (associated with pollution-tolerant taxa, such as *Gyraulus* and *Ilyodrilus templetoni*) and the positive end of CA Axis 2, associated with the oligochaetes *Nais barbata, N. pardalis, Ophidonais serpentina,* Enchytraeidae and the midge *Chironomus,* most of which are at least moderately tolerant taxa. Cluster Group 2 stations separated along the positive end of CA Axis 1, associated with *Nais bretscheri, N. variabilis, N. pardalis* and *Stylodrilus heringianus*. These taxa range from slight to severe pollution tolerant. *Stylodrilus* is an indicator of relatively clean sediment conditions and is commonly found in sandy substrates. CA Axis 1 appears to represent, at least in part, a particle size gradient running from silty ooze at the negative end to sandy-gravel at the positive end.



Bivariate Plots of the Associations Between St. Clair River Stations and Taxa Relative to CA Axes Based on the $Log_{10}(x+1)$ Abundance Data Set (Taxon codes presented in Table 4.7)

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beak international incorporated	Figure 4.1	October 1997

TABLE 4.6: CORRESPONDENCE ANALYSIS FACTOR SCORES FOR STATIONS IN THE UPPER ST. CLAIR RIVER - JUNE 1994

	Coordinates along CA Axes			Contribution to CA Axes			Correlation with CA Axes		
Station	CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3
18-I	-0.21534	-0.36116	0.09677	0.01248	0.04552	0.00447	0.10708	0.30118	0.02162
18-M	-0.16587	-0.32861	0.06945	0.00701	0.03565	0.00218	0.05692	0.22342	0.00998
18-O	-0.09911	-0.47914	0.14986	0.00095	0.02877	0.00384	0.00805	0.18824	0.01842
44-I	-0.15479	-0.12316	-0.24223	0.00591	0.00485	0.02562	0.04416	0.02795	0.10814
44-M	-0.27937	-0.20168	0.23681	0.02427	0.01640	0.03089	0.14438	0.07525	0.10374
44-O	0.03777	-0.51696	0.30537	0.00030	0.07390	0.03523	0.00165	0.30872	0.10773
20-I	-0.06964	-0.56989	-0.46525	0.00047	0.04037	0.03675	0.00368	0.24654	0.16431
20-M	-0.24406	-0.30040	-0.20007	0.00800	0.01572	0.00953	0.06131	0.09288	0.04120
20-O	0.20064	-0.02691	0.53988	0.00398	0.00009	0.05109	0.02928	0.00053	0.21198
IS9-I	0.31635	0.06550	-0.26640	0.02306	0.00128	0.02897	0.13192	0.00566	0.09355
IS9-M	0.02962	-0.03244	-0.11661	0.00028	0.00043	0.00761	0.00222	0.00266	0.03441
IS9-O	0.18740	-0.15384	0.19919	0.00813	0.00710	0.01627	0.05351	0.03606	0.06045
45-I	0.61122	0.55947	-0.61686	0.04048	0.04397	0.07302	0.17724	0.14849	0.18053
45-M	0.08066	0.03130	-0.21737	0.00151	0.00030	0.01944	0.01314	0.00198	0.09542
45-O	-0.21239	-0.18110	-0.22937	0.00302	0.00284	0.00623	0.02967	0.02157	0.03460
46-I	-0.18201	-0.22461	-0.29269	0.00521	0.01028	0.02385	0.03073	0.04680	0.07946
46-M	-0.28108	0.26651	-0.11536	0.01612	0.01879	0.00481	0.08673	0.07797	0.01461
46-O	0.39963	-0.11999	0.27070	0.01528	0.00179	0.01242	0.17191	0.01550	0.07888
IS12-I	-0.13631	-0.03910	-0.34222	0.00419	0.00045	0.04676	0.02696	0.00222	0.16994
IS12-M	-0.83203	0.75130	0.28679	0.18504	0.19563	0.03894	0.43771	0.35690	0.05200
IS12-O	-0.13349	-0.25950	-0.05644	0.00232	0.01135	0.00073	0.03028	0.11441	0.00541
47-I	-0.05366	-0.02586	-0.32364	0.00039	0.00012	0.02514	0.00324	0.00075	0.11782
47-M	-0.49177	0.38503	0.20402	0.07026	0.05584	0.02142	0.33933	0.20801	0.05841
47-O	-0.16734	-0.31107	-0.10773	0.00467	0.02090	0.00343	0.04526	0.15638	0.01876
22-I	-0.38662	-0.02509	-0.45063	0.02190	0.00012	0.05270	0.18568	0.00078	0.25225
22-M	-0.60416	0.51469	0.05675	0.08369	0.07875	0.00131	0.38850	0.28195	0.00343
22-O	0.15029	0.18246	-0.19429	0.00404	0.00773	0.01197	0.03335	0.04916	0.05574
IS14-I	0.93372	0.73563	-0.25059	0.07477	0.06018	0.00954	0.36778	0.22829	0.02649
IS14-M	0.30465	0.10070	-0.04220	0.02398	0.00340	0.00082	0.20001	0.02185	0.00384
IS14-O	0.76168	0.75274	0.24309	0.08677	0.10988	0.01565	0.35644	0.34813	0.03631
48-I	0.06551	-0.20015	-0.40457	0.00071	0.00863	0.04815	0.00565	0.05270	0.21531
48-M	-0.26973	0.00558	0.14432	0.01675	0.00001	0.00850	0.12908	0.00006	0.03696
48-O	0.48255	0.29709	0.34591	0.04099	0.02015	0.03731	0.24345	0.09228	0.12510
49-I	0.50983	0.23521	-0.38189	0.05322	0.01469	0.05289	0.31430	0.06690	0.17635
49-M	0.33553	-0.14565	-0.03457	0.02615	0.00639	0.00049	0.24551	0.04626	0.00261
49-O	0.49494	-0.10287	0.57841	0.03218	0.00180	0.07784	0.27060	0.01169	0.36957
IS15-I	0.14055	-0.34449	0.26494	0.00345	0.02689	0.02173	0.02867	0.17221	0.10186
IS15-M	0.76445	0.14972	0.48039	0.08086	0.00402	0.05656	0.47719	0.01831	0.18844
IS15-O	0.23819	-0.38935	0.58003	0.00723	0.02505	0.07593	0.05340	0.14270	0.31670

TABLE 4.7: CORRESPONDENCE ANALYSIS FACTOR SCORES FOR SPECIES IN THE UPPER ST. CLAIR RIVER - JUNE 1994

	Taxon Code	Coordinates along CA Axes			Contribution to CA Axes			Correlation with CA Axes		
		CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3
Hydra	1	-0.00834	0.04114	0.24741	0.00001	0.00042	0.02068	0.00020	0.00488	0.17646
Nematoda	2	0.06654	-0.01078	-0.03876	0.00135	0.00005	0.00081	0.06718	0.00176	0.02280
Turbellaria	3	-0.87039	0.60113	0.37845	0.03656	0.02261	0.01224	0.32580	0.15540	0.06159
Prostoma	4	0.37747	0.09937	0.23448	0.01273	0.00114	0.00870	0.15217	0.01055	0.05872
Enchytraeidae	5	1.08374	1.11171	0.31900	0.04714	0.06432	0.00724	0.25357	0.26682	0.02197
Nais barbata	6	0.45789	0.59120	-0.11945	0.03368	0.07279	0.00406	0.22700	0.37842	0.01545
Nais bretscheri	7	1.28023	0.65510	-0.03051	0.13240	0.04495	0.00013	0.58654	0.15358	0.00033
Nais pardalis	8	1.19351	0.96452	-0.87575	0.06678	0.05655	0.06369	0.27016	0.17644	0.14546
Nais variabilis	9	1.00980	0.49504	-0.14090	0.10294	0.03208	0.00355	0.60970	0.14653	0.01187
Ophidonais serpentina	A	-0.61895	0.94483	0.18379	0.03714	0.11221	0.00580	0.17341	0.40408	0.01529
Ilyodrilus templetoni	B	-0.52577	0.14385	-0.15903	0.04483	0.00435	0.00727	0.37608	0.02815	0.03441
Limnodrilus claparedianus	C	-0.06324	-0.38102	-0.21001	0.00064	0.02994	0.01242	0.00651	0.23638	0.07181
Limnodrilus hoffmeisteri	D	-0.09497	-0.10698	-0.06398	0.00330	0.00542	0.00265	0.08639	0.10962	0.03920
Limnodrilus udekemianus	E	-0.20759	-0.10038	-0.13365	0.01358	0.00412	0.00997	0.25376	0.05933	0.10518
Potamothrix moldaviensis	F	-0.10618	-0.26428	-0.29858	0.00257	0.02064	0.03599	0.03230	0.20009	0.25541
Potamothrix vejdovskyi	G	0.25751	-0.50217	0.08688	0.00472	0.02325	0.00095	0.02736	0.10406	0.00312
Quistadrilus multisetosus	H	-0.41616	0.33529	0.16846	0.02490	0.02096	0.00723	0.18974	0.12317	0.03109
Spirosperma ferox	I	0.13448	-0.33566	0.04910	0.00343	0.02769	0.00081	0.03221	0.20064	0.00429
immatures with hair chaetae	J	0.03896	0.16465	-0.76560	0.00011	0.00256	0.07547	0.00064	0.01138	0.24607
immatures without hair chaetae	K	-0.07013	-0.05521	-0.09728	0.00188	0.00151	0.00642	0.07072	0.04384	0.13610
Stylodrilus heringianus	L	0.64980	0.03543	0.56777	0.05592	0.00022	0.07562	0.29558	0.00088	0.22567
Mooreobdella microstoma	M	-1.15121	0.57971	0.55231	0.03038	0.00999	0.01239	0.35555	0.09016	0.08184
Harpacticoida	N	-0.65630	0.51979	-0.15021	0.02764	0.02248	0.00256	0.21875	0.13722	0.01146
Hydracarina	O	-0.09461	0.03620	-0.20246	0.00160	0.00030	0.01294	0.04009	0.00587	0.18358
Gammarus	P	0.16205	-0.15709	0.38802	0.00182	0.00222	0.01846	0.02506	0.02355	0.14368
Caecidotea	Q	0.00046	-0.78714	0.86642	0.00000	0.01551	0.02566	0.00000	0.11954	0.14483
Hexagenia	R	-0.09289	-0.28555	0.04386	0.00060	0.00737	0.00024	0.00913	0.08625	0.00204
Ephemerella	S	-0.29659	-0.79479	0.59613	0.00190	0.01770	0.01360	0.01996	0.14336	0.08065
Stenonema terminatum	T	0.09350	-0.26776	0.15440	0.00016	0.00168	0.00076	0.00205	0.01678	0.00558
Cheumatopsyche	U	0.04434	-0.16775	0.55249	0.00021	0.00383	0.05679	0.00264	0.03783	0.41039
Hydropsyche scalaris	V	0.03615	-0.08789	0.73559	0.00013	0.00097	0.09310	0.00143	0.00842	0.58995
Pyralidae - indeterminate	W	-0.81576	0.62352	-0.35348	0.03156	0.02391	0.01050	0.25872	0.15115	0.04858
Chironomus	X	-1.15676	1.34345	0.35262	0.02480	0.04338	0.00408	0.20933	0.28235	0.01945
Cryptochironomus	Y	0.16200	-0.27518	-0.14060	0.00383	0.01432	0.00511	0.06771	0.19537	0.05101
Demicryptochironomus	Z	0.04045	-0.57543	-0.08215	0.00016	0.04171	0.00116	0.00216	0.43623	0.00889
Dicrotendipes	a	-0.18945	0.32309	-0.21972	0.00384	0.01447	0.00914	0.05851	0.17017	0.07870
Paracladopelma	b	0.58529	0.47817	-0.76511	0.00863	0.00747	0.02613	0.07376	0.04923	0.12604
Paralauterborniella	c	-0.11926	-0.24734	-0.40380	0.00102	0.00570	0.02074	0.01047	0.04505	0.12008
Paratendipes	d	0.16647	-0.13891	-0.00868	0.00469	0.00424	0.00002	0.05441	0.03789	0.00015
Phaenopsectra	e	0.16791	0.06797	0.09902	0.00564	0.00120	0.00347	0.15818	0.02592	0.05501
Polypedilum	f	0.06175	-0.06218	-0.12942	0.00135	0.00177	0.01048	0.04520	0.04584	0.19859
Stempellina	g	-0.17041	-0.48816	-0.39377	0.00067	0.00711	0.00632	0.00615	0.05046	0.03283
Stictochironomus	h	0.22499	-0.37739	-0.22206	0.00562	0.02048	0.00969	0.05520	0.15531	0.05377
Tanytarsus	i	0.01120	0.01353	-0.14657	0.00002	0.00004	0.00652	0.00052	0.00076	0.08946
Tribelos	j	-0.22076	-0.34460	-0.17425	0.00923	0.02917	0.01019	0.12829	0.31261	0.07993
Cricotopus	k	0.64458	0.00915	-0.19558	0.02909	0.00001	0.00474	0.27472	0.00006	0.02529
Heterotrissocladius	l	0.06156	0.75638	-0.26304	0.00009	0.01674	0.00277	0.00091	0.13672	0.01653
Psectrocladius	m	0.64909	0.50736	-0.50355	0.01142	0.00905	0.01217	0.11117	0.06792	0.06691
Monodiamesa	n	0.05962	-0.65670	-0.28568	0.00026	0.04136	0.01069	0.00239	0.29025	0.05493
Ablabesmyia	o	-0.42120	0.02264	0.04341	0.01356	0.00005	0.00026	0.13803	0.00040	0.00147
Procladius	p	-0.22181	0.00014	-0.10220	0.01052	0.00000	0.00396	0.22924	0.00000	0.04867
Thienemannimyia complex	q	0.16250	-0.09137	0.32475	0.00303	0.00124	0.02144	0.04772	0.01509	0.19061
Hemerodromia	r	-0.35716	0.72209	0.81248	0.00313	0.01657	0.02866	0.03049	0.12464	0.15780
Amnicola limosa	s	-0.17203	-0.01882	0.09622	0.00788	0.00012	0.00436	0.28967	0.00347	0.09062
Gyraulus	t	-1.17400	0.77827	0.35493	0.06311	0.03596	0.01022	0.44164	0.19408	0.04037
Elimia livescens	u	0.63591	-0.41364	0.87286	0.03814	0.02093	0.12728	0.21736	0.09197	0.40951
Physella	v	-0.72737	0.39299	0.17769	0.01777	0.00673	0.00188	0.14856	0.04337	0.00887
Dreissena polymorpha	w	0.02142	0.10513	0.31597	0.00011	0.00338	0.04172	0.00202	0.04864	0.43941
Pisidium	x	-0.27372	-0.13468	0.18671	0.00983	0.00309	0.00810	0.13756	0.03330	0.06401

Stations of Cluster Groups 1, 4 and 5 generally separated along the negative end of CA Axis 2, associated with the chironomids *Tribelos*, *Demicryptochironomus* and *Monodiamesa*. These taxa are moderately tolerant of contaminants.

