AN ENVIRONMENTAL EVALUATION OF THE LOWER WELLAND RIVER

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AN ENVIRONMENTAL EVALUATION OF THE LOWER WELLAND RIVER

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for

The Niagara River Improvement Project
Ontario Ministry of the Environment

JULY 1993

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Executive Summary

An environmental evaluation of the lower Welland River was conducted by Tarandus Associates Limited during the summer and fall of 1990. The study involved an assessment of water and sediment quality, as well as an examination of aquatic flora and fauna.

The objectives of the study were:

1) to obtain a database subset for the lower Welland River for use in assessing possible remediation options where appropriate and for determining the need for further environmental investigations and;

2) to provide information for use in evaluating the significance of the Welland River regarding environmental quality issues in the Niagara River Area of Concern.

After an initial reconnaissance of the study area, field trips to the lower Welland River were completed during August and November, 1990. A total of 25 stations were evaluated. Analyses of sediments and water from these stations were conducted by Beak Analytical Laboratories.

Water quality varied considerably among stations. At several sites, iron, copper, mercury, and total phosphorus exceeded the Provincial Water Quality Objectives (PWQO). Most water-quality parameters, however, including most metals, phenols, total cyanide, PCBs, polyaromatic hydrocarbons (PAHs), and organochlorine (OC) pesticides were below detection limits.

Data from regular MOE water-quality monitoring stations indicate that levels of zinc, copper, mercury, chromium, and lead have decreased in the Welland River from 1979 to 1987. A slight increase in aluminum concentrations in water, however, has been noted from 1981 to 1987.

Sediment quality was also variable throughout the study area. Concentrations of lead, chromium, mercury, cadmium, zinc, iron, nickel, copper, arsenic, total Kjeldahl nitrogen, total organic carbon, total phosphorus, and PCBs exceeded the MOE Provincial Sediment Quality Guidelines (PSQG) lower effect limit (LEL) at some stations. The PSQG - Severe Effect Limits (SEL) for chromium, mercury, nickel, iron, and copper were also exceeded at several stations in sections B and C of the study area. Concentrations of total cyanide and oil and grease exceeded the Open Water Disposal Guidelines (OWDG) at some stations. PAHs were also detected at several stations, most notably stations 9 and 10. All organochlorine pesticides were below detection limits.

Degraded sediment quality, as indicated by concentrations of several metals, oil and grease, total cyanide, and PAHs were found at stations 9, 10, 24, 11, and 12, in the lower Welland River between the syphons, as well as at stations 17, 18, 19 and 20 in the section east of Port Robinson. Sediments at station 7, located in the western portion of the City of Welland also had elevated concentrations of several contaminants. A number of contaminant inputs are located in the vicinity of these stations, including storm sewers, a landfill site, a water pollution control plant (WPCP), and several industries.

Ninety benthic-invertebrate taxa were identified at the 25 sampling stations. The total is significantly higher than the 28 taxa reported previously (Johnson, 1964). The number of taxa varied among stations, ranging from a low of 12 species at stations 6 and 25 to a high of 29 species at station 10.

Two invertebrate species were common to all the sampling stations; *Procladius sp.* and immature tubificids, although *Chryptochironomus sp.*, *Limnodrilus hoffmeisteri,* and *Sphaerium sp.* were found at 24 of the 25 sites. Johnson (1964) also noted *Procladius* and *Limnodrilus* throughout the Welland River. Sampling stations located upstream of the City of Welland were characterized by relatively high numbers of *Hexagenia sp.* and *Coelotanyus sp.* These species were generally absent from stations downstream of Welland, indicating degraded environmental conditions. Stations located below the urbanized areas were characterized by relatively high numbers of the more pollution-tolerant taxa, *Spirosperma ferox* and immature tubificids, as well as *Valvata sp.*, and Hydrobiidae.

The total abundance of benthic invertebrates varied among stations in the study area, and ranged from a low of 634 individuals per square meter at station 12 to a high of 5900 individuals per square meter at station 22. Generally, stations located in and below the City of Welland had higher total abundances than those located in the rural area above Welland.

Benthic-invertebrate diversity (Shannon-Weaver and Brillouin) fluctuated considerably, especially in the river below the City of Welland. Diversities at all the stations upstream of Welland were relatively constant, ranging from 3.02 to 3.53. Shannon diversities ranged from a high of 3.96 at station 11 to a low of 2.52 at station 25. Similar trends were noted with the Brillouin diversity index. Diversities greater than 3.0 are generally indicative of unpolluted conditions.

Discriminant analysis of the stations, based on the results of cluster analyses, indicated that benthic-invertebrate communities below the City of Welland and above the Queenston-Chippawa Canal were associated with sediments characterized by elevated concentrations of several metals including chromium, copper, and arsenic. In contrast, benthic communities at stations above the City of Welland, occurred in an area characterized by sediments having relatively low levels of metals, and a high loss on ignition. Aluminum was also found at higher concentrations in this part of the Welland River than at stations further downstream.

The fish community of the lower Welland River was dominated by warmwater species, including catfish, white crappie, carp, suckers, and freshwater drum. Salmonid species were not found in the lower Welland River, although they are common in the Niagara River.

The Welland River shoreline was dominated by several emergent aquatic macrophytes, including *Typha latifolia* and *Sagittaria latifolia*. A number of submerged aquatic macrophytes were also noted including *Myriophyllum spicatum*, *Vallisneria americana*, and *Ceratophyllum demersum*. These species have been previously reported in the study area by Johnson (1964) and Dickman *et al.* (1983). Previous authors have also noted areas devoid of higher aquatic plants below several industrial discharges (Dickman and Haynes, date unknown; Dickman *et al.*, 1983). During this study, sparse macrophyte growth was only noted below the Thompson's Creek confluence.

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Introduction

In July, 1990, Tarandus Associates Limited was contracted by the Ontario Ministry of the Environment (MOE) to complete an environmental evaluation of the lower Welland River (Figure 1). The study included an assessment of water and sediment quality, as well as an evaluation of aquatic flora and fauna.

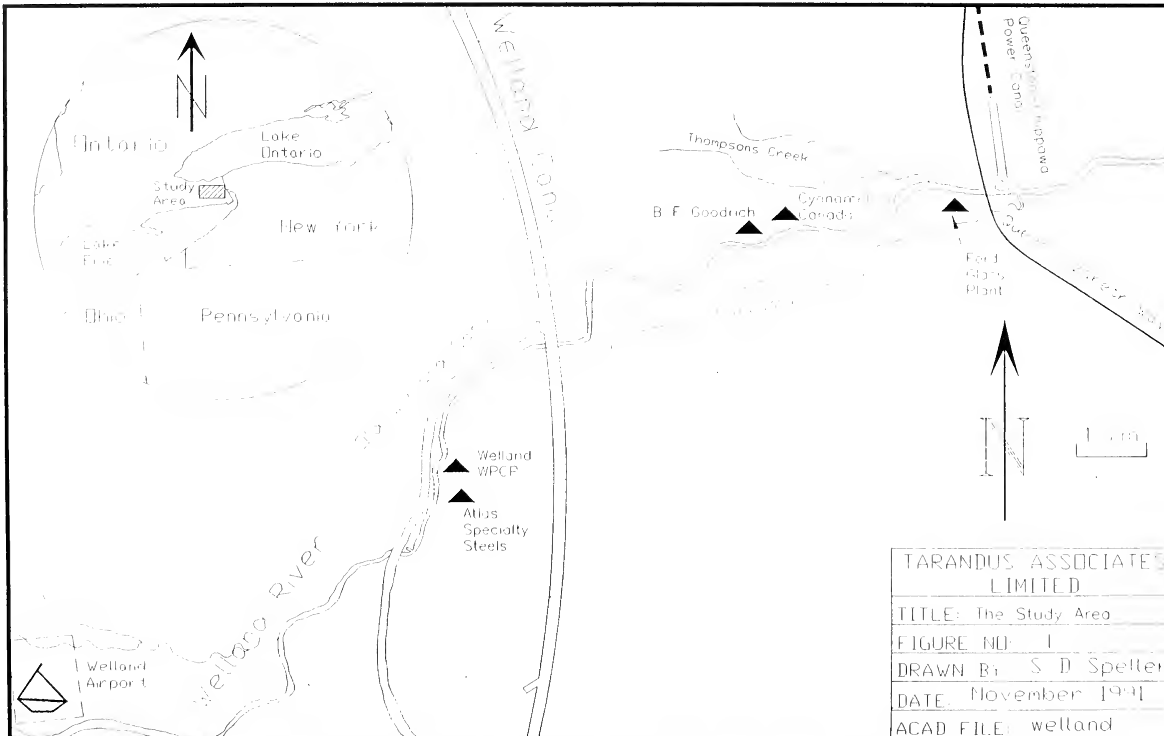
The objectives of the study were:

1) to obtain a database subset for the lower Welland River to allow assessment of remediation similar to that presently underway for the Niagara River as well as to determine the need for further environmental investigations and;

2) to provide information for use in evaluating the significance of the Welland River regarding environmental quality issues in the Niagara River Area of Concern.

A number of environmental studies have been completed on the Welland River, including sediment and water quality assessments (Kaiser and Comba, 1983; Brindle *et al.*, 1988; Johnson, 1964; Hart, 1986; Acres, 1990), fisheries studies (Johnson, 1964; Steele, 1981), benthic invertebrate surveys (Johnson, 1964), and aquatic-macrophyte surveys (Dickman *et al.*, 1980; Dickman *et al.*, 1983; Dickman and Hayes, date unknown). Much of the information in the earlier studies is appropriate only for historical purposes, given that the discharges to the river have changed significantly in recent years.

Twenty six years ago, Johnson (1964) concluded that domestic sewage and industrial wastes led to serious water quality impairment in the lower Welland River. More recently, a number of sources of contaminants to the Welland River have been identified and investigated. Industrial sources include Atlas Specialty Steels, Cyanamid Canada Inc., B. F. Goodrich and Ford Motor Company. Various municipal sources such as the Welland Water Pollution Control Plant (WPCP), and a number of combined sewer outfalls and overflows also exist (NRTC, 1984).



TARANDUS ASSOCIATES LIMITED

TITLE: The Study Area

FIGURE NO: 1

DRAWN BY: S D Speller

DATE: November 1991

ACAD FILE: welland

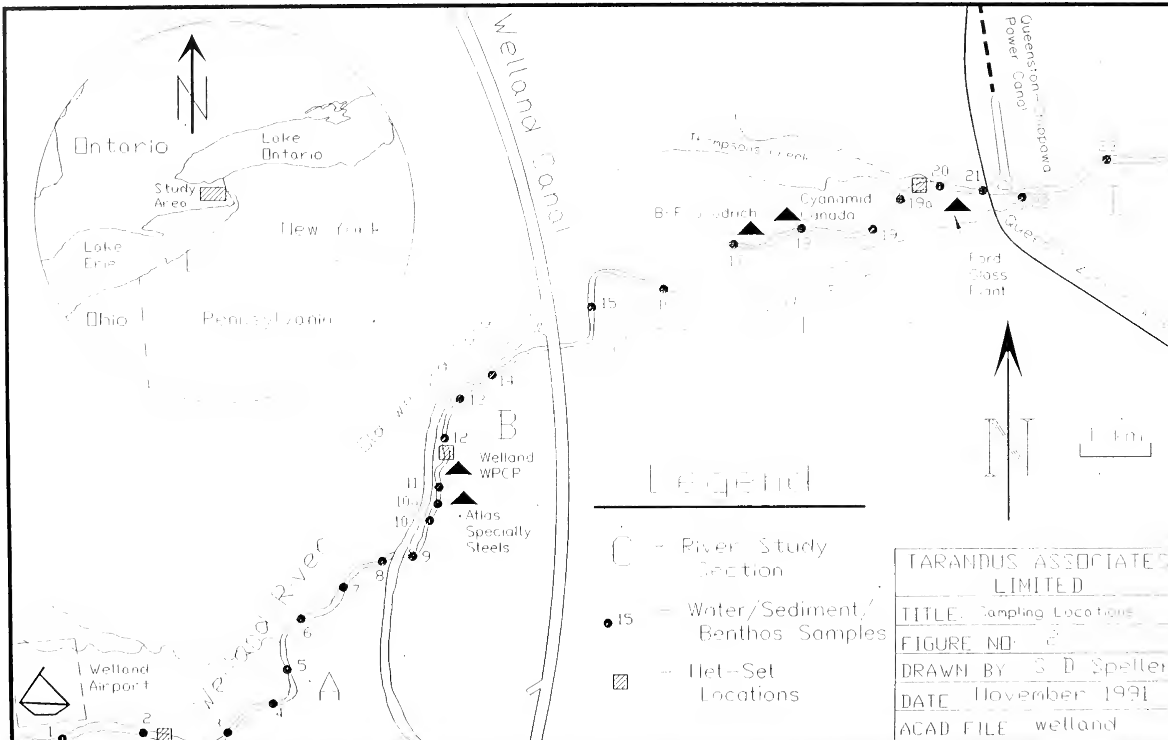
Study Methods

The Study Area

The Welland River is approximately 70 kilometres long, and extends from just south of Hamilton to the Queenston-Chippawa Power Canal. The section of the Welland River from Chippawa westwards to the Queenston-Chippawa Power Canal is 6.4 km long and is locally known as Chippawa Creek. This portion of the Welland River now flows westerly carrying Niagara River water to the power-canal delta where it mixes with Welland River water and proceeds down the Queenston-Chippawa Power Canal. The Welland River drains an area of approximately 906 km^2 and has an average gradient of three feet per mile to the Chippawa-Queenston Power Canal. The Welland River is not navigable where it flows beneath the old and new Welland Ship Canals by way of inverted syphon systems.

The study area extends from O'Reilly's Bridge, which is located south of the Welland Airport, to the lighthouse in King's Bridge Park at Chippawa, excluding the Queenston-Chippawa Power Canal. The study area was separated into four sections: A, B, C, and D (Table 1) based on access, the various land uses, and the nature of developments in each section (Figure 1).

A total of 25 stations were selected for water and sediment analyses, and benthic-invertebrate collections (Figure 2). Fish were sampled at three net-set locations. Station locations were selected in consultation with MOE personnel. Sampling intensity was increased in sections B and C where industrial and municipal discharges are more common. Sampling was reduced in section A, where agricultural land uses are predominant, and in section D, where the flow consists of Niagara River water exclusively. The field work for this project was completed during the periods of August 20th to the 24th, 1990, and November 6th to the 9th, 1990.



Ontario
Lake Ontario
Study Area
New York
Lake Erie
Ohio
Welland Canal
Queenston–Chippawa Power Canal
Cyanamid Canada
Ford Glass Plant
Welland WPCP
Atlas Specialty Steels
Welland River
Welland Airport
A
B
1
2
4
5
6
7
8
9
10
11
12
14
15
19a
20
21
Legend
River Study Section
15 Water/Sediment/Benthos Samples
Net-Set Locations
TARANDUS ASSOCIATES LIMITED
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DATE November 1991
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Table 1 : The four sections of the study area.

Section (See Fig. 2)	General Description
A - O'Reilly's Bridge to the old Welland Canal	- limited residential - predominately rural - agricultural activities common
B - old Welland Canal to the new Welland Canal	- mostly residential - several municipal discharges - several industrial discharges - water diverted from the old Welland Ship Canal
C - the new Welland Canal to the power canal	- predominately rural - several industrial discharges
D - the power canal to the Niagara River	- Niagara River water diverted to the power canal through this section - predominately rural

Water Quality

Water samples were collected at all stations with the use of a Van Dorn water-sampler. Each station sample was a composite of water taken at a depth of 1 meter below the surface at three locations: from the middle and from both sides of the river. All samples were placed in the appropriate labelled containers and were preserved as necessary. Samples were stored in a cooler on ice, until delivery to the laboratory for chemical analysis.

Water samples were collected from all 25 stations between August 20th and August 24th, 1990. These water samples were analyzed for either an "extensive list" or an "indicator list" of parameters (Table 2). Samples from stations 1, 9, 15, 21, and 23 were analyzed for the "extensive list" of parameters, and the remaining 20 stations were analyzed for the "indicator list". Water temperature, dissolved oxygen, and pH were determined in the field at all stations.

Table 2: Analytical parameters - water. A glossary of parameter abbreviations is presented in Appendix XI.

	Extensive List	Indicator List
Metals	Pb, Zn, Cd, Cr, Fe, Se, As, Sb, Ba, Be, Co, Cu, Mo, Ni, V, Ag, Hg, CN, Mn, Mg Al	Pb, Zn, Cd, Cr, Cu As, Hg, CN, Al
Organics	PCB/OC pesticide scan PAHs, Phenolics	PCB/OC pesticide scan Phenolics
Nutrients	NH_4, TP, TKN, NO_2, NO_3	TP, TKN
Miscellaneous	pH, conductivity, dissolved oxygen turbidity, colour, suspended solids temperature	pH, conductivity, dissolved oxygen turbidity temperature

A second set of water samples was collected from all stations during the period of November 6th to the 9th, 1990. All of these water samples were analyzed for phenolics. Water samples from stations 1-10, 15, 21, and 23 were analyzed for aluminum and copper, and samples from stations 1-5, 10, 15, 21 and 23 were analyzed for mercury. Water temperature, conductivity, and dissolved oxygen measurements were determined in the field, at most stations. Dissolved oxygen depth-profiles were also taken at some stations.

All water analyses were conducted by Beak Consultants Limited according to standard analytical methods approved by MOE. In addition, water samples were collected from stations 6 and 21 for subsequent analysis at the MOE laboratory in Rexdale. Chemical parameters included volatile organics, extractable organics, and organochlorine pesticides.

Spatial and temporal trends in water quality were examined throughout the study area. Data from previous studies, when available, were also incorporated in these analyses. Water-quality results were compared to the MOE Provincial Water Quality Objectives (PWQO) where possible, and to the water quality of other river systems in the area.

Sediment Quality

Surficial sediments were collected with a stainless-steel ponar grab sampler, and consisted of composites of three sub-samples taken at the middle and both sides of the river. All sediment samples were homogenized and placed in appropriate labelled jars. Miscellaneous observations regarding sediment texture and colour, as well as the presence of any odour or oily sheen were also recorded where evident.

Sediment samples were collected at a total of 25 stations during the period of August 20th to the 24th, 1990. Samples from stations 1, 9, 15, 21, and 23 were analyzed for an "extensive list" of parameters, and the remaining 20 samples were analyzed for an "indicator list" (Table 3).

A second set of sediment samples was also collected during the November survey. A modified set of chemical analyses based on the results of the August survey was conducted on each of these samples (Table 4).

Table 3: Analytical parameters - sediments

	Extensive	Indicator
Metals	Pb, Zn, Cd, Cr, Fe, Se, As, Sb, Ba, Be, Co, Cu, Mo, Ni, V, Ag, Hg, CN, Mn, Mg Al	Pb, Zn, Cd, Cr, Cu As, Hg, CN, Al
Organics	PCB/OC pesticide scan PAHs, Phenol	PCB/OC pesticide scan Phenol
Nutrients	TP, TKN, TOC, LOI	LOI
Miscellaneous	pH, SAR, Oil and Grease	pH, Oil and Grease

Table 4: Sediment-quality parameters evaluated during the fall survey.

Parameter(s)	Stations
Zn, Cd, Mn, Co, Cu, Fe, Pb, Cr, Ni	5-19,20
Total Cyanide (CN)	17-22
Mercury (Hg)	7-13
Arsenic (As)	7-10,11-20
PAH Scan	1, 3, 5, 7-10, 15
PCB	1, 3, 5, 7-10, 15, 19a, 21, 23
Oil and Grease	1-23

All sediment analyses were completed by Beak Consultants Limited according to standard methods approved by MOE.

In addition, sediments were collected from stations 9, 15 and 21 at the request of MOE for subsequent analysis at the MOE laboratory in Rexdale. Parameters determined included volatile organics, extractable organics, organo-chlorine pesticides, and dioxins.

Trends in sediment quality were examined throughout the study area. Data from previous studies, when available, were also used for these analyses. Sediment-quality results were compared to Provincial Sediment Quality Guidelines (PSQG), and to the sediment quality of other local river systems such as Thompsons Creek, Lyons Creek and the Niagara River.

Benthic Invertebrates

Benthic-invertebrate samples were collected from the middle and both sides of the river at each of the 25 stations in August, for a total of 75 samples. All samples were collected with the use of a ponar grab sampler, and the sediments were sieved through a 200-u mesh sieve-bucket. Residual materials were placed in appropriately labelled jars, and preserved in 10% buffered formalin.

All samples were manually washed, picked, and sorted to separate all organisms from associated debris. All samples were picked in their entirety with the use of a stereomicroscope. The organisms found in each sample were sorted into similar taxonomic groups and placed in separate labelled vials for subsequent identification.

All benthic invertebrates were identified to the lowest practical taxonomic level by Dr Richard Vineyard and Mr Brad Hubley of the firm Original Insect Ideas. Prior to identification, tubificids and chironomids were cleared and mounted on labelled microscope slides with the use of polyvinyl lactophenol. In cases where the immature forms of some invertebrates prevented identification to species, classification was usually completed to the genus level.

All sorted invertebrate samples were provided to MOE at the completion of the project. In addition, a reference collection was prepared for use in confirming identifications and to ensure the repeatability of the benthic invertebrate classification in future studies. Slides were labelled with species identification, date, location, taxonomist and station.

All species counts were tabulated by sample and station, and were converted to abundance counts (number/m^2) for use in subsequent statistical analysis.

Aquatic Macrophytes

A visual qualitative assessment of the aquatic-macrophyte community was completed at all stations in the study area. Assessments of both submergent and emergent macrophytes were completed, including observations regarding species present, dominant species, and the presence of any unusual or rare plants. Photographs of existing aquatic-macrophyte communities in the study area were also taken where possible to supplement the community descriptions.

A species list of aquatic macrophytes was prepared for the study area. Trends in species composition and species association were noted, and any atypical occurrences were recorded. Unusual community patterns, particularly those that may result from anthropogenic disturbances were also described.

Fisheries

Fish were collected during both field trips to evaluate community composition in the study area. A Scientific Collector's Fish Permit was obtained from the Ministry of Natural Resources in Fonthill before the field work for the fish survey was initiated.

Sampling methods included the use of hoop nets, a seine net, and minnow traps. The identity of all species sampled during the survey was recorded, and any observations of abnormalities, disease, or parasites were noted. All fish were released alive if possible.

The hoop nets used during the study had a rectangular opening of approximately 47 by 38 inches (190.5 by 96.5 cm) and hoops measuring about 36 inches (91.4 cm) in diameter. The hoop-net enclosure measured approximately 20 feet (6.1 m) in length, and had an attached lead of 100 feet (30.5 m). At all sets, the lead was attached to trees or rocks at the shore, and the trap was positioned in deeper water at an angle that varied from about 45° to 90° to the shoreline. Water depths in which the hoop net was set ranged from 1.0 to 2.5 meters. This fish survey was intended to provide general overview information only and was not designed to be a detailed assessment of the fish populations in the Lower Welland River.

A total of 5 hoop-net sets were completed during the summer and fall surveys. The hoop net was set once in sections A, B, and C during the August survey and once in sections A and C during the November survey. Each hoop-net set was placed overnight for a period of approximately 24 hours. All net-set locations are illustrated in Figure 2.

Fish were also collected with the use of a 5-meter beach seine at a number of locations in sections A, C, and D during the August survey. The steep banks of section B prevented the completion of any seining in that part of the river.

A total of 8 minnow traps were also set in sections A, B, and C. The traps were baited with bread and set overnight.

Flow measurements

Water velocity was measured with the use of a Montedoro-Whitney portable velocity meter at 5-meter intervals across several sections of the river. Velocity measurements were taken at 0.2 and 0.8 times the water depth at each measuring point as recommended by Arseneault (1976). Individual velocity measurements consisted of the average instantaneous velocity measured during a 20 second time interval. A number of surface spot velocities were also recorded at several stations.

Flow calculations were completed using the Velocity-Area Method. This technique involves dividing a cross-section of the river into a number of segments, each bounded by imaginary vertical lines from the water surface to the stream bed. The area of each segment is determined and the mean velocity of water flowing through it is determined from velocity measurements. The discharge for each segment is computed by multiplying the area of the segment by the corresponding mean velocity, and these individual discharges are added to obtain the total discharge.

Statistical Analyses

Several methods of data analysis were used to evaluate water and sediment quality, and selected biotic communities in the study area. Statistical methods were generally selected because of their recognized utility in delineating spatial and temporal variation, or ability to quantitatively summarize associations and trends. A brief summary of the rationale and application, and the mathematical formula for each analysis is presented below.

1) Indices

Indices provide a simple method of summarizing complex data. They are derived variables such as a ratio of one variable divided by a standard variable. When applied to invertebrate data, such indices generally involve ratios of numbers of taxa and numbers of individuals in the collected samples. These indices have interpretive value as data summaries.

i) Shannon-Weaver (or Shannon-Weiner) Diversity Index (H')

Diversity is a measure of the distribution of observations among categories (e.g. species). When applied to communities of invertebrates, diversity calculations incorporate counts of organisms within each taxonomic group. A low diversity is the result of a concentration of invertebrates in few categories; and conversely, a more uniform distribution of organisms among all categories results in a high diversity. Diversities greater than 3.0 are indicative of an unpolluted environment, whereas diversities less than 1.0 indicate severely polluted conditions (Weed and Rutschky, 1972). The formula for the Shannon-Weaver diversity index, H' is:

$$H' = -\sum_{i=1}^{s} \frac{N_i}{n} \log_2 \frac{N_i}{n}$$

where n = the total number of individuals in the sample
N_i = the number of individuals in the "i"th sample
S = the number of categories (taxa) with known proportional abundance

ii) Brillouin Diversity Index

Brillouin's Diversity H, is "the species diversity per individual of a collection in which all n specimens have been assigned to one of s species, and counted to give the N_i's" (Kaesler *et al.*, 1978). Unlike Shannon's index, it can give the actual diversity of a fully censused collection of invertebrates. In addition, it is an actual measurement of the diversity of the sample, and is not just a statistical estimate. The formula used to determine Brillouin's index of diversity is given below:

$$H=\frac{1}{N}(\log n!-\sum_{i=1}^{s}\log N_i!)$$

where n = the total number of individuals in the sample
N_i = the number of individuals in the "i"th sample
S = the number of categories (taxa) with known proportional abundace

2) Cluster Analysis

Benthic invertebrate communities were defined with the use of cluster analysis, which reduces the species abundance data to a graphical summary. The resultant groups or clusters characterize relatively homogeneous species assemblages (Green, 1979). The significance of group separation relative to environmental variables can be evaluated by multiple discriminant analysis, which is discussed on the following page.

In order to confirm the robust nature of the results, several cluster analysis techniques were used, including:

i) Minimum Variance Clustering (Ward's Method)
ii) Group Average Clustering
iii) Centroid Clustering

Cluster analysis was completed on abundance data and presence/ absence data with use of SYSTAT software (Wilkinson, 1988).

Some problems may be encountered in the use of cluster analysis, including: (i) the subjective choice of clustering method and similarity measure will affect the outcome; and (ii), clusters may be produced when they do not exist (Jackson *et al.*, 1989). The patterns revealed by the cluster analyses were confirmed with the use of Principal Components Analysis (PCA).

3) Principal Components Analysis

Principal components analysis (PCA) was used to analyze the benthic invertebrate data and to verify station groupings defined by cluster analysis. PCA is a technique for deriving linear combinations of the original variables, called principal components, that are orthogonal to one another, and that successively account for the largest portion of the residual sample variance (Rogers, 1971). This method, as with most multivariate statistics that reduce the dimensionality of multivariate observations, is used to generate a smaller number of variables that summarize most of the information contained in the original variables.

The "factor loadings" produced during principal components analysis are correlation coefficients between each original variable and each principal component. Since species abundance data rarely conform with the linearity assumptions associated with the use of correlations and covariances in PCA (Ludwig and Reynolds, 1988), we chose to use rank correlations in the PCA's (Rising and Somers, 1989). The data were ranked prior to completing the PCA, and the first two or three factors were graphed for presentation in this report.

The PCA's were calculated with use of the SYSTAT computer program and were presented graphically with use of SYGRAPH software (Wilkinson, 1988).

4) Discriminant Analysis

Discriminant analysis was used to evaluate differences among the defined benthic communities with respect to environmental conditions (sediment parameters). Discriminant analysis is a multivariate technique used to distinguish groupings (e.g. communities) on the basis of a series of quantitative descriptors (e.g. sediment chemistry). The resultant discriminant axes (functions) are linear combinations of the sediment chemical variables that maximize differences between the groups of communities. Each axis is interpreted with the use of correlation coefficients (r) between the discriminant functions and the original sediment parameters.

Eleven sediment variables were used to discriminate between benthic communities (Table 5). Grain (particle) size data was not available and could not be used in the analysis.

Table 5 : Sediment-quality parameters used in discriminant analysis.

METALS	NUTRIENTS	OTHERS
Zinc	Loss on Ignition	Oil and Grease
Cadmium		pH
Copper		
Lead		
Chromium		
Aluminum		
Mercury		
Arsenic		

All variables were logarithmically transformed prior to use in discriminant analysis. Concentrations below detection limits were set equal to the detection limit.

