

EVALUATION OF THE AQUATIC ENVIRONMENT IN THE SERPENT RIVER WATERSHED¹

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Abstract: The aquatic environment of the Serpent River Watershed on the north shore of Lake Huron's North Channel was first affected in the mid-1950's following the development of several uranium mines and the community of Elliot Lake. In 1993, an evaluation of the aquatic environment was carried out to establish the status of the Serpent River ecosystem. Samples were collected of water, sediment, fish and benthos in 19 lakes and the Serpent River for comparison to historical records. Water quality data for pH, ammonia, nitrate, radium-226, uranium and sulphate showed continual improvement since the 1960's. Levels of radionuclides in sediments decrease with increasing distance from the sources, but are well below levels of concern. Since 1976 the fisheries have increased in relative biomass, condition factor and growth rate, with the benthic diversity and density also increasing.

Key words: aquatic environment, surface water, sediment, fish, benthos, radionuclides, uranium mining

Introduction

Following discovery of uranium deposits in 1953 in the Elliot Lake area (north of Lake Huron), 12 mines and 11 mills were brought into production between 1954 and 1958. By 1959, a town serving over 25,000 people had been built on the east shore of Elliot Lake in the Serpent River Watershed (see Figure 1). By the early 1960's, all but two of the mines were closed as a result of cancellation of uranium contracts, and the population of the town declined to about 7,000. With increased demand for uranium in the 1970's, production was increased at the two operating mines, and two other mines were brought back into production. In 1990 the Quirke and Panel mines were closed by Rio Algom Limited, and in 1992 Denison Mines Limited shutdown its only operating mine. Four decades of uranium mining in the Elliot Lake area will end in 1996 when the last operating mine closes. Over the years, numerous practices and technologies have been applied to mitigate impacts on the water quality of the Serpent River Watershed resulting from mining and milling activities. This study was undertaken to assess the aquatic environment in the Serpent River Watershed in terms of water quality, sediment quality, fisheries and benthos.

Data Collection

Several sources were tapped as part of this investigation: historical data on water quality, sediment quality, fisheries and benthic organisms; data and reports from the Ontario Ministry of Environment and Energy (MOEE), the Ontario Ministry of Natural Resources (MNR), Rio Algom Limited, Denison Mines Limited; and consultant and research reports on extensive work in the area. During the summer of 1993,

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a three-week field program was conducted in the Serpent River Watershed to collect samples of water, sediment, fish and benthos for comparison to the historical data. In total, 29 water samples and 28 sediment samples were collected from 19 lakes and the Serpent River. The lakes are listed in Table I and illustrated in Figure 1. Fish were gill-netted in nine primary lakes of interest (indicated in Table I), and benthic organisms were collected at 22 river stations (inflow and outflow locations to lakes in the watershed) and 38 lake stations (two lake stations on each of the 19 lakes). Seine net hauls were used to collect small fish at several different locations in each of the nine primary lakes.