4.5.2 Principal Components Analysis

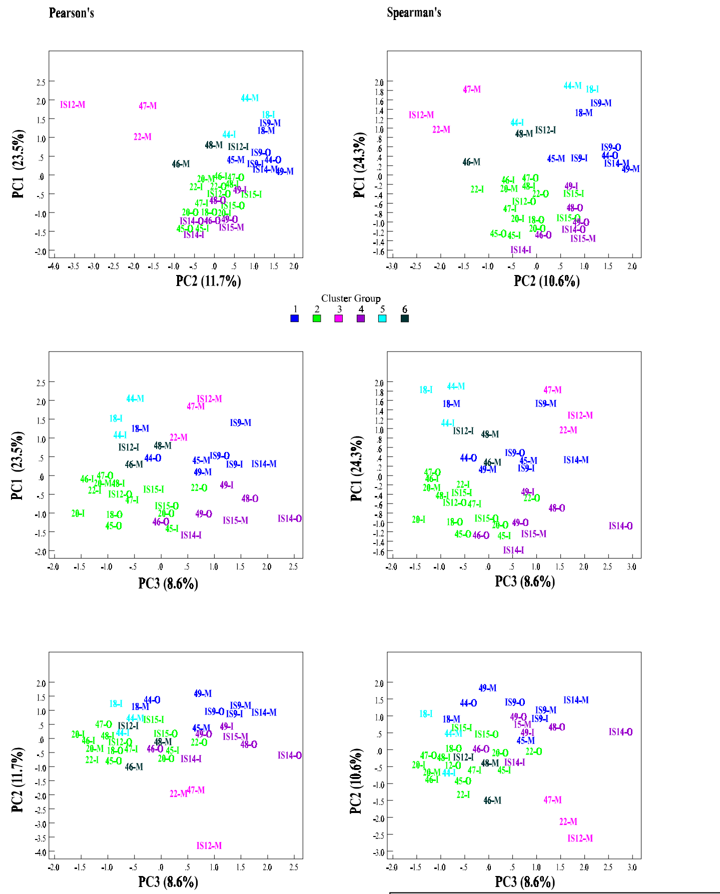
Results of the principal components analysis using Pearson's and Spearman's correlation matrices are presented in Figure 4.2. The first axis typically accounted for the largest fraction of the variance (23.5% and 24.3% for the Pearson's and Spearman's matrices) with Factor Axes 2 and 3 accounting for substantially less variance.

Station distribution patterns were similar for these two matrices, with the stations generally grouping in a pattern similar to that described by the non-hierarchical cluster analysis and the correspondence analysis (Figure 4.1). This suggests that the pattern described by these analyses is fairly consistent.

4.6 Relationship between the Benthic Community and Environmental Variables

Due to the limited number of stations in this study relative to the number of parameters, some reduction in the number of chemical and physical parameters was required prior to conducting the analysis. This included eliminating those parameters which did not exceed their LEL value, as well as grouping some parameters, such as chlorinated benzenes and the PAHs. A similar approached was applied in the sediment toxicity by Bedard and Petro (1997) to help explain a greater degree of the variation. The parameters included were $\log_{10}$-transformed prior to the analysis.

Discriminant analysis indicated significant differences between stations groups on four to five axes ($p<0.0005$). Only one axis (DF1) was found to be significant ($p=0.0035$), explaining 49% of the variance. This axis separated Station Groups 3 and 5 from the other four groups, primarily on the basis of a positive correlation with TKN and a negative correlation with lead (Table 4.8). There was no obvious biological meaning to this set of correlations, raising the likelyhood that it is a spurious result.



Bivariate Plots of the Associations Between St. Clair River Stations and PCA Axes Based on the $Log_{10}(x+1)$ Abundance Data Set
(Taxon codes presented in Table 4.7)
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TABLE 4.8: STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS FOR EACH SEDIMENT VARIABLE INCLUDED IN THE ANALYSIS, CORRELATION BETWEEN SEDIMENT PARAMETERS AND THE DISCRIMINANT FUNCTIONS AND SIGNIFICANCE OF THE DISCRIMINANT FUNCTIONS FROM THE ST. CLAIR RIVER - 1994

Parameter	Standardized Canonical Discriminant Function Coefficients DF1	Correlations between Sediment Parameters and Discriminant Functions DF1
Copper	-2.45160	-0.0925
Depth	0.14828	-0.0819
Iron	3.05539	-0.2287
%Fines	12.68264	0.2510
%Gravel	12.33725	0.2510
Hexachlorobenzene	11.22544	0.0173
Hexachlorobutadiene	10.81385	0.0486
Hexachloroethane	0.78179	0.0149
Mercury	0.00591	-0.0562
High Molecular Weight PAHs	-4.13030	0.1971
Potassium	-3.12176	-0.0918
Low Molecular Weight PAHs	6.15687	0.1683
Water Velocity	0.21104	0.0506
Manganese	-0.93018	-0.0117
Sodium	-0.85661	-0.1699
Ammonia	-1.45122	0.2301
Nickel	1.11099	-0.1532
Octachlorostyrene	-0.33316	-0.1209
Lead.	-1.20279	-0.2756
Pentachlorobenzene	-23.88440	-0.0639
Total PCBS	-1.87337	0.1229
Chlorinated Benzenes	4.46156	-0.0041
2,3,7,8-TCDD TEQs	-0.82181	-0.1026
Total Chlorinated Toluenes	-0.66436	0.0747
TKN	4.83411	0.4219
Total Organic Carbon	-1.22779	-0.0467
Total Phosphorus	-0.15277	0.0425
Total Petroleum Hydrocarbons	-2.81459	0.0565
Zinc	2.74164	0.1849
Chloride	-0.35522	0.1699
%Sand	11.91331	-0.1246

Canonical Discriminant Functions

Function	Eigenvalue	Percent of Variance	Cumulative Percent	Canonical Correlation	Chi-square	df	Significance
1	43.6969	48.75	48.75	0.9888	165.88	120	0.0035
2	27.5854	30.77	79.52	0.9824	100.498	87	0.1528
3	11.4022	12.72	92.24	0.9588	51.4	56	0.6494
4	5.9492	6.64	98.88	0.9253	13.597	27	0.9849
5	1.0083	1.12	100	0.7086			

Statistically significant at p=0.05

An alternative approach was conducted using Mantel's test, with the use of the CA axes from the benthic analysis and the PCA axes from the sediment analysis to determine if the patterns of similarity among the stations from the biological and chemical characterizations were correlated. Mantel's test was performed using all of the sediment chemistry data, as well as using reduced data sets (i.e., physical characteristics, nutrients, metals, and organics). The number of axes to be included was determined using the "broken stick" model to determine which of the CA axes for the benthos and PCA axes for the sediment chemistry were important (i.e., explained more variance than would be expected by chance alone). The CA and PCA axes were converted to Euclidean distance matrices. All of the Mantel's tests were done using 10,000 iterations.

Results indicated that significant associations existed between the benthic community distance matrix and the overall sediment matrix, the nutrient matrix, the chlorinated organic chemical matrix, and the physical parameter matrix (Table 4.9). Details of the parameter loadings for the PCA axes derived from each of these sediment parameter groups are presented in Appendix 3 (Table A3.3). Mantel's test between the benthic matrix and the overall sediment matrix indicated a significant association (r=0.267; p=0.0007). The plot of the first benthic CA axis (BCA1) versus the first sediment PCA axis (SPC1) reveals a gradient extending from the Upper Area where the sediments were characterized by elevated fine particles and nutrient levels, to the Lower Area where the sediments were characterized by high concentrations of chlorinated organic chemicals and mercury (Figure 4.3). The highest degree of association existed between the benthic community and the physical parameter matrices (r=0.352; p=0.0002) (Figure 4.3). Stations in the Upper and Middle Areas tended to be characterized by fine grained substrates with increasing particle size (gravel and coarse sand) in the Lower Area. The benthic community included taxa such as *Stylodrilus heringianus,* which prefer this type of habitat, in the Lower Area. The benthic community association with the chlorinated organics was the next highest (r=0.246; p=0.0077), followed by nutrient levels (r=0.213; p=0.0203). Nutrient levels tended to be higher in the Middle Area, followed by the Upper and Lower Areas (Figure 4.3).

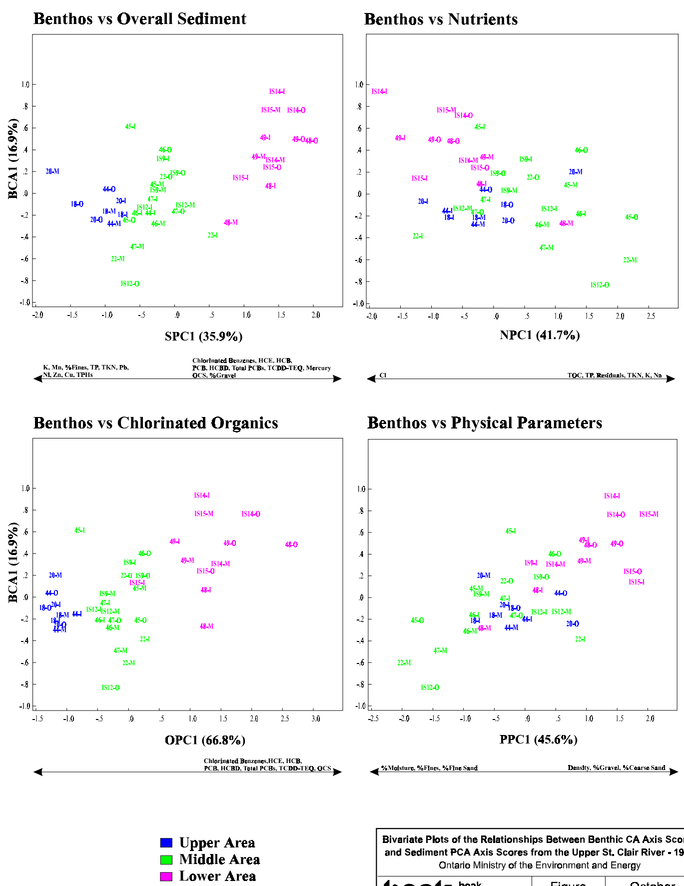
A Mantel's test between the physical parameters and chlorinated organics distance matrices indicated a significant association (r=0.137, p=0.0268). These results would suggest that, while the entire study area is impaired with a variety of contaminants to which the benthos may be responding, the primary source of variability between the stations are habitat characteristics such as particle size, water depth and current.

TABLE 4.9: SUMMARY OF BENTHIC COMMUNITY AND SEDIMENT QUALITY DISTANCE MATRIX COMPARISONS USING MANTEL'S TEST

	Benthic Macroinvertebrate Correspondence Analysis Axes Mantel's r Value
Overall Sediment PCA	**0.267** (0.0007)
Nutrient Parameters	**0.213** (0.0203)
Metal Parameters	-0.059 (0.302)
Organic Chemical Parameters	**0.246** (0.0077)
Individual PAHs	0.148 (0.0622)
Physical Parameters	**0.352** (0.0002)
Total Petroleum Hydrocarbons	-0.010 (0.468)

Statistically significant at p=0.05 (p value in brackets)

Figure 4.3



Bivariate Plots of the Relationships Between Benthic CA Axis Scores and Sediment PCA Axis Scores from the Upper St. Clair River - 1994

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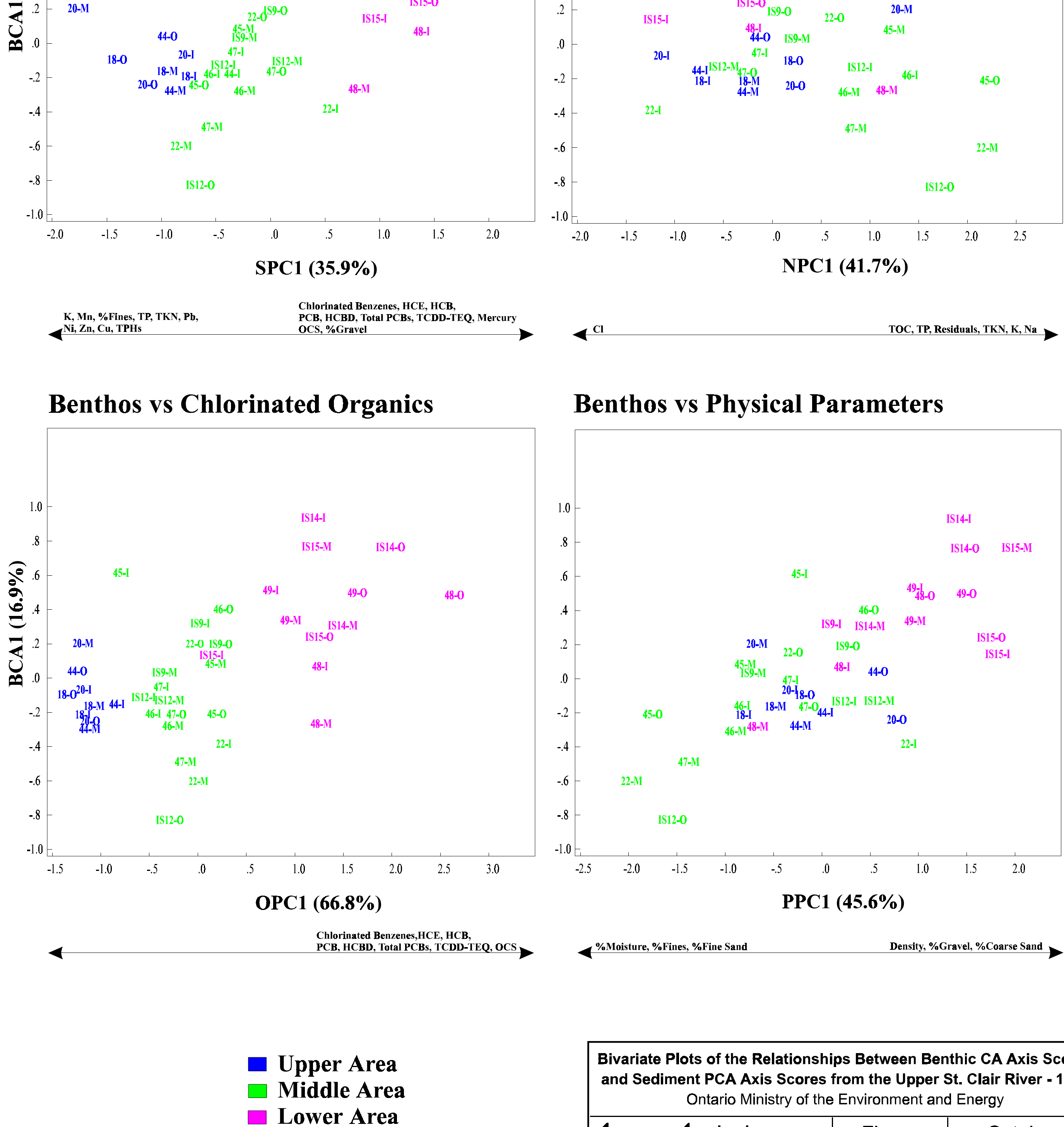

Bivariate Plots of the Relationships Between Benthic CA Axis Scores and Sediment PCA Axis Scores from the Upper St. Clair River - 1994

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Figure 4.3

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5.0 SUMMARY OF ENVIRONMENTAL STATUS AND TEMPORAL TRENDS

Results of the 1994 benthic macroinvertebrate community analyses indicated that all of the stations in the restricted study area were characterised as either impaired or degraded, reflecting current sediment quality conditions. Cluster analysis of the macroinvertebrate data indicated minor changes in the community structure among the station cluster groups. This precluded broad-based community characterizations as done in the 1985 and 1990 surveys of the entire river, whereby the community of one cluster group would be considered representative of degraded conditions, while the community of another cluster would be considered representative of impaired conditions. Because of the similarity in community structure among all stations, both within a cluster and among clusters, there were communities that reflected both impaired and degraded environmental conditions in each cluster group. Consequently, for consistency the community characteristics that were considered to represent impaired (I) or degraded (D) conditions in the 1985 and 1990 studies were used to classify the communities at the 1994 stations. The classification for each station is provided in Table A1.6, Appendix 1.