Discriminant analysis was completed on the benthic communities defined by cluster analysis, as well as on individual sampling stations. Discriminant analysis was conducted using SYSTAT computer software. Double precision was used during the analysis, as discriminant analysis is particularly sensitive to rounding errors (Green, 1979).

Results and Discussion

Water Quality

Water quality was evaluated at a total of 25 sites on the Welland River (Appendix I and Appendix XI). Water quality varied among stations, with concentrations of several parameters (including iron, copper and mercury) exceeding Provincial Water Quality Objectives (PWQO's) at some stations. Several water-quality parameters were below detection limits. A list of metals and other parameters which were below detection limits is presented in Table 6.

Table 6: Water-quality parameters below detection limits in all the Welland River water samples.

Parameter	Chemical Symbol	Detection Limit
Cadmium	Cd	0.002 mg/L
Cobalt	Co	0.005 mg/L
Lead	Pb	0.01 mg/L
Chromium	Cr	0.005 mg/L
Nickel	Ni	0.005 mg/L
Beryllium	Be	0.005 mg/L
Molybdenum	Mo	0.005 mg/L
Vanadium	V	0.005 mg/L
Arsenic	As	0.005 mg/L
Antimony	Sb	0.002 mg/L
Selenium	Se	0.001 mg/L
Silver	Ag	0.005 mg/L
Phenolics	-	0.001 mg/L
Total Cyanide	CN	0.002 mg/L

Following is a summary of the water-quality results. Concentrations of water-quality parameters are illustrated in Appendix 1.

Iron

Iron concentrations exceeded the PWQO at stations 1, 15, and 21 (Appendix I); and levels of iron ranged from a low of 0.06 mg/L at station 23 to a high of 2.1 mg/L at station 1. Iron levels reported by Hart (1986) near the Queenston-Chippawa Power Canal ranged from 0.420 mg/L to 0.840 mg/L respectively. A study by Johnson (1964) throughout the river noted levels between 0.62 mg/L and 6.16 mg/L.

Copper

During the summer survey, copper levels exceeded the PWQO at all stations with the exception of stations 3, 10a, 15, 19a, and 23. Levels of copper were reduced during the fall survey; however stations 2, 4, 10, 15, and 23 exceeded the PWQO. Copper concentrations ranged from below detection limits to 0.05 mg/L. Concentrations reported by Hart (1986) were within this range.

Mercury

Mercury concentrations ranged from a low of <0.05 μg/l at most stations to a high of 0.30 μg/l at station 1 (Appendix I). Mercury levels exceeded the PWQO at stations 1, 2, and 3 during the summer survey; however all the stations had concentrations below detection during the fall survey.

The high concentrations of mercury in water samples from stations 1 - 3 may be due to the bacterial methylation of mercury in an upstream reservoir (Lake Niapenco). Mercury levels may have been lower during the fall survey because of lower water temperatures which reduce the metabolic activity of bacteria. Mercury concentrations reported by Hart (1986) near the Queenston-Chippewa Power Canal ranged from below detection to 0.02 mg/L.

Aluminum, Magnesium, and Zinc

Aluminum levels ranged from a low of 0.09 mg/L at station 9 to a high of 3.4 mg/L at station 3, and concentrations were found to be higher in those water samples taken during the fall survey. The MOE guideline for total aluminum in clay-free samples is 0.075 mg/L. All stations exceeded this guideline. Elevated aluminum concentrations may be due to the high suspended clay content in the water column rather than the influence of any specific contaminant sources.

Magnesium concentrations at the "extensive" stations were between 8.4 mg/L and 14.1 mg/L (Appendix I). There is currently no PWQO for this parameter in water.

Zinc levels were below detection limits in all water samples except those from stations 1 and 24 (Appendix I). Concentrations noted at stations 1 and 24 were below the PWQO. Zinc concentrations reported by Hart (1986) ranged between 0.005 mg/L and 0.01 mg/L, and were all below the PWQO.

Long Term Monitoring

Water quality has also been monitored on an ongoing basis by MOE at a number of sites on the Welland River, including the Montrose Bridge (station 21). Temporal trends of zinc, copper, chromium, mercury, and lead concentrations at the Montrose Bridge between 1979 and 1987 are illustrated in Figure 3. There is generally a reduction over time in levels of these metals in the Welland River water at this site.

The Ministry has also monitored aluminum levels at the Montrose Bridge and at a site near Port Robinson (Figure 4). There appears to be a slight increase in mean aluminum concentrations between 1981 and 1987, with the highest levels noted during 1985 at both stations. As discussed on the previous page, the high aluminum concentrations may be due to high levels of suspended clay in the water, rather than a specific contaminant source.

Phosphorus

Total Phosphorus (TP) at the 25 stations ranged from 0.013 mg/L to 0.25 mg/L (Appendix I). The PWQO for TP was exceeded at all stations except for stations 9, 10, 22, 23, and 19a. Low levels of TP were found at stations 22 and 23, which receive water from the Niagara River that is diverted to the Queenston-Chippewa Power Canal. Water samples from stations 1 through 6, had high levels of TP, probably due to the influence of agricultural activities in and above section A.

Total phosphorus data during the period 1979 to 1987 at the MOE water quality stations are illustrated in Figure 5. The concentration of total phosphorus in the water varied among years; however, the Welland Airport station had consistently higher levels of total phosphorus than those found at the downstream stations. This pattern was most likely due to dilution of water in the lower reaches of the river from the Welland Ship Canal, and to assimilation of phosphorus by biota.

Figure 3: Concentrations of zinc, copper, chromium, mercury and lead in water samples collected at the Montrose Bridge from 1980 to 1987.

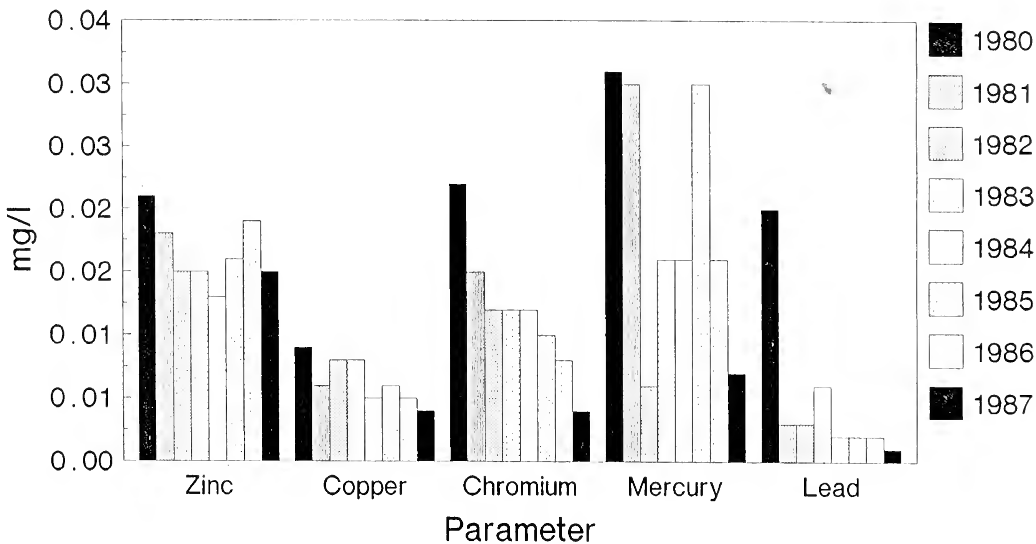


Figure 4: Aluminum concentrations in water samples collected at the Montrose Bridge and Port Robinson from 1981 to 1987.

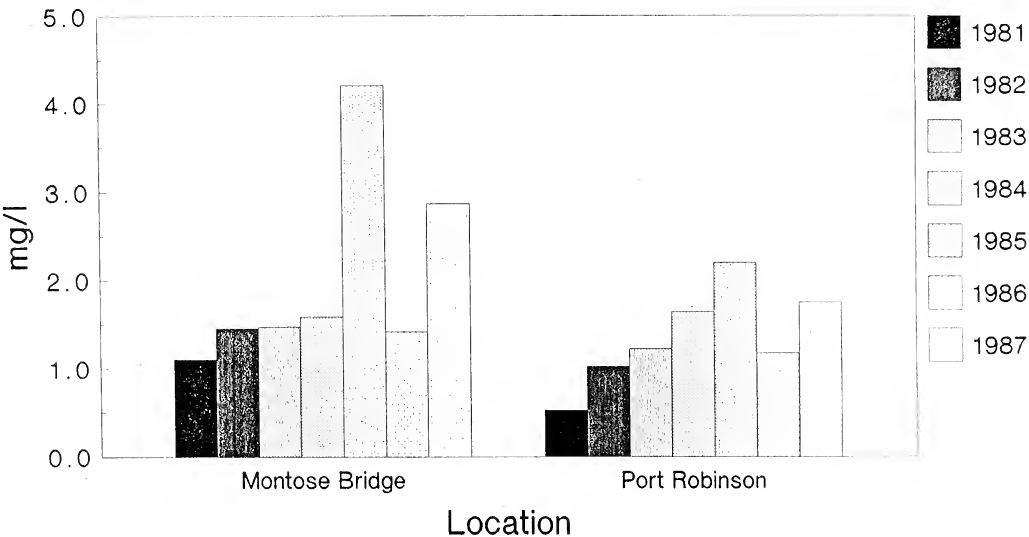
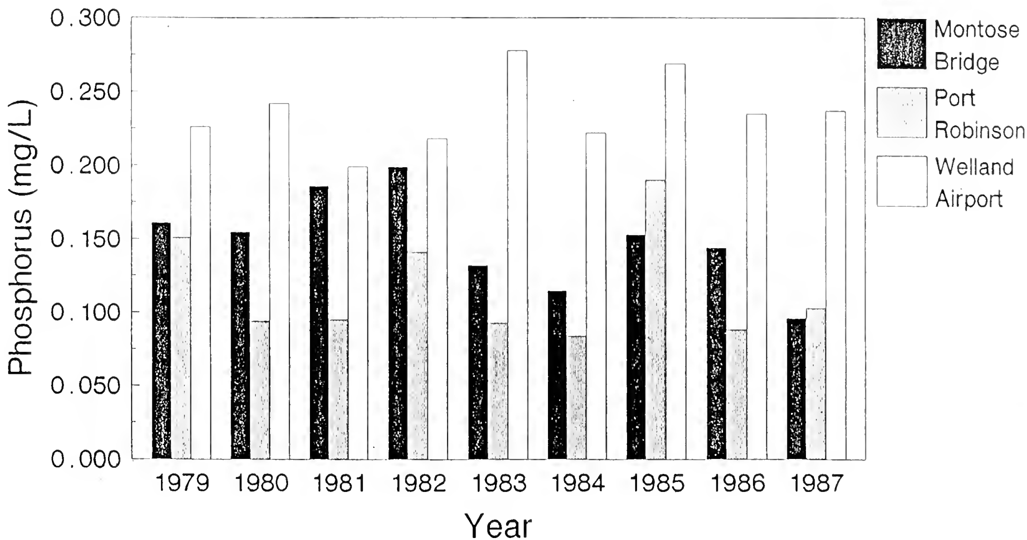


Figure 5: Total phosphorus levels in water samples collected at the Montrose Bridge, Port Robinson, and the Welland Airport from 1979 to 1987.



Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) levels during the August 1990 survey ranged from 0.28 mg/L to 2.6 mg/L (Appendix I). As with TP, higher levels of TKN were found at sampling stations located in section A, most probably due to the influence of agricultural activities. The highest level of TKN was noted at station 21 located below the Montrose Bridge.

Mean yearly TKN levels for the period 1979 to 1987 at MOE water quality stations are presented in Figure 6. TKN levels at MOE stations located at the Welland River Airport and at Port Robinson have remained fairly constant over the years, whereas TKN levels at the Montrose Bridge station have decreased dramatically. The decrease in TKN at the Montrose Bridge is most likely due to improvements in effluent quality from Cyanamid. The main nitrogen treatment system became operational in 1985.

Ammonia concentrations ranged from 0.008 to 0.333 mg/L, and levels of nitrite and nitrate ranged from 0.003 to 0.04 mg/L and 0.16 to 0.56 mg/L, respectively. Station 21, at the Montrose bridge, had the highest levels of these parameters due to the discharge of nitrogen species from Cyanamid to Thompson's Creek.

PAHs, PCBs, and OC Pesticides

All PAHs, OC pesticides and PCBs were below detection limits (Tables 7 and 8 respectively). The Ministry of the Environment has also monitored OC pesticide levels from 1981 to 1989 (MOE-unpublished data (1981-1989)). Most pesticides were below detection limits; however alpha-BHC and gamma-BHC were detected in trace quantities for all years. Endosulfan sulfate, beta-BHC, 4,4'-DDE, and 4,4'-DDT were also detected in trace amounts for some years.

Organic compounds from sites 6 and 21, which were analyzed at the MOE laboratory, were also below detection limits (Table 8b).

Figure 6: Mean Yearly TKN Levels in Water Samples Collected at the Montrose Bridge, Port Robinson, and the Welland Airport from 1979 to 1987.

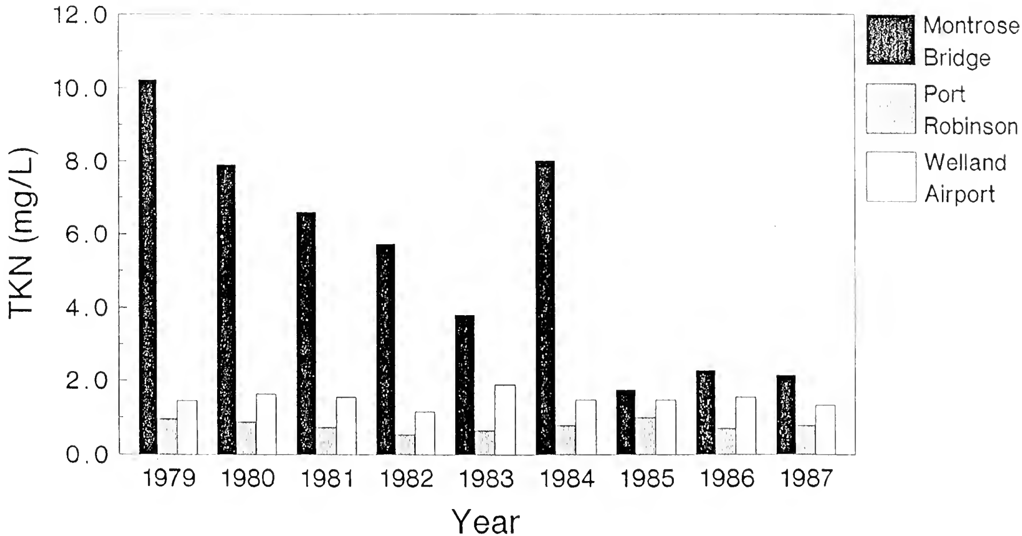


Table 7: Polycyclic aromatic hydrocarbons and associated detection limits

PAH	Detection Limit (μg/L)
Naphthalene	0.1
Acenaphthylene	0.1
Acenaphthene	0.1
Fluorene	0.1
Phenanthrene	0.2
Anthracene	0.2
Fluoranthene	0.2
Pyrene	0.2
Benzo(a)anthracene	0.2
Chrysene	0.2
Benzo(b)fluoranthene	0.5
Benzo(k)fluoranthene	0.5
Benzo(a)pyrene	0.5
Perylene	0.5
Indeno(1,2,3-c,d)pyrene	2
Dibenzo(a,h)anthracene	5
Benzo(g,h,i)perylene	1

Table 8: Organochlorine pesticides and associated detection limits

OC Pesticide	Detection Limit (μg/L)
Hexachlorobenzene	0.003
alpha-BHC	0.003
gamma-BHC	0.003
Heptachlor	0.003
Aldrin	0.003
beta-BHC	0.003
Oxychlordane	0.003
Heptachlor epoxide	0.003
Endosulfan I	0.003
gamma-Chlordane	0.003
alpha-Chlordane	0.003
4,4'- DDE	0.003
Dieldrin	0.003
Endrin	0.003
2,4'- DDT	0.003
4,4'- DDD	0.003
Endosulfan II	0.003
4,4'-DDT	0.003
Mirex	0.003
Endosulfan Sulfate	0.005
Methoxychlor	0.005
PCB's (Total)	0.050

Table 8b: MOE results for concentrations of chlorinated organics in water at stations 6 and 21.

Parameter	D. L. (ng/L)	6	21
Extractable Org.	N.A.	no numeric result	
Volatile Org.	N.A.	no numeric result	
Octachlorostyrene	N.A.	no suitable sample	
PCB, Total	20	below detection limit	
Hexachlorobenzene	1	below detection limit	
Heptachlor	1	below detection limit	
Aldrin	1	below detection limit	
PP-DDE	1	below detection limit	
Mirex	5	below detection limit	
A-BHC Hexachlorocyclohex	1	below detection limit	
B-BHC Hexachlorocyclohex	1	below detection limit	
G-BHC Hexachlorocyclohex	1	below detection limit	
A-Chlordane	2	below detection limit	
G-Chlordane	2	below detection limit	
Oxychlordane	2	below detection limit	
OP-DDT	5	below detection limit	
PP-DDD	5	below detection limit	
PP-DDT	5	below detection limit	
DMDT Methoxychlor	5	below detection limit	
Heptachlorepoxide	2	below detection limit	
Endosulfan I	2	below detection limit	
Dieldrin	4	below detection limit	
Endrin	4	below detection limit	
Endosulfan II	4	below detection limit	
Endosulfan Sulphate	4	below detection limit	

D.L. is detection limit. N.A. means no numeric value was reported.

Water temperature, conductivity, and dissolved oxygen as determined in the field are presented in Appendix III. All values are within ranges considered normal.

A comparison of the water quality in the study area of the Welland River with several of its tributaries and the Niagara River is presented in Table 9. Water quality of the Welland River is generally similar to that of Thompson's Creek, Lyons Creek, and the Niagara River, with the exceptions of TKN and total phosphorus. Concentrations of these parameters are higher in Thompson's Creek than in the lower Welland River, probably because of the influence of Cyanamid. Levels of iron and aluminum are also slightly elevated in the lower Welland River compared with concentrations in the other river systems. This phenomenon is probably due to the influence of metal industries located on the Welland River, and the high suspended cay load in the water column.

Table 9: Comparison of water quality of the Welland River with selected river systems in the area. All parameters are in mg/L unless otherwise specified.

Parameter	Welland River	Thompson's Creek[1]	Lyon's Creek[1]	Niagara River [2]
Fe	0.06-2.1	0.510-0.720	0.120-1.20	ND-0.3.2
Al	0.09-3.4	0.370-0.440	0.110-0.950	ND-2.6
Ni	ND	0.007-0.016	0.002-0.004	ND-0.04
Zn	ND-0.02	0.020-0.030	0.004-0.036	ND-0.03
Cu	ND-0.04	0.020-0.032	0.003-0.019	ND-0.029
Cr	ND	0.005-0.054	ND-0.002	ND-0.260
Pb	ND	ND-0.006	ND-0.011	ND-0.005
Cn	ND	NA	NA	ND
Cd	ND	0.0002-0.0003	ND-0.0005	ND-0.0004
Hg	ND-0.0003	0.040-0.050	ND-0.010	ND-0.0006
As	ND	0.001	ND	ND-0.003
TP	0.013-0.149	0.60-1.26	0.015-0.039	NA
TKN	0.28-2.6	97.5-485	0.020-0.310	NA

ND - not detected
NA - not analyzed
1 - Hart (1986)
2 - Kauss (1983); from stations in the Lower River, the Tonawanda Channel, and the Chippawa Channel.

Sediment Quality

Sediment quality was extremely variable throughout the study area (Appendices II and XII). When compared with the Draft Provincial Sediment Quality Guidelines (PSQG) and in some cases the existing Open Water Disposal Guidelines (OWDG), concentrations of a number of metals, nutrients, and oil and grease exceeded the criteria at several stations.

The OWDG's (Persaud and Wilkins, 1976) were originally intended for use in assessing the suitability of soils and dredged material proposed for open-water disposal. Until recently, these guidelines have also been used to evaluate contaminant levels in existing aquatic sediments. The Draft PSQGs (Persaud *et al.*, 1990) are recently developed guidelines which are specifically intended to protect aquatic biological resources. These guidelines are based on three levels of ecotoxic effects: a no-effect level (NOEL), a lowest effect level (LEL), and a severe effect level (SEL) (Table 10).

Table 10: Provincial Sediment Quality Guideline levels and their significance (Persaud *et al.*, 1990 - Draft)

Guideline Level	Sediment Quality	Potential Impact
> SEL	Grossly Polluted	Will significantly impair use of sediment by benthic organisms
< SEL > LEL	Significantly Polluted	Will impair sediment use by some benthic organisms
< LEL > NOEL	Clean - Marginally Polluted	Potential to impair some sensitive water uses
< NOEL	Clean	No Impact on water quality, water uses, or benthic organisms anticipated

Lead

Lead levels in sediments exceeded the PSQG-LEL of 31 μg/g at all stations during the summer survey, except for stations 2, 4, 11, 13, 14, 15, 16, 19a, 21, 22, and 23 (Appendix II). Stations 13 and 14 were the only stations having sediment lead levels below the LEL during the fall survey. The highest lead concentrations were found at stations 9 and 12 (138 μg/g and 91 μg/g, respectively) during the fall survey, whereas stations 22 and 23 had the lowest levels during the summer survey.

All sediment samples had lead levels less than the SEL of 250 μg/g.

Chromium

Chromium concentrations exceeded the PSQG-LEL of 26 μg/g at most stations (95%) with the exception of stations 22 and 23 located in Chippawa Creek (Appendix II). Extremely high chromium levels were noted in sediments collected from stations 10, 12, and 17 during both the summer and fall surveys. Chromium concentrations in sediments at stations 10 and 12 were approximately 26 and 18 times the LEL, respectively.

The SEL of 110 μg/g was only exceeded at stations located in sections B and C of the study area. Sediments from stations 12, 13, 15, 17, and 18 during the summer survey, and stations 10, 10a, 11, 12, 13, 14, 15, 16, 17, 18, and 19 during the fall survey were characterized by chromium concentrations in excess of the SEL.

Mercury

Sediment mercury levels exceeded PSQG-LEL of 0.2 μg/g at stations 8, 9, 10a, 12, 16, 18, and 19 during the summer survey, and at stations 7, 8, 9, 10, 11, and 12 during the fall survey (Appendix II). Sediments collected from station 9 had the highest mercury concentrations during both surveys (approximately 16 and 21 times the LEL).

The SEL of 2 μg/g was only exceeded at station 9 during both the summer and fall surveys.

Cadmium

Cadmium levels were extremely variable throughout the study area, and exceeded the PSQG-LEL of 0.6 μg/g at stations 9, 10, 12, 19, and 22 during the summer survey, and at stations 7, 9, 10, 10a, 11, 12, 17, and 19 during the fall survey (Appendix II). Station 12 was characterized by the highest cadmium levels during both the summer and fall surveys (1.4 μg/g and 1.5 μg/g, respectively).

All sediment samples had cadmium levels well below the SEL of 10 μg/g.

Arsenic

Arsenic levels exceeded the PSQG-LEL of 6 μg/g at stations 3, 9, 10, 10a, 12, 18, 19, and 20 during the summer survey and at stations 10, 12, 14, 15, 17, 19, 19a, and 20 during the fall survey (Appendix II). The highest concentrations were found in sediments at stations 10 and 12, and the lowest levels were found at stations 22 and 23.

All sediment samples had arsenic levels below the SEL of 33 μg/g.

Zinc

Zinc concentrations exceeded the PSQG-LEL of 120 μg/g at stations 7, 9, 10, 10a, 12, 17, 18, 19, and 19a during the summer survey, and at stations 5, 7, 8, 9, 10, 10a, 11, 12, 14, 15, 16, 17, 18, 19, 19a, and 20 during the fall survey (Appendix II). Sediments collected from stations 10 and 12 had the highest zinc levels; 555 μg/g and 620 μg/g respectively.

The SEL of 820 μg/g was not exceeded at any of the stations.

Iron

All sediment samples collected in the study area exceeded the PSQG-LEL of 20 mg/g (2%) for Iron, with the exception of station 23 during the summer survey (Appendix II). Of the five "extensive" stations evaluated during the summer survey, only station 15 had iron levels exceeding the SEL of 40 mg/g (4%).

Iron levels in excess of the SEL were found at stations 10, 10a, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20 during the fall survey, with the highest concentration from station 10 (118 mg/g).

Nickel

The PSQG-LEL of 16 μg/g for nickel was exceeded at the five "extensive" stations sampled in the summer, and at all the stations evaluated in the fall. Nickel concentrations ranged from highs of 390 μg/g and 270 μg/g at stations 10 and 12 respectively to a low of 19.5 μg/g at station 23 (Appendix II).

The SEL of 75 μg/g was exceeded at station 15 during the summer survey, and at all stations in sections B and C (with the exception of station 9) during the fall survey.

Copper

Most sediment samples had copper levels in excess of the PSQG-LEL of 16 μg/g, with the exception of stations 22 and 23 during the summer survey (Appendix II).

The SEL of 110 μg/g was exceeded at station 19 during the summer survey, and at stations 10, 19, 19a, and 20 during the fall survey. The highest copper concentrations were noted at station 10 and station 20.

Other Metals

Concentrations of several other metals were also evaluated during the summer survey, including aluminum and magnesium (Appendix II). Aluminum concentrations varied a great deal throughout the study area with the highest levels occurring stations 3, 12, and 19. Stations 22 and 23 had the lowest aluminum concentrations.

Magnesium levels were evaluated at the five "extensive" stations, and ranged from a low of 9.9 mg/g at station 1 to a high of 17.2 mg/g at station 23.

Nutrients

Loss on ignition (LOI) was measured at all the stations in the study area, whereas total kjeldahl nitrogen (TKN), total phosphorus (TP), and total organic carbon (TOC) were evaluated at all the "extensive" stations during the summer survey.

LOI is a measure of the particulate organic matter (leaves, bark, sewage, fibres) in the sediment. LOI for sediments ranged from a low of 2 percent at stations 11, 13, 14, and 15, to a high of 14 percent at station 1 (Appendix II). Sediment samples collected from section A of the river were also characterized by higher LOI levels.

Total kjeldahl nitrogen levels exceeded the PSQG-LEL of 550 μg/g at stations 1, 9, 21, and 23 (Appendix II). Concentrations ranged from a low of 290 μg/g at station 15 to a high of 2800 μg/g at station 1.. All sediment samples had TKN levels below the SEL of 4,800 μg/g. Similarly, TOC values exceeded the PSQG-LEL of 1 percent at stations 1, 9, 21, and 23 (Appendix II). TOC levels ranged from a low of 0.92 percent at station 15 to a high of 7.4 at station 1. The SEL of 10 percent was not exceeded at any station.

Total phosphorus concentrations exceeded the PSQG of 600 μg/g at all stations, and ranged from 620 μg/g at station 23 to 1300 μg/g at station 21 (Appendix II). All sediment samples had TP levels below the SEL of 2000 μg/g.

Total Cyanide

Total cyanide was determined at all stations during the summer survey and at a subset in the fall. Concentrations were below detection limits in most instances (Appendix II). The OWDG of 0.1 μg/g (no existing PSQG) was exceeded at station 1 and station 20 during the summer survey, and at stations 2, 17, 18, 19a, 20, and 21 during the fall survey. Sediments collected from station 20 had the highest cyanide level of 1.67 μg/g.

Oil and Grease

Concentrations of oil and grease ranged from a low of 195 $\mu g/g$ at station 13 to a high of 11,800 $\mu g/g$ at station 12 (Appendix II). Oil and grease levels exceeded the OWDG of 1,500 $\mu g/g$ (no existing PSQG) at a number of stations during both the summer and fall surveys, predominantly in the urban area of the City of Welland and the industrial section east of Port Robinson.

Polycyclic Aromatic Hydrocarbons

The polycyclic aromatic hydrocarbon (PAH) analytical results for all sediment samples collected in the summer and fall are presented in Table 11 and 12 respectively. Station 9, in downtown Welland, had extremely high levels of all the PAHs relative to those found at other stations during the summer and fall surveys. Station 10, located near the McMaster Avenue outfall, also had high levels of some PAHs during the fall survey.

Total PAH levels at stations 1 and 9 exceeded the PSQG-LEL of 2,000 ng/g during the summer survey. SEL levels were not exceeded at any of the stations tested during the summer survey. Total PAHs exceeded the PSQG-LEL at stations 7, 8, 9, 10, and 15 during the fall survey. SELs for organic compounds are dependent on the amount of organic carbon in the sediment (MOE 1991). SELs could not be calculated for the fall survey because TOC concentrations were not measured.

PAH concentrations were extremely variable, both between surveys, and between duplicate samples collected from the same station. This phenomenon probably reflects the uneven distribution of the contaminants within the sediments.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) were not detected in any sediment samples collected during the summer survey; however they were detected in several fall samples. Total PCB levels ranged from <0.05 $\mu g/g$ to 0.13 $\mu g/g$, and exceeded the PSQG-LEL of 0.07 $\mu g/g$ at stations 7, 8, 9, and 15 (Appendix II). The SEL could not be calculated as TOC levels were unavailable for the fall survey.