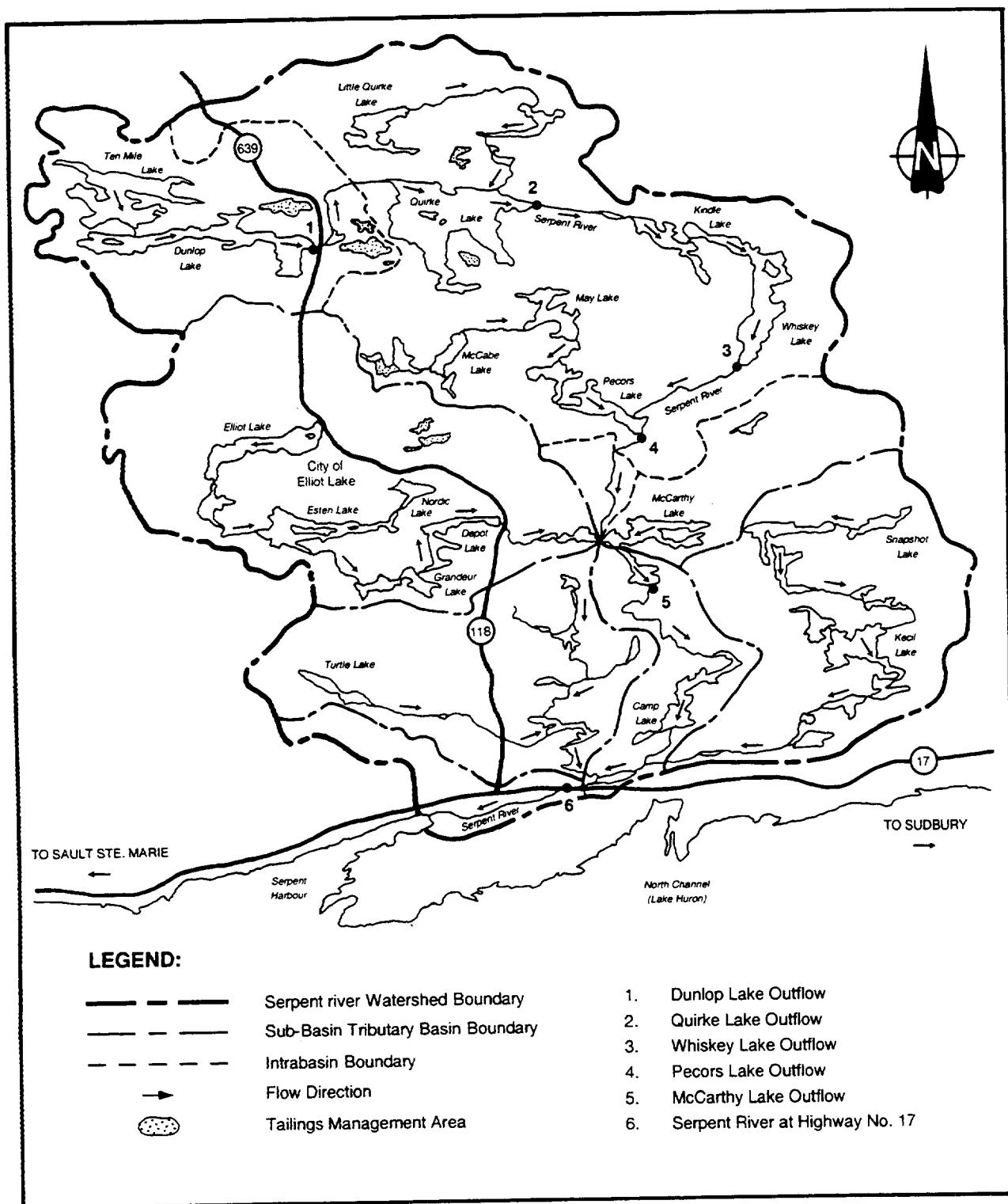


Figure 1 - Serpent River Watershed, Basins and Sub-Basins

Historical Water Quality

The key locations (Serpent River at Highway 17, and the outflows of five lakes: Dunlop, Quirke, Whiskey, Pecors and McCarthy) examined for water quality trends are shown on Figure 1. Parameters were evaluated against provincial water quality objectives (PWQOs) and guidelines (PWQGs) and Ontario drinking water objectives (ODWOs) (1). Two of the key water quality parameters are pH and radium-226.

Figure 2 is a graph of pH levels since 1966 at the six key locations. The pH in parts of the Serpent River Watershed was suppressed during the early years of mining in the 1950's by the discharge of acidic mine water. While this practice was stopped once the problem was identified, the pH in the system did not recover immediately due to other factors. The depression of pH has been attributed principally to the acid formed from the oxidation of ammonia introduced with the treated tailings effluents.

Data for the last five years indicated that the pH has been moving back toward neutrality at three of the five affected stations: Pecors Lake, McCarthy Lake and Serpent River at Highway 17. Whiskey Lake reflects Quirke Lake water quality trends, and the pH in both lakes is expected to recover to near neutrality over time once the existing ammonia burden has flushed from the system or oxidized. The pH in Quirke Lake over the last five years is essentially unchanged.

Figure 3 contains the historical radium-226 levels, and shows that activities have been below the ODWO/PWQO for the entire period of record, and that radium-226 levels have decreased dramatically since 1966 at all locations after commissioning of effluent treatment facilities at minesites.