The degraded communities in the 1985 and 1990 studies were characterized as being dominated by pollution tolerant oligochaetes (e.g., *Limnodrilus hoffmeisteri, Quistadrilus multisetosus*) and having low numbers of moderately tolerant taxa (e.g., *Amnicola, Spirosperma ferox*, clams). Impaired communities were also generally characterized by tubificid oligochaetes (*Limnodrilus hoffmeisteri and Spirosperma ferox*) and molluscs (Hydrobiidae and Sphaeriidae), with increased abundance of moderately tolerant chironomids and trichopterans. The unimpaired communities were dominated by moderately tolerant chironomids (*Polypedilum, Procladius* and *Tribelos*), with sensitive taxa such as *Hexagenia* and other Ephemeroptera and Trichoptera increasingly common (Griffiths, 1985, Pope, 1993).

In the 1994 study, none of the stations were characterized by a benthic community that was considered to reflect unimpaired conditions. In other words the benthic macroinvertebrate community structure in the upper St. Clair River study zone, including the reference transect (18), reflected impaired to degraded environmental conditions. This is not surprising, considering that the objective of the study was to focus on the upper degraded area that was identified in the 1990 study.

Results of the discriminant analysis using the benthic community cluster results to group sediment chemistry data indicated no meaningful relationships between the benthic community structure and sediment chemistry. Mantel’s test results between the benthic macroinvertebrate and sediment chemistry distance matrices (matrices of similarity measures between stations) indicated that a significant association existed between the benthic community and the overall sediment matrix. This relationship was characterized by a gradient in sediment quality, with elevated fine particles and nutrient levels in the Upper and Middle Areas relative to the Lower Area where the sediments were characterized by higher loadings from chlorinated organic chemicals and mercury relative to the upstream locations. Mantel’s tests using smaller groupings of sediment chemistry data (i.e., nutrients, metals, chlorinated organic chemicals, PAHs and physical parameters) indicated that the highest degree of association existed between the benthic community and the physical parameter matrices. The benthic community association with the chlorinated organics was the next highest, followed by nutrient levels. These results would suggest that, while the entire study area is impaired with a variety of contaminants to which the benthos may be responding, the primary source of variability between the stations are habitat characteristics.

Because of the marked differences in the benthic macroinvertebrate processing and identification techniques employed for the 1985, 1990 and 1994 surveys (see Section 2.5.7), it is difficult to make any conclusive statements on temporal changes in the health of the benthic macroinvertebrate communities, based on any of the biotic indices used for this study.

When only those transects which were sampled in all three surveys (1994, 1990, 1985) are considered (Transects 18, 20, IS9, IS12, 22, IS14 and IS15), the total number of taxa collected in 1994 was 96 compared to 51 and 45 taxa identified in the 1985 and 1990 surveys, respectively (Table 5.1). Generally, an increase in the number of taxa of this magnitude would suggest notable improvement in environmental quality. However, the large increase in the diversity of benthic macroinvertebrates in the upper St. Clair River in 1994 may be partially due

**TABLE 5.1: TAXA FOUND IN THE UPPER ST. CLAIR RIVER STUDY AREA - 1985, 1990 AND 1994
(ONLY THE OVERLAPPING 7 TRANSECTS WERE CONSIDERED IN THIS COMPARISON)**

85	90	94	Taxa	85	90	94	Taxa	85	90	94	Taxa
			P. Coelenterata				**F. Gammaridae**	x		x	*Harnischia*
	x	x	*Hydra*	x	x	x	*Gammarus*			x	*Glyptotendipes*
	x	x	**P. Nematoda**				**F. Haustoriidae**		x		*Macropelopia*
			P. Platyhelminthes	x			*Pontoporeia hoyi*	x			*Parachironomus*
x	x	x	**Cl. Turbellaria**				**F. Talitridae**	x	x	x	*Paracladopelma*
			P. Nemertea	x		x	*Hyallela c*			x	*Paralauterborniella*
x		x	*Prostoma*				**O. Isopoda**			x	*Paratanytarsus*
			P. Annelida				**F. Asellidae**			x	*Paratendipes*
			Cl. Oligochaeta	x		x	*Caecidotea*	x		x	*Phaenopsectra*
	x	x	**F. Enchytraeidae**				**Cl. Insecta**	x	x	x	*Polypedilum*
			F. Naididae				**O. Ephemeroptera**			x	*Stempellina*
	x		*Nais alpina*				**F. Baetiscidae**			x	*Stempellinella*
	x	x	*Nais barbata*	x		x	*Baetisca*			x	*Stictochironomus*
		x	*Nais behningi*				**F. Caenidae**			x	*Tanytarsus*
	x	x	*Nais bretscheri*	x		x	*Caenis*	x	x	x	*Tribelos*
	x		*Nais communis*				**F. Ephemeridae**	x			*Xenochironomus*
	x		*Nais elinguis*			x	*Ephemera*				**S.F. Orthocladiinae**
		x	*Nais pardalis*	x	x	x	*Hexagenia*	x		x	*Cricotopus*
		x	*Nais simplex*				**F. Ephemerellidae**			x	*Epoicocladius*
	x	x	*Nais variabilis*	x		x	*Ephemerella*			x	*Heterotrissocladius*
x		x	*Ophidonais serpentina*				**F. Heptageniidae**			x	*Paracladius*
	x	x	*Paranais frici*	x		x	*Stenonema*			x	*Psectrocladius*
	x	x	*Vejdovskyella intermedia*			x	*Stenonema femoratum*				**S.F. Prodiamesinae**
			F. Tubificidae			x	*Stenonema terminatum*			x	*Monodiamesa*
		x	*Aulodrilus americanus*				**O. Plecoptera**				**S.F. Tanypodinae**
x	x		*Aulodrilus pluriseta*				**F. Perlodidae**		x	x	*Ablabesmyia*
		x	*Bothrioneurum vejdovskyan*			x	*Isoperla*	x	x	x	*Procladius*
x	x	x	*Ilyodrilus templetoni*				**O. Trichoptera**			x	*Thienemannimyia complex*
		x	*Isochaetides freyi*				**F. Glossosomatidae**	x			**F. Empididae**
x		x	*Limnodrilus cervix*			x	*Protoptila*			x	*Hemerodromia*
x	x	x	*Limnodrilus claparedianus*				**F. Hydropsychidae**	x			**F. Psychodidae**
x	x	x	*Limnodrilus hoffmeisteri*	x	x	x	*Cheumatopsyche*			x	*Pericoma*
		x	*Limnodrilus maumeensis*	x	x		*Hydropsyche*				**P. Mollusca**
	x		*Limnodrilus profundicola*			x	*Hydropsyche scalaris*				**Cl. Gastropoda**
x		x	*Limnodrilus udekemianus*				**F. Hydroptilidae**				**F. Ancylidae**
x	x	x	*Potamothrix moldaviensis*			x	*Agraylea*			x	*Ferrissia*
	x	x	*Potamothrix vejdovskyi*				**F. Leptoceridae**				**F. Hydrobiidae**
x	x	x	*Quistadrilus multisetosus*			x	*Ceraclea*	x	x	x	*Amnicola limosa*
x	x	x	*Spirosperma ferox*				**F. Polycentropodidae**				**F. Lymnaeidae**
x		x	*Tubifex tubifex*			x	*Neureclipsis*	x			*Pseudosuccinea columella*
x	x	x	immatures with hair chaetae				**O. Lepidoptera**			x	*Stagnicola catascopium*
x	x	x	immatures without hair chae				**F. Pyralidae**				**F. Planorbidae**
			F. Lumbriculidae	x	x	x	indeterminate	x	x	x	*Gyraulus*
x		x	*Stylodrilus heringianus*				**O. Coleoptera**		x		**F. Pleuroceridae**
			Cl. Polychaeta				**F. Chrysomelidae**		x		*Goniobasis*
		x	*Manayunkia speciosa*			x	indeterminate	x		x	*Elimia livescens*
			Cl. Hirudinae				**O. Diptera**		x		*Pleurocera*
			F. Erpobdellidae	x			**F. Ceratopogonidae**		x		**F. Physidae**
x		x	*Mooreobdella microstoma*			x	*Probezzia*	x		x	*Physella*
x			**F. Piscicolidae**		x		**F. Chironomidae**		x		**F. Valvatidae**
			P. Arthropoda			x	Chironomidae pupae	x			*Valvata piscinalis*
			Cl. Maxillopoda				**S.F. Chironominae**	x	x		*Valvata tricarinata*
		x	**O. Harpacticoida**			x	*Axarus*				**Cl. Pelecypoda**
		x	**O. Ostracoda**		x	x	*Chironomus*				**F. Dreissenidae**
			Cl. Arachnoidea			x	*Cladotanytarsus*			x	*Dreissena polymorpha*
		x	*Hydracarina*	x	x	x	*Cryptochironomus*			x	*Dreissena (quagga)*
			Cl. Malacostraca			x	*Cryptotendipes*		x		**F. Sphaeriidae**
			O. Amphipoda	x	x	x	*Demicryptochironomus*	x	x	x	*Pisidium*
			F. Crangonyctidae			x	*Dicrotendipes*			x	*Sphaerium striatinum*
		x	*Crangonyx*		x		*Epoicocladius*	x	x		*Sphaerium*

- Present only at outer stations in 1994 to more intensive sampling: 39 stations sampled in 1994 compared to the 21 stations sampled in 1985 and 1990 surveys. Approximately 50% of the taxa identified in the 1994 survey were found in less than six of the 117 samples analysed. If less rigorous sorting and identification techniques were used in the earlier studies many of these taxa would have been overlooked. For example, harpacticoids and the polychaete *Manayunkia speciosa*, which are among the smaller benthic invertebrates, were found at 14 stations in 1994 but were not found anywhere in the St. Clair River in the 1985 and 1990 studies. These ubiquitous organisms were definitely present in the river in the earlier surveys.

In 1985, samples were processed in the field at the end of the day, by sorting the live animals in white enamel trays without the aid of a microscope. This processing technique is generally no longer accepted for long-term monitoring studies utilizing benthic macroinvertebrates (Gibbons *et al*., 1993) because it can result in underestimation of macroinvertebrate density and diversity by up to two orders of magnitude (Burt *et al*, 1988). It also biases the sorting towards selecting larger more motile animals (Hilsenhoff, 1982).

The samples for the 1990 study were processed with the aid of a stereomicroscope, however, the densities were uncharacteristically low for one of the Great Lakes interconnecting channels (Griffiths, 1989, Burt *et al.*, 1988, Farara and Burt, 1993, Creese, 1987). There is no substantive reason for this difference.

At six of the seven stations, numbers of taxa increased substantially in 1994 over those collected in either 1990 or 1985 (Table 5.2). The only exception was at Transect 20, where the number of taxa in 1994 (29) was similar to those collected in 1990 (25) and 1985 (28).

Comparisons of average total abundance also indicated substantially higher densities in 1994 at six of the seven stations. The only exception was again at Transect 20, where average density in 1994 (394) was similar to that in 1990 (226), with both substantially less than that from 1985 (2,127). In general, the densities in 1990 were consistently lower than those in either 1994 or 1985 and may be related to differences in sorting recoveries and likely do not reflect changes in habitat quality.

TABLE 5.2: COMPARISON OF ENVIRONMENTAL QUALITY ZONES IN 1985, 1990 AND 1994

	1985 - Griffiths (1989)			1990 - Pope (1993)			1994[1] - (this report)		
Station	Zone	Number of Taxa	Average Abundance per 0.05 m² sample	Zone	Number of Taxa	Average Abundance per 0.05 m² sample	Zone	Number of Taxa	Average Abundance per 0.05 m² sample
18	unimpaired	20	22	intermediate	21	43	impaired	53	1467
20	impaired	28	2127	impaired	25	226	degraded	29	394
IS9	impaired	31	349	impaired	20	75	impaired	52	1165
IS12	degraded	7	448	degraded	14	66	degraded	49	3813
22	degraded	12	655	degraded	21	203	impaired	42	1342
IS14	severely degraded:toxic	3	18	intermediate	15	21	degraded	46	283
IS15	severely degraded:toxic	5	13	intermediate	15	32	impaired	43	228

[1] Number of Taxa and Abundance calculated using inner and middle stations along transect

In general, the benthic macroinvertebrate assemblages collected from the study area appeared to be relatively similar over the three surveys in terms of the most common invertebrates found. Most of the stations were dominated by tubificid oligochaetes (primarily *L. hoffmeisteri*, immatures without hair setae, *Quistadrilus multisetosus* and *Spirosperma ferox*), chironomid larvae (*Polypedilum* and *Procladius*), naidid oligochaetes (*Ophidonais serpentina* and *Nais* spp.) and snails (*Amnicola limosa*) in all three surveys. A notable change in the 1994 assemblages was the appearance of zebra mussels (*Dreissena* spp.) at most stations. However, the abundances of these organisms was only significantly elevated at one location.

The 1990 environmental assessment of the bottom fauna and sediments of the St. Clair River indicated a general temporal trend towards improved sediment quality within the upper St. Clair River in the Upper, Middle and Lower Areas when compared to the 1985 sediment quality survey (Pope, 1993).