Results from detailed chemical analyses conducted by MOE on sediments from stations 6, 9, 15 and 21 indicated total PCB concentrations at station 21 also exceeded the LEL (Table 12b). The laboratory report noted that PCB congeners detected at site 21 resembled a mixture of Aroclor 1254 and 1260. PCBs were not detected at the other stations 6, 9 or 15.

Table 11 : Concentrations of PAHs in Welland River sediments collected during the summer survey. All concentrations are in ng/g.

PAH	Stn 1	Stn 9 *	Stn 15	Stn 21	Stn 23
Naphthalene	22	129 (290)	19	<10	16
Acenaphthylene	<10	<10 (15)	<10	<10	<10
Acenaphthene	13	200 (880)	<10	<10	<10
Fluorene	33	270 (710)	<10	<10	12
Phenanthrene	200	1630 (4100)	24	52	63
Anthracene	95	490 (1590)	14	25	55
Fluoranthene	400	2100 (7200)	82	210	210
Pyrene	370	2200 (7200)	104	240	210
Benzo(a)anthracene	125	1050 (4000)	30	79	126
Chrysene	148	1020 (3700)	35	101	175
Benzo(b)flouranthene	260	1600 (5700)	90	220	300
Benzo(k)flouranthene	260	1600 (1900)	90	220	116
Benzo(a)pyrene	69	1470 (5400)	61	140	170
Perylene	680	570 (1490)	31	97	101
Indeno(123,cd)pyrene	<100	1150 (5200)	<100	83	<100
Dibenzo(ah)anthracene	<100	1390 (4800)	<100	<100	<100
Benzo(ghi)perylene	<50	470 (1500)	<50	35	<50
Total PAH's[1]	2125	16774 (54185)	689	1475	1487

1 - Total PAHs is the sum of all the PAHs listed except for perylene. Concentrations of PAHs below detection limits were taken as equal to half the detection limit.

* - Value in brackets is the PAH concentration in a duplicate sample taken from the three ponar samples taken at each station

Table 12 : Concentrations of PAHs in Welland River sediments collected during the fall survey. All concentrations are in ng/g.

PAH	Stn 1	Stn 3	Stn 5	Stn 7	Stn 8	Stn 9	Stn 10	Stn 15
Naphthalene	<50	<50	<50	<50	<50	450 (<50)	60	<50
Acenaphthylene	<50	<50	<50	<50	<50	<50 (<50)	<50	<50
Acenaphthene	<50	<50	<50	50	<50	950 (<50)	70	<50
Fluorene	<50	<50	<50	<50	<50	1110 (760)	90	<50
Phenanthrene	<50	<50	<50	450	320	880 (450)	660	160
Anthracene	<50	<50	<50	200	110	3700 (140)	280	70
Fluoranthene	120	235	50	1330	670	9900 (480)	1230	340
Pyrene	<50	235	50	1130	600	8800 (630)	1220	360
Benzo(a)anthracene	<50	<100	<50	760	330	8300 (450)	1140	370
Chrysene	<50	<100	<50	840	80	6600 (560)	1090	320
Benzo(b)flouranthene	<100	<100	<100	540	<100	3800 (600)	610	<100
Benzo(k)flouranthene	<100	<100	<100	<100	<100	8100 (1600)	1910	<100
Benzo(a)pyrene	<200	<200	<200	<200	<200	2500 (1470)	2900	<200
Perylene	<200	<200	<200	<200	<200	6300 (970)	2000	700
Indeno(123,cd)pyrene	<500	<500	<500	<500	<500	600 (800)	1100	<500
Dibenzo(ah)anthracene	<500	<500	<500	<500	<500	2900 (<500)	800	<500
Benzo(ghi)perylene	<500	<500	<500	<500	<500	4000 (300)	1580	670
Total PAHs[1]	-	-	-	6250	3160	62615 (8565)	14765	3090

1 - Total PAHs is the sum of all PAHs listed except for perylene. Concentrations of PAHs below detection limits were taken as equal to half the detection limit. Total PAHs for stations 1, 3, and 5 were not calculated because most PAHs were below detection limits.

* - Values in brackets are concentrations of each PAH in a duplicate sample

Table 12 b: MOE results for concentrations of chlorinated organics at sites 6, 9, 15 and 21.

Parameter	Units	D.L.	Station			
			6	9	15	21
T4CDD	ppt	*	-	ND(4)	ND(7)	ND(6)
P5CDD	ppt	*	-	ND(7)	ND(12)	ND(9)
H6CDD	ppt	N.A.	-	79^3	31^2	60^3
H7CDD	ppt	N.A.	-	230^2	230^2	420^2
O8CDD	ppt	N.A.	-	1900^1	2300^1	3100^1
T4CDF	ppt	*	-	ND(5)	ND(8)	ND(7)
P5CDF	ppt	*	-	14^1	ND(12)	ND(7)
H6CDF	ppt	N.A.	-	30^3	12^1	28^2
H7CDF	ppt	N.A.	-	160^2	92^2	140^2
O8CDF	ppt	N.A.	-	63^1	36^1	81^1
Extractable Org.	N.A.	N.A.	no numeric result			
Volatile Org.	N.A.	N.A.	no numeric result			
PCB, Total	ng/g	20	ND	ND	ND	85(T)
Hexachlorobenzene	ng/g	1	below detection limit			
Heptachlor	ng/g	1	below detection limit			
Aldrin	ng/g	1	below detection limit			
Mirex	ng/g	5	below detection limit			
α-BHC	ng/g	1	below detection limit			
β-BHC	ng/g	1	below detection limit			
γ-BHC	ng/g	1	below detection limit			
A-Chlordane	ng/g	2	below detection limit			
G-Chlordane	ng/g	2	below detection limit			
Oxychlordane	ng/g	2	below detection limit			
PP-DDE	ng/g	1	2(T)	2(T)	ND	4(T)
OP-DDT	ng/g	5	below detection limit			

Table 12 b: Continued

Parameter	Units	D.L.	Station			
			6	9	15	21
PP-DDD	ng/g	5	below detection limit			
PP-DDT	ng/g	5	below detection limit			
DMDT Methoxychlor	ng/g	5	below detection limit			
Heptachlorepoxide	ng/g	1	below detection limit			
Dieldrin	ng/g	2	below detection limit			
Endrin	ng/g	4	below detection limit			
Endosulfan I	ng/g	2	below detection limit			
Endosulfan II	ng/g	4	below detection limit			
Endosulfan Sulphate	ng/g	4	below detection limit			
Octachlorostyrene	ng/g	1	below detection limit			

D.L. is the parameter detection limit.
Asterisks (*) indicate parameter detection limits may be found in brackets ( ) for each station.
N.A. indicates a numeric value or result was not reported.
A superscript denotes the number of isomers of that parameter detected at that station.
ND indicates that parameter exists at a concentration below D.L. at that station.
(T) means the parameter was measured in trace amounts at that station. Interpret with caution.

Pesticides

Organochlorine (OC) pesticides were not detected at any of the sampling stations. A list of all OC pesticides and their detection limits is presented in Table 13. The Ministry of the Environment has also routinely determined OC pesticides in Welland River sediments from 1981 to 1988 (MOE-unpublished data (1981-1988)). Alpha-BHC, alpha-chlordane, dieldrin, hexachlorobenzene, 4,4'DDE and gamma-chlordane were detected in some years. Concentrations were consistently low. With the exception of PP-DDE, which was detected in trace amounts at stations 6, 9 and 21, pesticides analyzed by MOE for the present study were below detection limits (Table 12b).

Dioxins and Furans

Polychlorinated dibenzo-p-dioxins were found at stations 9, 15, and 21 (Table 12b). Concentrations ranged between 31 and 79 ppt for hexachlorinated forms, 230 to 420 for the heptachlorinated forms, and 1,900 and 3,100 for the octachlorinated congener. Polychlorinated dibenzofurans were also detected at the same stations. A pentachlorinated congener was found only at station 9 and at a concentration of 14 ppt. The hexa, hepta, and octachlorinated forms were found at stations 9, 15, and 21 at levels ranging from 12 to 30, 92 to 160, and 36 to 81 ppt respectively.

The more highly chlorinated dioxin and furan congeners such as the octachlorinated forms are generally believed to be less of an environmental concern than are the tetrachlorinated isomers because of the relatively large size of the molecules. The larger molecules tend to bind tightly to sediment particles and have a high octanol-water partition coefficient; and because of the large size, they cannot cross cell membranes easily. The toxicity of these contaminants to aquatic biota is poorly understood at present; however, it is acknowledged that they can affect growth, reproduction, and hormonal processes in some organisms.

Table 13 : Organochlorine pesticides, PCBs and associated detection limits in sediments.

OC Pesticide	Detection Limit (μg/g)
Hexachlorobenzene	0.003
alpha-BHC	0.003
gamma-BHC	0.003
Heptachlor	0.003
Aldrin	0.003
beta-BHC	0.003
Oxychlordane	0.003
Heptachlor epoxide	0.003
Endosulfan I	0.003
gamma-Chlordane	0.003
alpha-Chlordane	0.003
4,4'- DDE	0.003
Dieldrin	0.003
Endrin	0.003
2,4'- DDT	0.003
4,4'- DDD	0.003
Endosulfan II	0.003
4,4'-DT	0.003
Mirex	0.003
Endosulfan Sulfate	0.003
Methoxychlor	0.003 - 0.005
PCBs	0.050 - 0.100

Sediment Contamination by Station

Sediment quality in the study area with respect to the PSQGs for metals, and OWDGs for oil and grease and total cyanide, is summarized in Table 14.

Sediments at stations 9, 10, 10a, 11, and 12, located in the upstream portion of section B, along with those at stations 15, 16, 17, 18, 19 and 20 in section C are the most contaminated, as indicated by the levels of several metals and oil and grease. Concentrations of chromium, mercury, iron, nickel, and copper also exceed the SEL's at several stations in sections B and C.

Station 7, which also has relatively contaminated sediments, is located in the eastern downstream portion of section A below a large storm sewer. Storm water is a known source of heavy metals and oil and grease. Inputs to this storm drain may be the cause of contaminants accumulating in sediments at this site.

Sediments at station 9 are characterized by high concentrations of metals, oil and grease and a number of PAHs. A large storm drain located upstream of this station is the suspected source of contaminants. Elevated levels of several metals have also been found in sediments at this location during previous studies (Acres 1990). A comparison of results from the Tarandus and Acres studies is presented in Table 15. Concentrations are also compared with PSQG lowest effect and severe effect levels.

Sediments at stations 10 and 10a, situated a short distance downstream from the Atlas Steel outfall and downstream from the old McMaster Avenue combined sewer outfall also have elevated levels of several metals, and oil and grease. A reef-type deposit of industrial waste was first noted off the Atlas outfall by Brindle and Dickman in 1980 (Acres, 1990). Acres (1990) examined this deposit in detail and also discovered two areas of further contamination, one at the outfall from the McMaster Avenue combined sewer, and one approximately 400 meters downstream from the Atlas outfall. The reef sediments contained elevated levels of copper, chromium, iron, lead, manganese, nickel, zinc, and oil and grease. A comparison of sediment quality results from the 1990 Tarandus survey and the Acres study is presented in Table 16.

The discharge outfall from Atlas Steel has been well documented as a source of contaminants to the Welland River (COA, 1981; NRTC, 1984). The industrial effluent was also documented as exceeding effluent guidelines for several parameters including chromium, copper, lead, nickel, zinc, iron, phosphorus, nitrogen, and sulphate (NRTC, 1984; Dalrymple in Dickman and Hayes, 1985).

Table 14: Summary of sediment quality at all stations with respect to the PSQG's. Shading indicates stations that exceeded the LEL guideline but not the SEL guideline for that specific parameter in either the summer or the fall survey. Asterisks indicate stations that exceeded the SEL guideline. The symbol "na" indicates that parameter was not tested at that station.

Section	A								B							C								D	
Station	1	2	3	4	5	6	7	8	9	10	10a	11	12	13	14	15	16	17	18	19	19a	20	21	22	23
Pb																									
Cr										**	**	**	**	**	**	**	**	**	**	**					
Hg									**																
Cd																									
As																									
Zn																									
Fe										**	**	**	**	**	**	**	**	**	**	**	**	**			
Ni										**	**	**	**	**	**	**	**	**	**	**	**	**	**		
Cu										**										**	**	**			
CN[1]																									
O&G[1]																									
TP		na	na	na	na	na	na	na		na	na	na	na	na	na		na	na	na	na	na	na		na	
TOC		na	na	na	na	na	na	na		na	na	na	na	na	na		na	na	na	na	na	na		na	
TKN		na	na	na	na	na	na	na		na	na	na	na	na	na		na	na	na	na	na	na		na	

1 - parameter compared to the Open Water Disposal Guideline
na - parameter was not evaluated at that station

Table 15: A comparison of selected sediment-quality parameters at station 9. All results are in $\mu g/g$.

Parameter	Tarandus (1990)	Acres (1990)	PSQG LEL	PSQG SEL
Chromium	50.0-320.0	14.0-79.0	26	110
Copper	79.0-126.0	33.0-146.0	16	110
Lead	49.0-138.0	24.0-339.0	31	250
Manganese	400.0-750.0	269.0-794.0	460	1100
Nickel	37.0-195.0	25.0-140.0	16	75
Zinc	158.0-460.0	242.0-2236.0	120	820

Table 16: Comparison of selected parameters in sediments collected offshore of the Atlas outfall. All results are in $\mu g/g$.

Parameter	Tarandus (1990)[1]	Acres (1990)[2]
Chromium	91.0-670.0	21.0-5,000
Copper	50.0-168.0	17.0-860.0
Iron	11,800	20,000-420,000
Lead	38.0-87.0	15.0-870.0
Manganese	1,210	470.0-6,600
Nickel	390	37.0-11,000
Zinc	270.0-550.0	36.0-690.0
PCBs	<0.05-0.045	<0.2-0.3[3]

1 - sediment quality results for stations 10 and 10a
2 - sediment quality results for 18 samples taken from an area 20 meters upstream and 20 meters downstream of the Atlas outfall
3 - PCBs analyzed at 3 stations directly off the outfall

Sediments at station 11, located downstream from the Welland Water Pollution Control Plant (WPCP) also exceed PSQG-LELs for several metals, and oil and grease. These sediments also exceeded SEL's for chromium, iron, and nickel. The WPCP effluent has also been documented as exceeding effluent guidelines for copper, lead and zinc (NRTC, 1984).

Solid waste (primarily slag) and liquid waste from Atlas Steel (primarily slag) has been deposited since 1930 at the company's landfill located on the east bank of the river and has in the past been documented as a source of contaminants to the Welland River through surface runoff (NRTC, 1984). Contaminants include aluminum, arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium, zinc, and cyanide.

All stations located in section C were also characterized by elevated levels of several metals, total cyanide, and oil and grease. The Cyanamid Canada plant located along this section of the Lower Welland River is considered a source of several contaminants found in the river sediments. Cyanamid formerly discharged at a point just upstream of station 18, but now discharges to Thompson's Creek. Thompson's Creek enters the Welland River slightly upstream of station 20. Cyanamid's discharge has been reported as a source of several contaminants including chromium, nickel, zinc, copper, and cyanide (NRTC, 1984). Hart (1986) also reported elevated sediment concentrations of silver, chromium, mercury, nickel, lead, zinc, and iron at the mouth of Thompson's creek.

A comparison of selected sediment contaminant concentrations found in several nearby river systems in the area is presented in Table 17. Means and ranges for the Welland River were calculated using data for all sites except sites 22 and 23, which are in Chippawa Creek. Mean sediment concentrations of lead, chromium, mercury, cadmium, arsenic, zinc, nickel and copper in the Welland River were higher than levels in sediments collected from the Upper Niagara River or, with the exception of cadmium, from Lyon's Creek. Niagara River sediments had higher PCB concentrations than Welland River sediments. Elevated levels of several contaminants in the sediments from Thompson's Creek may be the result of discharges from industrial processes. The Cyanamid effluent has been reported to be approximately 90 percent of the average annual flow in Thompson's Creek.

Table 17: Comparison of Welland River sediments with sediments from Thompson's Creek, Lyon's Creek, the Upper Niagara River. All concentrations are in $\mu g/g$.

	Welland River			Thompson's Creek[1]			Lyon's Creek[1]			Upper Niagara River[2]		
	mean	range	n	mean	range	n	mean	range	n	mean	range	n
Lead	47.11	21-138	40	120	110-130	2	29	26-32	2	34.4	4-200	14
Chromium	178.61	19-670	40	265	180-350	2	35.5	34-37	2	20.3	5.8-79	14
Mercury	0.522	<0.02-1.64	31	0.725	0.45-1.0	2	.055	.05-.06	2	0.20	<0.01-0.67	14
Cadmium	0.532	0.1-1.5	40	N/A	ND-0.75	2	0.675	0.35-1.0	2	0.42	<.4-.88	14
Arsenic	6.67	4-17	37	7.39	6.08-8.7	2	4.785	4.02-5.55	2	4.64	1.9-14	14
Zinc	192.19	69.5-620	40	235	190-280	2	130	110-150	2	140.3	26-460	14
Nickel	152.14	33-390	21	140	120-160	2	32.5	30-35	2	13.6	6-38	14
Copper	63.23	24-168	40	90.5	71-110	2	30.5	29-32	2	22.3	3.8-110	14
Oil/Grease	1993.59	195-11800	46	2175	1270-3080	2	3135	2870-3400	2	-	-	14
TP	1096.25	1005-1300	4	2700	2700	1	600	600	1	-	-	14
TKN	1450	290-2800	4	2700	2700	1	2000	2000	1	-	-	14
PCBs	0.068	<0.05-0.71	9	0.575	0.22-0.93	2	.05	.025-.075	2	0.46	ND-0.96	14

1 - Hart (1986) - sampled at the creek mouths.
2 - Kauss (1983) - Includes stations in the Tonawanda Channel and the Chippawa Channel

Benthic Invertebrates

i) Species Composition, Abundance, and Diversity

In total, 90 benthic invertebrate taxa were identified at the 25 sampling stations in the study area (Appendix IV). The total number of taxa was higher than the number of genera (28) Johnson in 1964. As might be expected because of the range of habitat types and environmental quality, the number of taxa at each station varied. It ranged from a low of 12 taxa at stations 6 and 25 to a high of 29 taxa at station 10 (Table 18). The abundance of taxa at stations 9 and 10 may reflect the diversion of relatively cleaner water from the Welland Canal at the inverted syphon. The distribution of the various invertebrate species, by number/sample and number/m^2 for each station are presented in Appendix V and VI respectively.

Only two invertebrate species were common to all the sampling stations; *Procladius sp.* and immature tubificids, although *Chryptochironomus sp.*, *Limnodrilus hoffmeisteri*, and *Sphaerium sp.* were found at 24 of the 25 sites. Similarly, Johnson (1964) found that *Procladius* and *Limnodrilus* were common throughout the Welland River system.

Tubificids have been used extensively as indicator organisms (Lauritsen *et al.*, 1985; Cook and Johnson, 1974). *Limnodrilus hoffmeisteri*, for example, is a species known to be characteristic of organically enriched sediments and is generally tolerant of high concentrations of some heavy metals (Winner et al. 1980). It should be noted, however, that *Limnodrilus spp.* are not necessarily confined to polluted waters (Hynes, 1971; Brinkhurst and Cook, 1974). The abundance of several tubificids, including *L. hoffmeisteri* at all the sampling sites is illustrated in Figure 7. Relatively high numbers of this species were found at station 9 and station 16.

The chironomids, *Procladius sp.* and *Chironomus sp.* are usually common in polluted conditions (Cook and Johnson, 1974). The relative abundances of *Chironomus chironomus* and *Procladius sp.* at all sampling sites in the study area are illustrated in Figure 8. High numbers of *Chironomus sp.* were found at station 9. High abundances of *Procladius sp.* were found at stations 10, 11, 15, and 22.

Mayflies, such as *Hexagenia sp.* are considered intolerant of polluted conditions (Schloesser, 1988; Fremling, 1964; Winner *et al.*, 1980), and as a result, their presence is usually indicative of uncontaminated conditions. Mayflies were relatively abundant in Section A (stations 1-8), but were generally absent from the rest of the study area (Figure 9). Johnson (1964) also noted an absence of mayflies from the same sections of the Welland River.

Figure 7:

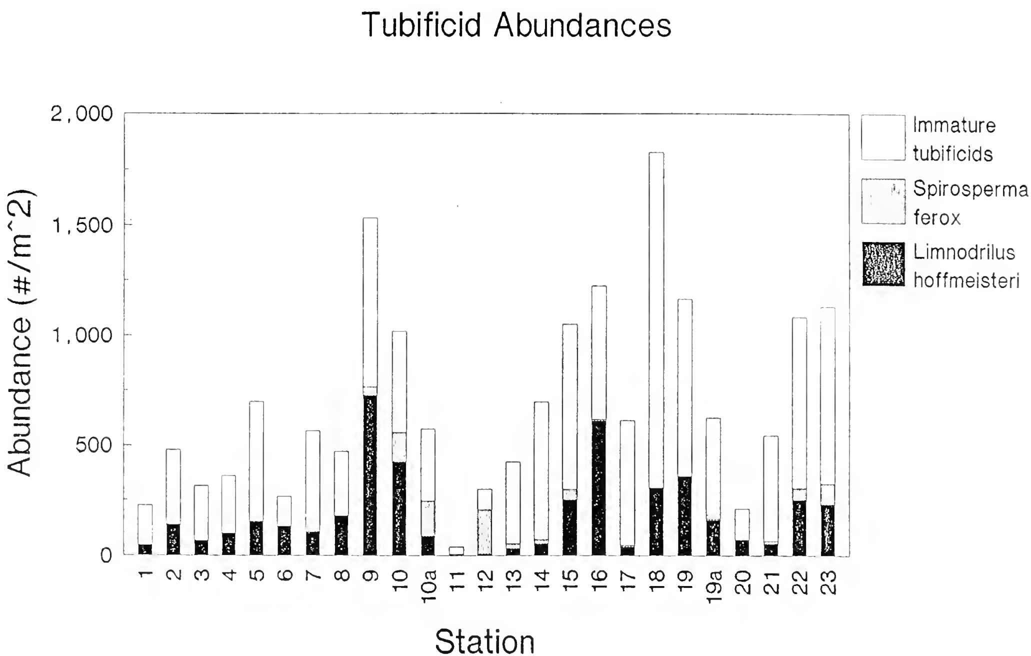

Tubificid Abundances
2,000
1,500
1,000
500
0
Abundance (#/m^2)
1
2
3
4
5
6
7
8
9
10
10a
11
12
13
14
15
16
17
18
19
19a
20
21
22
23
Station
Immature tubificids
Spirosperma ferox
Limnodrilus hoffmeisteri

Figure 8:

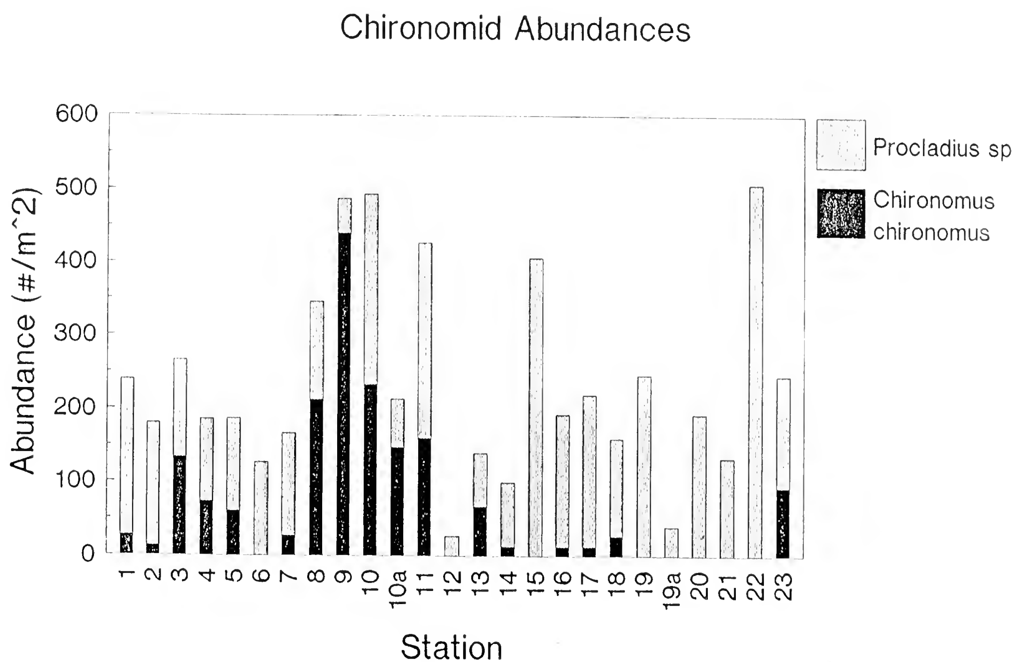
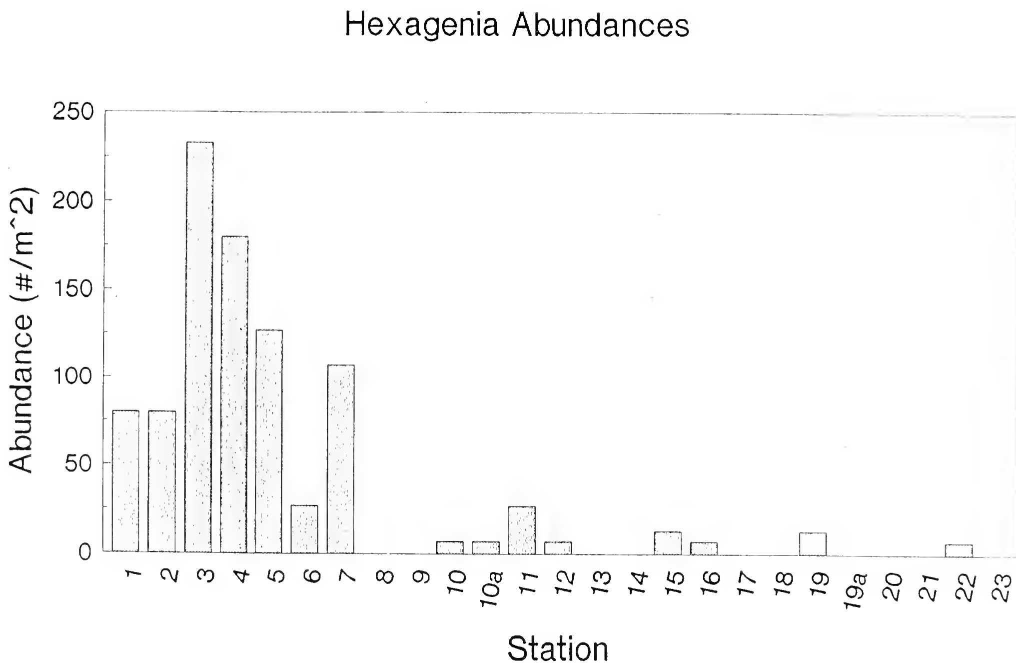

Chironomid Abundances
Abundance (#/m^2)
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
10a
11
12
13
14
15
16
17
18
19
19a
20
21
22
23
Station
Procladius sp.
Chironomus chironomus

Figure 9


Hexagenia Abundances
Abundance (#/m^2)
0
50
100
150
200
250
1 2 3 4 5 6 7 8 9 10 10a 11 12 13 14 15 16 17 18 19 19a 20 21 22 23
Station

Zebra mussels (*Dreissena polymorpha*) are a recent addition to the benthic community in the study area. Adult Zebra mussels were noted at several stations in sections B, C, and D, most likely the result of veligers introduced to the Welland River from the Welland Canal at the upper syphon by the diversion structures. The mussel was not found in section A, probably because of its inability to move upstream into this section of the river. Zebra mussels found in sections B, C, and D were attached to rocks and other solid debris as well as to aquatic macrophytes. Station 9 had the highest density of zebra mussels (1013/m^2).

The total abundance of benthic invertebrates ranged from a low of 634 individuals per square meter at station 12 to a high of 5900 individuals per square meter at station 22 (Table 18). Station 9 also had a relatively high mean total abundance of 4013 invertebrates per square metre. Generally, stations located in sections B, C, and D had higher total abundances than those found in section A, primarily due to higher densities of oligochaetes. Johnson (1964) observed total invertebrate densities between 97/m^2 and 3,757/m^2 and also noted higher densities in the eastern sections of the Welland River.

Figure 10 illustrates the total Oligochaete abundances throughout the study area. The reduction in the density of oligochaetes at stations below the Atlas Steel discharge and Cyanamid Canada may be due to the toxicity of the high metal concentrations in these sediments.

The Shannon-Weaver and Brillouin diversity indices for all stations are presented in Table 18. Benthic-invertebrate diversity fluctuated a great deal, especially in sections B, C, and D. Diversities at all the stations in section A, were relatively constant. Shannon-Weaver diversities ranged from a high of 3.96 at station 11 to a low of 2.52 at station 19a. Similar trends were noted with the Brillouin diversity index. Benthic invertebrate diversities (Shannon-Weaver index) calculated from Johnson's (1964) data ranged from 0.34 to 3.48. Weed and Rutschky (1972) considered Shannon-Weaver diversities greater than 3.0 to represent unpolluted conditions, a diversity of 1.0-2.0 moderately polluted, and a diversity of less than 1.0 severely polluted.