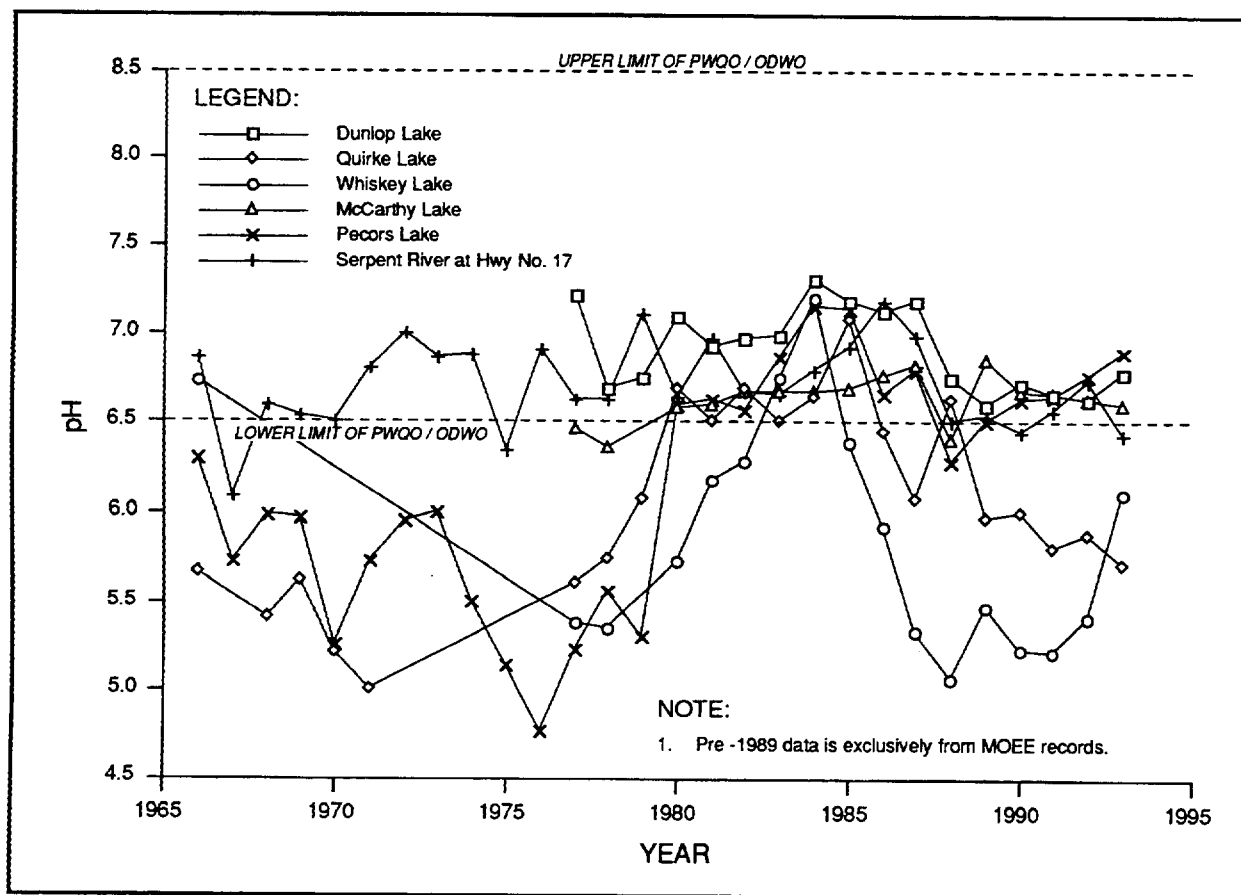
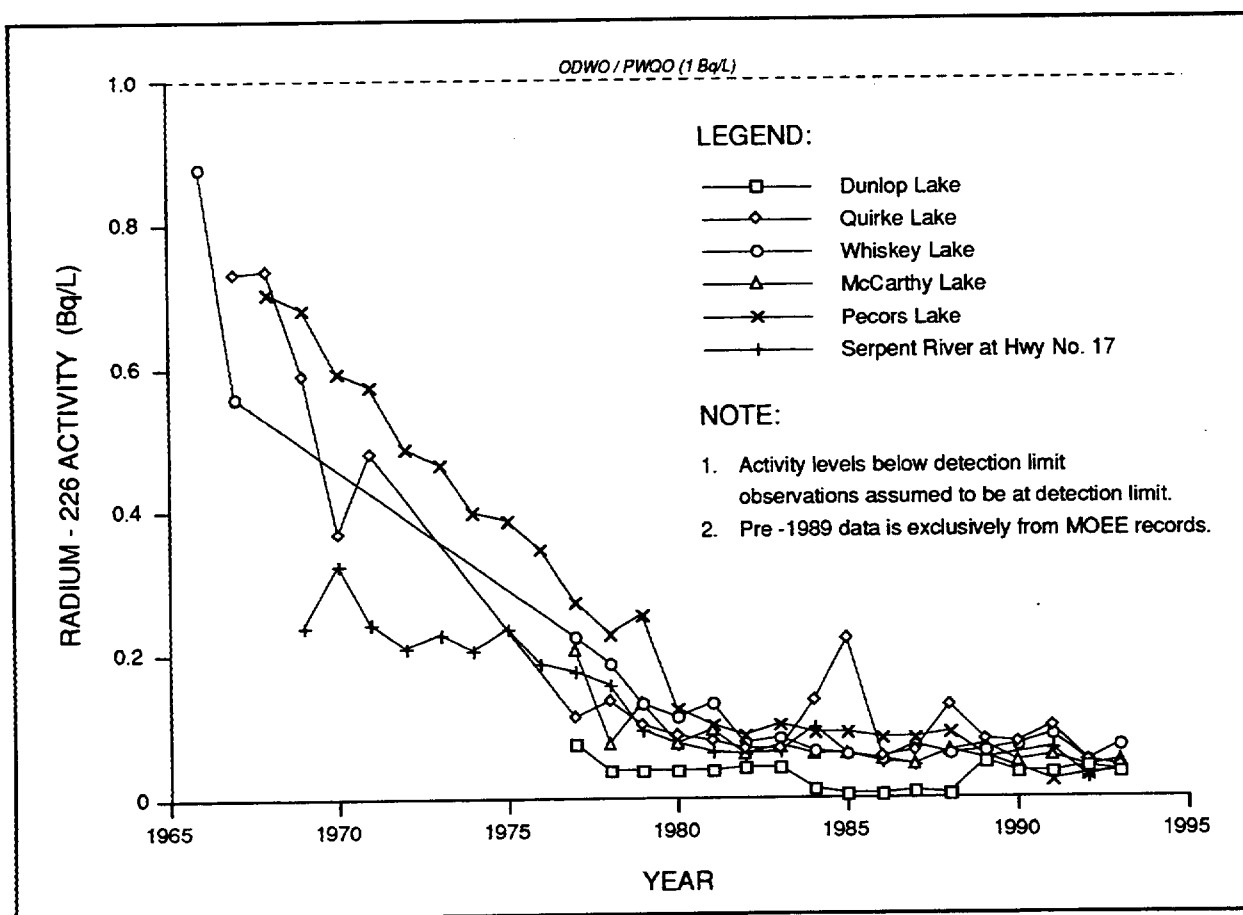