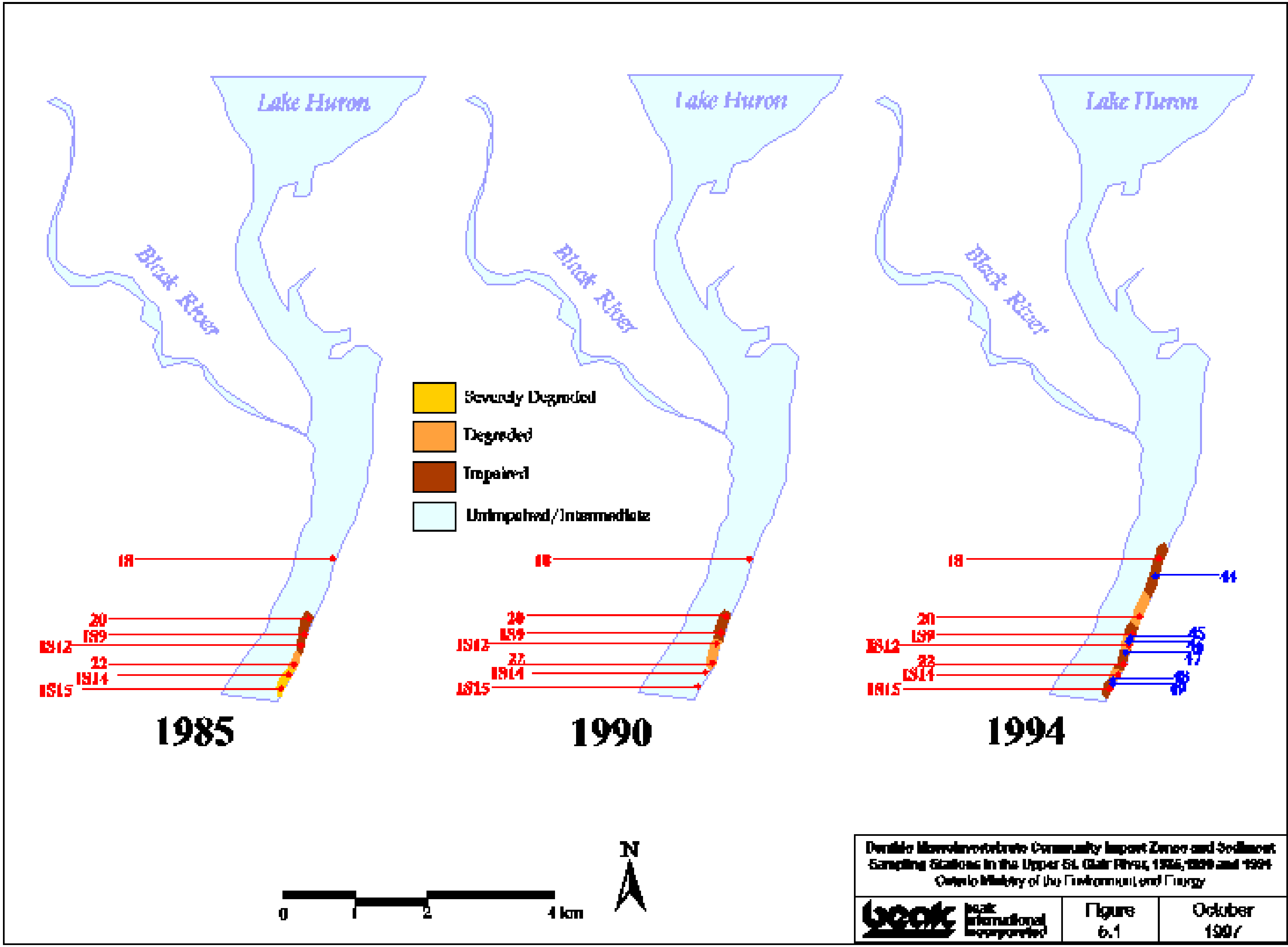
In 1985, the seven stations located in the Upper to Lower Areas were characterized as “unimpaired” (1 station) to “severely degraded-toxic” (2 stations) (Griffiths, 1989), respectively. Pope (1993) reported that the areas characterized as “severely degraded-toxic” in the Lower Area in 1985 (Griffiths, 1989) were no longer present in 1990, and the areas were reclassified as “intermediate” (between unimpaired and impaired), but Transect 18 went from “unimpaired” to “intermediate”. No change was evident at Transects 20, IS9, IS12 and 22; however, the other transects downstream of the Upper and Middle Areas were also reported to have improved considerably showing that the impaired and degraded zones were separated by unimpacted areas (Figure 11, Appendix 1 in Pope, 1993). In spite of this decrease in the size of the area of impairment, sediment quality within this area remained extremely poor (Pope, 1993). Sediments within this part of the upper St. Clair River were characterised by elevated levels of PAHs, chlorinated benzenes, octochlorostyrene, PCBs and mercury. In contrast to these suggested improvements in habitat quality, a closer review of the data indicates that sensitive to moderately tolerant taxa such as the mayflies *Baetisca, Caenis, Ephemerella,* and *Stenonema*, the crustaceans *Hyalella, Pontoporeia hoyi* and *Asellus*, and the oligochaete *Stylodrilus* were all present in the study area in 1985 but lacking in 1990, suggesting that conditions may in fact not have improved to the level suggested by the interpretation of the cluster analysis communities.

Sediment chemistry results from 1985 and 1994 indicated that three parameters differed significantly ($p<0.05$) between the two surveys: water depth, copper and zinc, all of which were lower in 1994. With the exception of TKN, HCB, octachlorostyrene and gravel, most parameters either remained unchanged overall or decreased slightly between the two surveys. The former four parameters increased overall from 1985 to 1994. Sediment chemistry results from 1994 indicated some improvements relative to 1990, reflected in lower PAH concentrations at most stations, but little or no improvement in contaminant levels of other parameters since 1990. There were no significant differences ($p>0.05$) in mean contaminant concentrations throughout the study area compared to mean levels in 1990. PAH levels generally decreased at stations in the Middle and Lower Areas.

In 1994, degraded benthic communities were noted in all three areas, including in the Lower Area. There were no areas within the study zone that were considered capable of supporting unimpaired communities. The 1994 data appear to more closely support the sediment quality zones of the 1985 survey (Table 5.2, and Figure 5.1), in that benthic communities from the Upper Area to downstream of the Lower Area are impaired to degraded. Also, there has been an apparent deterioration of conditions at Transect 18 over the three surveys. This would suggest that there has been little improvement in the health of the benthic invertebrate community in this area of the upper St. Clair River since 1985. In addition, the sensitive to moderately tolerant taxa noted as present in 1985 and absent in 1990 were still absent in the 1994 study, again suggesting that there has not been much change in community structure since 1985 in the study area.

Remedial Action Plan Priority Areas

The categorization of contaminated areas of the upper St. Clair River followed the rationale that chemical, biological and toxicological information must be considered together to understand the status of environmental quality. Consideration of synoptic data of these three types permits a “weight of evidence” evaluation regarding impacts of sediment quality on the ecosystem. This approach has been referred to as the Sediment Quality Triad (SQT) (Chapman, 1990).



Lake Huron
Black River
Severely Degraded
Degraded
Impaired
Unimpaired/Intermediate
18
20
189
1812
22
1814
1815
1985
1990
1994
0
1
2
4 km
N
Benthic Macroinvertebrate Community Impact Zones and Sediment Sampling Stations in the Upper St. Clair River, 1985, 1990 and 1994
Ontario Ministry of the Environment and Energy
Figure 6.1
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The essence of this integrated approach is that there should be concordance between chemical stress, toxicity response and benthic community impairment before the benthic community status can be attributed to chemical toxicity. If the benthic community condition correlates with sediment chemistry, but there is no evidence of toxicity, then trophic factors such as organic enrichment may be important. If there is concordance with sediment toxicity but not with any chemical measurements, then some unmeasured chemical factors may be important. If community condition does not correlate with either chemistry or toxicity, then habitat factors are implicated. It would be expected that in areas of severe degradation or pristine conditions that there would likely be agreement between the three components.

The St. Clair River RAP criterion for delisting an area of concern with regard to the "degradation of benthos" is that the benthic macroinvertebrate community structure must be documented as either unimpaired or of intermediate status (OMOEE and MDNR, 1995). The importance of selecting the most appropriate reference locations (where physical and habitat features are similar to the exposure areas) becomes paramount in determining when the area under study achieves a satisfactory status. The establishment of pristine reference sites in the St. Clair River is difficult due to the long history of industrialization and urbanization within the watershed. In this case it would likely be more appropriate to select reference areas generally regarded as unimpacted or intermediate in quality.

The integration and presentation of the results of the SQT can be achieved in a variety of approaches (Chapman, 1996). The approach used in this study involved the derivation of a numerical sediment quality index. Results of the sediment chemistry, toxicity and benthic community structure were each evaluated on a scale of 1, 3 or 9 (worst, intermediate, best) according to the following set of criteria:

Sediment Quality

Score	Criteria (exceedance of)
1	one or more SELs
3	number of LELs >5, no SELs
9	number of LELs <5, no SELs

The range of LELs (i.e., > or < 5) was established based on the sediment chemistry at the transects furthest upstream (reference) and at those other sites in the study area that had the best sediment quality.

Sediment Toxicity

Score	Criteria
1	acute toxicity to any organism ≥ 80% (i.e., ≥ 80% mortality)
3	40% to <80% acute toxicity to any organism and/or >-40% sublethal toxicity (i.e., growth impairment) to any organism
9	no toxicity to any organism

The 40% acute toxicity value was derived from the ASTM guideline of 30% acceptable toxicity for Control exposures of *Chironomus* (ASTM, 1995), while the 80% acute toxicity relates to the St. Clair River RAP Sediment/Habitat Task Team criteria for the designation of priority contaminated zones.

Benthic Macroinvertebrates

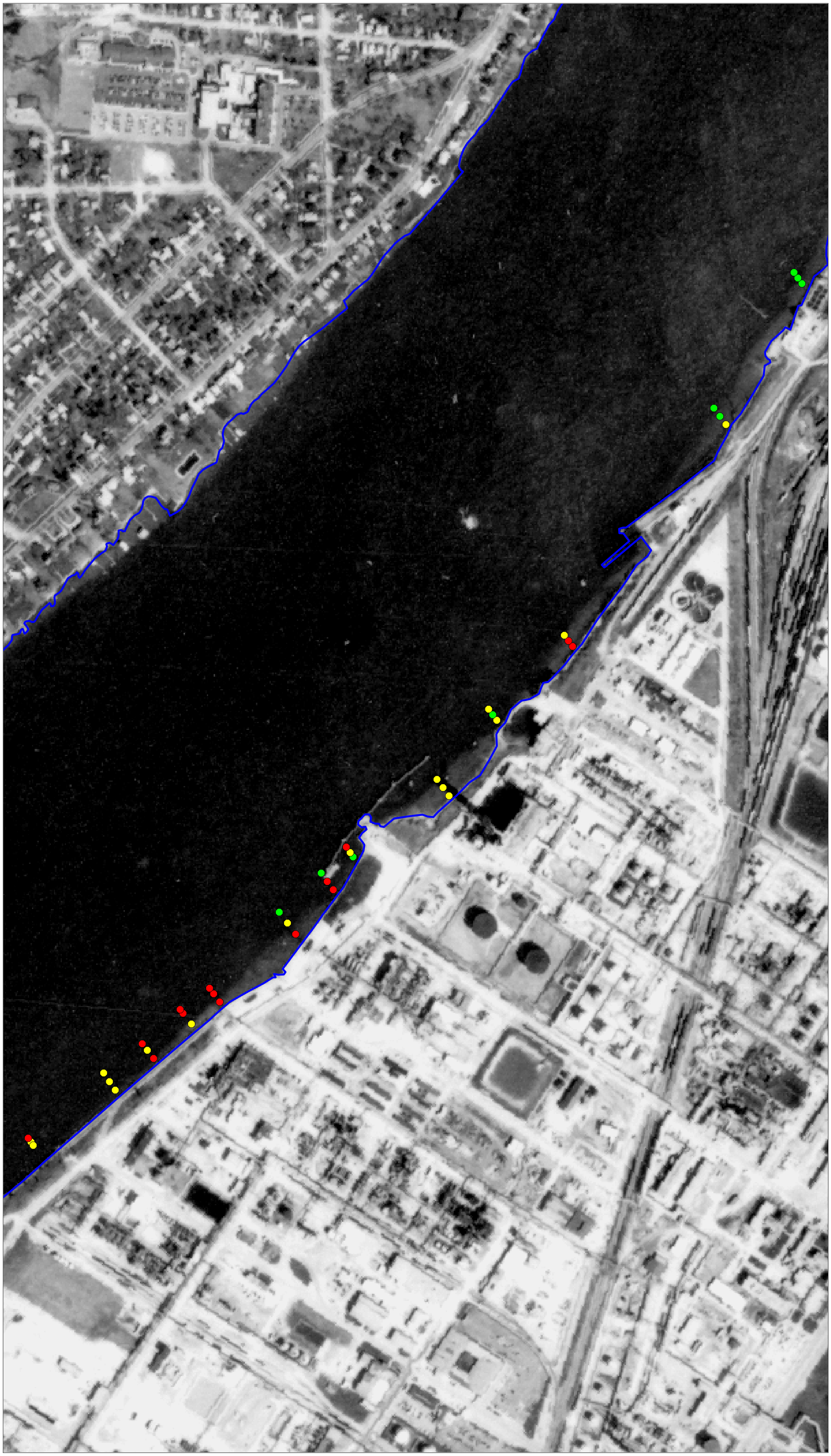
Score	Criteria	
1	meets at least two of the following criteria:	EPT index is <2 tubificid density ≥80% total number of taxa <25
3	meets at least two of the following criteria:	EPT index is 2 to 3 tubificid density 50% to <80% total number of taxa is 25 to 34
9	meets at least two of the following criteria:	EPT index is ≥ 4 tubificid density <50% total number of taxa is ≥35

In creating a ranking system for the benthic macroinvertebrate communities in the upper St. Clair River Study Zone 1, the objective was to compare the benthic communities among stations in the study area and to rank them according to their relative degree of impairment in relation to one another.

Data collected by the Lambton Industrial Society along the American shoreline in 1994, which was considered to reflect healthier conditions compared to the Canadian shoreline, were also used in establishing the ranges for the three metrics (EPT, %Tubificids, number of taxa) used to rank the benthic communities. The rationale was that higher EPT and number of taxa scores and lower dominance by tolerant tubificid oligochaetes represent healthier benthic communities. The scoring system, once developed, was also applied to the LIS data set and was found to characterize stations quite well (T. Moran, Pollutech, pers. comm., 1997). Reference sites along the American side (LIS data) and upstream in Study Zone 1 generally scored a 9 (healthy community), while sites located in known degraded zones generally scored 1 (degraded). Initial scoring and development of the categories based on the 1994 and 1995 LIS data was done blindly (i.e., location of reference and exposure sites unknown) by D. Farara and the results indicated that the reference and exposed sites could be correctly identified using this approach.

Results of the scoring at individual stations for each of the three components is presented in Table 5.3. The maximum score for any station was 27 (3x9), with the range of 19 to 27 representing the areas with the best sediment quality, 10 to 18 representing intermediate sediment quality (grey areas) and 5 to 9 representing the worst sediment quality. These data were then plotted using GIS and contouring techniques to map the gradient in sediment quality from areas with no priority for remedial action (scores 19 to 27) to those areas with the highest priority (scores 5 to 9)(Figure 5.2).