Figure 10:

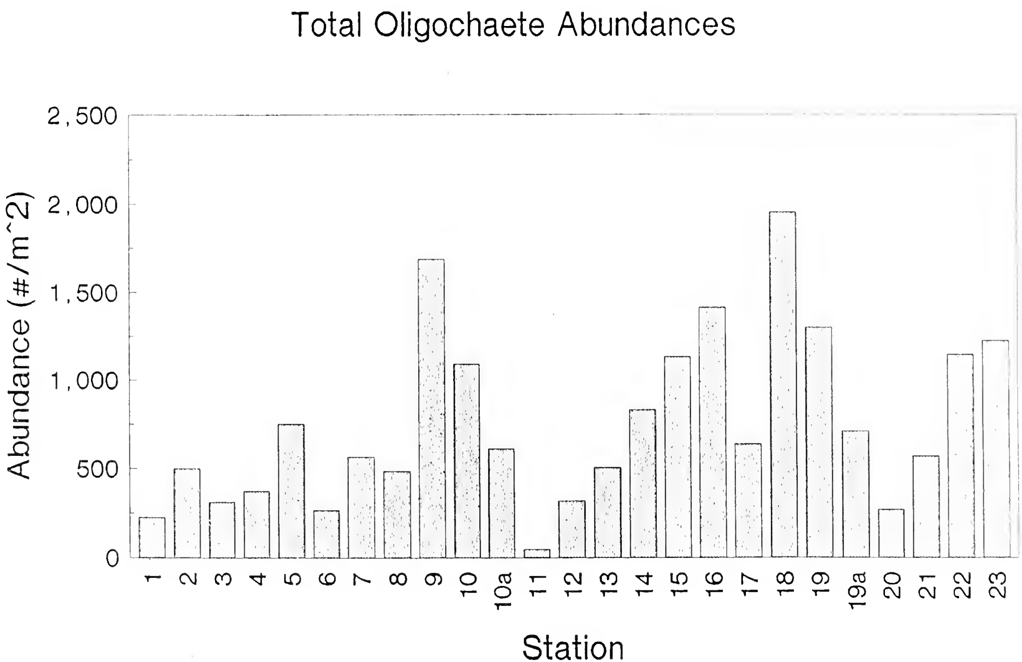

Total Oligochaete Abundances
Abundance (#/m^2)
2,500
2,000
1,500
1,000
500
0
1
2
3
4
5
6
7
8
9
10
10a
11
12
13
14
15
16
17
18
19
19a
20
21
22
23
Station

Table 18: Number of taxa, total abundance ($\#/m^2$), and diversity indices (Shannon and Brillouin) for all stations.

Station	# of Taxa	Total Abundance	Diversity Shannon	Diversity Brillouin
1	18	1,387	3.45	2.36
2	20	1,447	3.50	2.39
3	18	1,387	3.53	2.42
4	19	1,140	3.49	2.38
5	21	1,473	3.30	2.25
6	12	666	3.02	2.05
7	21	1,240	3.20	2.18
8	18	1,113	3.30	2.25
9	26	4,013	3.34	2.30
10	29	2,407	3.84	2.64
10a	28	2,093	3.91	2.68
11	27	1,394	3.96	2.70
12	16	634	3.08	2.10
13	22	1,300	3.49	2.38
14	23	1,447	3.07	2.09
15	24	2,360	3.29	2.26
16	19	2,380	3.10	2.13
17	22	1,793	3.17	2.17
18	24	2,793	2.57	1.76
19	22	2,700	3.16	2.17
19a	12	1,367	2.52	1.73
20	14	1,147	3.18	2.17
21	20	1,607	3.03	2.07
22	27	5,900	2.83	1.95
23	26	2,407	3.14	2.16

ii) Benthic-Community Classification

The benthic invertebrate communities were defined by means of cluster analysis. Based on the total species composition at each station, the cluster analysis split the twenty-five sampling locations into four groups or communities (1, 2, 3, and 4). The taxonomic composition of the four communities is presented in Appendix VII. The cluster analysis using euclidean distance and Ward's Method produced the best defined clusters (Figure 11).

Principal components analysis (PCA) was used to verify station groupings revealed by cluster analysis (Figure 12). The PCA was completed on all the benthic invertebrate genera. The component loadings and percent total variance for the principal components are presented in Appendix VIII. Approximately 24 percent of the variation is explained by the first two factors. Although the percent variation explained is relatively low, the PCA results generally confirm those of the cluster analysis. All the stations from section A of the study area form a fairly distinct group (community 1) in the PCA diagram. This group is characterized by relatively high numbers of the *Hexagenia*, and the *Coelotanypus sp.* Communities 2, 3, and 4 revealed by the cluster analysis is also fairly distinct in the PCA diagram. The stations found these communities are influenced by the relative abundances of Hirudinea, *Spirosperma ferox*, and immature tubificids, as indicated by their positive correlation with the first axis of the PCA axis. Community 4 is separated from the other communities along the second PCA axis and is influenced by the relative abundances of *Polypedelium (Polypedelium) sp.* and planaria.

Figure 11: Cluster analysis results using Euclidean distance and Ward's method. Large numbers indicate groups of sites (small numbers) with similar benthic invertebrate communities.

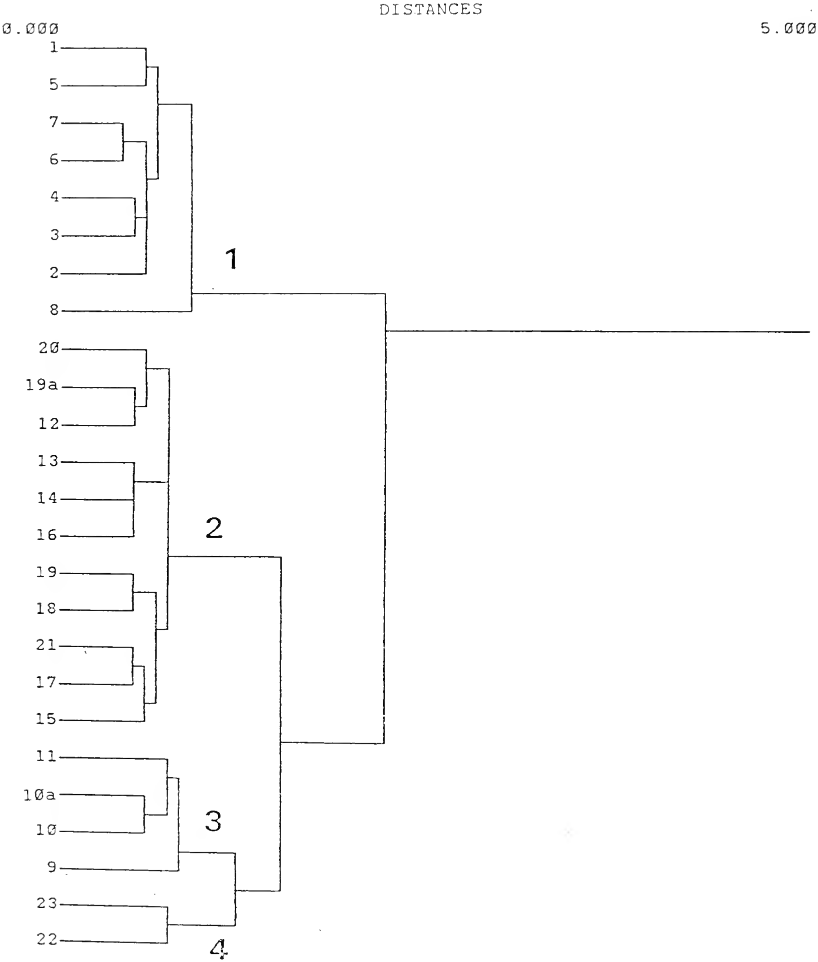
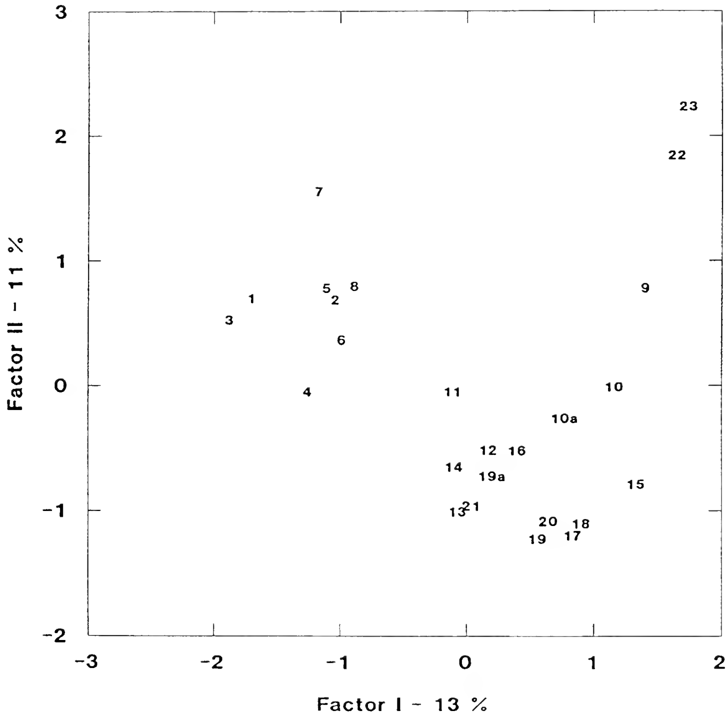


Figure 12: Scatterplot of sample locations on the first two principal components. Sites grouped together have similar benthic invertebrate communities



iii) Environmental Quality Evaluation

Figure 13 illustrates the separation in discriminant space of the four groups of stations defined by cluster analysis and PCA. Correlations between sediment parameters and the first two discriminant functions are given in Table 19.

The first discriminant axis (DA I) separates the communities characterizing the Welland River sites (communities 1, 2, and 3) from community 4, located in Chippawa Creek (Figure 13). The axis indicates that communities 1, 2, and 3 are found in sediments with high concentrations of metals such as chromium, copper, aluminum, lead, mercury, and arsenic relative to those associated with community 4. The sediments of community 1, however are characterized by lower levels of these metals relative to communities 2 and 3.

The second discriminant axis (DA II) separates community 1 from the remaining communities in discriminant space (Figure 13). This axis indicates that community 1 is found in sediments with slightly higher levels of aluminum and LOI relative to the sediments in communities 2, 3, and 4.

This analysis suggests that the separation of communities is due to differences in concentrations of sediment parameters. It indicates that communities 1, 2, and 3, located in the Welland River, reflect degraded environmental conditions, relative to community 4 located in Chippawa Creek. Of the Welland River communities, 2 and 3 are more degraded than 1. This observation is not surprising, given the fact that communities 2 and 3 are located in urbanized sections of the river which receive inputs from various industrial and municipal sources. Community 1, which consists of all the stations in Section A of the river, may be in more organically enriched sediments, as is illustrated by the relatively high loss on ignition (LOI). The only exception to the general pattern of correspondence between contamination and community type is aluminum, which is found in higher amounts in community 1 than in communities 2 and 3. The mean concentrations of all sediment parameters associated with each community are presented in Table 20.

Figure 13: Plot of the benthic invertebrate communities in discriminant space as defined by the first two discriminant functions.

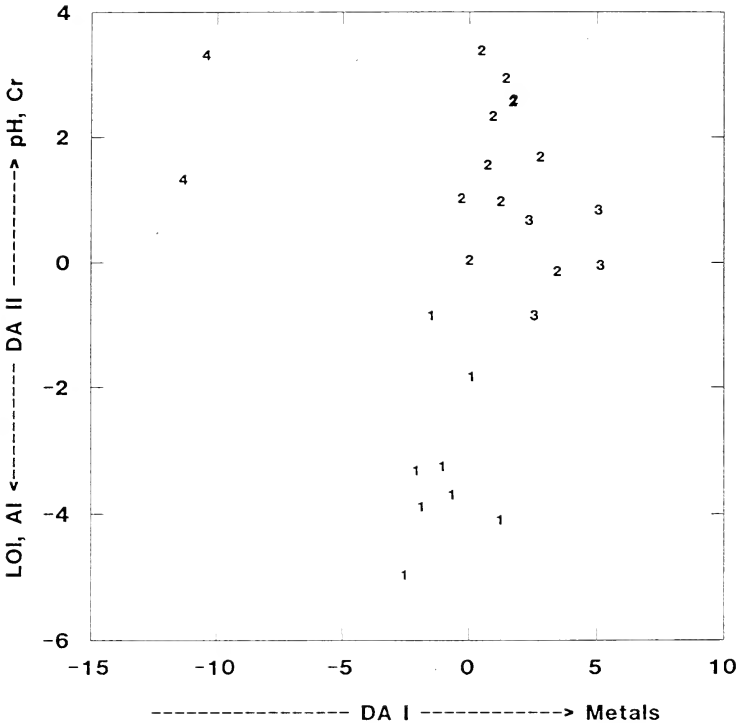


Table 19: Correlations between sediment parameters and the first two discriminant functions for benthic invertebrate communities.

Parameter	Discriminant Function I	II
Zinc	0.163	-0.031
Cadmium	-0.004	-0.064
Copper	0.218	0.121
Lead	0.142	-0.134
Chromium	0.220	-0.258
Aluminum	0.244	-0.256
Mercury	0.120	0.040
Arsenic	0.184	0.092
Loss on Ignition	-0.093	-0.453
Oil and Grease	-0.014	-0.048
pH	0.091	0.264

Table 20: Mean concentrations of sediment parameters associated with benthic invertebrate communities. All units are expressed as $\mu g/g$, dry weight unless otherwise stated.

	Benthic Community			
Parameter	1	2	3	4
Zinc	112.5	176.9	313.3	65.3
Cadmium	0.48	0.40	0.58	0.49
Copper	33.5	58.3	62.1	17.0
Lead	42.0	34.9	55.9	18.3
Chromium	43.1	156.8	73.6	20.8
Aluminum	32375	29182	30438	14075
Mercury	0.116	0.175	0.955	0.065
Arsenic	5.38	7.36	7.50	3.50
Loss on Ign.	10.09	4.00	5.25	5.50
Oil/ Grease	1500.6	1399.6	2198	1455
pH	6.98	7.23	7.08	7.00

To evaluate the Welland River environment by itself, community 4 was removed from the data set and discriminant analysis was again performed. Figure 14 illustrates the separation in discriminant space of the three Welland River communities. Correlations between sediment parameters and the first two discriminant functions are given in Table 21. Results confirm patterns observed in the discriminant analysis on the whole data set. However, they reveal differences between conditions in which communities 2 and 3 are found.

The first discriminant axis (DA I) separates community 1 from communities 2 and 3 (Figure 14). The axis indicates that communities 2 and 3 are found in sediments with higher concentrations of metals such as chromium, copper, mercury, zinc, and arsenic relative to the sediments in which community 1 exists. The sediments of community 1, however, are characterized by lower levels of these metals, and higher LOI than those associated with communities 2 and 3. The absence of high numbers of pollution-sensitive species such as the mayfly, *Hexagenia sp.* and the presence of large numbers of *Spirosperma ferox* and immature tubificids in communities 2 and 3 could be due to high concentrations of various metals in the sediments.

The second discriminant axis (DA II) separates communities 2 and 3 in discriminant space (Figure 14). This axis indicates that community 1 is found in sediments with slightly higher levels of chromium, as well as a higher sediment pH, relative to community 3. Similarly community 3 is found in sediments with higher mercury, lead, zinc, and LOI levels relative to community 2.

The analysis suggests that communities 2 and 3 reflect degraded environmental conditions with respect to various metals, relative to community 1. Community 2 and community 3 are located in urbanized sections of the river which receive inputs from various industrial and municipal sources. Community 1, which consists of all the stations in Section A of the river, may be more organically enriched, as illustrated by the high loss on ignition. Mean concentrations of all sediment parameters associated with each community are presented in Table 20.

Figure 14: Plot of the Welland River benthic-invertebrate communities in discriminant space as defined by the first two discriminant functions.

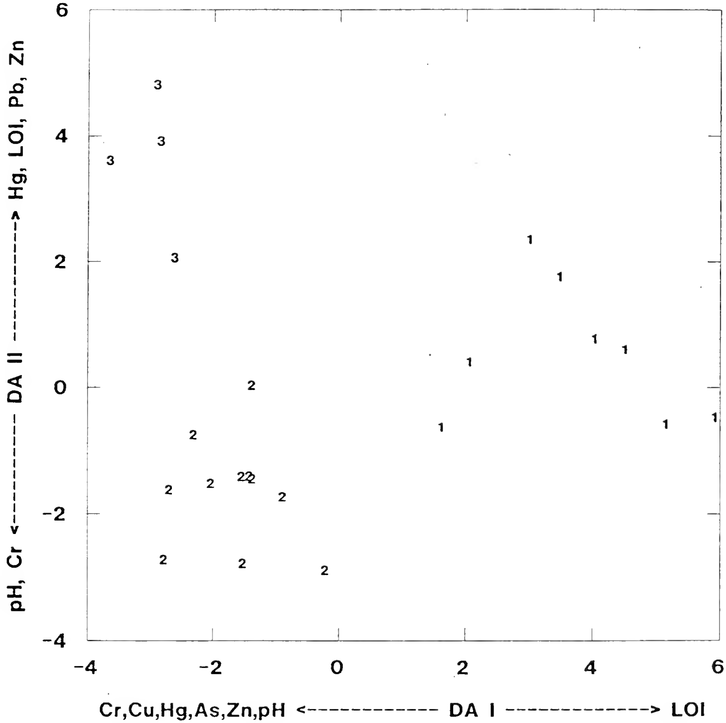


Table 21: Correlations between the sediment parameters and the first two discriminant functions for the three benthic invertebrate communities in the Welland River.

Parameter	Discriminant Function I	Discriminant Function II
Zinc	-0.144	0.186
Cadmium	0.033	0.128
Copper	-0.210	-0.013
Lead	0.009	0.192
Chromium	-0.282	-0.256
Aluminum	0.099	0.041
Mercury	-0.148	0.275
Arsenic	-0.169	-0.013
Loss on Ignition	0.402	0.200
Oil and Grease	0.031	0.088
pH	-0.226	-0.240

Fisheries

The fish community of the Welland River is characterized by warmwater fish species including catfish, carp, suckers, and freshwater drum (Appendix IX, Table 22). Salmonids are not endemic to the Welland River but are common in the Niagara River. Appendix IX also compares the Welland River fish community with those of 12-Mile Creek and the Niagara River area. All fish species caught in the Welland River during this survey are also found in the Niagara River.

The most common fish species caught during the field surveys were channel catfish (fall survey) and white crappie (summer survey), both warmwater species. Substantially more fish were caught in the hoop nets in section A than in Sections B and C (Table 23). A fisheries study by Johnson (1964) found that the more common fish included brown bullhead and sunfish (including crappies). The author also noted a decrease in the number of fish in the area covered by sections B, C, and D of the river.

During a twelve month survey by Steele (1981) on the Welland River, 25 species and two-hybrids were caught (Appendix IX). Dominant fish species included white crappie, brown bullhead, and channel catfish. Most of the species observed by Steele were tolerant of low dissolved oxygen concentrations, and high turbidity.

Table 22: Fish species caught in the Welland River during the summer and fall surveys.

HOOP NET	Summer[1]	Fall[2]
White Crappie[3]	25	2
White Bass	2	0
White Perch	0	10
Channel Catfish	0	59
Gizzard Shad	0	7
Freshwater Drum	0	8
White Sucker[3]	0	1
Yellow Bullhead	0	2
Shorthead Redhorse	0	2
Carp	0	1
Pumpkinseed[3]	0	1
Rock Bass[3]	0	3
Seine net/Minnow traps	**Summer**	**Fall[4]**
Smallmouth Bass	*	-
Spottail Shiner	*	*
Emerald Shiner	*	-
Johnny Darter	*	-
Brook Silverside	*	-
Sculpin	*	-
Banded Killifish	*	-

* - Fish species present (no numbers available)
1 - Three hoop-net sets - summer survey
2 - Two hoop-net sets - fall survey
3 - Fish species also caught in the seine net.
4 - No seining was conducted during the Fall Survey.

Table 23: Numbers of fish caught in hoop-net sets in sections A, B, and C.

HOOP NET	A	B	C	Total
White Crappie	23	2	0	27
White Bass	2	0	0	2
White Perch	10	0	0	10
Channel Catfish	59	0	0	59
Gizzard Shad	6	0	1	7
Freshwater Drum	8	0	0	8
White Sucker	1	0	0	1
Yellow Bullhead	2	0	0	2
Shorthead Redhorse	1	0	1	2
Carp	1	0	0	1
Pumpkinseed	1	0	0	1
Rock Bass	0	0	3	3
Total	114	2	5	121

Aquatic Macrophytes

The Welland River shoreline throughout the study area was characterized by the presence of several emergent aquatic macrophytes, particularly *Typha latifolia* and *Sagittaria latifolia* (Table 24). Johnson (1964) and Dickman *et al.* (1983) also noted an abundance of these species during previous surveys.

Several studies have been completed regarding effects of industrial discharges on the macrophyte community (Dickman and Haynes, date unknown; Dickman *et al.*, 1983). Dickman and Haynes (date unknown) noted areas devoid of higher aquatic plants downstream of the previous 36" Cyanamid outfall to the Welland River, as well as below the Thompson's Creek confluence. The summer Tarandus survey also revealed an area below the Thompson's Creek confluence that had sparse macrophyte growth; however the area below the previous outfall to the Welland River now has a relatively luxuriant growth of macrophytes; this outfall was sealed in 1985. Dickman and Haynes (Date unknown), also noted a similarly impacted zone downstream of the Atlas Steel outfall. This impacted area was not observed during the summer survey by Tarandus personnel. Several submerged aquatic macrophytes were also noted including *Myriophyllum spicatum*, *Vallisneria americana*, *Ceratophyllum demersum*, and *Heteranthera dubia* (Table 24).

Submerged macrophytes noted by Johnson (1964) included *Ceratophyllum demersum* and *Potamogeton spp.*. Dickman *et al.* (1983) found that the submerged aquatic macrophytes were dominated by *Elodea canadensis*, *Myriophyllum sp.*, *Potamogeton pectinatus*, and *Ceratophyllum sp.*.

Table 24: Species of submergent and emergent aquatic macrophytes found in the study area during the summer survey.

Common Name	Scientific Name	Abundance
Water Lily	*Nymaphaea variegatum*	Common
Cattail	*Typha latifolia*	Common
Eurasian Milfoil	*Myriophyllum spicatum*	Common
Smartweed	*Polygonum sp.*	Occasional
Wild Celery	*Vallisneria americana*	Common
Duckweed	*Lemna sp.*	Occasional
Bulrush	*Scirpus sp.*	Occasional
Arrowhead	*Sagittaria latifolia*	Common
Spiked Loosestrife	*Lythrum salicaria*	Occasional
Mud Plantain	*Heteranthera dubia*	Common
Pondweed	*Potamogeton crispus*	Rare
Pondweed	*Potamogeton richardsonii*	Rare
Coontail	*Ceratophyllum demersum*	Rare
Sedge	*Carex sp.*	Rare
Joe-Pie Weed	*Eupatorium maculatum*	Rare
Wild Rice	*Zizania aquatica*	Rare
Bushy Pondweed	*Najas flexilis*	Rare
Waterweed	*Elodea canadensis*	Rare

Flow Measurements

Water velocities and depth were determined at cross-sections of the river in sections A, B, and C. The flow calculations ranged from 19.24 m^3/s in section A to 37.12 m^3/s in section B, and are presented in Appendix X. The flow estimate for section C was 25.09 m^3/s. Welland River flow estimates cited in Acres (1990) ranged from 0 to 48 m^3/s.

The increased flows observed in section B are mainly the result of diversion of water from the old Welland Ship Canal to the Welland River. The amount of water diverted from the old ship canal has been estimated at 14.2 m^3/s (Acres 1990).

Flow in section C would normally be expected to be higher than that in section B because of added diversion of canal water at Port Robinson and inputs from natural sources. During the survey on November 9, 1990, however, the flow was found to be 25.09 m^3/s in this section, a significant drop from that noted the previous day in section B. This apparent reduction in flow may be the result of fluctuations of water flows in the Queenston-Chippawa Power Canal. Reductions in flow in this facility have been known to temporarily "back up" and/or reduce the flows in the lower sections of the Welland River (P. Odom, MOE, pers. com.).

Conclusions

Water Quality

1) Water quality parameters, including iron, copper and total phosphorus frequently exceeded the PWQOs. Mercury concentrations at stations 1 and 2 exceeded the PWQO for this metal. Between stations 1 to 5 there was a distinct and progressive decrease in mercury levels in water. The elevated concentrations of mercury in the most upstream stations may originate in the reservoir located upstream of the study area.

2) Most other water-quality parameters, including most metals, phenolics, total cyanide, PCBs, PAHs, and organo-chlorine pesticides were generally below detection limits.

3) MOE monitoring data from several stations indicate that levels of zinc, copper, mercury, chromium, and lead in Welland River water appear to have decreased from 1979 to 1987. However, there has been a slight increase in the concentration of aluminum in the water from 1981 to 1987.

Sediment Quality

1) Concentrations of several parameters including lead, chromium, mercury, cadmium, zinc, iron, nickel, copper, arsenic, total kjeldahl nitrogen, total organic carbon, total phosphorus, and PCBs exceeded the PSQG Lowest Effect Level at some stations. Consistently, stations 9, 10, 12, 18 and 19 had the most elevated concentrations of most of these parameters. Station 9 is situated at a major stormwater discharge, stations 10 and 12 are located in the vicinity of the Atlas Steel plant and the Welland WPCP respectively, and stations 18 and 19 are located downstream of the Cyanamid Canada plant. Severe Effect Levels (SELs) were also exceeded for chromium, iron, nickel and copper in the river from station 10 through at least station 19a. Mercury was only above the SEL at station 9; however, mercury concentrations in the fall sediment sample at station 11 were equal to the SEL. Levels of total cyanide and oil and grease also exceeded the OWDGs at some stations.

2) PAHs were also detected at several stations in the study area, with particularly high concentrations noted at station 9. With the exception of trace amounts of PP-DDE, which were detected at stations 6, 9 and 21, all organo-chlorine pesticides were below detection limits. The more highly chlorinated furans were detected at stations 9, 15 and 21. Concentrations of hexa- and hepta-chlorinated furans were highest at station 9. Sediments at station 21 had the highest concentration of octachloro-dibenzofuran. Although the more highly chlorinated dioxin and furan congeners such as octachlorinated forms are generally believed to be less of an environmental concern than are the tetrachlorinated isomers, the toxicity of these contaminants to aquatic biota is poorly understood at present.

3) Sediments in section D are relatively uncontaminated. The only water in this section is diverted from the Niagara River to the Queenston-Chippawa Power Canal.

4) Sediments located in the western portion of section A are characterized by high levels of total phosphorus, total kjeldahl nitrogen, and loss on ignition, probably due to the influence of agricultural activities.

Benthic Invertebrate Community and Environmental Quality

1) Stations in section A, located upstream of the City of Welland, were characterized by relatively high numbers of the pollution sensitive species *Hexagenia sp.* and *Coelotanyus sp.*. These taxa were generally absent from stations in downstream sections. Stations in sections B, C, and D were characterized by relatively high numbers of the more pollution tolerant taxa *Spirosperma ferox, Valvata sp.*, and Hydrobiidae, further substantiating the relatively poorer quality of the sediments.

2) The total abundance of benthic invertebrates varied throughout the study area, ranging from a low of 634 individuals per square meter at station 12 to a high of 5900 individuals per square meter at station 22. Generally, stations located in sections B, C, and D had higher total abundances than those found in section A, and in most cases were also characterized by large number of oligochaetes.

3) Benthic invertebrate diversity (Shannon-Weaver and Brillouin Indices) varied more in sections B, C, and D than in section A, where the indices were relatively constant. Almost all diversity indices were greater than 3, which suggests that the study area represents conditions that are relatively unpolluted.

4) Statistical analyses identified four separate benthic invertebrate communities, corresponding to the four sections of the study area. The structure of each community was governed by concentrations of certain sediment parameters. The benthic communities located in sections A, B, and C (Welland River) were distinguished by their association with sediments which had elevated concentrations of several metals (i.e. aluminum, chromium, copper, arsenic, zinc, lead, mercury) relative to those in section D (Chippawa Creek). . The benthic community of section A occurred in sediments with lower metal levels and higher loss on ignition (organic content) relative to the other two Welland River communities (sections B and C).

Fisheries

1) The fish community of the Welland River is dominated by warmwater fish species including catfish, white crappie, carp, suckers, and freshwater drum. No salmonid species were found, although they are common in the Niagara River. The fish community in section D was not sampled.

2) Higher numbers of fish were caught in hoop-net sets in section A than in sections B and C.

Aquatic Macrophytes

1) The Welland River shoreline is dominated by several emergent aquatic macrophytes, particularly *Typha latifolia* and *Sagittaria latifolia*. A number of submerged aquatic macrophytes were also noted including *Myriophyllum spicatum, Vallisneria americana, and Ceratophyllum demersum*. Sparse macrophyte growth was noted only below the Thompson's Creek confluence.