Figure 2 - Annual Mean pH Values for Selected Stations in the Serpent River System



**Figure 3 - Annual Mean Radium-226 Activity (Bq/L)
for Selected Stations in the Serpent River System**

Existing Water Quality

Data on existing water quality obtained from the summer 1993 campaign was compared to average values of the last four years of historic MOEE and company data for the six key parameters in water samples collected at the six key locations in the Watershed. Approximately two thirds of the measurements from the 1993 program showed the water quality to be better than or comparable to the average values of the previous four years. Over the period of record (1966 to 1993), water quality observations have shown a measurable improvement due to reductions in fresh water use, and improvements in effluent treatment technology.

Summer 1993 sampling results demonstrated that pH, ammonia, nitrate, radium-226, uranium-238 and sulphate levels are well within the limits set for protection of aquatic life and for drinking water, with the exception of pH in Quirke, Kindle and Whiskey Lakes, and sulphate in McCabe Lake (Table I).

Specific findings drawn from the comparison included:

- The pH in the summer of 1993 was within the PWQO range of 6.5 to 8.5 in the Serpent River at Highway 17 and on 16 of the 19 lakes tested. The pH was marginally below the lower limit at Quirke, Kindle and Whiskey Lakes. The pH in the summer of 1993 was consistent with the average pH recorded over the last four years at the five key locations in the Serpent River Watershed downstream of the mining properties.

Table I: Levels of Six Key Parameters For 19 Lakes and Serpent River, Summer 1993 Survey

Lake	pH (field)	Ammonia (mg/L)		Nitrate (mg/L)	Radium-226 (mBq/L)	Uranium-238 ^B (µg/L)	Sulphate (mg/L)
		Total	Un-ionized				
Ten Mile [*]	7.0	0.09	0.0004	0.13	16.9	<0.5	14.4
Evans ^F	7.3	0.07	0.0006	0.14	27.4	1.63	17.1
Dunlop ^{*F}	7.3	0.11	0.0009	0.13	23.1	<0.5	5.8
Quirke ^F	6.3	2.09	0.0016	8.02	66.9	15.28	172.8
Kindle	6.3^E	1.79	0.0016	6.60	38.1	8.07	143.6
Whiskey ^F	6.2	1.62	0.0011	6.65	69.0	7.17	136.7
McCabe ^F	7.0^E	1.11	0.0049	2.31	87.7	6.95	884.8
May	7.8	0.30	0.0085	1.01	136.6	4.28	429.6
Hough	7.4	0.11	0.0013	0.69	110.3	1.68	280.2
Pecors ^F	7.0	0.70	0.0036	4.27	53.3	7.27	160.1
Elliot ^F	6.6	0.08	0.0001	0.22	42.1	<0.65	10.5
Quimby	7.2	0.11	0.0008	0.17	24.6	<0.5	10.3
Esten	7.6	0.09	0.0016	0.19	19.0	<0.5	8.2
Grandeur	6.8	0.07	0.0002	0.19	24.4	<0.5	10.7
Nordic ^F	7.5	0.19	0.0028	0.47	67.4	3.78	259.5
Depot	8.25	0.21	0.0183	0.58	42.8	<0.5	94.2
McCarthy ^F	6.7	0.47	0.0012	3.46	59.6	3.84	86.5
Camp	6.5	0.53	0.0008	11.02 ^A	49.3	2.57	90.1
Kecil [*]	6.7	0.07	0.0002	0.14	21.2	<0.5	1.2
Highway 17	7.0	0.37	0.0019	2.83	41.0	1.43	53.1
PWQO/PWQG	6.5-8.5	-	0.02 ^C	-	1000	-	-
ODWO	6.5-8.5	-	-	10.0	1000	100	500
Baseline	7.1	0.07	0.0005	0.13	20.4	<0.5	7.1

A - Questionable measurement.

B - Uranium-238 is given in µg/L, while ammonia, nitrate and sulphate are in mg/L.

C - Objective is for un-ionized ammonia which is only a fraction of the total ammonia concentration.

D - Values outside PWQOs/PWQGs or ODWOs values are shown in bold.

E - pH value estimated as measurement was not made in the field.

F - Primary lakes of interest

* - Baseline lakes unaffected by mining activity or urban development.