Each of the Upper, Middle and Lower Areas contain stations classified by low Total Scores (5 to 9). Such stations in the Upper Area include Stations 20-I and 20-M, those in the Middle Area include Stations 46-O, IS12-I, IS12-M, 47-I, 22-I, 22-M and 22-O while those in the Lower Area include Stations IS14-M, IS14-O, 48-I, 48-O and IS15-O (Figure 5.2). The two stations in the Upper Area were characterized by several PAHs and metals in excess of their LEL values, stations in the Middle Area were characterized by several contaminants including total PAHs and/or metals above their respective LEL levels or hexachlorobenzene above the SEL level. The five stations in the Lower Area were characterized by levels of mercury and hexachlorobenzene above their respective SEL values. Stations in the Upper Area were characterized by one station with acute toxicity to *Chironomus*, while the other had 40% mortality in *Hexagenia*. Both stations had chronic toxicity to *Chironomus* in excess of 40%. In the Middle Area, six of the



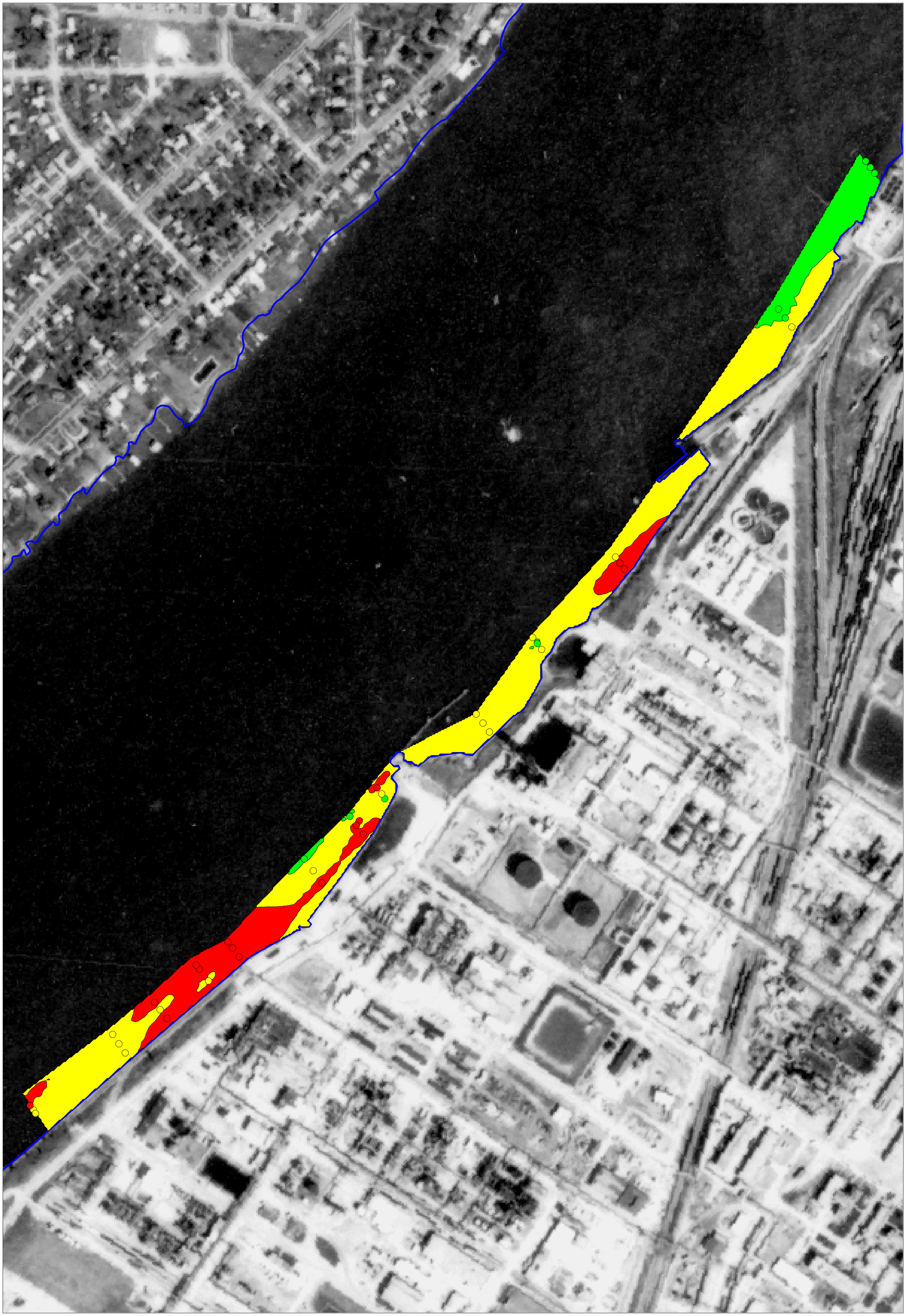


TABLE 5.3: SCORING OF UPPER ST. CLAIR RIVER STATIONS BASED ON SEDIMENT QUALITY, TOXICITY AND BENTHIC MACROINVERTEBRATE COMMUNITY RESULTS

	Station	Sediment Quality	Sediment Toxicity	Benthic Macroinvertebrates	Total Score
Upper Area	18-I	9	9	9	27
	18-M	1	9	9	19
	18-O	9	9	9	27
	44-I	9	1	3	13
	44-M	9	1	9	19
	44-O	9	1	9	19
	20-I	3	3	1	7
	20-M	3	1	1	5
	20-O	3	1	9	13
Middle Area	IS9-I	1	1	9	11
	IS9-M	9	9	3	21
	IS9-O	1	1	9	11
	45-I	1	9	1	11
	45-M	1	3	9	13
	45-O	3	1	9	13
	46-I	9	9	1	19
	46-M	3	9	3	15
	46-O	3	1	1	5
	IS12-I	3	1	3	7
	IS12-M	3	1	3	7
	IS12-O	9	9	3	21
	47-I	3	3	3	9
	47-M	1	1	9	11
	47-O	9	9	9	27
	22-I	1	1	3	5
	22-M	1	1	3	5
	22-O	1	1	3	5
Lower Area	IS14-I	1	9	1	11
	IS14-M	1	1	3	5
	IS14-O	1	1	3	5
	48-I	1	1	3	5
	48-M	1	9	3	13
	48-O	1	1	3	5
	49-I	1	3	9	13
	49-M	1	9	3	13
	49-O	1	1	9	11
	IS15-I	1	9	3	13
	IS15-M	1	9	3	13
	IS15-O	1	3	3	7

Scoring Criteria:

Sediment Chemistry	9 = number of LELs £ 5, no SELs	
	3 = number of LELs > 5, no SELs	
	1 = one or more SELs	
Sediment Toxicity	9 = no toxicity to any organism	
	3 = 40% to < 80% acute toxicity in any organism and/or > -40% subleathal toxicity in any organism	
	1 = acute toxicity in any organism ³ 80%	
Benthic Macroinvertebrates	9 = meets at least two of the following criteria:	- EPT index ³ 4
		- tubificid density < 50%
		- total number of taxa ³ 35
	3 = meets at least two of the following criteria:	- EPT index is 2 to 3
		- tubificid density 50% to < 80%
		- total number of taxa is 25 to 34
	1 = meets at least two of the following criteria:	- EPT index is < 2
		- tubificid density ³ 80%
		- total number of taxa < 25

seven stations exhibited low scores, one with acute toxicity to *Chironomus* (46-O), one with acute toxcicity to *Chironomus* (22-O) and the other four with acute toxicity to *Pimephales*. At Station 47-I, an intermediate score reflected 70% acute toxicity to *Hexagenia* in addition to chronic toxicity to *Chironomus* and *Hexagenia*. In the Lower Area, four of the five stations exhibited low scores, reflecting acute toxicity to *Pimephales* (IS14-M and 48-I), *Hexagenia* and *Chironomus* (IS14-O) and *Hexagenia* (48-O). Intermediate scores at Station IS15-O reflected 50% acute toxicity to *Hexagenia*. The benthic macroinvertebrate community indicated low scores at both stations, with either low EPT index scores, tubificids accounting for>80% of the community and/or total taxa <25. In the Middle Area only one station was characterized by a low score (46-O), while the rest were characterized by intermediate scores. All five stations in the Lower Area were characterized by intermediate benthic scores.

Sixteen stations in the study area were classified by intermediate Total Scores (10-18). Seven of these stations were located in the Lower Area (IS14-I, 48-M, 49-I, 49-M, 49-O, IS15-I and IS15-M). Seven stations in the Middle Area (IS9-I, IS9-O, 45-I, 45-M, 45-O, 46-M and 47-M), and two in the Upper Area (44-I and 20-O) were also characterized by intermediate Total Scores. Stations in the Lower Area were characterized by levels of mercury and hexachlorobenzene above their respective SEL guidelines, while stations in the Middle Area were generally characterized by either elevated copper, iron, hexachlorobenzene or total PAHs levels above SEL guidelines. Of the two stations in the Upper Area, Station 44-I was characterized by generally low sediment contaminant levels, while Station 20-O was characterized by metals and PAHs above their respective LEL guidelines and total petroleum hydrocarbons elevated above the 1,500 mg/kg level associated with toxicity (Bedard and Petro, 1997). Stations in the Upper Area were characterized by acute toxicity to *Pimephales* at Station 44-I, while 20-O had acute toxicity (100%) to *Chironomus* and *Hexagenia*. In the Middle Area, low scores occurred at four stations. Acute toxicity to *Chironomus* and *Hexagenia* occurred at Stations IS9-I, IS9-O and 47-M, while acute toxicity to *Pimephales* occurred at Stations IS9-I and 47-M. One station (45-M) was characterized by an intermediate score due to chronic toxicity to *Chironomus*. Two stations (45-I and 46-M) did not demonstrate either acute or chronic toxicity to any species. In the Lower Area, only one station (49-O) was characterized by a low score due to acute toxicity to *Hexagenia* and *Pimephales*. One station (49-I) was characterized by an intermediate score due to 40% acute toxicity to *Pimephales*. The remaining five stations (IS14-I, 48-M, 49-M, IS15-I and IS15-M) in the Lower Area were characterized by neither acute nor chronic toxicity. The benthic macroinvertebrate community in the Upper Area indicated a low score at Station 44-1 (EPT Index=1, tubificids density 50% to <80%), while 20-O was characterized by a high score. In the Middle Area two stations were characterized by intermediate scores (45-I and 46-M), while the remaining five stations (IS9-I, IS9-O, 45-M, 45-O and 47-M) had high scores. In the Lower Area, one station (IS14-I) was characterized by a low score due to low numbers of taxa and a low EPT index score. Four stations were characterized by an intermediate score (48-M, 49-M, IS15-I and IS15-M), while two stations (49-I and 49-O) were characterized by high scores.

Nine stations were characterized by high Total Scores (19 to 27) representing areas with the best sediment quality. These include 5 stations along the reference transects (18-I, 18-M, 18-O, 44-M and 44-O) in the Upper Area and Stations IS9-M, 46-I, IS12-O and 47-O from the Middle Area. With one exception, all of these stations were characterized by low levels of sediment contamination. The exception occurred at Station 18-M where copper occurred above the SEL guidelines in addition to five other contaminants above their LEL limits. None of the stations in the Lower Area were characterized by high Total Scores. Two stations (44-M and 44-O) in the Upper Area were characterized by low scores for toxicity. At 44-M, *Pimephales* exhibited acute toxicity ≥80%. In addition, *Chironomus* and *Hexagenia* exhibited acute toxicity of 60% and *Chironomus* exhibited chronic toxicity of 84%. At 44-O, acute toxicity was exhibited by all three test species. The other three stations (18-I, 18-M, and 18-O) were characterized by the absence of substantial acute or chronic toxicity to any of the three species. In the Middle Area, all four stations (IS9-M, 46-I, IS12-O and 47-O) were characterized by the absence of substantial acute or chronic toxicity to any of the three species. In the Upper Area, all five stations (18-I, 18-M, 18-O, 44-M and 44-O) were characterized by high benthic community scores. In the Middle Area, one station (46-I) was characterized by a low score due to low numbers of taxa, EPT taxa and a high percentage of tubificid oligochaetes. Two stations (IS9-M and IS12-O) were characterized by intermediate scores, while one station (47-O) was characterized by a high benthic community score.

The Total Scores tend to suggest a decline in sediment quality from the Upper to the Lower Area, although the pattern is patchy, likely reflecting the influence of specific discharges and sediment type (i.e., depositional versus hard).

6.0 REFERENCES

6.1 Taxonomic References

Bednarik, A.F. and W.P. McCafferty., 1979. Biosystematic Revision of the Genus *Stenonema* (Ephemeroptera: Heptageniidae).

Bousfield, E.L., 1967. Freshwater amphipod crustaceans of glaciated North America

Brinkhurst, R.O. and B.G.M. Jamieson. 1971. *Aquatic Oligochaeta of the World*.

Brinkhurst, R.O. 1986. Guide to the freshwater aquatic oligochaetes of North America

Burch, J.B. 1989 *North American Freshwater Snails*.

Clarke, A.H. 1973. *The freshwater molluscs of the Canadian Interior Basin*.

Clarke, A.H. 1981. *The Freshwater Molluscs of Canada*.

Crocker, D.W. and D.W. Barr. 1968. *Handbook of the Crayfishes of Ontario*.

Edmunds, G.F., Jr., S.L. Jensen and L. Berner. 1976. *The Mayflies of North and Central America*.

Erseus, Christer. 1991. A generic revision of the Phallodrilinae (Oligochaeta, Tubificidae).

Harman, W.N. and C.O. Berg. 1971. *The Freshwater Snails of Central New York*.

Hilsenhoff, W.L. 1981. Aquatic Insects of Wisconsin.

Hiltunen, J.K. and D.J. Klemm. 1980. A guide to the Naididae (Annelida:Clitellata: Oligochaeta) of North America. U.S. EPA, EPA 600/4-80-03.

Hitchcock, S.W. 1974. Guide to the Insects of Connecticut. Part VII: The Plecoptera or Stoneflies of Connecticut.

Hobbs, H.Jr. 1976. Crayfishes (Astacidae) of North and Middle America.

Holsinger, J.R. 1976. The Freshwater Amphipod Crustaceans (Gammaridae) of North America.

Klemm, D.J. 1972. Freshwater Leeches (Annelida:Hirudinea) of North America.

Klemm, D.J. (Ed.). 1985. *Guide to the Freshwater Annelida (Polychaeta, Naidid, Tubificid, Oligochaeta and Hirudinea) of North America*.

Mackie, G.L., D.S. White and T.W. Zdeba. 1980. A guide to freshwater molluscs of the Laurential Great Lakes with special reference to the *Pisidium*.

McCafferty, W.P. 1974. The burrowing mayflies of the United States (Ephemeroptera: Ephemeroidea).

Merritt, R.W. and K.W. Cummins. 1984. *An Introduction to the Aquatic Insects of North America*.