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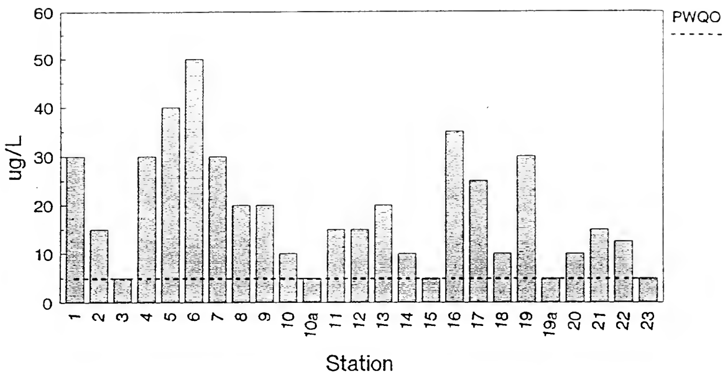
Appendix I

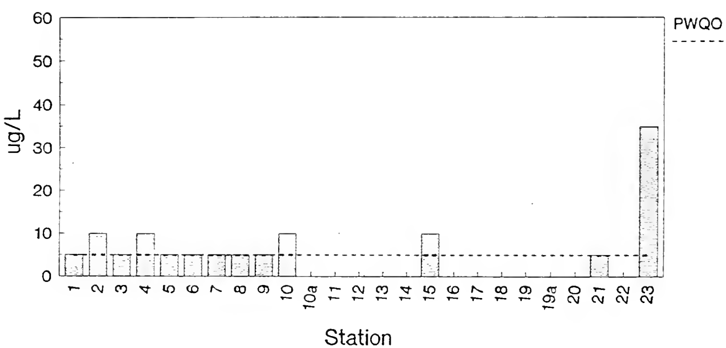
Water-Quality Graphics

Parameter concentrations at each station sampled are indicated with shaded bars for summer and fall sampling periods. Existing Provincial Water Quality Objectives (PWQOs) are indicated with horizontal lines.

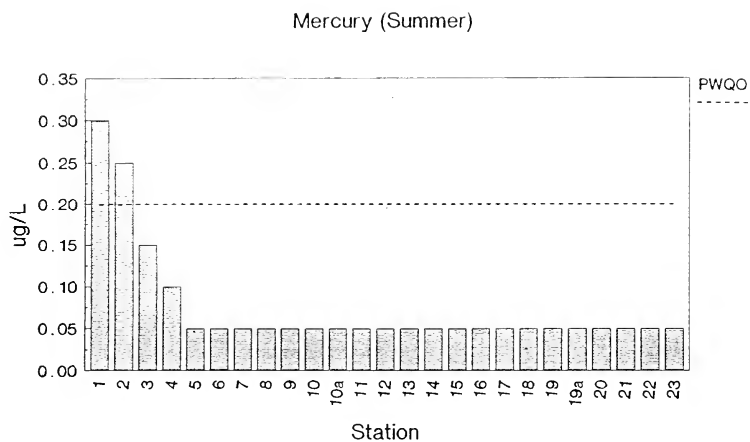
Copper (Summer)

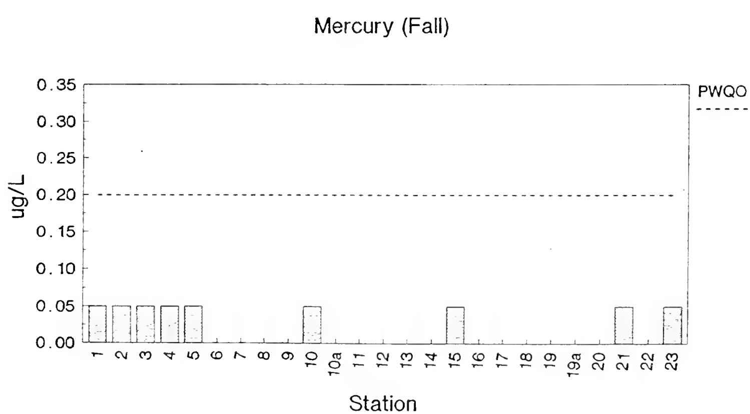


Copper (Fall)



Detection Limit = 5.0 ug/L
PWQO = 5.0 ug/L

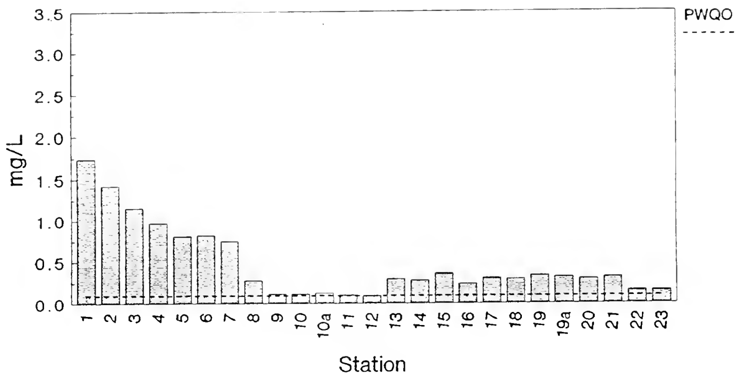




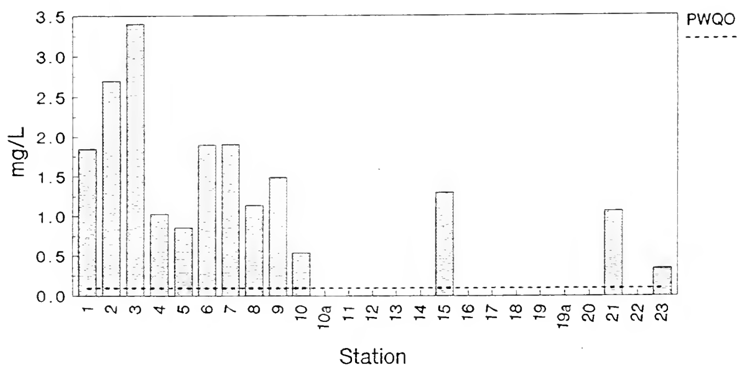
Detection Limit = 0.05 ug/L

PWQO = 0.2 ug/L

Aluminum (Summer)

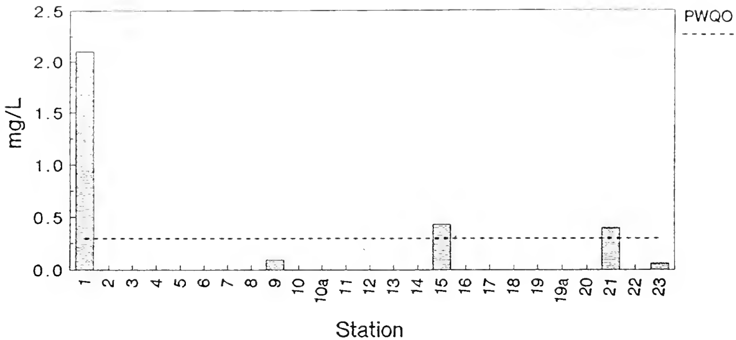


Aluminum (Fall)



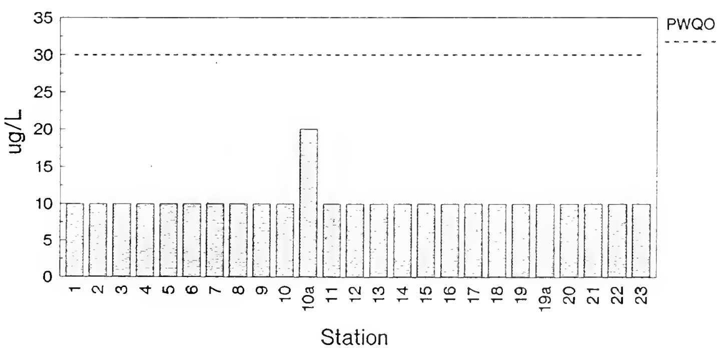
PWQO = 0.075 mg/L

Iron (Summer)



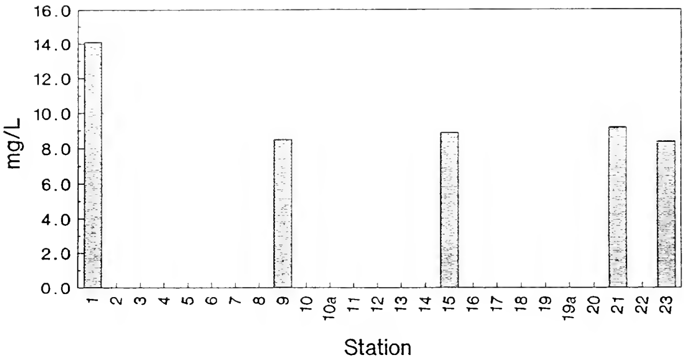
Detection Limit = 0.01 mg/L
PWQO = 0.3 mg/L

Zinc (Summer)



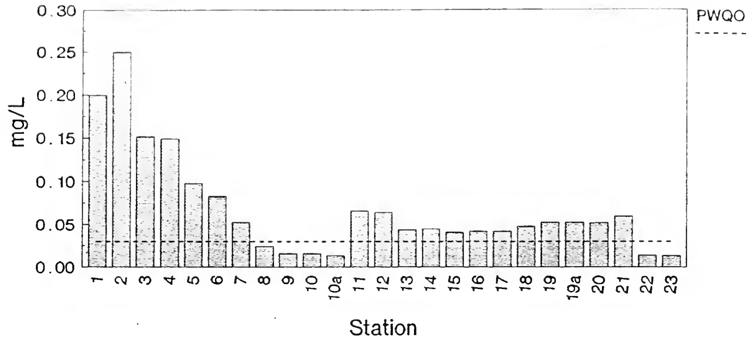
Detection Limit = 10 ug/L
PWQO = 30 ug/L

Magnesium (Summer)



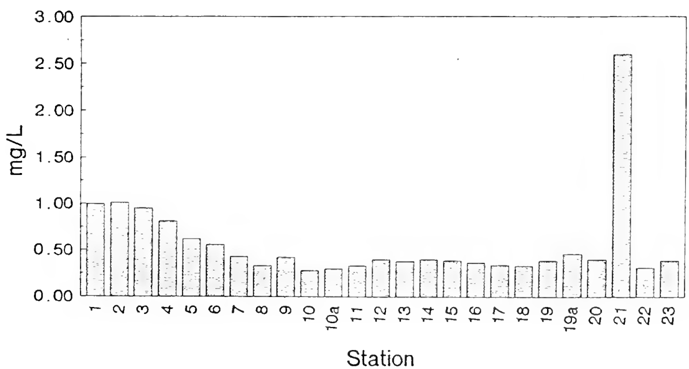
no PWQO available

Total Phosphorus (Summer)



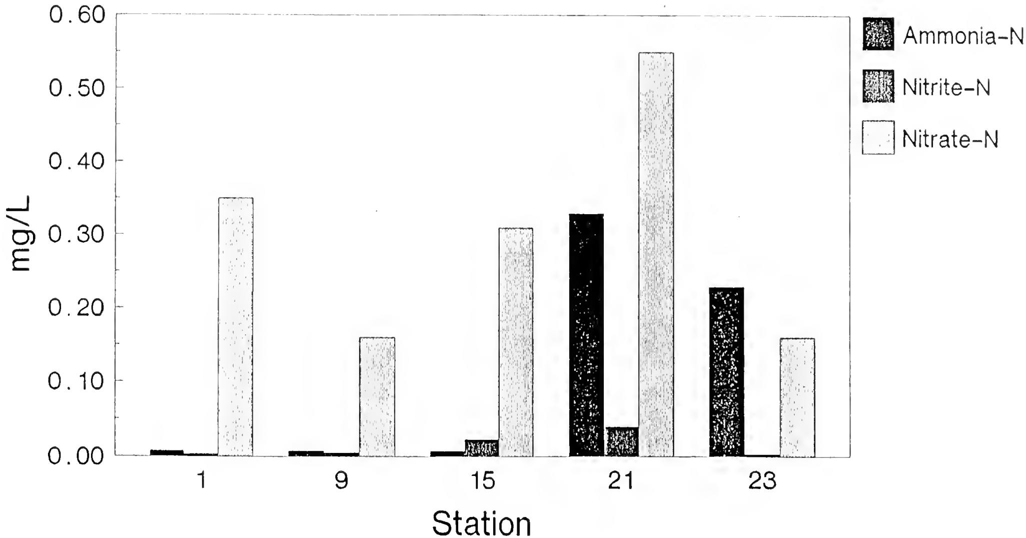
Detection limit = 0.0014
PWQO = 0.03 mg/L

Total Kjeldahl Nitrogen (Summer)



no PWQO available

Ammonia, Nitrite, and Nitrate Nitrogen (Summer)



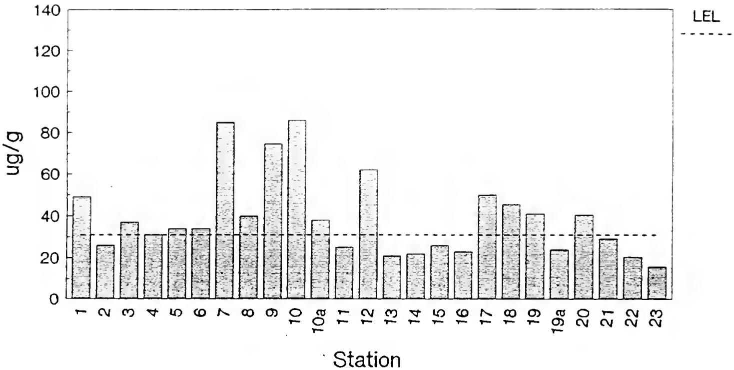
no PWQOs available

Appendix II

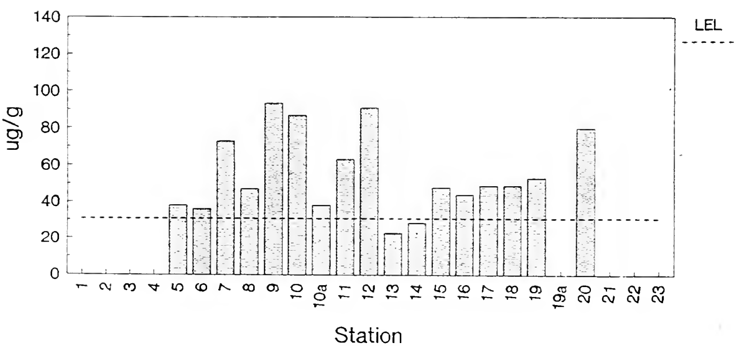
Sediment Quality Graphics

Parameter concentrations at each station sampled are indicated with shaded bars for summer and fall sampling periods. Provincial Sediment Quality Guideline lowest effect levels (LELs) are indicated with horizonal lines. Where concentrations approach or exceed severe effect levels (SELs), these levels are also graphed. Open Water Disposal Guidelines are indicated where Provincial Sediment Quality Guidelines are not available.

Lead (Summer)

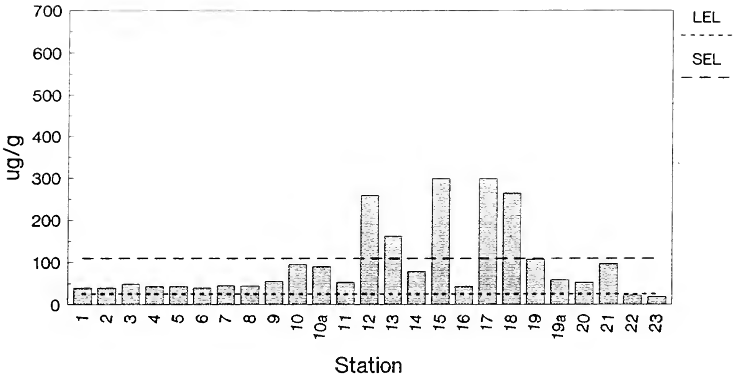


Lead (Fall)

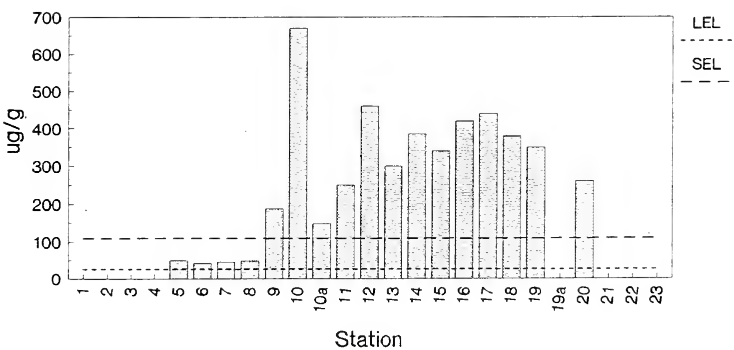


LEL = 31 ug/g
SEL = 250 ug/g

Chromium (Summer)

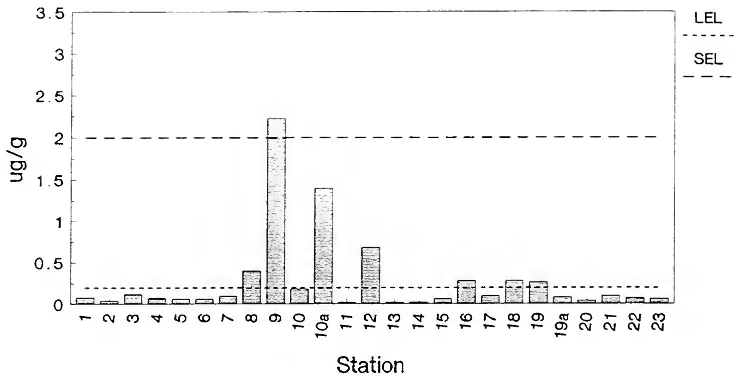


Chromium (Fall)

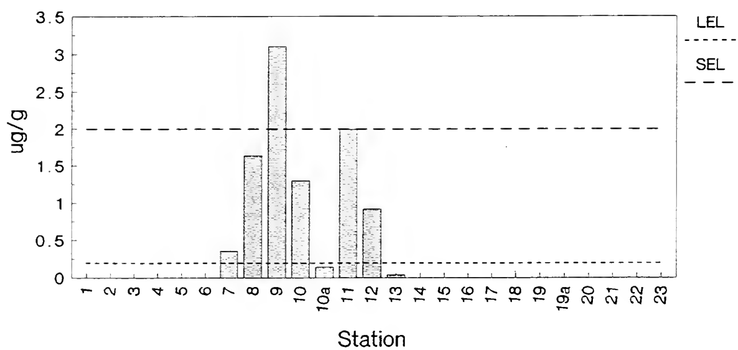


LEL = 26 ug/g
SEL = 110 ug/g

Mercury (Summer)

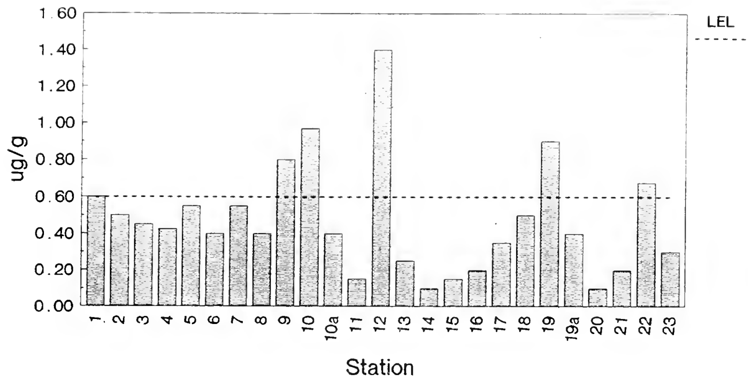


Mercury (Fall)

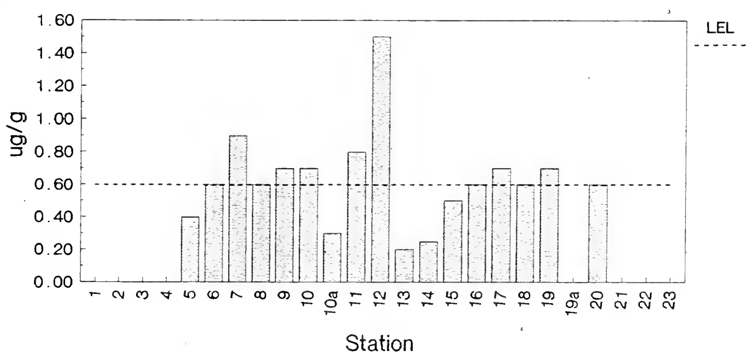


LEL = 0.2 ug/g
SEL = 2 ug/g

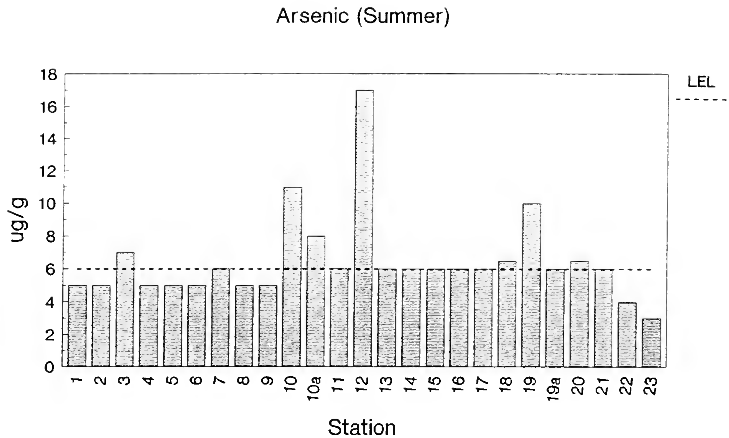
Cadmium (Summer)

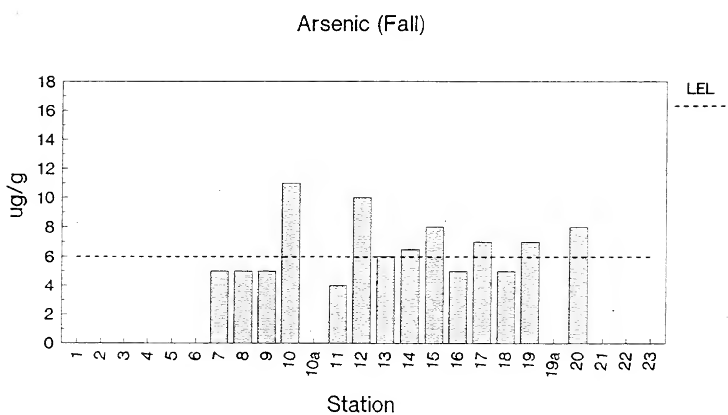


Cadmium (Fall)



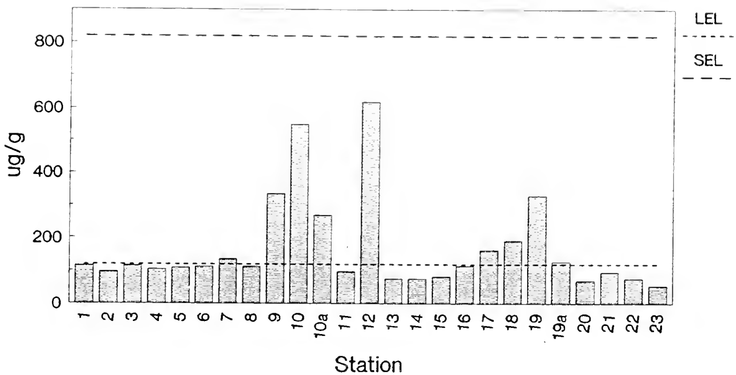
LEL = 0.6 ug/g
SEL = 10 ug/g



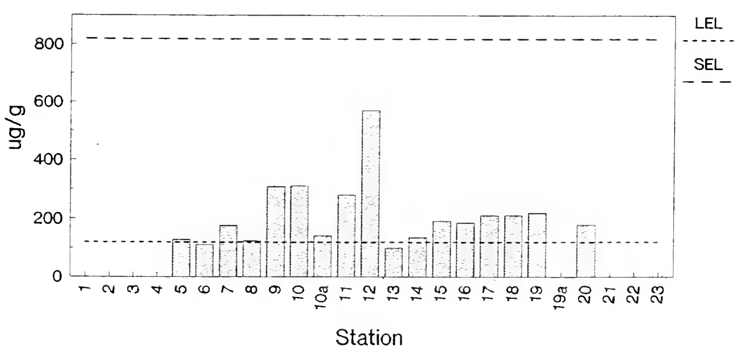


LEL = 6 ug/g
SEL = 33 ug/g

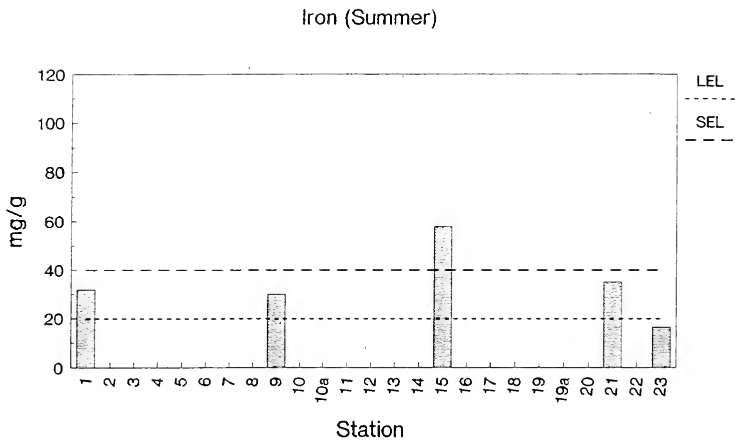
Zinc (Summer)

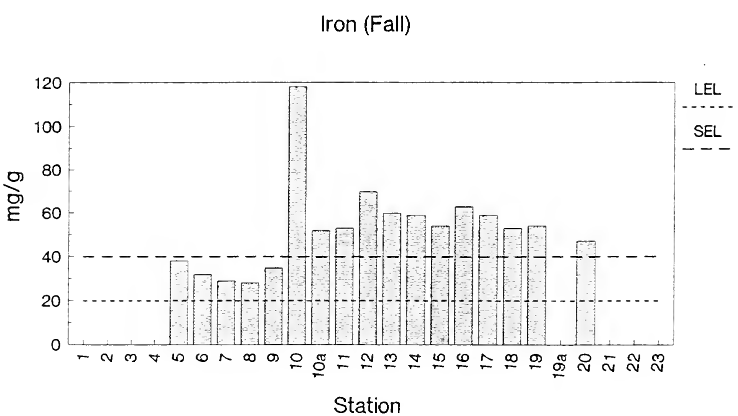


Zinc (Fall)



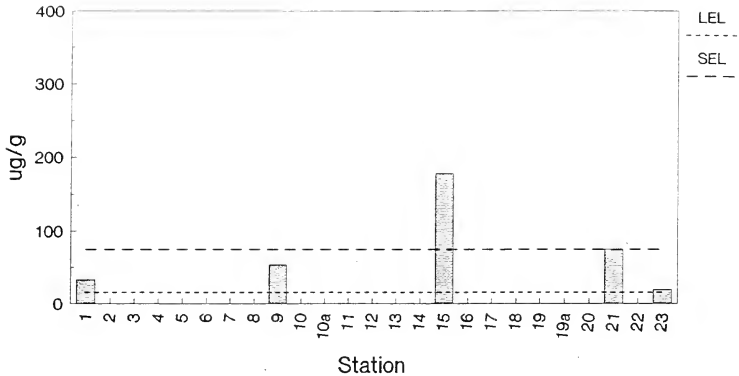
LEL = 120 ug/g
SEL = 820 ug/g



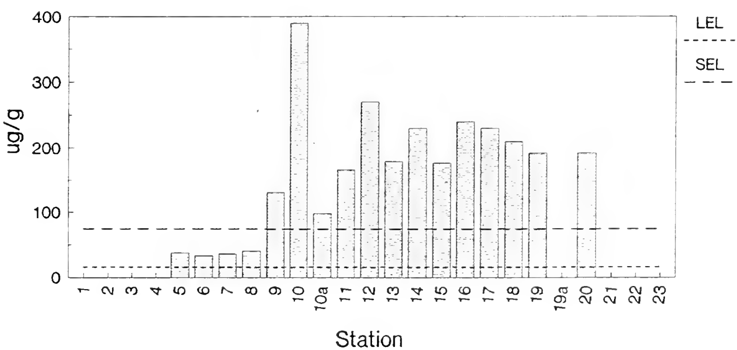


LEL = 2% (20 mg/g)
SEL = 4% (40 mg/g)

Nickel (Summer)

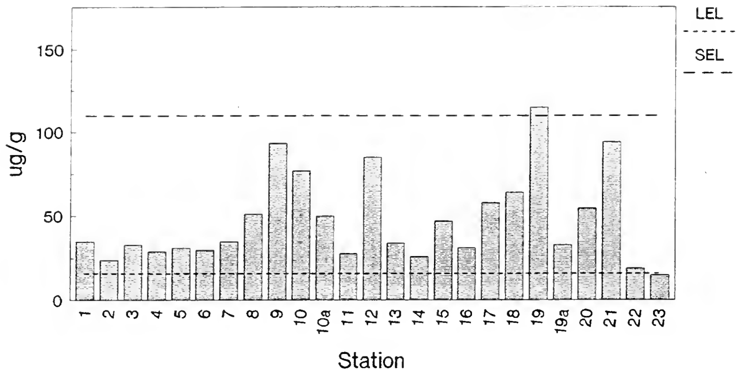


Nickel (Fall)