- The calculated un-ionized ammonia levels (which are a function of total ammonia, temperature and pH) in the summer of 1993 were below 0.020 mg/L at all locations, which conforms to the PWQO for protection of aquatic life. Levels in baseline lakes (Ten Mile, Dunlop and Kecil) were low and consistent with levels recorded on Dunlop Lake over a much longer time. The highest calculated un-ionized ammonia level was in Depot Lake but this was still within guidelines. Depot Lake receives the treated effluent from the City of Elliot Lake sewage treatment plant, as well as the treated effluent from the Nordic mine treatment plant. Compared to the average value for total ammonia for the last four years, the total ammonia concentration in summer 1993 was marginally higher at one affected key location (Pecors Lake), and lower at the other four affected key locations (Quirke, Whiskey and McCarthy Lakes, and the Serpent River at Highway 17).
- In the summer 1993, only one of the 29 locations had a nitrate level above the ODWO of 10 mg/L (Camp Lake) but this result is considered anomalous. The average value of nitrate for the three reference lakes was lower than the nitrate values recorded for all the remaining 25

stations sampled. Compared to the average nitrate concentration for the last four years, the nitrate level in summer 1993 was higher at two of the affected key stations (Quirke Lake and Pecors Lake), essentially the same at one affected key station (Serpent River at Highway 17), and lower at two other affected key stations (Whiskey Lake and McCarthy Lake).

- In the summer of 1993, the radium-226 level at all 29 stations was at least 7 times lower than the ODWO/PWQO of 1 Bq/L (1,000 mBq/L). Compared to the average radium-226 value for baseline lakes, the highest radium-226 concentration (measured in May Lake) was a factor of 6.8 greater. Compared to average values for the last four years, the summer 1993 radium-226 levels were higher at two affected key stations (Pecors Lake and McCarthy Lake), and the same at the other three affected key stations (Quirke and Whiskey Lake and the Serpent River at Highway 17).
- All 29 stations sampled in the 1993 program were found to have uranium levels significantly below the ODWO of 0.10 mg/L. The baseline lakes were all below the method detection limit (MDL) of the analytical procedure. Compared to the average of the last four years, the 1993 uranium levels were marginally higher at two affected key stations (Quirke Lake and Pecors Lake), the same at two affected key stations (McCarthy Lake, and the Serpent River at Highway 17), and lower at one affected key station (Whiskey Lake).
- The sulphate levels measured during the July/August 1993 field program work were below the ODWO of 500 mg/L at 27 of the 29 stations. The two stations exceeding the ODWO were both in McCabe Lake. The average sulphate level for the baseline lakes was lower than all other measurements. As anticipated, the highest sulphate levels were found in McCabe, Quirke and Nordic Lakes, and sulphate concentrations decreased downstream of these lakes. Compared to the four year averages, the 1993 levels were higher at two of the key stations (Quirke Lake and Pecors Lake), and lower at three of the key stations (Whiskey Lake, McCarthy Lake, and the Serpent River at Highway 17).

Besides the comparisons noted above for the six key parameters investigated in detail, the following findings are noteworthy respecting other water quality parameters measured during 1993:

- Alkalinity and acidity were low throughout the watershed (<13 mg/L) which is typical of lakes on the Canadian Precambrian Shield.
- Dissolved oxygen (D.O.) profiles indicated low D.O. in the hypolimnions of Depot, Evans and Nordic Lakes. However, the other 16 lakes exhibited high D.O. throughout their water columns.
- Total dissolved solids and conductivity were highest in McCabe Lake, and decreased downstream with dilution. McCabe Lake is downstream of the only active Elliot Lake mine.
- Phosphorus levels are generally low and growth-limiting throughout the watershed, so that the artificially elevated nitrogen levels have not caused eutrophication in the Serpent River Watershed.
- Of 26 metals measured in water samples collected for the 1993 field program, there exist PWQOs, PWQGs or ODWOs for 21 metals either for protection of aquatic life, or for drinking. Over 89% of the measurements on the Serpent River Watershed water samples satisfied the guidelines and objectives. The only metals found at concentrations above existing or proposed objectives or guidelines were aluminum (in 4 of 29 samples), cadmium (in 4 of 29 samples), manganese (in 18 of 29 samples), strontium (all 29 samples including baseline lakes), vanadium (in 1 of 29 samples) and zinc (in 1 of 29 samples). Even on those samples with elevated metal content, the measured levels were generally only marginally greater than the respective objectives or guidelines.

- The levels of thorium-230, thorium-232, lead-210 and polonium-210 were found to be low on all samples, far below the calculated Maximum Acceptable Concentration (MAC) for drinking water, and frequently less than the analytical method detection limits.

Sediment Quality

For sediment, 26 different metals were measured. There was no consistent trend between sediments in baseline and affected lakes based upon sediment metal levels. Generally, the following metals were:

- Found at similar levels in sediments in baseline and affected lakes:
Ag, B, Be, Cr, Mg, Mn, Mo, Na, P, Pb and Th
- Typically found at higher concentrations in the baseline lake sediments:
Cd, Cu, Si and Zn
- Typically found at higher concentrations in the affected lake sediments:
Al, Ba, Ca, Co, Fe, K, Ni, Sr, Ti, V and Zr

Of 26 metals measured in sediment samples collected during the 1993 field program, the MOEE has issued provincial sediment quality guidelines (PSQGs) for nine of the metals (2). Compared to PSQGs, zinc levels were found to be naturally elevated above the upper guideline values (Severe Effect Level - SEL) in the sediments of the entire Serpent River Watershed, including baseline lakes. Iron and manganese levels were also found to be elevated above the SEL in many of the water bodies, including the baseline lakes. Cadmium, chromium, copper, nickel, phosphorus and lead levels were typically above the lower guideline value (Lowest Effect Level - LEL), but below the SEL throughout the watershed. These findings concur with the results of other research in the region, which has shown that the levels of some metals in lakes in the Precambrian Shield are naturally above sediment quality guideline values (3).