Moller Andersen, N. 1982. The Semiaquatic Bugs (Hemiptera, Gerromorpha) Phylogeny, Adaptations, Biogeography and Classification. Entomonograph Volume 3.

Oliver, D.R. and M.E. Roussel. 1983. The genera of larval midges of Canada. In: The Insects and Arachnids of Canada, Part II.

Oliver, D.R., D. McClymont and M.E. Roussel. 1978. A key to some larvae of Chironomidae (Diptera) from the MacKenzie and Porcupine River watersheds.

Pennak, R.W. 1989. *Freshwater Invertebrates of the United States* (3rd Ed.).

Saether, O.A. 1972. VI. Chaoboridae. In: Das Zooplankton der Binengewasser.

Saether, O.A. 1975. Nearctic and Paleaarctic *Heterotrissocaldius* (Diptera: Chironomidae).

Saether, O.A. 1976. Revision of Hydrobaenus, *Trissocladius, Zalutschia, Paratrissocladius* and some related genera (Diptera: Chironomidae).

Saether, O.A. 1977. Taxonomic studies on Chironomidae: *Nanocladius, Pseudochironomus* and the *Harnischia* complex.

Stewart, K.W. and B.P. Stark. 1988. Nymphs of North American Stonefly Genera (Plecoptera).

Stimpson, K.S., D.J. Klemm and J.K. Hiltunen. 1982. A Guide to the Freshwater Tubificidae (Annelida:clitellata:Oligochaeta) of North America.

Thorp, J.H. and A.P. Covich. 1991. *Ecology and Classification of North American Freshwater Invertebrates*.

Usinger, R.L. (Ed.). 1956. *Aquatic Insects of California*.

Walker, E.M. 1953. The Odonata of Canada and Alaska. Vol. 1: Part I: General. Part II: The Zygoptera - Damselflies.

Walker E.M. 1958. The Odonata of Canada and Alaska. Vol. 2: Part III: The Anisoptera - Four Families.

Walker, E.M. and P.S. Corbet. 1975. The Odonata of Canada and Alaska. Vol. 3: Part III: The Anisoptera - Three Families.

Ward, H.B. and G.C. Whipple. 1959. *Freshwater Biology*

Wiederholm, T. 1983. Chironomidae of the Halarctic region keys and diagnoses.

Wiggins, G.B. 1977. *Larvae of the North American Caddisfly Genera (Trichoptera).*

6.2 Literature Cited

Anderberg, M.R. 1973. *Cluster Analysis Applications*. Academic Press, New York.

Ankley, G.T., D.A. Benoit, J.C. Balogh, T.B. Reynoldson, K.E. and R.A. Hoke. 1994. Evaluation of Potential Confounding Factors in Sediment Toxicity Tests with Three Freshwater Benthic Invertebrates. Environ. Toxicol. Chem. 13:627-635.

ASTM. 1995. Standard Guide for Conducting Sediment Toxicity Tests with Freshwater Invertebrates. Designation: E 1383-94a, Annual Book of ASTM Standards, Vol. 11.05, American Society for Testing and Materials, Philadelphia, PA.

Beak Consultants Limited. 1992. Standard Operating Procedures for Biological Services. Biological Services Department. 24 pp.

Beals, E.W. 1973. Ordination: mathematical elegance and ecological naivete. J. Ecol. 61:23-25.

Beals, E.W. 1984. Bray-Curtis ordination: an effective strategy for analysis of multivariate ecological data. Adv. Ecol. Res. 14:1-55.

Bedard D. and S. Petro. 1992. St. Clair River Study 1990 Laboratory Sediment Bioassay Report, Ontario Ministry of the Environment and Energy, Water Resources Branch, Internal Technical Report, Toronto, Ontario. 14 p.

Bedard D. and S. Petro. 1997. Laboratory Sediment Bioassay Report on Upper St. Clair River Sediments in the Vicinity of Industrial Point Sources. Ontario Ministry of the Environment and Energy, Standards Development Branch, Toronto, Ontario

Bedard, D., A. Hayton and D. Persaud. 1992. Ontario Ministry of the Environment Sediment Biological Testing Protocol. OMOE, Water Resources Branch, Toronto, Ontario. 26 pp.

Bloom, S.A. 1981. Similarity indices in community studies: Potential pitfalls. Marine ecology. 5:125-128.

Boecklen, W.J. and P.W. Price. 1989. Size and shape of sawfly assemblages on Arroyo willow.Ecology. 70(5): 1463-1471.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monogr. 27:325-349.

Burt, A.J., D.R. Hart and P.M. McKee. 1988. Benthic invertebrate survey of the St. Marys River, 1985. Report prepared for Ontario Ministry of the Environment, Great Lakes Section by Beak Consultants Limited, Brampton, Ontario. Vol. I. 88pp.

Chapman, P.M. 1990. The Sediment Quality Triad Approach to Determining Pollution Induced Degradation. Sci. Tox. Environ. 97-8:815-825.

Chapman, P.M. 1996. Presentation and interpretation of Sediment Quality Triad data. Ecotoxicology. 5:327-339.

Chapman, P.M., E.A. Power and G.A. Burton Jr. 1992. Integrative assessments in aquatic ecosystems. In: *Sediment Toxicity Assessment*. Burton, Jr., (Ed.). Lewis Publishers, Chelsea, MI. Pp. 313-340.

Creese, E.E. 1987. Report on the 1983 Benthic Invertebrate Survey of the Niagara River and Nearby Lake Ontario. A Report Prepared by Integrated Explorations for the Ontario Ministry of the Environment, Water Resources Branch, Toronto, Ontario.

Cooley, W.W. and P.R. Lohnes. 1971. *Multivariate data analysis*. J. Wiley & Sons, Inc. N.Y.

Elliott, J.M. 1971. Some methods of the statistical analysis of samples of benthic invertebrates. Freshwater Biological Association. No. 25.

Environment Canada. 1994. Canadian Environmental Quality Guidelines for Polychlorinated Dibenzo-*p*-Dioxins and Polychlorinated Dibenzofurans Supporting Document (draft). Evaluation and Interpretation Branch, Ecosystem Conservation Directorate. Ottawa, Ontario.

Environment Canada (EC) and Ontario Ministry of the Environment (OMOE). 1986. St. Clair River Pollution Investigation. Report of the Review Board of the Canada-Ontario Agreement Respecting Great Lakes water Quality, Ottawa, Ontario, Canada. 135 pp.

Faith D., P. Minchin and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio. 69:57-68.

Farara, D.G. and A.J. Burt. 1993. Environmental Assessment of the Detroit River Sediments and Benthic Communities - 1991. Report prepared for the Ontario Ministry of Environment and Energy by Beak Consultants Ltd. Brampton, Ontario. 193 pp.

Gauch, H.G. Jr. 1973. The relationship between sample similarity and ecological distance. Ecology. 54:618-622.

Gauch, H.G. Jr. and R.H. Whittaker. 1972. Comparison of ordination techniques. Ecology. 53:868-875.

Gibbons, W.N., M.D. Munn and M.D. Paine. 1993. Guidelines for monitoring benthos in freshwater environments. Report prepared for Environment Canada, North Vancouver, B.C. by EVS Consultants, North Vancouver, B.C. 81 pp.

Gobas, F.A.P.C., D.C. Bedard, J.J.H. Ciborowski and G.D. Haffner. 1993. Bioaccumulation of Chlorinated Hydrocarbons by the Mayfly (*Hexagenia limbata*) in Lake St. Clair. J. Great Lakes Res. 15:581-588.

Golini, V.I. 1979. Benthic macro- and microinvertebrates of Lake Ontario, 1977: distribution and relative abundance. Environment Canada, Fish. Mar. Serv., Manus. Rep. 1519.

Greenacre, M.J. 1984. *Theory and applications of correspondence analysis*. Academic Press. New York. 364pp.

Griffiths, R.W. 1989. Environmental Quality Assessment of the St. Clair River as reflected by the 1985 Distribution of Benthic Invertebrates. Aquatic Ecostudies Limited, (Kitchener, Ontario) report for the Ontario Ministry of the Environment, Southwestern Region, and Water Resources Branch. London and Toronto, Ontario. 41 pp. + appendices

Hilsenhoff, W.L. 1982. Using a biotic index to evaluate water quality in streams. Tech. Bull. Wisconsin Dept. Nat. Resour. 132. 22 pp.

Hilsenhoff, W.L. 1987. An Improved Biotic Index of Organic Stream pollution. The Great Lakes Entomol. 20(1):31-39.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family level biotic index. J. N. Am. Benthol. Soc. 7: 65-68.

Hiltunen, J.K. 1980. Composition, Distribution and Density of Benthos in the Lower St. Clair River, 1976-1977. U.S. Fish and Wildlife Service, Great Lakes Fish. Lab., Admin. Rep. 80-4 Ann Arbor, Michigan.

Hoiland, W.K. and F.W. Rabe. 1992. Effects of Increasing Zinc Levels and Habitat Degradation on Macroinvertebrate Communities in Three North Idaho Streams. J. Freshw. Ecol. 7 94): 373-380.

Jaagumagi, R. 1988. The In-Place Pollutants Program Volume V, Part B, Benthic Invertebrate Studies Results. Report Prepared for the Ontario Ministry of the Environment, Water Resources Branch, Aquatic Biology Section.

Jackson, D.A., K.H. Somers and H.H. Harvey. 1989. Similarity measures: measures of co-occurrence and association or simply measures of occurrence? Am. Nat. 133:436-453.

Kauss, P.B. 1994. Concentrations of Polychlorinated dibenzo-p-dioxins and dibenzofurans in Detroit River Surficial Sediments, 1991. Ministry of the Environment, ISBN, 0-7778-3624-6. Toronto, Ontario.

King, L. and G. Sherbin. 1986. Point Sources of Toxic Organics to the Upper St. Clair River. Water Poll. Res. J. Canada, 21 (3):433-445.

Klemm, D.J., P.A. Lewis, F. Fulk and J.M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. EPA/600/4-90/030. 256pp.

Ludwig, J.A. and J.F. Reynolds. 1988. *Statistical Ecology*. John Wiley and Sons, New York.

Magurran, A.E. 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton.

Marriott, F.H.C. 1974. *The interpretation of multiple observations*. Academic Press, London.

McCarty, L.S., G.W. Ozburn, A.D. Smith and D.G. Dixon. 1992. Toxico kinetic Modeling of Mixtures of Organic Chemicals. Environ. Toxicol. Chem. 11:1037-1047.

Moran, T., D. Adams, K. Walker and B. Zajdlik. 1997. 1994/1995 St. Clair River Sediment Program Defining Spatial Extent and Environmental Conditions. A report prepared for the Lambton Industrial Society by Pollutech Enviroquatics Limited, Point Edward, Ontario.

Norusis M.J. 1992. *SPPS for Windows: Advanced Statistics, Release 5*. SPSS Inc., Chicago, IL.

Oliver, B.G. and C.W. Pugsley. 1986. Chlorinated Contaminants in the St. Clair River Sediments. Water Poll. Res. J. Canada. 21(3):368-380.

OMOE (Ontario Ministry of the Environment). 1979. St. Clair River Organics Study, Biological Surveys 1968 and 1977. Water Resources Assessment Unit, Technical Support Section, Southwestern Region.

OMOE (Ontario Ministry of the Environment). 1989a. A guide to the collection and submission of samples for laboratory analysis. 6th edition. Laboratory Services Branch Toronto, Ontario. 81 pp.

OMOE (Ontario Ministry of the Environment), 1989b. The Determination of Mercury in Soils,Sediments and Vegetation by Cold Vapour-Atomic Absorption Spectrophotometry (CV-AAS). Laboratory Services Branch. Etobicoke, Ontario.

OMOE (Ontario Ministry of the Environment), 1990. The Determination of Arsenic, Selenium and Antimony in Vegetation, Soil and Sediments by Hydride-Flameless Atomic Absorption Spectrophotometry (HYD-FAAS). Laboratory Services Branch. Etobicoke, Ontario.

OMOE (Ontario Ministry of the Environment). 1991. St. Clair River MISA Pilot Site Investigation. Volume II. Part II-Detailed Technical Findings. Toronto, Ontario.

OMOE (Ontario Ministry of the Environment). 1992. Report on the 1990 Industrial Direct Discharges in Ontario.

OMOEE (Ontario Ministry of Environment and Energy), 1994a. The Determination of Trace Metals in Sediments by the Spectro Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). HMARSOIL-E3062A. Laboratory Services Branch. Etobicoke, Ontario. March 28. 45 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1994b. The Determination of Organic Solvent Extractable Materials in Solids by Soxhlet Extraction. SXTS-E3241A. Laboratory Services Branch. Etobicoke, Ontario. June 2.

OMOEE (Ontario Ministry of Environment and Energy), 1994c. The Determination of Polychlorinated Biphenyls (PCBs), Organochlorines (OCs) and Chlorobenzenes (CBs) in Soil and Sediments by Gas Liquid Chromatography-Electron Capture Detection (GLC-

ECD). PSAOC-E3270A. Laboratory Services Branch. Etobicoke, Ontario. July 18. 37 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1994d. The Determination of Polynuclear Aromatic Hydrocarbons in Soil and Sediments by Gel Permeation Chromatography-high Performance Liquid Chromatography (PC-HPLC). PSAPAH-E3350A. Laboratory Services Branch. Etobicoke, Ontario. July 20. 28 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1995a. The Determination of Total Carbon in Sediments by the LECO Carbon Analyzer. CARBONTC-E3142A. Laboratory Services Branch. Etobicoke, Ontario. July 1. 19 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1995a. The Determination of Moisture Content, RST, RSTA and LOI in Sediments by Gravimetry. PHYSOLID-E3139A. Laboratory Services Branch. Etobicoke, Ontario. October 16. 18 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1995b. The Determination of Particle Size on Sediment Samples by Microtrac Particle Size Analyzer Model 7991-2. PZSIZE-E3262A and SMPART-E3128A. Laboratory Services Branch. Etobicoke, Ontario. November 4. 25 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1995c. The Determination of Polychlorinated Dibenzo-*p*-Dioxins and Dibenzofurans in Soil and Sediment by GC-MS. PSAFD-E3151B. Laboratory Services Branch. Etobicoke, Ontario. November 25. 34 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1995d. The Determination of Total Kjeldahl Nitrogen and Total Phosphorus in Soil and Sediments by Colourimetry (NPSED-E3116A). Laboratory Services Branch. Etobicoke, Ontario.

OMOEE (Ontario Ministry of Environment and Energy), 1996. The Determination of Volatile Organohalides and Hydrocarbons in Sediments, Sludges and Kiln Dust by Headspace Capillary Gas Chromatography (GC). LFHS/S-E3254A. Laboratory Services Branch. Etobicoke, Ontario. January 17. 22 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1997a. The Determination of Total Petroleum Hydrocarbons (C_5-C_{50}) in Soils by Headspace Gas Chromatography-Flame Ionization Detection (GC-FID) Combined with Microwave Solvent Extraction. TPH-E3397A. Laboratory Services Branch. Etobicoke, Ontario. February 22. 39 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1997b. The Determination of Water-Extractable Chloride in Soil and Sediments by Ion Chromatography (IC). E3013A. Laboratory Services Branch. Etobicoke, Ontario. 31 pp.