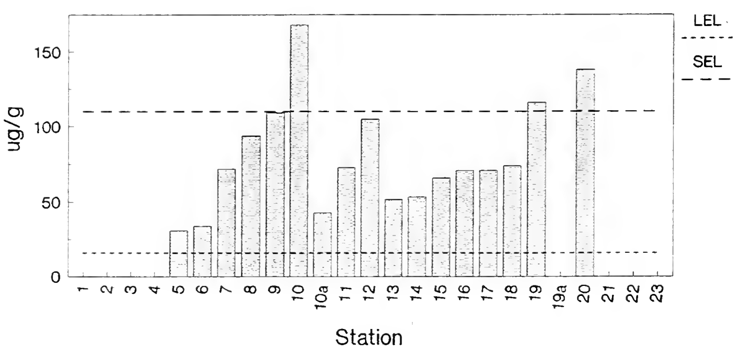


LEL = 16 ug/g
SEL = 75 ug/g

Copper (Summer)

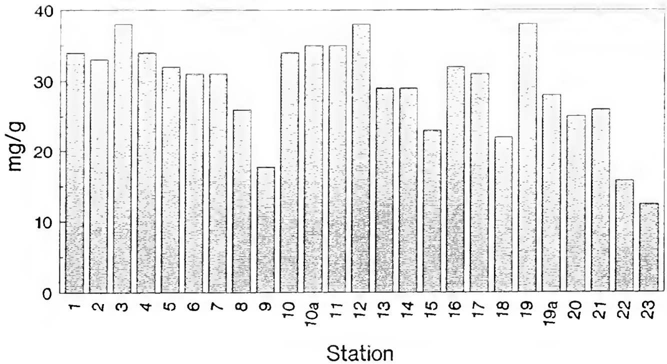


Copper (Fall)



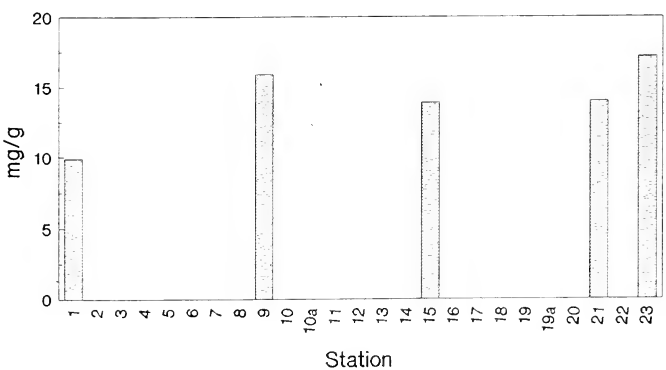
LEL = 16 ug/g
SEL = 110 ug/g

Aluminum (Summer)

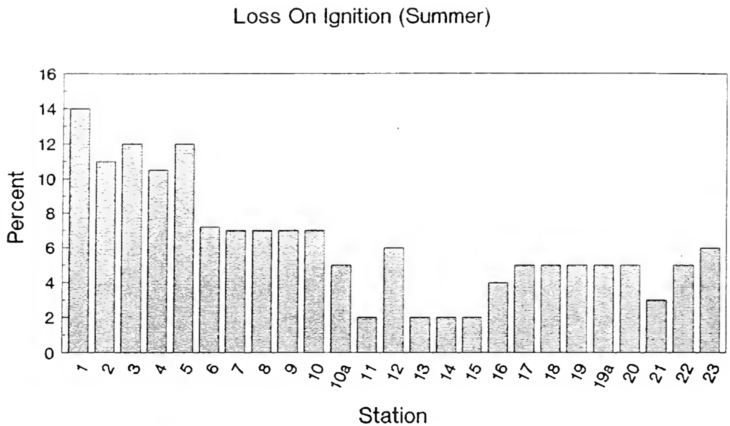


No LEL, SEL or OWDG available

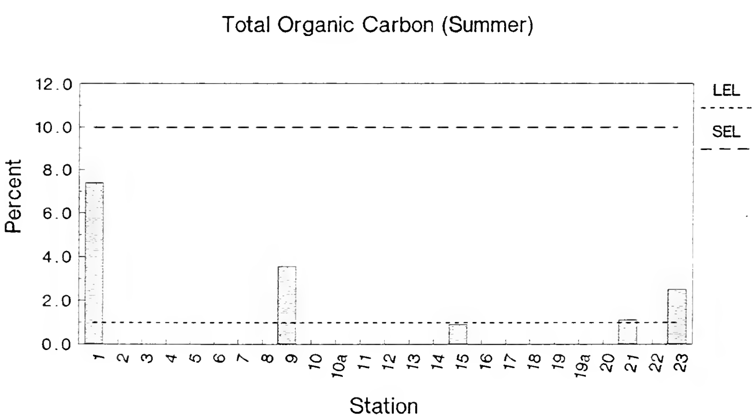
Magnesium (Summer)



No LEL, SEL or OWDG available

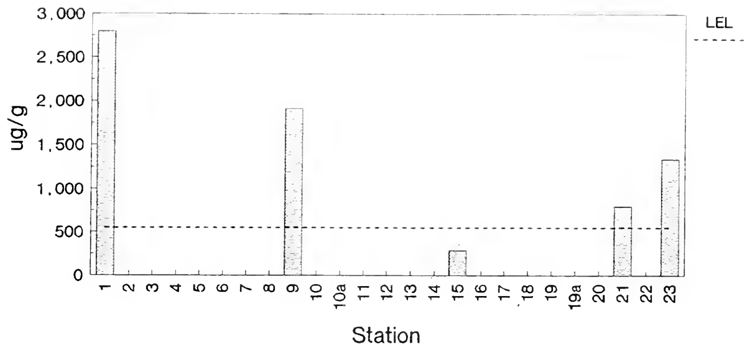


no LEL, SEL or OWDG available



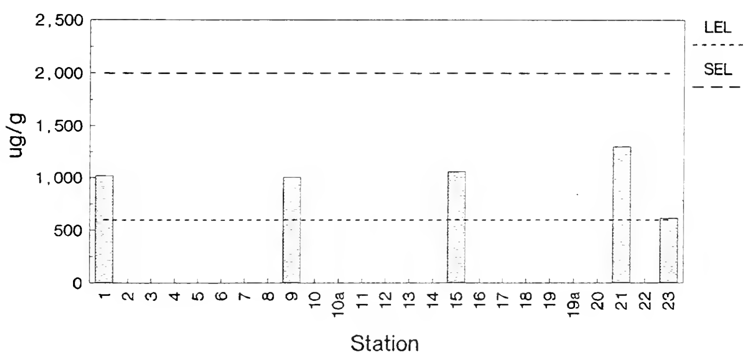
LEL = 1 percent
SEL = 10 percent

Total Kjeldahl Nitrogen (Summer)



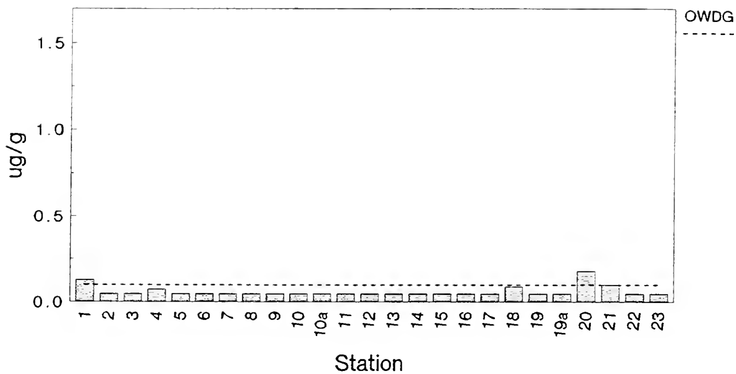
LEL = 550 ug/g
SEL = 4,800 ug/g

Total Phosphorus (Summer)

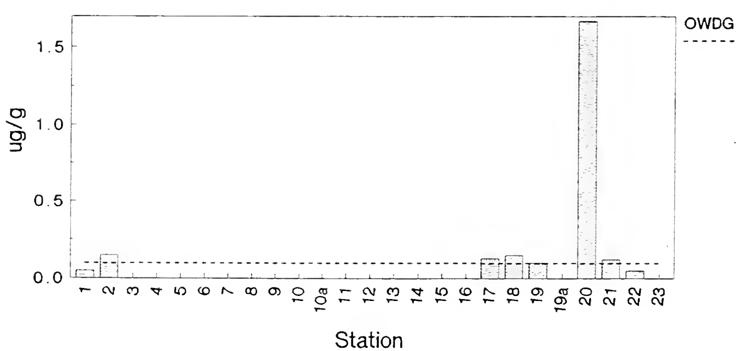


LEL = 600 ug/g
SEL = 2000 ug/g

Total Cyanide (Summer)

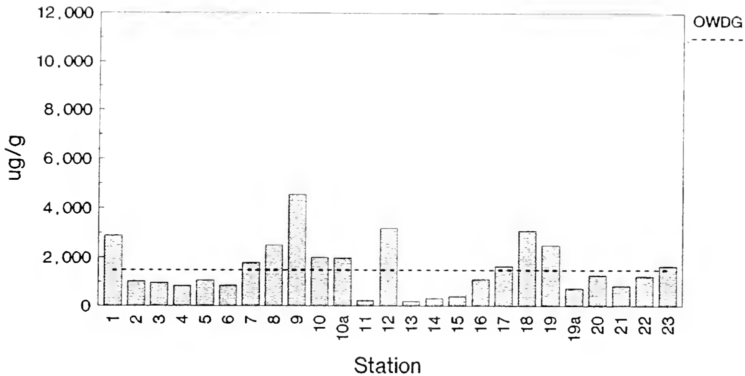


Total Cyanide (Fall)

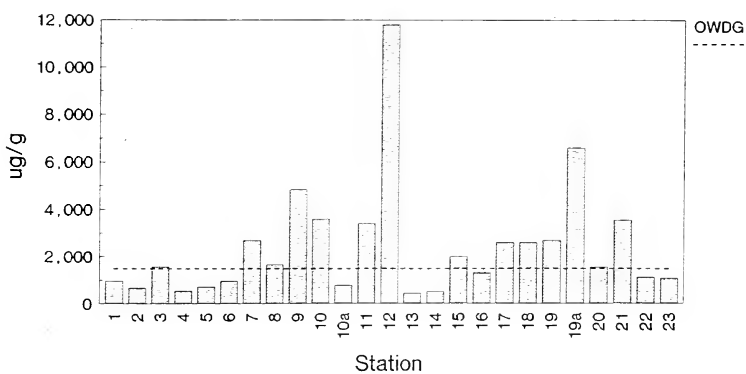


OWDG = 0.1 ug/g
Detection limit = 0.05 ug/g

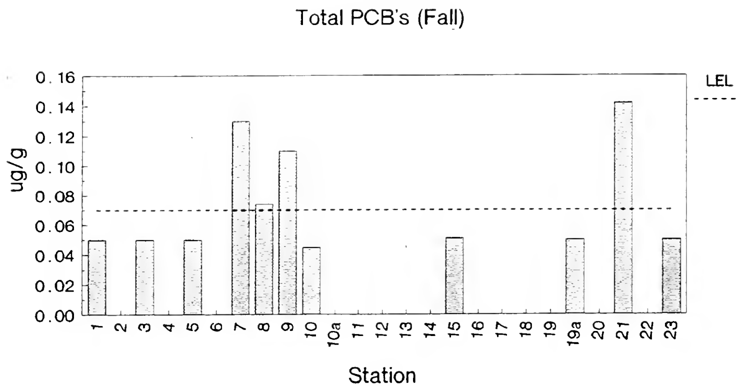
Oil and Grease (Summer)



Oil and Grease (Fall)



OWDG = 1,500 ug/g



LEL = 0.07 ug/g
SEL cannot be calculated
Detection limit = 0.05 ug/g

Appendix III

Field observations of conductivity, dissolved oxygen, and water temperature during the fall survey.

	November Survey Conductivity μmhos/cm		
Station	North	Center	South
1	N/A	N/A	N/A
2	N/A	N/A	N/A
3	N/A	N/A	N/A
4	540	540	550
5	510	530	530
6	500	500	500
7	500	500	505
8	540	500	500
9	450	400	400
10	425	430	425
10a	410	415	425
11	425	415	450
12	425	400	420
13	440	425	470
14	450	450	435
15	425	425	450
16	425	425	430
17	425	430	425
18	425	420	425
19	430	440	430
19a	450	450	450
20	475	450	450
21	450	450	450
22	310	315	360
23	340	325	325

	November Survey - Temperature and Dissolved Oxygen					
	North		Center		South	
Station	Temp °C	D.O. mg/L	Temp °C	D.O. mg/L	Temp °C	D.O. mg/L
1	7.2	10.8	7.2	10.5	7.9	10.3
2	7.5	10.2	7.8	10.0	7.5	10.2
3	7.5	10.2	7.9	10.1	7.7	10.1
4	6.9	8.6	7.0	8.4	7.0	8.4
5	7.0	9.4	7.2	9.1	7.1	9.1
6	6.8	9.6	6.5	9.6	6.7	9.5
7	6.2	9.4	6.4	9.4	7.1	9.7
8	6.5	9.8	6.5	9.5	6.5	9.6
9	7.5	8.8	8.0	8.7	8.0	9.1
10	8.0	9.6	8.7	9.4	8.5	9.3
10a	8.2	9.2	8.5	9.4	8.7	9.3
11	8.0	9.7	8.0	9.7	8.5	9.6
12	8.5	9.6	8.3	9.5	8.8	9.4
13	8.2	9.2	8.3	9.5	8.5	9.5
14	8.5	9.8	8.5	9.6	8.5	9.6
15	8.5	9.3	8.1	8.3	8.1	8.3
16	7.5	8.8	7.5	8.7	8.1	8.6
17	8.4	8.9	8.1	8.9	8.4	8.7
18	8.0	8.8	8.0	8.8	8.2	8.8
19	8.0	8.8	7.9	8.9	8.0	8.9
19a	7.9	8.9	7.9	8.9	7.9	8.9
20	8.9	8.7	8.2	8.7	8.1	8.7
21	8.1	8.9	8.1	8.8	8.2	8.8
22	8.0	9.8	6.0	8.8	4.5	7.9
23	9.0	10.0	9.1	10.0	9.0	9.9

Appendix IV

Benthic Invertebrate Species List

INSECTA:
DIPTERA
Chironomidae:
Chironominae:
Chironomini
Chironomus (Chaetolabis) sp.
Chironomus (Chironomus) sp.
Chironomus (C.) anthracinus group
Chironomus (C.) halophilus group
Chironomus (C.) plumosus group
Chironomus (C.) salinarius group
Chironomus (C.) staegeri group
Chironomus (C.) thummi group
Cladopelma sp.
Cryptochironomus sp.
Cryptotendipes sp.
Dicrotendipes sp.
Endochironomus sp.
Glyptotendipes (Glyptotendipes) sp
Microchironomus sp.
Parachironomous sp.
Paralauterborniella sp.
Polypedilum (Polydelium) sp.
Polypedilum (Tripodura) sp.
Pseudochironomus sp.
Rheotanytarsus sp.
Tanytarsus sp.

Tanypodinae:
Apsectrotanypus sp.
Coelotanypus sp.
Procladius sp.
Tanypus (Tanypus) sp.
Djalmabatista sp.
Macropelopia sp.

Orthocladinae:
Diplocladius sp.
Paracricotopus sp.

Ceratopogonidae:
- Bezzia sp.
- Culicoides sp.
- Mallochohelis sp.

Chaoboridae:
- Chaoborus sp.

EPHEMEROPTERA:

Ephemeridae:
- Hexagenia sp.

Caenidae:
- Caenis sp.

COLEOPTERA:

Elmidae:
- Dubiraphia sp.

Dytiseidae:
- Coptotomus sp.

MEGALOPTERA

Sialidae:
- Sialis sp.

LEPTIDOPTERA

Pyralidae:

TRICOPTERA

Polycentropodidae:
- Polycentropus sp.
- Cyrnellus sp.

Hydropsychidae:
- Cheumatopsyche sp.

Hydroptilidae:
- Hydroptila sp.

Leptoceridae:
- Oecetis sp.

ODONATA

Coenagrionidae:
- Enallagma sp.

OLIGOCHAETA:

Tubificidae:

- Limnodrilus hoffmeisteri
- L. profundicola
- L. angustipennis
- L. claparedianus
- L. sp.
- Spirosperma ferox
- Quistadrilus multisetosus
- Aulodrilus sp.
- Tubificidae immature

Naididae

- Pristinella sp.
- P. sima
- P. osborni
- P. jenkinae
- Pristina ? sp.
- Nadidae

Lumbriculidae

NEMATODA:

PLANARIA:

HIRUDINEA:

HYDRACHNIDIA:

CRUSTACEA:

Amphipoda

- Gammarus sp.
- Hyalella sp.

Isopoda

- Caecidotea sp.

MOLLUSCA:

GASTROPODA

Valvatidae

- Valvata sp.
- V. tricarinata
- V. sincera

Hydrobiidae

- Hydrobiidae

Bithyniidae

Bithynia tentaculata

Lymnaeidae

Physa sp.

Stagnicola sp.

Fossaria sp.

Planorbidae

Gyralus sp.

Helisoma anceps

BIVALVA

Sphaeriidae

Sphaerium sp.

Musculium sp.

Psidium sp.

Corbiculidae

Corbicula sp

Unionidae

Quadrula quadrula

Ligumia sp.

Ligumia nasuta

Dressenidae

Dreissena polymorpha

Appendix V

Benthic Invertebrate Species Counts

	Station											
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini		4			3							
Chironomus (Chaetolabis) sp.				16		10		2				
Chironomus (Chironomus) sp.												
Chironomus (C.) anthracinus group						2						
Chironomus (C.) halophilus group										4		
Chironomus (C.) plumosus group			4									
Chironomus (C.) salinarius group										1		
Chironomus (C.) staegeri group									20			6
Chironomus (C.) thummi group												
Cladopelma sp.												
Cryptochironomus sp.	2		6	8			4		5		1	4
Cryptotendipes sp.												
Dicrotendipes sp.												
Endochironomus sp.						2						
Glyptotendipes (Glyptotendipes) sp	10											
Microchironomus sp.												
Parachironomous sp.												
Paralauterborniella sp.												
Polypedilum (Polydelium) sp.				4								
Polypedilum (Tripodura) sp.	14											
Pseudochironomus sp.												
Rheotanytarsus sp.									5			
Tanytarsus sp.	4											
Tanypodinae:												
Apsectrotanypus sp.					12		6	4		3	5	4
Coelotanypus sp.		44	6	4	6	8	8	8	5	4	7	2
Procladius sp.	6	16	10	8	3	14	4	6	10	9	6	2
Tanypus (Tanypus) sp.		20			21		6	8	5		3	
Djalmabatista sp.												
Macropelopia sp.												
Orthocladinae:												
Diplocladius sp.												
Paracricotopus sp.							4					
Ceratopogonidae:												
Bezzia sp.		1			2	1		2			2	
Culicoides sp.												
Mallochohelis sp.												
Chaoboridae:												
Chaoborus sp.											3	
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.	1	7	4		7	5	26	7	2	7	9	11
Caenidae:												
Caenis sp.												

	Station											
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.	5		1		1				1			
Dytiseidae:												
Coptotomus sp.							1					
MEGALOPTERA												
Sialidae:												
Sialis sp.												
LEPTIDOPTERA												
Pyralidae:												
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.												
Cyrnellus sp.												
Hydropsychidae:												
Cheumatopsyche sp.												
Hydroptilidae:												
Hydroptila sp.												
Leptoceridae:												
Oecetis sp.	1						1		1			
ODONATA												
Coenagrionidae												
Enallagma sp.												
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri	5	1	1	4	13	4	5	2	3	3	9	3
L. profundicola												
L. angustipennis												
L. claparedianus												
L. sp.				1		1						
Spirosperma ferox												
Quistadrilus multisetosus										1		
Aulodrilus sp.												
Tubificidae immature	12	11	4	17	31	3	14	17	6	8	26	5
NADIDAE												
Pristinella sp.												
P. sima												
P. osborni												
P. jenkinae												
Pristina ? sp.												
Nadidae						1						1
LUMBRICULIDAE												
Nematoda:			1						1			
Planaria:												
Hirudinea:												
Hydrachnidia												

	Station											
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
Crustacea:												
AMPHIPODA												
Gammarus sp.				1						3		
Hyalella sp.												
PODOCOPA							1		3			
ISOPODA												
Caecidotea sp.			1	1								
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.												
V. tricarinata												
V. sincera												
Hydrobiidae												
Hydrobiidae												
Bithyniidae												
Bithynia tentaculata												
Lymnaeidae												
Physa sp.												
Stagnicola sp.												
Fossaria sp.												
Planorbidae												
Gyralus sp.												2
Helisoma anceps												
BIVALVA												
Sphaeriidae												
Sphaerium sp.	4		2	3			6		3	12	2	2
Musculium sp.											1	
Psidium sp.												
Corbiculidae												
Corbicula sp												
Unionidae												
Quadrula quadrula												
Ligumia sp.												
Ligumia nasuta												
Dressenidae												
Dreissena polymorpha												

	Station											
	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini									1		4	2
Chironomus (Chaetolabis) sp.												
Chironomus (Chironomus) sp.										4	6	5
Chironomus (C.) anthracinus group												
Chironomus (C.) halophilus group												
Chironomus (C.) plumosus group												
Chironomus (C.) salinarius group			9				4					
Chironomus (C.) staegeri group												
Chironomus (C.) thummi group										16	1	
Cladopelma sp.										8		
Cryptochironomus sp.	1	1		10			4	6	4		5	3
Cryptotendipes sp.			6									
Dicrotendipes sp.									1			
Endochironomus sp.												
Glyptotendipes (Glyptotendipes) sp.			3									
Microchironomus sp.							2					
Parachironomous sp.										4		
Paralauterborniella sp.												
Polypedilum (Polydelium) sp.									1	8		
Polypedilum (Tripodura) sp.												
Pseudochironomus sp.							2					
Rheotanytarsus sp.									1			
Tanytarsus sp.			6								1	
Tanypodinae:												
Apsectrotanypus sp.		6				2	6	8				
Coelotanypus sp.		4		4	5	4	6		2			1
Procladius sp.		1	18	10	7	2	6	4	11	12	5	3
Tanypus (Tanypus) sp.		5										
Djalmabatista sp.												
Macropelopia sp.												
Orthocladinae:												
Diplocladius sp.												
Paracricotopus sp.								2				
Ceratopogonidae:												
Bezzia sp.		4										
Culicoides sp.				1								
Mallochohelis sp.												
Chaoboridae:												
Chaoborus sp.				1	1							1
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.	10	9				4	12		4			
Caenidae:												
Caenis sp.							1					

	Station											
	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.	1			5					2	2		
Dytiseidae:												
Coptotomus sp.												
MEGALOPTERA												
Sialidae:												
Sialis sp.												
LEPTIDOPTERA												
Pyralidae:												
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.										1		
Cyrnellus sp.												
Hydropsychidae:												
Cheumatopsyche sp.												
Hydroptilidae:												
Hydroptila sp.												
Leptoceridae:												
Oecetis sp.	1											
ODONATA												
Coenagrionidae												
Enallagma sp.												
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri		23		11	9		5	8	3	13	9	5
L. profundicola												2
L. angustipennis												
L. claparedianus												
L. sp.		7										
Spirosperma ferox												
Quistadrilus multisetosus												
Aulodrilus sp.												
Tubificidae immature		63	19	13	7			28	41	13	23	8
NADIDAE												
Pristinella sp.												
P. sima			1									
P. osborni												
P. jenkinae												
Pristina ? sp.												
Nadidae												
LUMBRICULIDAE												
Nematoda:												
Planaria:												
Hirudinea:												
Hydrachnidia			1						1			

	Station											
	5A	5B	5C	6A	6B	6C	7A	7B	7C	8A	8B	8C
Crustacea:												
AMPHIPODA												
Gammarus sp.	2		1				1	1				
Hyalella sp.												
PODOCOPA	1			2								
ISOPODA												
Caecidotea sp.				2			1	1	1			1
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.												
V. tricarinata												
V. sincera												
Hydrobiidae												
Hydrobiidae		2										
Bithyniidae												
Bithynia tentaculata												
Lymnaeidae												
Physa sp.												
Stagnicola sp.												
Fossaria sp.												
Planorbidae												
Gyralus sp.												
Helisoma anceps												
BIVALVA												
Sphaeriidae												
Sphaerium sp.	3	1	13	2			2	3				
Musculium sp.												
Psidium sp.												
Corbiculidae												
Corbicula sp											1	
Unionidae												
Quadrula quadrula												
Ligumia sp.												
Ligumia nasuta												
Dressenidae												
Dreissena polymorpha												

	Station											
	9A	9B	9C	10A	10B	10C	11A	11B	11C	12A	12B	12C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini	2											
Chironomus (Chaetolabis) sp.												
Chironomus (Chironomus) sp.					6			10				
Chironomus (C.) anthracinus group		20							2			
Chironomus (C.) halophilus group												
Chironomus (C.) plumosus group												
Chironomus (C.) salinarius group		12	8			15	4		6			
Chironomus (C.) staegeri group												
Chironomus (C.) thummi group		12	14	14					2			
Cladopelma sp.												
Cryptochironomus sp.		8	4	6			6	10	4	1	5	
Cryptotendipes sp.												
Dicrotendipes sp.		8					4					
Endochironomus sp.												
Glyptotendipes (Glyptotendipes) sp.	1											
Microchironomus sp.												
Parachironomous sp.												
Paralauterborniella sp.												
Polypedilum (Polydelium) sp.						5						
Polypedilum (Tripodura) sp.												
Pseudochironomus sp.												
Rheotanytarsus sp.												
Tanytarsus sp.												
Tanypodinae:												
Apsectrotanypus sp.				2	1	5			6			
Coelotanypus sp.												
Procladius sp.	1		6	2	2	35	10	22	8			4
Tanypus (Tanypus) sp.									2			
Djalmabatista sp.												
Macropelopia sp.												
Orthocladinae:							6	4				
Diplocladius sp.						5						
Paracricotopus sp.			2			5			6	1		
Ceratopogonidae:												
Bezzia sp.						1						
Culicoides sp.												
Mallochohelis sp.												
Chaoboridae:												
Chaoborus sp.												
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.					1		1	2	1	1		
Caenidae:												
Caenis sp.												