The levels of radionuclides in sediment generally decreased with increasing distance from the tailings management area discharges. Compared to radionuclide levels in sediments from unaffected lakes, radium-226 levels in sediments from affected lakes showed the biggest increase of the six radionuclides measured. This is consistent with the activity of radium-226 in tailings porewater, which is higher than other radionuclides. Comparing sediments of unaffected and affected lakes, uranium levels in affected lakes were relatively the lowest of the six radionuclides. There was a great variability amongst historical and recent measurements of radionuclides in sediment. Trends with time were not readily discernible.

Moisture, total organic carbon, phosphorus and total Kjeldahl nitrogen in Serpent River Watershed sediments are typical of unaffected lakes, and do not appear to be changed by mining-related activities.

Fish Community

During the summer 1993 field work, 22 species of fish were collected, compared to 17 species collected in 1977 by the Ontario Ministry of Natural Resources (Table II). The main reason for the difference in species composition was due to sampling procedures rather than environmental changes.

Although fish were collected from nine lakes during the 1993 survey, this discussion focusses on Dunlop, Elliot, Quirke, Whiskey, Pecors and McCarthy Lakes because in 1977 the MNR conducted a detailed fisheries impact assessments on these same lakes. In 1977, Dunlop and Elliot Lake were used as control lakes while Quirke, Whiskey, Pecors and McCarthy Lake were viewed as potentially affected lakes. Where possible, the level of effort and sampling locations used in 1977 were utilized in 1993.

Fish relative abundance and total biomass have greatly increased within Quirke, Whiskey, and

Table II: Serpent River Watershed Fish Species

Scientific Name	Common Name	1993	1977
<i>Couesius plumbeus</i>	lake chub		X
<i>Luxilus cornutus</i>	common shiner	X	X
<i>Margariscus margarita</i>	pearl dace	X	
<i>Notemigonus crysoleucas</i>	golden shiner	X	
<i>Phoxinus eos</i>	northern redbelly dace	X	
<i>Pimephales promelas</i>	fathead minnow	X	
<i>Semotilus atromaculatus</i>	creek chub	X	
<i>Catostomus catostomus</i>	longnose sucker	X	X
<i>Catostomus commersoni</i>	white sucker	X	X
<i>Ameiurus nebulosus</i>	brown bullhead	X	X
<i>Osmerus mordax</i>	rainbow smelt	X	X
<i>Coregonus artedii</i>	cisco or lake herring	X	X
<i>Coregonus clupeaformis</i>	lake whitefish	X	X
<i>Prosopium cylindraceum</i>	round whitefish		X
<i>Salvelinus fontinalis fontinalis</i>	brook trout	X	X
<i>Salvelinus namaycush</i>	lake trout	X	X
<i>Lota lota</i>	burbot	X	X
<i>Culaea inconstans</i>	brook stickleback	X	
<i>Ambloplites rupestris</i>	rock bass	X	X
<i>Lepomis gibbosus</i>	pumpkinseed	X	X
<i>Micropterus dolomieu</i>	smallmouth bass	X	X
<i>Etheostoma exile</i>	Iowa darter	X	
<i>Perca flavescens</i>	yellow perch	X	X
<i>Stizostedion vitreum vitreum</i>	walleye	X	X
Total Number of Species Caught		22	17

Pecors Lakes, with only a slight increase for Dunlop Lake between 1977 and 1993. A slight decrease in abundance and biomass was found for McCarthy Lake while there was a dramatic decrease for Elliot Lake. Figure 4 illustrates the differences in relative abundance and biomass between the two studies.