OMOEE (Ontario Ministry of Environment and Energy), 1997c. The Determination of Total Cyanide in Solid Samples by Colourimetry. E3007A. Laboratory Services Branch. Etobicoke, Ontario. 27 pp.

Ontario Ministry of Environment and Energy (OMOEE) and Michigan Department of Natural Resources (MDNR). 1995. The St. Clair River Area of Concern, Water Use Goals Remedial Measures and Implementation Strategy. Remedial Action Plan - Stage 2. March 7, 1995. Sarnia, Ontario. 121 p.

Persaud, D., R. Jaagumagi and A. Hayton. 1993 Guidelines for the protection and management of aquatic sediment quality in Ontario. Water Resources Branch. Ontario Ministry of the Environment. Toronto, Ontario. 23 pp.

Pielou. 1966. Shannon's formula as a measure of specific diversity: its use and misuse. Am. Nat. 100:463-465.

Pope, R. 1993. Assessment of the St. Clair River Benthic Macroinvertebrate Communities Relative to Sediment Quality. Report prepared by Tarandus Associates Limited for the Ontario Ministry of Environment and Energy, Southwestern Region and Water Resources Branch. Toronto, Ontario.

Pugsley, C.W., P.D.N. Hebert, G.W. Wood, G. Brotea and T.W. Obal. 1985. Distribution of Contaminants in Clams and Sediments from the Huron-Erie Corridor. I-PCBs and Octachlorostyrene. J. Great Lakes Res. 11:275-289.

Rohlf, F.J. 1994. *NTSYS-pc. Numerical Taxonomy and Multivariate Analysis System*. Exeter V1.8. Software, Setauket, NY, USA.

Shannon, C.E. and W. Weaver. 1949. *The mathematical theory of communication*. The University of Illinois Press, Urbana, Il.

St. Clair River Remedial Action Plan Team. 1991. The St. Clair River Area of Concern Remedial Action Plan Stage 1. Environmental Conditions and Problem Definitions. Ontario Ministry of Environment and Michigan Department of Natural Resources. Toronto, Ontario.

Suns, K., G. Hitchin and D. Toner. 1991. Spatial and Temporal Trends of Organochlorine Contaminants in Spottail Shiners (*Notropis hudsonius*) from the Great Lakes and their Connecting Channels (1975-1988). Ministry of Environment report ISBN 0-7729-8411-5. Toronto, Ontario.

Tomczak, M. 1997. Designation of Sediment Quality Zones in Upper Portion of the St. Clair River - Interpolation, Contouring and Cross-validation. A draft report prepared for the Ontario Ministry of the Environment and Energy, Sarnia, Ontario.

Upper Great Lakes Connecting Channels Study (UGLCCS). 1988. Final Report of the Upper Great Lakes Connecting Channels Study. U.S. EPA, Environment Canada, Michigan Department of Natural Resources and Ontario Ministry of the Environment.

van Groenewoud, H. 1976. Theoretical considerations on the covariations of plant species along ecological gradients with regard to multivariate analysis. J. Ecol. 64:837-847.

Washington, H.G. 1984. Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. Water Res. 18(6):653-694.

Whittaker, R.H. and C.W Fairbanks. 1958. A study of plankton and copepod communities in the Columbia basin, southeastern Washington. Ecology. 39:46-65.

Wilhm, J.L. and T.C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience. 18:477-481.

TABLE A1.2: SEDIMENT QUALITY PARAMETERS MEASURED IN UPPER ST. CLAIR RIVER SEDIMENTS, JUNE 1994

Field (Wet) Density	1,2,3,5-Tetrachlorobenzene	Coarse Sand
Loss on Ignition	1,2,4,5-Tetrachlorobenzene	Fine Sand
Total Organic Carbon	Pentachlorobenzene	Silt+Clay
Calcium	Hexachlorobenzene	Heptachlor
Chloride	Octachlorostyrene	Aldrin
Potassium	Total PCBs	Mirex
Sodium	Total Petroleum Hydrocarbons	α–BHX
Ammonium	Chloroform	β–BHX
Total Kjeldahl Nitrogen	1,1,1-Trichloroethane	γ–BHX
Nitrates	Trichloroethene	α–Χηλορδανε
Total Phosphorus	1,1,2-Trichloroethane	γ–Χηλορδανε
Solvent Extractables	Tetrachloroethene ("Perc")	Oxychlordane
Aluminum	Carbon Tetrachloride	o,p´-DDT
Arsenic	Benzene	p,p´-DDD
Cadmium	Toluene	p,p´-DDT
Chromium	meta- & para-Xylenes	p,p´-DDE
Cobalt	ortho-Xylene	Methoxychlor
Copper	Ethylbenzene	Heptachlor Epoxide
Cyanide	Acenaphthene	α–Ενδοσυλπηαν
Iron	Acenaphthylene	β–Ενδοσυλπηαν
Lead	Anthracene	Endosulphan Sulphate
Magnesium	Benzo(a)anthracene	Dieldrin
Manganese	Benzo(b)fluoranthene	Endrin
Mercury	Benzo(k)fluoranthene	Dichloromethane
Nickel	Benzo(g,h,I)perylene	1,1-Dichloromethane
Zinc	Benzo(a)pyrene	Trans-2-Dichloroethene
Hexachloroethane	Chrysene	Bromodichloromethane
Hexachlorobutadiene	Dibenzo(a,h)anthracene	Dibromochloromethane
2,3,6-Trichlorotoluene	Fluoranthene	Bromoform
2,4,5-Trichlorotoluene	Fluorene	Chlorobenzene
2,6,a-Trichlorotoluene	Indeno(1,2,3-cd)pyrene	1,2-Dichlorobenzene
1,2,3-Trichlorobenzene	Naphthalene	1,3-Dichlorobenzene
1,2,4-Trichlorobenzene	Phenanthrene	1,4-Dichlorobenzene
1,3,5-Trichlorobenzene	Pyrene	Polychlorinated dibenzo-p-dioxins
1,2,3,4-Tetrachlorobenzene	Gravel	and dibenzofurans (scan)*

* Polychlorinated dibenzo-p-dioxins and dibenzofuran scan included 10 coNgener groups and 17 2,3,7,8-substituted isomer

TABLE A2.1: RESULTS OF SORTING EFFICIENCY CHECKS ON SAMPLES FROM THE UPPER ST. CLAIR RIVER AS PART OF THE QA/QC PROGRAM AT BEAK'S BENTHIC ECOLOGY LABORATORY

Station	Replicate	Initial Sorting	Organisms Recovered After Resorting	Initial %Recovery
IS14-O	3	31	2	93.5
46-I	1	261	7	97.3
20-O	2	65	1	98.5
49-M	3	291	10	96.6
IS14-M	2	375	12	96.8
14-I	1	56	6	89.3
18-O	2	36	2	94.4
20-O	1	52	1	98.1
48-I	3	272	3	98.9
15-O	1	163	18	89.0
			Average	**95.2**

TABLE A3.1: SEDIMENT QUALITY DATA FOR SAMPLES FROM STATIONS IN THE UPPER ST. CLAIR RIVER - JUNE 1994 A

			Upper Area								
		Station	18-I	18-M5	18-O	44-I	44-M	44-O	20-I	20-M5	20-O
Parameters[3]	MDL4	Units									
Distance from Canadian Shore		m	15	25	35	15	30	45	10	20	30
TOC		g/kg	**10.8**	**12.0**	9.9	8.8	**10.4**	**13.3**	2.4	**13.6**	**15.1**
Mercury		mg/kg	0.07	0.05	0.02	0.12	0.09	0.06	0.03	0.06	0.10
Hexachlorobutadiene	1	µg/kg	11	2	<1	94	33	<1	3	7	5
Hexachlorobenzene	1	µg/kg	<1	**20**	<1	**20**	5	5	6	6	12

			Middle Area									
		Station	IS9-I	IS9-M	IS9-O	45-I	45-M	45-O	46-I	46-M5	46-O	S12-I5
Parameters[3]	MDL4	Units										
Distance from Canadian Shore		m	10	20	30	5	20	35	7	15	25	10
TOC		g/kg	**17.5**	**12.4**	**10.3**	9.0	**81.1**	**97.3**	**46.9**	**42.9**	**48.3**	**33.6**
Mercury		mg/kg	**0.27**	0.10	0.13	**0.27**	**0.23**	**0.29**	**0.29**	**0.40**	**0.99**	**0.57**
Hexachlorobutadiene	1	µg/kg	380	1800	875	210	3500	900	435	996	912	156
Hexachlorobenzene	1	µg/kg	**260**	**120**	**1100**	**20**	**400**	**200**	**47**	**129**	**121**	**86**

			Middle Area							
		Station	12-M5	12-O5	47-I5	47-M	47-O	22-I	22-M	22-O
Parameters[3]	MDL4	Units								
Distance from Canadian Shore		m	25	40	15	35	55	5	20	30
TOC		g/kg	**30.4**	**12.8**	**19.1**	**25.4**	**18.8**	3.8	**28.4**	**20.6**
Mercury		mg/kg	**0.21**	0.18	**0.26**	0.07	0.13	**0.77**	**0.36**	**0.66**
Hexachlorobutadiene	1	µg/kg	347	655	256	338	1300	3480	4000	2000
Hexachlorobenzene	1	µg/kg	**190**	**75**	**74**	**205**	**196**	**450**	**2000**	**750**

			Lower Area											
		Station	IS14-I	14-M5	S14-O	48-I	48-M	48-O	49-I	49-M	49-O	IS15-I	S15-M	S15-O
Parameters[3]	MDL4	Units												
Distance from Canadian Shore		m	10	30	37	10	25	37	10	25	40	22	28	35
TOC		g/kg	3.7	9.6	**15.8**	8.3	**25.1**	**13.6**	4.7	9.4	8.5	4.3	8.1	**23.9**
Mercury		mg/kg	**5.20**	**6.20**	**1.60**	**60**	**29**	**3**	**163**	**84**	**44**	**13**	**24**	**24**
Hexachlorobutadiene	1	µg/kg	3400	****	****	****	6700	****	4400	4940	****	1430	4000	****
Hexachlorobenzene	1	µg/kg	**1950**	****	****	****	**7400**	****	**8750**	**4570**	****	**800**	**6300**	**5900**

							1995 Ac												
		Station	195	196	197	IS16-I	S16-M	S16-O	192	193	194	24-I	24-M	24-O	189	190	191	PSQG	PSQG
																		LEL[1]	SEL[1]
Parameters[3]	MDL4	Units																	
Distance from Canadian Shore		m	15	20	30	5	20	35	10	20	30	10	15	40	10	20	30	-	-
TOC		g/kg	8.4	<0.2	4.2	7.3	**18.0**	**13.0**	**11.0**	**14.0**	3.7	7.0	**10.0**	<1	1.2	6.5	3.9	10	100
Mercury		mg/kg	**3.9**	**13**	**12**	**32**	**15**	**7**	**1.8**	**1.6**	**1.70**	**0.86**	**1.50**	**3.20**	**1.60**	**1.50**	**1.80**	0.2	2
Hexachlorobutadiene	1	µg/kg	260	720	5400	420	200	5700	210	1800	-	36	97	330	96	2200	2	-	-
Hexachlorobenzene	1	µg/kg	**81**	**100**	**1100**	**1700**	**1100**	**1300**	**870**	**840**	-	16	**62**	**100**	**30**	**280**	**190**	20	****

[1] Ontario Ministry of the Environment Provincial Sediment Quality Guidelines (Persaud et al., 1993) - LEL = Lowest Effect Level; SEL = Severe Effect Level
[3] Parameters expressed on a dry weight basis
4 MDL - Method Detection Limit (Values less than MDL considered = 0)
6 SEL value adjusted by site-specific TOC value
- parameter not measured or no applicable score

(grey) Equal to or exceeds LEL or open water disposal guideline - fails guideline and may have an adverse effect on some benthic organisms
(black) Equal to or exceeds SEL - highly contaminated and likely will have an adverse effect on benthic organisms

TABLE A3.2; POLYCHLORINATED DIOXINS AND FURANS CONCENTRATIONS IN ST. CLAIR RIVER SEDIMENT SAMPLES.

All concentrations in pg/g (ppt), dry weight.