	Station											
	9A	9B	9C	10A	10B	10C	11A	11B	11C	12A	12B	12C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.	1					1			1			
Dytiseidae:												
Coptotomus sp.												
MEGALOPTERA												
Sialidae:												
Sialis sp.							1	1				
LEPTIDOPTERA												
Pyralidae:	5					2						
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.												
Cyrnellus sp.												
Hydropsychidae:												
Cheumatopsyche sp.												
Hydroptilidae:												
Hydroptila sp.	1											
Leptoceridae:												
Oecetis sp.												
ODONATA												
Coenagrionidae												
Enallagma sp.						1						
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri	64	40	5			64				1		
L. profundicola	12				1							
L. angustipennis												
L. claparedianus												
L. sp.		2										
Spirosperma ferox		4	2	7	11	2			1	10	10	10
Quistadrilus multisetosus		4	1	1		6	1					1
Aulodrilus sp.												
Tubificidae immature	80	32	3	7	10	52	5			5	4	5
NADIDAE												
Pristinella sp.	4											
P. sima					1					1		
P. osborni												
P. jenkinae												1
Pristina ? sp.					2							
Nadidae												
LUMBRICULIDAE												
Nematoda:				1			12		2			
Planaria:												
Hirudinea:	6			4		10						
Hydrachnidia							1					

	Station											
	9A	9B	9C	10A	10B	10C	11A	11B	11C	12A	12B	12C
Crustacea:												
AMPHIPODA												
Gammarus sp.		1	6	1		2						
Hyalella sp.		1										
PODOCOPA						1						
ISOPODA												
Caecidotea sp.	27	9		1		2		1				
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.				1		3	3	1	16	2	7	3
V. tricarinata									3	1	9	3
V. sincera												
Hydrobiidae												
Hydrobiidae				10	1	4	5	4	18	1	3	
Bithyniidae												
Bithynia tentaculata												
Lymnaeidae												
Physa sp.												
Stagnicola sp.							1					
Fossaria sp.												
Planorbidae												
Gyralus sp.												
Helisoma anceps											1	
BIVALVA												
Sphaeriidae												
Sphaerium sp.	13	22	6		16	18	2	2	7			4
Musculium sp.												
Psidium sp.			1				3					
Corbiculidae												
Corbicula sp												
Unionidae											1	
Quadrula quadrula												
Ligumia sp.												
Ligumia nasuta												
Dressenidae												
Dreissena polymorpha	73	77	2		2	12	1		1			

	Station											
	13A	13B	13C	14A	14B	14C	15A	15B	15C	16A	16B	16C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini				1								
Chironomus (Chaetolabis) sp.												
Chironomus (Chironomus) sp.			3			2						2
Chironomus (C.) anthracinus group												
Chironomus (C.) halophilus group												
Chironomus (C.) plumosus group	2											
Chironomus (C.) salinarius group	2											
Chironomus (C.) staegeri group												
Chironomus (C.) thummi group	2		1									
Cladopelma sp.												2
Cryptochironomus sp.	14	1	2	2	9	14	2	8	2	3	1	4
Cryptotendipes sp.												
Dicrotendipes sp.												4
Endochironomus sp.									2			
Glyptotendipes (Glyptotendipes) sp.												
Microchironomus sp.												
Parachironomous sp.			2									
Paralauterborniella sp.												
Polypedilum (Polydelium) sp.												
Polypedilum (Tripodura) sp.												
Pseudochironomus sp.												
Rheotanytarsus sp.												
Tanytarsus sp.												
Tanypodinae:												
Apsectrotanypus sp.	2			1				2	2	1		2
Coelotanypus sp.												
Procladius sp.	4	2	5		5	8	26	13	22	3	2	22
Tanypus (Tanypus) sp.			1			2				2		4
Djalmabatista sp.												
Macropelopia sp.												
Orthocladinae:												
Diplocladius sp.												
Paracricotopus sp.												
Ceratopogonidae:												
Bezzia sp.												1
Culicoides sp.												
Mallochohelis sp.												
Chaoboridae:												
Chaoborus sp.								1				
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.							1	1				1
Caenidae:												
Caenis sp.									1			

	Station 13A	13B	13C	14A	14B	14C	15A	15B	15C	16A	16B	16C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.					1							
Dytiseidae:												
Coptotomus sp.												
MEGALOPTERA												
Sialidae:												
Sialis sp.												
LEPTIDOPTERA												
Pyralidae:												
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.									1			
Cyrnellus sp.									3			
Hydropsychidae:												
Cheumatopsyche sp.												
Hydroptilidae:												
Hydroptila sp.												
Leptoceridae:												
Oecetis sp.				1								
ODONATA												
Coenagrionidae												
Enallagma sp.												
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri	5				4	4	4		34			92
L. profundicola	1											
L. angustipennis												
L. claparedianus												
L. sp.												
Spirosperma ferox	3			3				1	6	1		
Quistadrilus multisetosus	6			3	2				2			16
Aulodrilus sp.												
Tubificidae immature	52	2	2	53	29	12	42	35	36	3		88
NADIDAE												
Pristinella sp.												
P. sima	5					2		1	8			8
P. osborni												
P. jenkinae				7		1						4
Pristina ? sp.					2							
Nadidae				2		1	1					
LUMBRICULIDAE												
Nematoda:			1			12						
Planaria:												
Hirudinea:								4	2			
Hydrachnidia												

	Station											
	13A	13B	13C	14A	14B	14C	15A	15B	15C	16A	16B	16C
Crustacea:												
AMPHIPODA												
Gammarus sp.									12			
Hyalella sp.												
PODOCOPA												
ISOPODA												
Caecidotea sp.	13					1			13			1
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.	6		31	7	2	14	20	16		13	13	2
V. tricarinata			6									
V. sincera												
Hydrobiidae												
Hydrobiidae			10	2		2	7	9		19	17	6
Bithyniidae												
Bithynia tentaculata												
Lymnaeidae												
Physa sp.												
Stagnicola sp.												
Fossaria sp.												
Planorbidae												
Gyralus sp.												
Helisoma anceps												
BIVALVA												
Sphaeriidae												
Sphaerium sp.			3			3	4		5	5		15
Musculium sp.				2								
Psidium sp.	6			1				3				
Corbiculidae												
Corbicula sp												
Unionidae												
Quadrula quadrula												
Ligumia sp.												
Ligumia nasuta									1			
Dressenidae												
Dreissena polymorpha								1				

	Station											
	17A	17B	17C	18A	18B	18C	19A	19B	19C	20A	20B	20C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini												
Chironomus (Chaetolabis) sp.												
Chironomus (Chironomus) sp.												
Chironomus (C.) anthracinus group			2			4						
Chironomus (C.) halophilus group												
Chironomus (C.) plumosus group												
Chironomus (C.) salinarius group												
Chironomus (C.) staegeri group												
Chironomus (C.) thummi group												
Cladopelma sp.			2									
Cryptochironomus sp.	2	4	10	6		2	1	3	4	1		
Cryptotendipes sp.												
Dicrotendipes sp.												
Endochironomus sp.												
Glyptotendipes (Glyptotendipes) sp.												
Microchironomus sp.												
Parachironomous sp.												
Paralauterborniella sp.												
Polypedilum (Polydelium) sp.												
Polypedilum (Tripodura) sp.												
Pseudochironomus sp.												
Rheotanytarsus sp.												
Tanytarsus sp.												
Tanypodinae:												
Apsectrotanypus sp.	1		6	2					6			
Coelotanypus sp.												
Procladius sp.	6	13	12	5	1	14	1	16	20		1	28
Tanypus (Tanypus) sp.		1	2	1		2			2			
Djalmabatista sp.												4
Macropelopia sp.						2						8
Orthocladinae:												
Diplocladius sp.												
Paracricotopus sp.												
Ceratopogonidae:												
Bezzia sp.								1				
Culicoides sp.	1		2									
Mallochohelis sp.												2
Chaoboridae:												
Chaoborus sp.												
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.								1	1			
Caenidae:												
Caenis sp.												

	Station											
	17A	17B	17C	18A	18B	18C	19A	19B	19C	20A	20B	20C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.							1	1				
Dytiseidae:												
Coptotomus sp.												
MEGALOPTERA												
Sialidae:												
Sialis sp.												
LEPTIDOPTERA												
Pyralidae:												
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.												
Cyrnellus sp.												
Hydropsychidae:												
Cheumatopsyche sp.												
Hydroptilidae:												
Hydroptila sp.												
Leptoceridae:												
Oecetis sp.												
ODONATA												
Coenagrionidae												
Enallagma sp.												
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri	2	1	3	30	3	13		4	50		1	10
L. profundicola						4		4				
L. angustipennis												
L. claparedianus												
L. sp.												
Spirosperma ferox			1									
Quistadrilus multisetosus		1		2		1		4	3			
Aulodrilus sp.						1						
Tubificidae immature	19	18	48	26	137	65	6	52	63			21
NADIDAE												
Pristinella sp.				2	3				3		7	2
P. sima												
P. osborni						2						
P. jenkinae			2			1						
Pristina ? sp.								4				
Nadidae			1			3		2				
LUMBRICULIDAE												
Nematoda:												
Planaria:												
Hirudinea:	1			2					2			
Hydrachnidia												

	Station											
	17A	17B	17C	18A	18B	18C	19A	19B	19C	20A	20B	20C
Crustacea:												
AMPHIPODA												
Gammarus sp.		2		2							1	2
Hyalella sp.												
PODOCOPA												
ISOPODA												
Caecidotea sp.	3											
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.	9	13	17		6	6	27		2		5	22
V. tricarinata					1	1						
V. sincera								10				
Hydrobiidae							63	13				
Hydrobiidae		22	21		34	9					19	20
Bithyniidae												
Bithynia tentaculata												
Lymnaeidae												
Physa sp.												3
Stagnicola sp.												
Fossaria sp.												
Planorbidae												
Gyralus sp.												
Helisoma anceps												
BIVALVA												
Sphaeriidae												
Sphaerium sp.		6	6	9	6	4	5	20	4	8	3	3
Musculium sp.												
Psidium sp.	2		2	3	2			1	2			
Corbiculidae												
Corbicula sp												
Unionidae				1								
Quadrula quadrula	1								2			
Ligumia sp.						1						
Ligumia nasuta												
Dressenidae												
Dreissena polymorpha	4						1					1

	Station											
	21A	21B	21C	22A	22B	22C	23A	23B	23C	24A	24B	24C
INSECTA:												
DIPTERA												
Chironomidae:												
Chironominae:												
Chironomini												
Chironomus (Chaetolabis) sp.												
Chironomus (Chironomus) sp.							14					
Chironomus (C.) anthracinus group												
Chironomus (C.) halophilus group												
Chironomus (C.) plumosus group												
Chironomus (C.) salinarius group											6	12
Chironomus (C.) staegeri group												
Chironomus (C.) thummi group												4
Cladopelma sp.												
Cryptochironomus sp.						10		1		2	1	
Cryptotendipes sp.						10						
Dicrotendipes sp.				24	20				2			
Endochironomus sp.				228	90	110	35					
Glyptotendipes (Glyptotendipes) sp.											2	
Microchironomus sp.												
Parachironomous sp.												
Paralauterborniella sp.				12								
Polypedilum (Polydelium) sp.			2		20	10	70					
Polypedilum (Tripodura) sp.												
Pseudochironomus sp.								1				
Rheotanytarsus sp.												
Tanytarsus sp.					10							
Tanypodinae:												
Apsectrotanypus sp.	2	1	2								2	12
Coelotanypus sp.	1											
Procladius sp.	1	7	12	36		40	21		2	4	2	4
Tanypus (Tanypus) sp.		1	2							2		
Djalmabatista sp.												
Macropelopia sp.												
Orthocladinae:											2	
Diplocladius sp.												
Paracricotopus sp.										12		8
Ceratopogonidae:												
Bezzia sp.	1											
Culicoides sp.		1										
Mallochohelis sp.												
Chaoboridae:												
Chaoborus sp.		1										
EPHEMEROPTERA:												
Ephemeridae:												
Hexagenia sp.					1					1		
Caenidae:												
Caenis sp.												

	Station											
	21A	21B	21C	22A	22B	22C	23A	23B	23C	24A	24B	24C
COLEOPTERA:												
Elmidae:												
Dubiraphia sp.					3		1			1	1	1
Dytiseidae:												
Coptotomus sp.												
MEGALOPTERA												
Sialidae:												
Sialis sp.												
LEPTIDOPTERA												
Pyralidae:					3				5			
TRICOPTERA												
Polycentropodidae:												
Polycentropus sp.												
Cyrnellus sp.												1
Hydropsychidae:												
Cheumatopsyche sp.								1				
Hydroptilidae:												
Hydroptila sp.												
Leptoceridae:												
Oecetis sp.												
ODONATA												
Coenagrionidae												
Enallagma sp.												
Oligochaeta:												
TUBIFICIDAE												
Limnodrilus hoffmeisteri	1	5	2	22		16			35	3	1	9
L. profundicola							1					
L. angustipennis						1						
L. claparedianus									3			
L. sp.				2								1
Spirosperma ferox	2			2	6			14			8	16
Quistadrilus multisetosus		1								4		1
Aulodrilus sp.							9					
Tubificidae immature	26	24	22	30	54	33	29	9	83	25	3	21
NADIDAE												
Pristinella sp.				2								
P. sima					4							
P. osborni		1										
P. jenkinae												
Pristina ? sp.												
Nadidae		1	1									
LUMBRICULIDAE								1				
Nematoda:												
Planaria:					2				1			
Hirudinea:	3	2	1	2	1	1	7			1		
Hydrachnidia												

	Station											
	21A	21B	21C	22A	22B	22C	23A	23B	23C	24A	24B	24C
Crustacea:												
AMPHIPODA												
Gammarus sp.				10	5		1		3	1		6
Hyalella sp.					1							
PODOCOPA												
ISOPODA												
Caecidotea sp.	1			1	1					4		5
DECAPODA												
Cambaridae												
Mollusca:												
GASTROPODA												
Valvatidae												
Valvata sp.	4	10						1		1	4	
V. tricarinata						2						
V. sincera												
Hydrobiidae												
Hydrobiidae	18	22		1		2		1		2	8	
Bithyniidae												
Bithynia tentaculata										1		
Lymnaeidae												
Physa sp.												
Stagnicola sp.												
Fossaria sp.								2				
Planorbidae												
Gyralus sp.												
Helisoma anceps												
BIVALVA												
Sphaeriidae												
Sphaerium sp.	10	34	7	14	1		6		1	30	8	26
Musculium sp.												
Psidium sp.		9		4		38						9
Corbiculidae												
Corbicula sp												7
Unionidae												
Quadrula quadrula												
Ligumia sp.												1
Ligumia nasuta												
Dressenidae												
Dreissena polymorpha								1		18		10

	Station 25A	25B	25C
INSECTA:			
DIPTERA			
Chironomidae:			
Chironominae:			
Chironomini			
Chironomus (Chaetolabis) sp.			
Chironomus (Chironomus) sp.			
Chironomus (C.) anthracinus group			
Chironomus (C.) halophilus group			
Chironomus (C.) plumosus group			
Chironomus (C.) salinarius group			
Chironomus (C.) staegeri group			
Chironomus (C.) thummi group			
Cladopelma sp.			
Cryptochironomus sp.	8		
Cryptotendipes sp.			
Dicrotendipes sp.			
Endochironomus sp.			
Glyptotendipes (Glyptotendipes) sp.			
Microchironomus sp.			
Parachironomous sp.			
Paralauterborniella sp.			
Polypedilum (Polydelium) sp.			
Polypedilum (Tripodura) sp.			
Pseudochironomus sp.			
Rheotanytarsus sp.			
Tanytarsus sp.			
Tanypodinae:			
Apsectrotanypus sp.		1	
Coelotanypus sp.			
Procladius sp.	4		2
Tanypus (Tanypus) sp.			
Djalmabatista sp.			
Macropelopia sp.			
Orthocladinae:			
Diplocladius sp.			
Paracricotopus sp.			
Ceratopogonidae:			
Bezzia sp.			
Culicoides sp.			
Mallochohelis sp.			
Chaoboridae:			
Chaoborus sp.			
EPHEMEROPTERA:			
Ephemeridae:			
Hexagenia sp.			
Caenidae:			
Caenis sp.			

	Station 25A	25B	25C
COLEOPTERA:			
Elmidae:			
Dubiraphia sp.			
Dytiseidae:			
Coptotomus sp.			
MEGALOPTERA			
Sialidae:			
Sialis sp.			
LEPTIDOPTERA			
Pyralidae:			
TRICOPTERA			
Polycentropodidae:			
Polycentropus sp.			
Cyrnellus sp.			
Hydropsychidae:			
Cheumatopsyche sp.			
Hydroptilidae:			
Hydroptila sp.			
Leptoceridae:			
Oecetis sp.			
ODONATA			
Coenagrionidae			
Enallagma sp.			
Oligochaeta:			
TUBIFICIDAE			
Limnodrilus hoffmeisteri	22		2
L. profundicola			
L. angustipennis			
L. claparedianus			
L. sp.			
Spirosperma ferox		1	
Quistadrilus multisetosus			
Aulodrilus sp.	12		
Tubificidae immature	34	23	12
NADIDAE			
Pristinella sp.			
P. sima			
P. osborni			
P. jenkinae			
Pristina ? sp.			
Nadidae			1
LUMBRICULIDAE			
Nematoda:			
Planaria:			
Hirudinea:	1		
Hydrachnidia			

	Station 25A	25B	25C
Crustacea:			
AMPHIPODA			
Gammarus sp.			
Hyalella sp.			
PODOCOPA			
ISOPODA			
Caecidotea sp.			
DECAPODA			
Cambaridae			
Mollusca:			
GASTROPODA			
Valvatidae			
Valvata sp.	1	4	3
V. tricarinata			
V. sincera			
Hydrobiidae			
Hydrobiidae		37	28
Bithyniidae			
Bithynia tentaculata			
Lymnaeidae			
Physa sp.			
Stagnicola sp.			
Fossaria sp.			
Planorbidae			
Gyralus sp.			
Helisoma anceps			
BIVALVA			
Sphaeriidae			
Sphaerium sp.	8	1	
Musculium sp.			
Psidium sp.			
Corbiculidae			
Corbicula sp			
Unionidae			
Quadrula quadrula			
Ligumia sp.			
Ligumia nasuta			
Dressenidae			
Dreissena polymorpha			

Appendix VI

Benthic Invertebrate Species Abundances
(#/m^2)

	Station 1	2	3	4	5	6	7	8	9
INSECTA:									
DIPTERA									
Chironomidae:									
Chironominae:									
Chironomini	27	20					7	40	13
Chironomus (Chaetolabis) sp.		173	13						
Chironomus (Chironomus) sp.								100	
Chironomus (C.) anthracinus group		13							133
Chironomus (C.) halophilus group				27					
Chironomus (C.) plumosus group	27								
Chironomus (C.) salinarius group				7	60		27		133
Chironomus (C.) staegeri group			133	40					
Chironomus (C.) thummi group								113	173
Cladopelma sp.								53	
Cryptochironomus sp.	53	53	60	33	13	67	93	53	80
Cryptotendipes sp.					40				
Dicrotendipes sp.							7		53
Endochironomus sp.		13							
Glyptotendipes (Glyptotendipes) sp.	67				20				7
Microchironomus sp.							13		
Parachironomous sp.								27	
Paralauterborniella sp.									
Polypedilum (Polydelium) sp.		27					7	53	
Polypedilum (Tripodura) sp.	93								
Pseudochironomus sp.							13		
Rheotanytarsus sp.			33				7		
Tanytarsus sp.	27				40			7	
Tanypodinae:									
Apsectrotanypus sp.		80	67	80	40	13	93		
Coelotanypus sp.	333	120	140	87	27	87	53	7	
Procladius sp.	213	167	133	113	127	127	140	133	47
Tanypus (Tanypus) sp.	133	140	127	20	33				
Djalmabatista sp.									
Macropelopia sp.									
Orthocladinae:									
Diplocladius sp.									
Paracricotopus sp.			27				13		13
Ceratopogonidae:									
Bezzia sp.	7	20	13	13	27				
Culicoides sp.						7			
Mallochohelis sp.									
Chaoboridae:									
Chaoborus sp.				20		13		7	
EPHEMEROPTERA:									
Ephemeridae:									
Hexagenia sp.	80	80	233	180	127	27	107		
Caenidae:									
Caenis sp.							7		

	Station								
	1	2	3	4	5	6	7	8	9
COLEOPTERA:									
Elmidae:									
Dubiraphia sp.	40	7	7		7	33	13	13	7
Dytiseidae:									
Coptotomus sp.			7						
MEGALOPTERA									
Sialidae:									
Sialis sp.									
LEPTIDOPTERA									
Pyralidae:									33
TRICOPTERA									
Polycentropodidae:									
Polycentropus sp.								7	
Cyrnellus sp.									
Hydropsychidae:									
Cheumatopsyche sp.									
Hydroptilidae:									
Hydroptila sp.									7
Leptoceridae:									
Oecetis sp.	7		13		7				
ODONATA									
Coenagrionidae									
Enallagma sp.									
Oligochaeta:									
TUBIFICIDAE									
Limnodrilus hoffmeisteri	47	140	67	100	153	133	107	180	727
L. profundicola								13	80
L. angustipennis									
L. claparedianus									
L. sp.		13			47				13
Spirosperma ferox									40
Quistadrilus multisetosus				7					33
Aulodrilus sp.									
Tubificidae immature	180	340	247	260	547	133	460	293	767
NADIDAE									
Pristinella sp.									27
P. sima					7				
P. osborni									
P. jenkinae									
Pristina ? sp.									
Nadidae		7		7					
LUMBRICULIDAE									
Nematoda:	7		7						
Planaria:									
Hirudinea:									40
Hydrachnidia					7		7		

	Station								
	1	2	3	4	5	6	7	8	9
Crustacea:									
AMPHIPODA									
Gammarus sp.		7		20	20		13		47
Hyalella sp.									7
PODOCOPA			27		7	13			
ISOPODA									
Caecidotea sp.	7	7				13	20	7	240
DECAPODA									
Cambaridae									
Mollusca:									
GASTROPODA									
Valvatidae									
Valvata sp.									
V. tricarinata									
V. sincera									
Hydrobiidae									
Hydrobiidae					13				
Bithyniidae									
Bithynia tentaculata									
Lymnaeidae									
Physa sp.									
Stagnicola sp.									
Fossaria sp.									
Planorbidae									
Gyralus sp.				13					
Helisoma anceps									
BIVALVA									
Sphaeriidae									
Sphaerium sp.	40	20	60	107	113	13	33		273
Musculium sp.				7					
Psidium sp.									7
Corbiculidae									
Corbicula sp								7	
Unionidae									
Quadrula quadrula									
Ligumia sp.									
Ligumia nasuta									
Dressenidae									
Dreissena polymorpha									1013

	Station								
	10	10a	11	12	13	14	15	16	17
INSECTA:									
DIPTERA									
Chironomidae:									
Chironominae:									
Chironomini						7			
Chironomus (Chaetolabis) sp.									
Chironomus (Chironomus) sp.	40		67		20	13		13	
Chironomus (C.) anthracinus group			13						13
Chironomus (C.) halophilus group									
Chironomus (C.) plumosus group					13				
Chironomus (C.) salinarius group	100	120	67		13				
Chironomus (C.) staegeri group									
Chironomus (C.) thummi group	93	27	13		20				
Cladopelma sp.								13	13
Cryptochironomus sp.	40	20	133	40	113	167	80	53	107
Cryptotendipes sp.									
Dicrotendipes sp.			27					27	
Endochironomus sp.							13		
Glyptotendipes (Glyptotendipes) sp.		13							
Microchironomus sp.									
Parachironomous sp.					13				
Paralauterborniella sp.									
Polypedilum (Polydelium) sp.	33								
Polypedilum (Tripodura) sp.									
Pseudochironomus sp.									
Rheotanytarsus sp.									
Tanytarsus sp.									
Tanypodinae:									
Apsectrotanypus sp.	53	93	40		13	7	27	20	47
Coelotanypus sp.									
Procladius sp.	260	67	267	27	73	87	407	180	207
Tanypus (Tanypus) sp.		13	13		7	13		40	20
Djalmabatista sp.									
Macropelopia sp.									
Orthocladinae:		13	67						
Diplocladius sp.	33								
Paracricotopus sp.	33	133	40	7					
Ceratopogonidae:									
Bezzia sp.	7							7	
Culicoides sp.									20
Mallochohelis sp.									
Chaoboridae:									
Chaoborus sp.							7		
EPHEMEROPTERA:									
Ephemeridae:									
Hexagenia sp.	7	7	27	7			13	7	
Caenidae:									
Caenis sp.							7		

	Station								
	10	10a	11	12	13	14	15	16	17
COLEOPTERA:									
Elmidae:									
Dubiraphia sp.	7	20	7			7			
Dytiseidae:									
Coptotomus sp.									
MEGALOPTERA									
Sialidae:									
Sialis sp.			13						
LEPTIDOPTERA									
Pyralidae:	13								
TRICOPTERA									
Polycentropodidae:									
Polycentropus sp.							7		
Cyrnellus sp.		7					20		
Hydropsychidae:									
Cheumatopsyche sp.									
Hydroptilidae:									
Hydroptila sp.									
Leptoceridae:									
Oecetis sp.						7			
ODONATA									
Coenagrionidae									
Enallagma sp.	7								
Oligochaeta:									
TUBIFICIDAE									
Limnodrilus hoffmeisteri	427	87		7	33	53	253	613	40
L. profundicola	7				7				
L. angustipennis									
L. claparedianus									
L. sp.		7							
Spirosperma ferox	133	160	7	200	20	20	47	7	7
Quistadrilus multisetosus	47	33	7	7	40	33	13	107	7
Aulodrilus sp.									
Tubificidae immature	460	327	33	93	373	627	753	607	567
NADIDAE									
Pristinella sp.									
P. sima	7			7	33	13	60	53	
P. osborni									
P. jenkinae				7		53		27	13
Pristina ? sp.	13					13			
Nadidae						20	7		7
LUMBRICULIDAE									
Nematoda:	7		93		7	80			
Planaria:									
Hirudinea:	93	7					40		7
Hydrachnidia			7						

	Station								
	10	10a	11	12	13	14	15	16	17
Crustacea:									
AMPHIPODA									
Gammarus sp.	20	47					80		13
Hyalella sp.									
PODOCOPA	7								
ISOPODA									
Caecidotea sp.	20	60	7		87	7	87	7	20
DECAPODA									
Cambaridae									
Mollusca:									
GASTROPODA									
Valvatidae									
Valvata sp.	27	33	133	80	247	153	240	187	260
V. tricarinata			20	87	40				
V. sincera									
Hydrobiidae									
Hydrobiidae	100	67	180	27	67	27	107	280	287
Bithyniidae									
Bithynia tentaculata		7							
Lymnaeidae									
Physa sp.									
Stagnicola sp.			7						
Fossaria sp.									
Planorbidae									
Gyralus sp.									
Helisoma anceps				7					
BIVALVA									
Sphaeriidae									
Sphaerium sp.	227	427	73	27	20	20	60	133	80
Musculium sp.						13			
Psidium sp.		60	20		40	7	20		27
Corbiculidae									
Corbicula sp		47							
Unionidae				7					
Quadrula quadrula									7
Ligumia sp.		7							
Ligumia nasuta							7		
Dressenidae									
Dreissena polymorpha	93	187	13				7		27

	Station						
	18	19	19a	20	21	22	23
INSECTA:							
DIPTERA							
Chironomidae:							
Chironominae:							
Chironomini							
Chironomus (Chaetolabis) sp.							
Chironomus (Chironomus) sp.							93
Chironomus (C.) anthracinus group	27						
Chironomus (C.) halophilus group							
Chironomus (C.) plumosus group							
Chironomus (C.) salinarius group							
Chironomus (C.) staegeri group							
Chironomus (C.) thummi group							
Cladopelma sp.							
Cryptochironomus sp.	53	53	53	7		67	7
Cryptotendipes sp.						67	
Dicrotendipes sp.						293	13
Endochironomus sp.						2853	233
Glyptotendipes (Glyptotendipes) sp.							
Microchironomus sp.							
Parachironomous sp.							
Paralauterborniella sp.						80	
Polypedilum (Polydelium) sp.					13	200	467
Polypedilum (Tripodura) sp.							
Pseudochironomus sp.							7
Rheotanytarsus sp.							
Tanytarsus sp.						67	
Tanypodinae:							
Apsectrotanypus sp.	13	40	7		33		
Coelotanypus sp.					7		
Procladius sp.	133	247	40	193	133	507	153
Tanypus (Tanypus) sp.	20	13			20		
Djalmabatista sp.				27			
Macropelopia sp.	13			53			
Orthocladinae:							
Diplocladius sp.							
Paracricotopus sp.							
Ceratopogonidae:							
Bezzia sp.		7			7		
Culicoides sp.					7		
Mallochohelis sp.				13			
Chaoboridae:							
Chaoborus sp.					7		
EPHEMEROPTERA:							
Ephemeridae:							
Hexagenia sp.		13				7	
Caenidae:							
Caenis sp.							