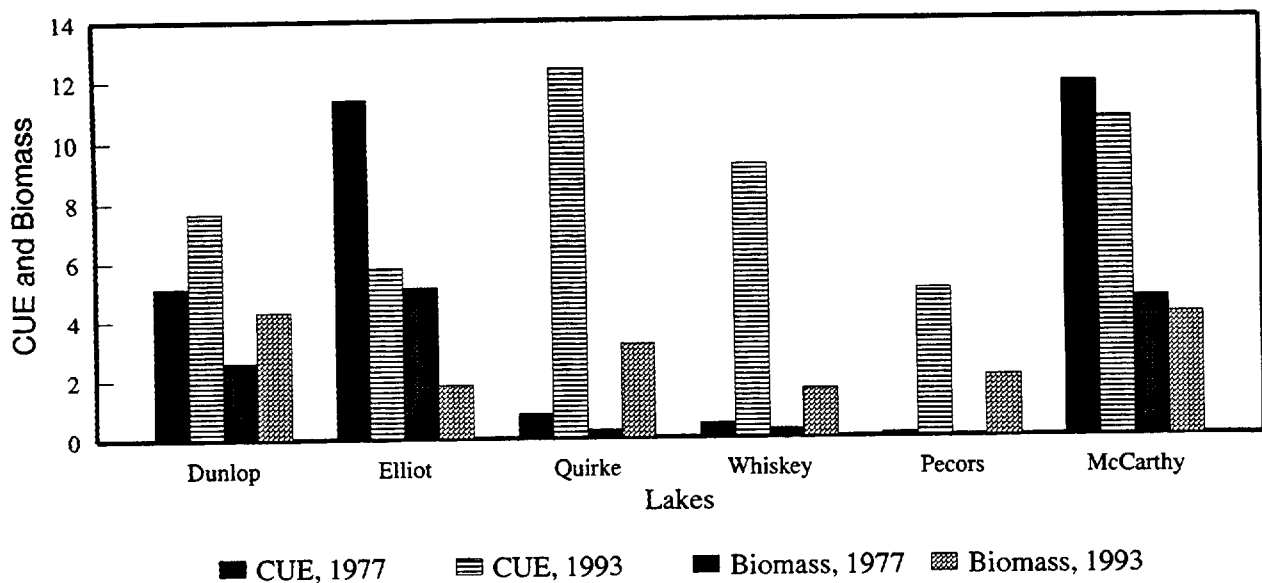


Figure 4: Comparison of Relative Abundance (CUE) and Biomass Between the 1977 and 1993 Surveys
CUE - # fish/overnight set/100 ft. net, Biomass - kg of fish/overnight set/ 100 ft. net.

The greatest improvement was found in the lakes which were most severely impacted in the past by mining activity. Of particular importance is the success of the reintroduction of game fish to Quirke Lake and Whiskey Lake. Data collected in 1993 indicate that lake trout within Quirke Lake are now naturally reproducing, with smallmouth bass naturally reproducing throughout the watershed. The growth rate of lake trout within Quirke Lake was only marginally slower than that for Elliot and Dunlop Lake (Figure 5), a significant improvement since 1977 when lake trout had been extirpated from Quirke Lake.