Station Number	Distance from CDN shore, m.	Core Section, cm.	Sample Date	Field Sample Number	TetraCDF	TetraCDD	PentaCDF	PentaCDD	HexaCDF	HexaCDD	HeptaCDF	HeptaCDD	OctaCDF	OctaCDD	2,3,7,8-TetraCDF	2,3,7,8-TetraCDD	1,2,3,7,8-PentaCDF	2,3,4,7,8-PentaCDF	1,2,3,7,8-PentaCDD	1,2,3,4,7,8-HexaCDF	1,2,3,6,7,8-HexaCDF	2,3,4,6,7,8-HexaCDF	1,2,3,7,8,9-HexaCDF	1,2,3,4,7,8-HexaCDD	1,2,3,6,7,8-HexaCDD	1,2,3,7,8,9-HexaCDD	1,2,3,4,6,7,8-HeptaCDF	1,2,3,4,7,8,9-HeptaCDF	1,2,3,4,6,7,8-HeptaCDD	Total 2,3,7,8-TetraCDD TEQ
Upper Area																														
18	15	0 - 5	94/06/14	71784	2.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.7 (1)	6.7 (2)	16 (2)	4.3	45	2.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.1	1.0 <	6.9	0.1
	25	"	"	71785	35 (13)	4.9 (2)	13 (3)	3.0 <	9.1 (4)	8.3 (3)	14 (2)	35 (2)	8.6	85	6.8	1.0 <	1.0 <	1.0 <	1.0 <	2.2	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	7.1	1.0 <	13	1.2
	35	"	"	71788	2.1 (1)	1.0 <	5.5 (3)	1.0 <	9.7 (4)	5.1 (3)	19 (3)	24 (2)	17	49	2.1	1.0 <	1.0 <	1.0 <	1.0 <	1.9	1.0 <	1.8	1.0 <	1.0 <	1.0 <	1.0 <	8.0	1.0 <	10	0.6
44	15	"	94/06/13	71774	2.1 (1)	1.0 <	5.5 (2)	1.5 (1)	24 (6)	18 (5)	49 (4)	47 (2)	29	79	2.1	1.0 <	1.0 <	1.0 <	1.0 <	3.4	1.5	1.8	1.0 <	1.0 <	3.0	2.1	17	2.0	30	2.0
	30	"	"	71773	2.5 (1)	1.0 <	4.4 (2)	1.0 <	7.3 (3)	9.3 (3)	21 (2)	38 (2)	23	120	2.5	1.0 <	1.0 <	1.0 <	1.0 <	1.8	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	9.0	1.0 <	19	0.9
	45	"	"	71775	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.4 (3)	6.4 (2)	12 (2)	8.5	35	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.4	1.0 <	5.9	0.1
20	10	"	94/06/16	10385	1.0 <	1.0 <	1.0 <	1.0 <	5.2 (2)	1.0 <	5.9 (2)	8.3 (2)	13	20	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.5	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.7	1.0 <	4.3	0.5
	20	"	94/06/15	71793	1.0 <	1.0 <	5.1 (2)	1.0 <	5.7 (3)	1.7 (2)	9.3 (2)	20 (2)	11	56	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.6	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	4.8	1.0 <	7.5	0.4
	30	"	"	71792	1.0 <	1.0 <	1.0 <	2.0 (1)	1.0 <	3.4 (2)	4.8 (2)	9.4 (2)	3.4	26	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	2.7	1.0 <	4.0	0.1
Middle Area																														
IS9	10	0 - 5	94/06/07	71701	10 (3)	3.5 (1)	39 (6)	10 (2)	65 (11)	25 (6)	110 (4)	59 (2)	890	200	5.8	3.5	13	9.5	8.8	14	7.7	6.5	4.7	5.2	5.3	4.6	35	19	29	20
	20	"	"	71697	2.2 (1)	1.0 <	1.7 (1)	1.0 <	5.2 (3)	4.9 (2)	13 (3)	25 (2)	39	54	2.2	1.0 <	1.0 <	1.0 <	1.0 <	1.6	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	6.7	1.1	8.4	0.6
	30	"	94/06/06	71692	22 (6)	1.0 <	70 (12)	3.0 <	150 (11)	39 (7)	300 (4)	190 (2)	2900	730	8.5	1.0 <	9.9	4.7	2.0 <	37	8.6	10	3.6	3.4	4.3	4.1	100	46	89	17
45	5	"	94/06/06	71691	1.0 <	2.7 (2)	1.3 (1)	2.7 (2)	2.8 (2)	4.4 (3)	6.5 (2)	14 (2)	29	64	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.1	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	1.0 <	3.3	1.0 <	6.9	0.3
	20	"	"	71690	37 (10)	84 (6)	50 (12)	180 (6)	55 (9)	150 (6)	75 (4)	130 (2)	590	230	9.4	2.0	3.7	3.6	6.8	12	4.4	4.6	1.0 <	8.5	14	13	28	10	68	16
	35	"	"	71689	53 (9)	28 (6)	160 (15)	170 (5)	330 (11)	260 (7)	660 (4)	290 (2)	7600	740	19	1.6	23	11	5.8	72	21	25	12	7.2	22	22	240	120	140	45
46	7	"	94/06/16	10387	4.4 (2)	6.2 (2)	2.1 (1)	12 (3)	9.6 (2)	17 (4)	11 (4)	46 (2)	62	100	1.0 <	2.0 <	1.0 <	2.1	1.0 <	6.8	2.8	2.0 <	1.0 <	1.0 <	1.5	3.1	9.7	1.5	17	1.9
	15	"	"	10388	10 <	10 <	8.0 <	17 (2)	10 <	18 (2)	21 (1)	59 (2)	96	160	10 <	10 <	4.0 <	4.0 <	3.0 <	9.0 <	8.0 <	9.0 <	10 <	9.0 <	9.0 <	9.0 <	10 <	4.0 <	19	0.4
	25	"	"	10391	4.0 <	2.0 <	4.0 <	3.0 <	11 (2)	18 930	91 (3)	81 (2)	570	370	4.0 <	2.0 <	4.0 <	4.0 <	3.0 <	8.3	3.0 <	2.0 <	1.0 <	2.0 <	2.0 <	1.0 <	30	11	43	2.6
IS12	10	"	94/06/09	71745	3.0 <	4.0 <	5.0 <	3.0 <	6.0 <	8.0 <	21 (3)	12 (1)	52	110	3.0 <	4.0 <	4.0 <	5.0 <	3.0 <	5.0 <	5.0 <	6.0 <	5.0 <	8.0 <	8.0 <	8.0 <	9.9	2.1	12	0.4
	25	"	"	71722	6.8 (1)	4.0 <	6.0 <	5.0 (1)	8.0 <	27 (3)	20 <	68 (2)	170	190	6.8	4.0 <	6.0 <	3.0 <	3.0 <	8.0 <	7.0 <	8.0 <	5.0 <	3.0 <	3.0 <	3.0 <	20 <	10 <	22	1.3
	40	"	"	71713	3.0 <	2.0 <	2.0 <	3.0 <	3.0 <	3.0 <	19 (2)	14 (1)	150	140	3.0 <	2.0 <	2.0 <	2.0 <	3.0 <	3.0 <	3.0 <	3.0 <	3.0 <	2.0 <	2.0 <	2.0 <	7.4	3.0 <	14	0.5
47	15	"	94/06/10	71759	5.6 (2)	2.0 <	6.5 (1)	3.0 <	6.9 (1)	19 (4)	20 (1)	46 (2)	350	170	5.0 <	2.0 <	2.0 <	2.0 <	1.0 <	6.0 <	4.0 <	4.0 <	2.0 <	2.1	2.0 <	1.0 <	20	4.0 <	20	1.1
	35	"	"	71762	5.4 (2)	3.4 (1)	8.3 (2)	7.3 (2)	12 (2)	24 (3)	31 (2)	68 (2)	110	180	5.0 <	2.0 <	2.3	1.0 <	3.0 <	4.4	3.0 <	3.0 <	3.0 <	4.0 <	4.0 <	4.0 <	14	4.0 <	22	1.1
	55	"	"	71763	2.0 <	2.0 <	4.0 <	5.3 (2)	4.0 <	4.8 (1)	8.2 (1)	54 (2)	86	170	2.0 <	2.0 <	3.0 <	3.0 <	1.0 <	3.0 <	3.0 <	3.0 <	4.0 <	3.0 <	3.0 <	3.0 <	8.2	2.0 <	21	0.5
22	5	"	94/06/02	44392	32 (6)	6.9 (2)	3.2 (1)	3.0 <	12 (3)	8.0 <	14 (3)	24 (2)	65	71	8.5	3.0 <	3.0 <	3.0 <	2.0 <	3.0	1.0 <	2.0 <	1.0 <	4.0 <	3.0 <	4.0 <	6.3	1.3	10	1.5
	20	"	"	44389	26 (4)	2.9 (1)	20 (3)	9.5 (1)	34 (3)	46 (3)	71 (3)	93 (2)	140	230	12	4.0 <	4.0 <	4.0 <	1.0 <	8.4	3.0 <	3.0 <	4.0 <	3.0 <	3.0 <	3.0 <	41	5.2	33	3.2
	30	"	"	44394	15 (2)	3.0 <	8.5 (1)	6.9 (2)	14 (1)	36 (5)	58 (3)	88 (2)	370	210	8.8	3.0 <	4.0 <	4.0 <	3.0 <	4.0 <	4.0 <	4.0 <	4.0 <	2.2	3.3	7.8	24	6.8	39	3.5
Lower Area																														
IS14	10	0 - 5	94/06/07	71704	330 (9)	160 (5)	140 (11)	33 (5)	100 (6)	18 (3)	200 (6)	32 (2)	430	73	37	4.6	12	9.6	6.6	40 <	11	10	2.0 <	1.0 <	3.0 <	2.1	76	18	17	21
	30	"	"	71705	130 (7)	23 (1)	140 (8)	19 (3)	290 (6)	44 (5)	380 (4)	53 (2)	1100	160	45	3.0 <	43	17	2.0 <	170	30	10 <	5.0 <	2.0 <	4.4	1.9	190	56	27	40
	37	"	"	71710	740 (10)	390 (5)	550 (10)	330 (5)	660 (12)	870 (6)	1100 (5)	1100 (2)	2700	2200	110	6.7	30 <	30	19	130	48	43	5.2	11	110	66	510	97	580	100
48	10	"	94/06/10	71769	580 (7)	300 (4)	320 (13)	88 (6)	540 (13)	86 (5)	720 (5)	150 (2)	1600	460	59	7.0 <	18	24	14	110	45	44	7.1	3.2	13	8.6	370	78	77	56
	25	"	"	71770	630 (10)	150 (3)	350 (8)	300 (6)	380 (9)	900 (5)	610 (4)	1100 (2)	1100	1400	96	2.0 <	12	16	9.6	58	25	23	1.0 <	7.0 <	120	63	310	51	600	64
	37	"	"	71771	1100 (10)	400 (8)	1600 (15)	800 (5)	1000 (9)	1400 (5)	2400 (4)	3700 (2)	8600	17000	220	4.2	39	42	19	260	62	40 <	10	30 <	94	44	1000	200	1900	162
49	10	"	94/06/15	71789	180 (9)	39 (2)	130 (8)	28 (4)	220 (9)	56 (4)	330 (4)	120 (2)	740	370	34	3.0 <	13	10 <	2.3	72	21	18	3.0 <	2.0 <	6.0 <	3.5	180	35	64	21
	25	"	"	71790	580 (13)	34 (3)	590 (7)	20 (2)	1800 (6)	61 (4)	1700 (3)	130 (2)	2600	520	240	1.0 <	240	73	2.0 <	1200	270	65	20 <	2.0 <	6.5	3.9	930	360	66	244
	40	"	"	71791	300 (10)	160 (4)	520 (14)	92 (3)	1000 (14)	210 (4)	1300 (4)	220 (2)	4200	470	62	1.0 <	56	27	4.0 <	280	59	31	5.0 <	1.0 <	23	16	460	170	120	76
IS15	22	"	94/06/14	71777	53 (4)	20 (3)	41 (3)	16 (2)	32 (5)	30 (2)	52 (2)	120 (2)	220	630	14	1.0 <	5.1	4.0 <	1.0 <	10 <	4.0 <	3.5	1.0 <	1.0 <	2.0 <	1.0 <	40 <	8.4	70	3.6
	28	"	"	71780	170 (9)	93 (4)	140 (9)	27 (3)	290 (10)	120 (5)	210 (3)	150 (2)	3300	250	49	1.1	32	14	3.1	61	12	5.0 <	3.0 <	2.0 <	17	11	62	24	86	32
	35	"	"	71782	240 (4)	2.0 <	520 (7)	1.4 (1)	1100 (6)	7.0 <	910 (4)	73 (2)	1200	320	120	2.0 <	220	74	1.4	760	150	40 <	7.9	2.0 <	2.0 <	2.0 <	420	190	41	161

TABLE A3.3: COMPONENT LOADINGS AND PERCENT OF TOTAL VARIANCE FOR THE PCA ANALYSI OF THE UPPER ST. CLAIR RIVER, STUDY AREA 1 SEDIMENT CHEMISTRY DATA JUNE 1994

Nutrients				
Parameter	NPC1	NPC2	NPC3	NPC4
Total Organic Carbon	0.85870	-0.20860	0.30668	0.09524
Total Phosphorus	0.85194	-0.02961	0.04831	-0.04037
Residuals	0.84425	-0.11265	0.22270	0.01557
TKN	0.84056	0.32326	-0.11731	-0.08047
Potassium	0.81404	-0.09811	-0.36162	-0.15970
Sodium	0.63886	-0.05264	0.13628	0.50955
Calcium	0.01859	0.75419	0.01896	-0.32397
Ammonia	0.36134	0.62132	-0.48666	0.15268
Nitrates	0.14253	0.23734	0.69055	-0.52792
Chloride	-0.25306	0.51814	0.43284	0.64144
Percent of Total Variance Explaine	41.7	14.5	12.1	11.2
Metals				
	MPC1	MPC2	MPC3	
Aluminum	0.92785	0.05704	-0.24974	
Arsenic	0.89144	-0.12800	0.05993	
Cobalt	0.87693	-0.29116	-0.15786	
Nickel	0.82331	-0.33884	-0.02462	
Manganese	0.76812	0.32013	-0.42354	
Iron	0.75599	-0.51178	0.12918	
Lead	0.72475	0.00817	0.35166	
Chromium	0.67870	-0.35640	0.05267	
Cadmium	0.66239	0.01576	0.02025	
Copper	0.59996	0.47334	0.52935	
Mercury	-0.51761	-0.32495	-0.03931	
Zinc	0.36031	0.74783	0.40970	
Magnesium	0.37480	0.64134	-0.60005	
Percent of Total Variance Explaine	50.7	15.5	9.4	
Chlorinated Organics				
	OPC1	OPC2	OPC3	
1,2,3,4-TCB	0.83997	0.16309	0.00151	
1,2,3,5-TCB	0.94851	-0.08079	0.05854	
1,2,3-TCB	0.72761	0.54081	-0.14584	
1,2,4,5-TCB	0.91062	-0.07199	-0.04303	
1,2,4-TCB	0.80033	-0.08630	0.30860	
1,3,5-TCB	0.72954	-0.35539	-0.34484	
1,3,6-TCT	0.74839	0.47646	-0.00924	
1,4,5-TCT	0.51352	-0.03650	0.74807	
1,6a-TCT	0.42256	0.63737	0.23202	
Hexachlorobutadiene	0.92237	-0.22742	0.04035	
Hexachlorobenzene	0.96247	-0.12406	0.02712	
Hexachloroethane	0.88752	0.13417	-0.28856	

Octachlorostyrene	0.82474	-0.40859	0.07344
Pentachlorobenzene	0.95662	-0.20337	0.05590
Total PCBs	0.78173	0.14982	-0.28957
2,3,7,8-TCDD TEQs	0.88596	-0.04809	-0.08698
Percent of Total Variance Explaine	66.8	8.9	6.5

PAHs		
	PaPCA1	PaPCA2
Pyrene	0.96112	-0.04217
Phenanthrene	0.94054	0.15797
Fluoranthene	0.93043	-0.05182
Benzo(g,h,i)perylene	0.90456	-0.11452
Anthracene	0.90259	-0.09738
Benzo(k)fluoranthene	0.89699	-0.24622
Benzo(a)anthracene	0.89696	-0.17765
Benzo(b)fluoranthene	0.86833	-0.27484
Benzo(a)pyrene	0.86095	-0.23513
Indeno(1,2,3-cd)pyrene	0.85481	-0.17234
Chrysene	0.84149	-0.12636
Acenaphthene	0.82361	0.41515
Dibenzo(a,h)anthracene	0.80387	0.02367
Acenaphthylene	0.78885	0.20597
Fluorene	0.72950	0.45246
Naphthalene	0.63574	0.55542
Percent of Total Variance Explaine	73.3	6.6

Physical Parameters		
	PPC1	PPC2
Density	0.87408	-0.26483
%Gravel	0.86172	0.21329
%Moisture	-0.85321	0.30562
%Fines	-0.81819	0.07686
%Coarse Sand	0.80147	-0.34911
%Fine Sand	-0.51374	-0.14614
Distance from Shore	0.05829	0.90861
Water Depth	0.22017	0.85970
Water Velocity	0.49496	0.67443
Percent of Total Variance Explaine	45.6	26.4