	Station 18	19	19a	20	21	22	23
COLEOPTERA:							
Elmidae:							
Dubiraphia sp.		13				20	7
Dytiseidae:							
Coptotomus sp.							
MEGALOPTERA							
Sialidae:							
Sialis sp.							
LEPTIDOPTERA							
Pyralidae:						20	33
TRICOPTERA							
Polycentropodidae:							
Polycentropus sp.							
Cyrnellus sp.							
Hydropsychidae:							
Cheumatopsyche sp.							7
Hydroptilidae:							
Hydroptila sp.							
Leptoceridae:							
Oecetis sp.							
ODONATA							
Coenagrionidae							
Enallagma sp.							
Oligochaeta:							
TUBIFICIDAE							
Limnodrilus hoffmeisteri	307	360	160	73	53	253	233
L. profundicola	27	27					7
L. angustipennis						7	
L. claparedianus							20
L. sp.						13	
Spirosperma ferox			7		13	53	93
Quistadrilus multisetosus	20	47			7		
Aulodrilus sp.	7		80				60
Tubificidae immature	1520	807	460	140	480	780	807
NADIDAE							
Pristinella sp.	33	20		60		13	
P. sima						27	
P. osborni	13				7		
P. jenkinae	7						
Pristina ? sp.		27					
Nadidae	20	13	7		13		
LUMBRICULIDAE							7
Nematoda:							
Planaria:						13	7
Hirudinea:	13	13	7		40	27	47
Hydrachnidia							

	Station						
	18	19	19a	20	21	22	23
Crustacea:							
AMPHIPODA							
Gammarus sp.	13			20		100	27
Hyalella sp.						7	
PODOCOPA							
ISOPODA							
Caecidotea sp.					7	13	
DECAPODA							
Cambaridae							
Mollusca:							
GASTROPODA							
Valvatidae							
Valvata sp.	80	193	53	180	93		7
V. tricarinata	13					13	
V. sincera		67					
Hydrobiidae		507					
Hydrobiidae	287		433	260	267	20	7
Bithyniidae							
Bithynia tentaculata							
Lymnaeidae							
Physa sp.				20			
Stagnicola sp.							
Fossaria sp.							13
Planorbidae							
Gyralus sp.							
Helisoma anceps							
BIVALVA							
Sphaeriidae							
Sphaerium sp.	127	193	60	93	340	100	47
Musculium sp.							
Psidium sp.	33	20			60	280	
Corbiculidae							
Corbicula sp							
Unionidae	7						
Quadrula quadrula		13					
Ligumia sp.	7						
Ligumia nasuta							
Dressenidae							
Dreissena polymorpha		7		7			7

Appendix VII

Taxonomic Composition of Benthic Communities
as defined by Cluster Analysis

Numbers are mean abundances ($\#/m^2$)

Invertebrate Taxa	Community			
	1	2	3	4
DIPTERA				
Chironomidae:				
Chironominae:				
Chironomini	12	1	3	0
Chironomus (Chaetolabis) sp.	23	0	0	0
Chironomus (Chironomus) sp.	13	4	27	47
Chironomus (C.) anthracinus group	2	4	37	0
Chironomus (C.) halophilus group	3	0	0	0
Chironomus (C.) plumosus group	3	1	0	0
Chironomus (C.) salinarius group	12	1	105	0
Chironomus (C.) staegeri group	22	0	0	0
Chironomus (C.) thummi group	14	2	77	0
Cladopelma sp.	7	2	0	0
Cryptochironomus sp.	53	66	68	37
Cryptotendipes sp.	5	0	0	33
Dicrotendipes sp.	1	2	20	153
Endochironomus sp.	2	1	0	1543
Glyptotendipes (Glyptotendipes) sp.	11	0	5	0
Microchironomus sp.	2	0	0	0
Parachironomous sp.	3	1	0	0
Paralauterborniella sp.	0	0	0	40
Polypedilum (Polydelium) sp.	11	1	8	333
Polypedilum (Tripodura) sp.	12	0	0	0
Pseudochironomus sp.	2	0	0	3
Rheotanytarsus sp.	5	0	0	0
Tanytarsus sp.	9	0	0	33
Tanypodinae:				
Apsectrotanypus sp.	47	19	47	0
Coelotanypus sp.	107	1	0	0
Procladius sp.	144	157	160	330
Tanypus (Tanypus) sp.	57	12	7	0
Djalmabatista sp.	0	2	0	0
Macropelopia sp.	0	6	0	0
Orthocladinae:	0	0	20	0
Diplocladius sp.	0	0	8	0

Invertebrate Taxa	Community			
	1	2	3	4
Paracricotopus sp.	5	1	55	0
Ceratopogonidae:				
Bezzia sp.	10	2	2	0
Culicoides sp.	1	2	0	0
Mallochohelis sp.	0	1	0	0
Chaoboridae:				
Chaoborus sp.	5	1	0	0
EPHEMEROPTERA:				
Ephemeridae:				
Hexagenia sp.	104	4	10	3
Caenidae:				
Caenis sp.	1	1	0	0
COLEOPTERA:				
Elmidae:				
Dubiraphia sp.	15	2	10	13
Dytiseidae:				
Coptotomus sp.	1	0	0	0
MEGALOPTERA				
Sialidae:				
Sialis sp.	0	0	3	0
LEPTIDOPTERA				
Pyralidae:	0	0	12	27
TRICOPTERA				
Polycentropodidae:				
Polycentropus sp.	1	1	0	0
Cyrnellus sp.	0	2	2	0
Hydropsychidae:				
Cheumatopsyche sp.	0	0	0	3
Hydroptilidae:				
Hydroptila sp.	0	0	2	0
Leptoceridae:				
Oecetis sp.	3	1	0	0
ODONATA				
Coenagrionidae				
Enallagma sp.	0	0	2	0

Invertebrate Taxa	Community			
	1	2	3	4
TUBIFICIDAE				
Limnodrilus hoffmeisteri	116	178	310	243
L. profundicola	2	5	22	3
L. angustipennis	0	0	0	3
L. claparedianus	0	0	0	10
L. sp.	8	0	5	7
Spirosperma ferox	0	29	85	73
Quistadrilus multisetosus	1	25	30	0
Aulodrilus sp.	0	8	0	30
Tubificidae immature	308	584	397	793
NADIDAE				
Pristinella sp.	0	10	7	7
P. sima	1	15	2	13
P. osborni	0	2	0	0
P. jenkinae	0	10	0	0
Nadidae	2	8	0	0
LUMBRICULIDAE	0	0	0	3
Nematoda:	2	8	25	0
Planaria:	0	0	0	10
Hirudinea:	0	11	35	37
Hydrachnidia	2	0	2	0
Crustacea:				
AMPHIPODA				
Gammarus sp.	8	12	28	63
Hyalella sp.	0	0	2	3
ISOPODA				
Caecidotea sp.	7	19	82	7
GASTROPODA				
Valvatidae				
Valvata sp.	0	161	48	3
V. tricarinata	0	13	5	7
V. sincera	0	6	0	0

Invertebrate Taxa	Community			
	1	2	3	4
Hydrobiidae	0	46	0	0
Hydrobiidae	2	186	87	14
Bithyniidae				
Bithynia tentaculata	0	0	2	0
Lymnaeidae				
Physa sp.	0	2	0	0
Stagnicola sp.	0	0	2	0
Fossaria sp.	0	0	0	7
Planorbidae				
Gyralus sp.	2	0	0	0
Helisoma anceps	0	1	0	0
BIVALVA				
Sphaeriidae				
Sphaerium sp.	48	105	250	73
Musculium sp.	1	1	0	0
Psidium sp.	0	19	22	140
Corbiculidae				
Corbicula sp	1	0	12	0
Unionidae	0	1	0	0
Quadrula quadrula	0	2	0	0
Ligumia sp.	0	1	2	0
Ligumia nasuta	0	1	0	0
Dressenidae				
Dreissena polymorpha	0	4	327	3

Appendix VIII

Component loadings and percent total variance explained for the PCA on benthic invertebrate abundances

Appendix VIII: Component loadings and percent total variance for the PCA of the benthic invertebrate abundances

	Component Loadings	
TAXA	Factor I	Factor II
Chironomini	-0.337	0.364
Chironomus (Chaetolabis) sp.	-0.459	0.187
Chironomous (Chironomous) sp.	-0.098	0.361
Cladopelma sp.	-0.009	-0.127
Cryptochironomus sp.	-0.083	-0.046
Cryptotendipes sp.	0.125	0.385
Dicrotendipes sp.	0.390	0.524
Endochironomus sp.	0.432	0.511
Glyptotendipes (Glyptotendipes) sp.	-0.132	0.227
Microchironomus sp.	-0.194	0.304
Parachironomous sp.	-0.104	-0.005
Paralauterborniella sp.	0.350	0.381
Polypedilum (Polydelium) sp.	0.263	0.639
Polypedilum (Tripodura) sp.	-0.339	0.172
Pseudochironomus sp.	0.134	0.579
Rheotanytarsus sp.	-0.447	0.304
Tanytarsus sp.	-0.141	0.463
Apsectrotanypus sp.	-0.335	-0.120
Coelotanypus sp.	-0.821	0.372
Procladius sp.	0.196	0.129
Tanypus (Tanypus) sp.	-0.522	-0.182
Djalmabatista sp.	0.069	-0.258
Macropelopia sp.	0.166	-0.369
Orthocladinae:	0.009	-0.095
Diplocladius sp.	0.194	0.038
Paracricotopus sp.	-0.060	0.134
Bezzia sp.	-0.492	0.078
Culicoides sp.	-0.024	-0.230
Mallochohelis sp.	0.069	-0.258
Chaoborus sp.	-0.172	-0.056
Hexagenia sp.	-0.631	0.288
Caenis sp.	0.024	0.128
Dubiraphia sp.	-0.197	0.602
Coptotomus sp.	-0.417	0.124
Sialis sp.	-0.094	-0.054
Pyralidae:	0.649	0.608
Polycentropus sp.	0.061	0.016
Cyrnellus sp.	0.250	-0.149
Cheumatopsyche sp.	0.403	0.506
Hydroptila sp.	0.257	0.182
Oecetis sp.	-0.548	0.151
Enallagma sp.	0.194	0.038

Appendix VIII: (continued)

TAXA	Component Loadings Factor I	Factor II
L. sp.	0.484	0.282
Spirosperma ferox	0.668	0.032
Quistadrilus multisetosus	0.380	-0.546
Aulodrilus sp.	0.359	0.094
Tubificidae immature	0.663	0.084
Pristinella sp.	0.493	-0.473
Pristina ? sp.	0.149	-0.222
Nadidae	0.085	-0.509
LUMBRICULIDAE	0.403	0.506
Nematoda:	-0.309	-0.044
Planaria:	0.542	0.637
Hirudinea:	0.806	0.099
Hydrachnidia	-0.293	0.237
Gammarus sp.	0.560	0.341
Hyalella sp.	0.438	0.406
Caecidotea sp.	0.247	0.085
Valvata sp.	0.444	-0.730
Hydrobiidae	0.472	-0.710
Bithynia tentaculata	0.115	-0.078
Physa sp.	0.069	-0.258
Stagnicola sp.	-0.094	-0.054
Fossaria sp.	0.403	0.506
Gyralus sp.	-0.227	-0.028
Helisoma anceps	-0.028	-0.158
Sphaerium sp.	0.418	-0.208
Musculium sp.	-0.194	-0.142
Psidium sp.	0.480	-0.305
Corbicula sp	-0.012	0.045
Unionidae	0.104	-0.299
Quadrula quadrula	0.142	-0.344
Ligumia sp.	0.305	-0.275
Dreissena polymorpha	0.537	-0.087
Percent Variance	12.791	10.687

Appendix IX

Fish Species found in the study area

Appendix IX: Fish species found in the study area

	Lower Welland River[1]	Lower Welland River[2]	Welland River[3]	Welland River[4]	12-Mile Creek[5]	Niagara River[6]
White Crappie	*	*		*		*
White Bass		*		*		*
White Perch		*				*
Channel Catfish		*	*	*		*
Gizzard Shad		*	*	*		*
Freshwater Drum		*	*	*		*
White Sucker	*	*		*	*	*
Yellow Bullhead		*		*		*
Shorthead Redhorse		*				*
Carp	*	*	*	*		*
Pumpkinseed	*	*		*		*
Rock Bass	*	*	*	*	*	*
Smallmouth Bass		*			*	*
Spottail Shiner	*	*				*
Emerald Shiner	*	*	*	*		*
Johnny Darter	*	*			*	*
Brook Silverside		*				*
Sculpin		*				*
Banded Killifish	*	*				*
Golden Shiner	*		*	*		*
Creek Chub	*				*	*
Blntnose minnow	*				*	*
Brown Bullhead	*			*	*	*
Tadpole Madtom	*					*
Mudminnow	*				*	*
Northern Pike	*			*		*
Black Crappie	*					*
Yellow Perch	*			*		*
Smelt			*			*
Bluegill Sunfish			*			*
Sea Lamprey					*	*
Brown Trout					*	*
Brook Trout					*	*
Hog Sucker					*	*
Northern Pearl Dace					*	*

	Lower Welland River[1]	Lower Welland River[2]	Welland River[3]	Welland River[4]	12-Mile Creek[5]	Niagara River[6]
Redside Dace					*	*
Northern Redbelly Dace					*	*
Finescale Dace					*	*
River Chub					*	*
Blacknose Dace					*	*
Longnose Dace					*	*
Rosyface Shiner					*	*
Common Shiner				*	*	*
Brassy Minnow					*	*
Fathead Minnow					*	*
American Eel					*	*
Rainbow Darter					*	*
Fantail Darter					*	*
Brook Stickleback					*	*
Longnose Sucker						*
Silver Redhorse						*
River Redhorse				*		
Black Redhorse						*
Greater Redhorse						*
Stonecat				*		*
Brindled Madtom						*
Black Bullhead				*	*	
Lake Sturgeon						*
Longnose Gar						*
Bowfin				*		*
Alewife						*
Rainbow Trout				*		*
Lake Trout						*
Coho Salmon						*
Cisco						*
Lake Whitefish						*
Round Whitefish						*
Mooneye						*
Muskellunge						*
Lake Chub						*

Appendix IX - continued

	Lower Welland River[1]	Lower Welland River[2]	Welland River[3]	Welland River[4]	12-Mile Creek[5]	Niagara River[6]
Blackchin Shiner						*
Blacknose Shiner						*
Spotfin Shiner						*
Sand Shiner						*
Mimic Shiner						*
Burbot						*
Threespine Stickleback						*
Ninespine Stickleback						*
Trout-Perch						*
Green Sunfish						*
Largemouth Bass				*		*
Sauger						*
Walleye						*
Iowa Darter						*
Least Darter						*
Log-Perch						*
Blackside Darter						*
Goldfish			*	*		
Chain Pickerel				*		

1 - Johnson, 1964
2 - Tarandus Associates Limited, 1990 - Summer and Fall field surveys
3 - Brindle *et al.*, 1988 - goldfish actually a carp/golfish hybrid
4 - Steele, 1981
5 - Department of Commerce and Development, 1960
6 - Fish species thought to occur in the Niagara River area - Scott and Crossman, 1973

Appendix X

Flow calculations for sections A, B, and C.

Section A - Old railway tressel located slightly upstream of station 6 - 07/11/90.

SECTION	1	2	3	4	5	6	7	8	TOTAL
Section width (m)	5	5	5	5	5	5	5	5	40
Mean Depth (m)	0.70	1.30	1.60	1.70	2.05	2.50	1.93	1.13	**********
XS Area (m^2)	3.50	6.50	8.00	8.50	10.25	12.50	9.65	5.65	64.55
Velocities [1] (m/s)	0.18 | 0.29	0.29 | 0.325	0.325 | 0.35	0.35 | 0.31	0.31 | 0.25	0.25 | 0.35	0.35 | 0.335	0.335 | 0.01	**********
Mean Velocity [2] (m/s)	0.235	0.3075	0.3375	0.33	0.28	0.30	0.3425	0.1725	**********
Flow (Q)(m^3/s)	0.82	2.00	2.70	2.81	2.87	3.75	3.31	0.98	**19.24**

Section B - Railway tressel located upstream of station 14 - 08/11/90.

SECTION	1	2	3	4	5	6	7	8	9	10	Total
Section width (m)	5	5	5	5	5	5	5	5	5	5	50
Mean Depth (m)	1.75	2.60	2.95	2.98	3.15	3.30	3.20	2.75	2.10	1.33	******
XS Area (m^2)	8.75	13.00	14.75	14.90	15.75	16.50	16.00	13.75	10.50	6.63	130.53
Velocities[1] (m/s)	0.12 | 0.23	0.23 | 0.27	0.27 | 0.36	0.36 | 0.29	0.29 | 0.355	0.355 | 0.37	0.37 | 0.275	0.275 | 0.265	0.265 | 0.115	0.115 | 0.14	******
Mean Velocity[2] (m/s)	0.18	0.25	0.315	0.33	0.323	0.3625	0.3225	0.27	0.19	0.1275	******
Flow (Q)(m^3/s)	1.53	3.25	4.65	4.92	5.08	5.98	5.16	3.713	1.96	0.85	**37.12**

Section C - Velocity measurements taken slightly upstream of station 16 - 09/11/90.

SECTION	1	2	3	4	5	6	7	8	9	10	11	Total
Section width (m)	5	5	5	5	5	5	5	5	5	5	5	55
Mean Depth (m)	0.50	1.85	2.90	3.25	3.70	3.75	3.45	3.10	2.53	1.75	0.75	*****
XS Area (m^2)	2.50	9.25	14.50	16.25	18.50	18.75	17.25	15.50	12.65	8.75	3.75	137.65
Velocities[1] (m/s)	0.00 0.075	0.075 0.165	0.165 0.165	0.165 0.185	0.185 0.17	0.17 0.245	0.245 0.23	0.23 0.21	0.21 0.18	0.18 0.115	0.115 0.00	*****
Mean Velocity[2] (m/s)	0.0375	0.120	0.165	0.175	0.1775	0.2075	0.2375	0.22	0.195	0.1475	0.0575	*****
Flow (Q)(m^3/s)	0.09	1.11	2.39	2.84	3.28	3.89	4.10	3.41	2.47	1.29	0.22	25.09

1 - Velocity averages for each side of the section based on measurements taken at 0.2 and 0.8 times the depth.
2 - Average of all velocities

Appendix XI

Water Quality Data

Water and Sediment Parameter Abbreviations:

Abbreviation	Parameter
Pb	Lead
Zn	Zinc
Cd	Cadmium
Cr	Chromium
Fe	Iron
Se	Selenium
As	Arsenic
Sb	Antimony
Ba	Barium
Be	Beryllium
Co	Cobalt
Cu	Copper
Mo	Molybdenum
Ni	Nickel
V	Vanadium
Ag	Silver
Hg	Mercury
CN	Cyanide
Mn	Manganese
Mg	Magnesium
Al	Aluminum
PCB	Polychlorinated biphenyls
OC	Organochlorine
PAH	Polycyclic Aromatic Hydrocarbons
NH_4	Ammonia
TP	Total Phosphorus
TKN	Total Kjeldahl Nitrogen
NO_2	Nitrite
NO_3	Nitrate
TOC[1]	Total Organic Carbon
LOI[1]	Loss on Ignition
SAR[1]	Sodium Adsorption Ratio

Water - Summer Survey

SITE	Zn mg/L	Cd mg/L	Mn mg/L	Co mg/L	Cu mg/L	Fe mg/L	Pb mg/L	Cr mg/L
1	<0.01	<0.002	0.18	<0.005	0.03	2.1	<0.01	<0.005
2	<0.01	<0.002			0.015		<0.01	<0.005
3	<0.01	<0.002			0.005		<0.01	<0.005
4	<0.01	<0.002			0.03		<0.01	<0.005
5	<0.01	<0.002			0.04		<0.01	<0.005
6	<0.01	<0.002			0.05		<0.01	<0.005
7	<0.01	<0.002			0.03		<0.01	<0.005
8	<0.01	<0.002			0.02		<0.01	<0.005
9	<0.01	<0.002	0.01	<0.005	0.02	0.095	<0.01	<0.005
10	<0.01	<0.002			0.01		<0.01	<0.005
10a	0.02	<0.002			0.005		<0.01	<0.005
11	<0.01	<0.002			0.015		<0.01	<0.005
12	<0.01	<0.002			0.015		<0.01	<0.005
13	<0.01	<0.002			0.02		<0.01	<0.005
14	<0.01	<0.002			0.01		<0.01	<0.005
15	<0.01	<0.002	0.02	<0.005	0.005	0.43	<0.01	<0.005
16	<0.01	<0.002			0.035		<0.01	<0.005
17	<0.01	<0.002			0.025		<0.01	<0.005
18	<0.01	<0.002			0.01		<0.01	0.0075
19	<0.01	<0.002			0.03		<0.01	<0.005
19a	<0.01	<0.002			0.005		<0.01	<0.005
20	<0.01	<0.002			0.01		<0.01	<0.005
21	<0.01	<0.002	0.01	<0.005	0.015	0.4	<0.01	<0.005
22	<0.01	<0.002			0.0125		<0.01	<0.005
23	<0.01	<0.002	0.01	<0.005	0.005	0.06	<0.01	<0.005

Water - Summer Survey (Continued)

SITE	Ni mg/L	Be mg/L	Mo mg/L	V mg/L	Al mg/L	Ba mg/L	Hg µg/L	As µg/L
1	<0.005	<0.005	<0.005	<0.005	1.74	0.04	0.3	<5
2					1.42		0.25	<5
3					1.155		0.125	<5
4					0.97		0.1	<5
5					0.81		<0.05	<5
6					0.82		<0.05	<5
7					0.75		<0.05	<5
8					0.28		<0.05	<5
9	<0.005	<0.005	<0.005	<0.005	0.12	0.02	<0.05	<5
10					0.12		<0.05	<5
10a					0.13		<0.05	<5
11					0.11		<0.05	<5
12					0.1		<0.05	<5
13					0.3		<0.05	<5
14					0.28		<0.05	<5
15	<0.005	<0.005	<0.005	<0.005	0.36	0.02	<0.05	<5
16					0.24		<0.05	<5
17					0.31		<0.05	<5
18					0.295		<0.05	<5
19					0.34		<0.05	<5
19a					0.32		<0.05	<5
20					0.3		<0.05	<5
21	<0.005	<0.005	<0.005	<0.005	0.32	0.02	<0.05	<5
22					0.16		<0.05	<5
23	<0.005	<0.005	<0.005	<0.005	0.16	0.02	<0.05	<5

Water - Summer Survey (Continued)

SITE	Se	Ag	CN	Colour	Cond	Ammnia-N	Sb	Nitrite
	μg/L	mg/L	mg/L	TCU	uS/cm	mg/L	μg/L	mg/l
1	<1	<0.005	0.002	48	440	0.008	<2	0.003
2			0.002		440			
3			0.002		415			
4			0.002		420			
5			0.002		360			
6			0.002		350			
7			0.002		310			
8			0.002		290			
9	<1	<0.005	0.002	3	290	0.008	<2	0.005
10			0.002		290			
10a			0.002		290			
11			0.002		310			
12			0.002		310			
13			0.002		300			
14			0.002		300			
15	<1	<0.005	0.002	4	290	0.008	<2	0.023
16			0.002		290			
17			0.002		290			
18			0.002		300			
19			0.002		300			
19a			0.002		300			
20			0.002		310			
21	<1	<0.005	0.002	4	300	0.33	<2	0.04
22			0.002		280			
23	<1	<0.005	0.002	2	290	0.23	<2	0.003

Water - Summer Survey (Continued)

SITE	Mg mg/L	Nitrate mg/L	pH $-\log[H^+]$	Phenolics mg/L	TKN mg/L	SS mg/L	Turb NTU	TP mg/L
1	14.1	0.35	8	0.01	1	48	6.5	0.2
2			7.9	0.012	1.01		5.5	0.25
3			7.95	0.0025	0.955		7.3	0.1515
4			7.95	0.029	0.81		6.8	0.149
5			8.05	<0.001	0.62		4.3	0.098
6			8	0.004	0.56		4.2	0.083
7			8.15	0.004	0.43		1.8	0.053
8			8.1	<0.001	0.33		0.5	0.024
9	8.5	0.16	8.125	0.012	0.42	7	0.3	0.016
10			8.1	0.012	0.28		0.3	0.016
10a			8.2	0.001	0.3		0.3	0.013
11			8.25	0.002	0.33		0.8	0.066
12			8.15	0.001	0.4		1.1	0.064
13			8.15	0.022	0.38		0.7	0.044
14			8.1	0.03	0.4		0.8	0.045
15	8.9	0.31	8.1	0.024	0.39	14	0.5	0.041
16			8.05	0.016	0.37		0.5	0.042
17			8.1	0.031	0.34		0.4	0.042
18			8.45	0.008	0.33		0.55	0.048
19			8.15	0.002	0.39		0.6	0.053
19a			8.15	0.004	0.46		0.6	0.053
20			8.1	0.022	0.4		0.6	0.052
21	9.2	0.55	8.15	0.016	2.6	14	0.5	0.06
22			8.4	0.0015	0.315		0.3	0.0135
23	8.4	0.16	8.25	0.005	0.39	4	0.3	0.013

Water - Fall Survey

SITE	Cu	Al	Hg	Phenols
	mg/L	mg/L	µg/L	mg/L
1	0.005	1.85	<0.05	<0.001
2	0.01	2.7	<0.05	<0.001
3	0.005	3.4	<0.05	<0.001
4	0.01	1.03	<0.05	<0.001
5	0.005	0.86	<0.05	<0.001
6	0.005	1.9		<0.001
7	0.005	1.91		<0.001
8	0.005	1.14		<0.001
9	<0.005	1.49		<0.001
10	0.01	0.54	<0.05	<0.001
10a				<0.001
11				<0.001
12				<0.001
13				<0.001
14				<0.001
15	0.01	1.3	<0.05	<0.001
16				<0.001
17				<0.001
18				<0.001
19				<0.001
19a				<0.001
20				<0.001
21	<0.005	1.07	<0.05	<0.001
22				<0.001
23	0.035	0.34	<0.05	<0.001

Appendix XII

Sediment Quality Data

Sediments - Summer Survey

SITE	CN	LOI	O&G	phenolics	pH	Zn	Cd	TOC
	μg/g	%	μg/g	μg/g	-log[H+]	μg/g	μg/g	%
1	0.13	14	2900	0.01	6.8	116	0.6	7.4
2	<0.05	11	1040	0.01	7	97	0.5	
3	<0.05	12	980	0.01	6.9	116	0.45	
4	0.075	10.5	845	0.01	6.95	104	0.425	
5	<0.05	12	1070	0.02	7	108	0.55	
6	<0.05	7.2	870	0.01	7.3	112	0.4	
7	<0.05	7	1800	0.01	6.9	135	0.55	
8	<0.05	7	2500	0.01	7	112	0.4	
9	≤0.05	7	4550	0.01	7	335	0.8	3.55
10	<0.05	7	2000	0.01	7	550	0.975	
10a	<0.05	5	1990	0.01	7	270	0.4	
11	<0.05	2	250	0.01	7.3	98	0.15	
12	<0.05	6	3200	0.01	7.1	620	1.4	
13	<0.05	2	195	0.01	7.5	75	0.25	
14	<0.05	2	320	0.01	7.5	76	0.1	
15	<0.05	2	410	0.01	7.3	83	0.15	0.92
16	<0.05	4	1110	0.01	7.1	116	0.2	
17	<0.05	5	1670	0.01	7.2	163	0.35	
18	0.09	5	3100	0.01	7.1	191	0.5	
19	<0.05	5	2500	0.01	7.1	330	0.9	
19a	<0.05	5	750	0.01	7.2	127	0.25	
20	0.18	5	1280	0.01	7.2	69.5	0.1	
21	0.1	3	860	0.01	7.2	95	0.2	1.13
22	<0.05	5	1240	0.025	7	75.5	0.675	
23	<0.05	6	1670	0.01	7	55	0.3	2.5

Sediments - Summer Survey (Continued)

SITE	SAR	TKN	Mn	Co	Cu	Fe	Pb	Cr	Ni	Be
		μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
1	1.14	2800	580	14.5	35	32000	49	40	33	1.5
2					24		26	40		
3					33		37	49		
4					29		31	43.5		
5					31		34	43		
6					30		34	40		
7					35		85	45		
8					51		40	44		
9	0.76	1910	430	10.75	93.5	30000	74.5	55.5	54	1
10					77		86	95		
10a					50		38	91		
11					28		25	53		
12					85		62	260		
13					34		21	162		
14					26		22	79		
15	0.83	290	960	19	47	58000	26	300	178	1
16					31		23	43		
17					58		50	300		
18					64		45.5	265		
19					115		41	107		
19a					33		24	59		
20					54.5		40.5	53		
21	0.8	800	650	13	94	35000	29	97	75	1
22					19		20.5	22.5		
23	0.9	1340	330	6.5	15	16400	16	19	19.5	0.5

Sediments - Summer Survey (Continued)

SITE	Mo µg/g	V µg/g	Al µg/g	Mg µg/g	Ba µg/g	Hg µg/g	Ag µg/g	Sb µg/g	TP µg/g	As µg/g
1	0.5	58	34000	9400	139	0.08	0.5	1	1020	5
2			33000			0.04				5
3			38000			0.12				7
4			34000			0.07				5
5			32000			0.06				5
6			31000			0.06				5
7			31000			0.1				6
8			26000			0.4				5
9	1.75	34.5	17750	15900	102.5	2.22	0.5	1	1005	5
10			34000			0.18				11
10a			35000			1.4				8
11			35000			0.02				6
12			38000			0.68				17
13			29000			0.02				6
14			29000			0.02				6
15	24	42	23000	13900	118	0.06	0.5	1	1060	6
16			32000			0.28				6
17			31000			0.1				6
18			22000			0.28				6.5
19			38000			0.26				10
19a			28000			0.08				6
20			25000			0.04				5.5
21	3.5	43	26000	14000	127	0.1	0.5	1	1300	6
22			15750			0.07				4
23	0.5	27	12400	17200	51	0.06	0.5	1	620	3

Sediments - Fall Survey

SITE	PCBs µg/g	Hg µg/g	Zn µg/g	Cd µg/g	CN µg/g	O&G µg/g
1	<0.05				<0.05	960
2					0.15	670
3	<0.05					1570
4						540
5	<0.05		130	0.4		720
6			112	0.6		970
7	0.13	0.36	177	0.9		2700
8	0.074	1.64	125	0.6		1660
9	0.11	3.11	309	0.7		4850
10	0.045	1.3	310	0.7		3600
10a		0.14	142	0.3		780
11		2	280	0.8		3400
12		0.92	570	1.5		11800
13		0.04	99	0.2		450
14			137	0.25		515
15	0.051		192	0.5		2000
16			187	0.6		1320
17			210	0.7	0.13	2600
18			210	0.6	0.15	2600
19			220	0.7	0.1	2700
19a	<0.05					6600
20			179	0.6	1.67	1560
21	0.142				0.12	3550
22					<0.05	1120
23	<0.05					1080

Sediments - Fall Survey (Continued)

SITE	Mn	Co	Cu	Fe	Pb	Cr	Ni	As
	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
5	850	15	31	38000	38	50	38	
6	680	12.5	34	32000	36	43	34	
7	570	12	72	29000	73	46	37	5
8	630	12	94	28000	47	49	41	5
9	615	13.3	109.5	35000	93.5	188.5	131	5
10	1210	38	168	118000	87	670	390	11
10a	810	16.5	43	52000	38	149	98	
11	740	18.5	73	53000	63	250	166	4
12	730	23	105	70000	91	460	270	10
13	980	17	52	60000	23	300	179	6
14	995	19	53.5	59000	28.5	385	230	6.5
15	940	18	66	54000	48	340	177	8
16	990	19.5	71	63000	44	420	240	5
17	960	20	71	59000	49	440	230	7
18	840	19	74	53000	49	380	210	5
19	840	19	116	54000	53	350	192	7
20	820	22	138	47000	80	260	192	8