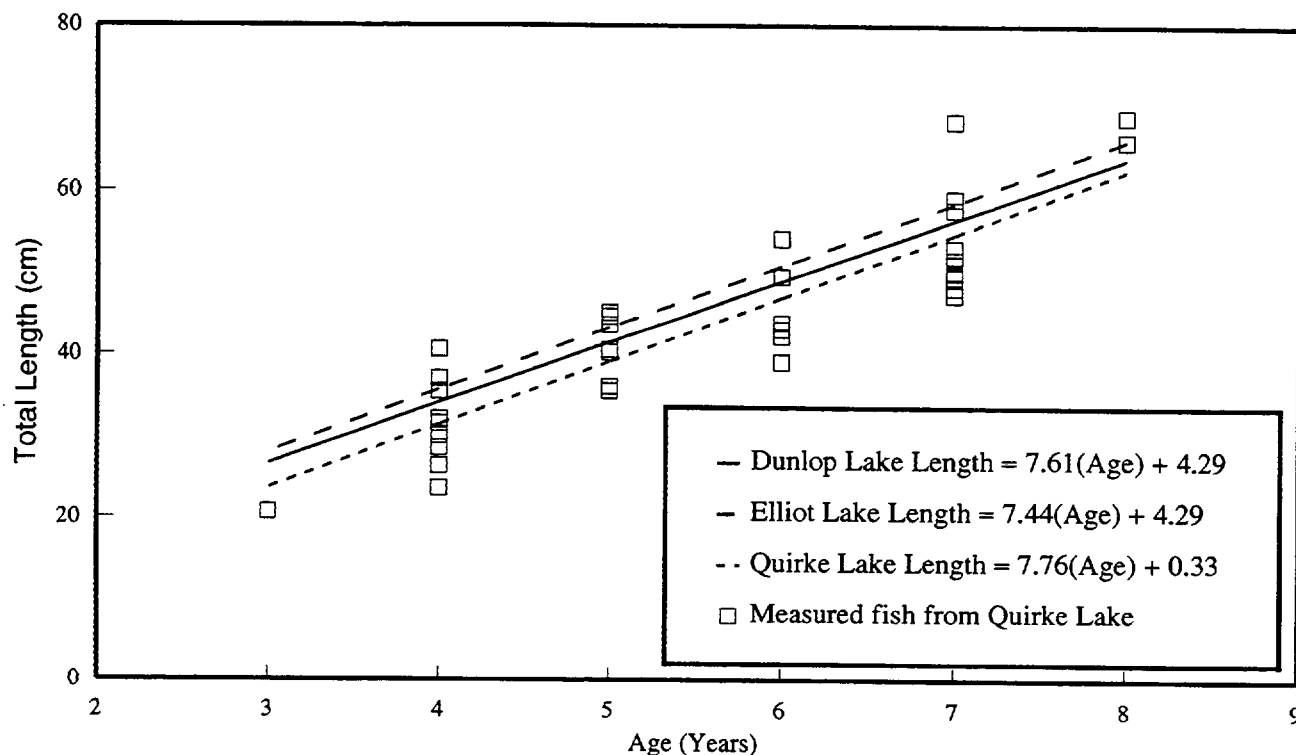


Figure 5: Lake Trout Growth in Quirke Lake Versus Elliot Lake and Dunlop Lake

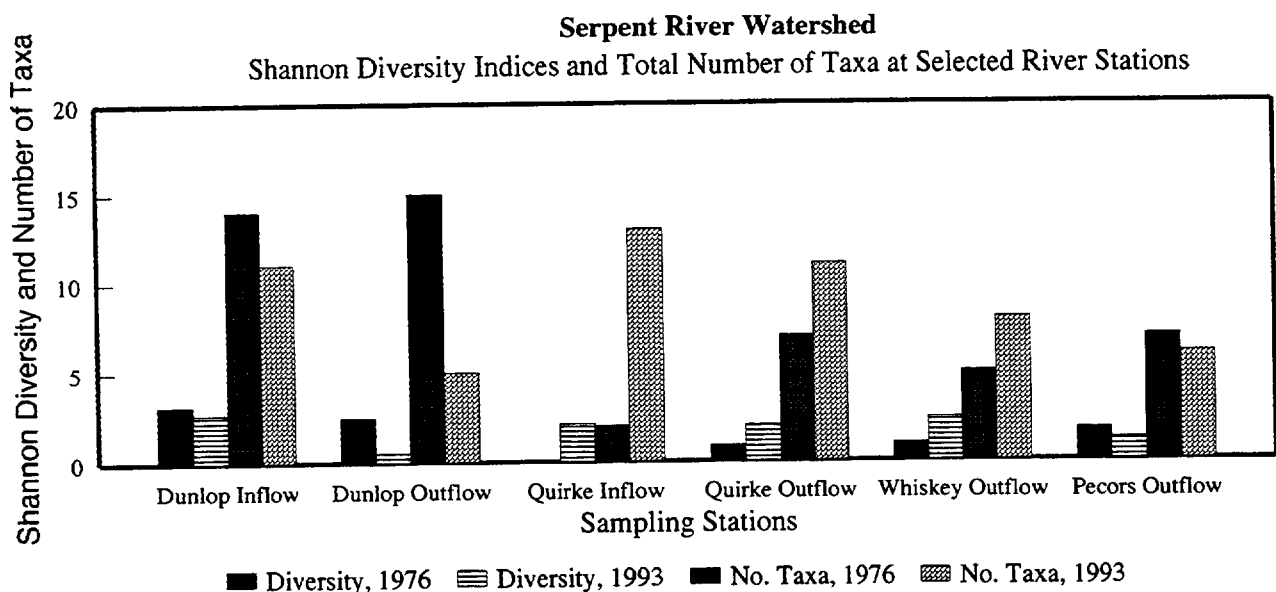
Benthic Community

At river sampling stations, the benthic macroinvertebrate fauna is dominated by caddisflies and blackflies, which account for 91% of all organisms collected. Caddisflies were the most abundant group and accounted for 52.5% of all benthic organisms captured, while blackflies accounted for 38.5%.

Improvements in the benthic macroinvertebrate population downstream of mine discharges were greatest in the Serpent River at the Quirke Lake inflow and outflow and the Whiskey Lake outflow (Figure 6). The Serpent River outflow from Pecors Lake showed little change. Between studies, the Dunlop Lake inflow was similar, while the Dunlop Lake outflow showed signs of stress. The change in benthic community at the Dunlop Lake outflow was attributed to water level manipulations within the lake.

The benthic community within the lakes of the Serpent River watershed showed similar signs of improvement as did the river stations. One exception to this was the communities of the McCabe-May-Hough Lake chain. The benthos within this chain of lakes remains indicative of poor water quality.

Generally the benthic community within the Serpent River watershed has improved greatly from 1976 to the present. Large improvements to the benthic populations within the upper reaches of the watershed, i.e. Quirke Lake and Whiskey Lake, have been documented while benthos in the lower reaches remain relatively similar to those found in 1976. As with the fisheries data, benthic data show greatest recovery in lakes that were previously most affected.



Figures 6: Comparison of Diversity Indices and the Number of Taxa at each Sampling Stations
No diversity index was calculated for Quirke Lake Inflow (1976) due to low numbers of benthos.

Conclusions

Water quality trends have shown a continuing improvement since mine effluent treatment was initiated in the 1960's. Sediment quality data indicate spatial differences in levels of radionuclides, with activities being higher near sources. The radionuclide content of sediment however is not a concern. Benthic density and diversity are much higher throughout the river reaches downstreams of mine-related discharges. Fisheries in affected lakes (Quirke, Whiskey, and Pecors) are greatly improved since 1977.

With the exception of the McCabe-May-Hough lake chain, the water quality as it stands today in the Serpent River Watershed is not an impediment to fish viability or benthic productivity.

The overall health of the aquatic habitat in the Serpent River continues to improve, with the exception of the McCabe-May-Hough lake chain. With the planned closing of the only remaining operating mine scheduled for 1996, and eventual decommissioning of the waste management area, it is anticipated that the health of the aquatic habitat in the McCabe-May-Hough lake chain will also recover, following the trend of continuing improvement of the rest of the Serpent River Watershed.

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