Environmental Recovery at the Elliot Lake Historical Mines Sites.

(R692.1)

REPORT

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NOTES

This report is in two sections:

a) ***Metals and radionuclides contribution from a watershed containing former U operations and an adjacent watershed with unexploited U deposits to Lake Huron.***

and

b) Human intake of radionuclides from biota near Elliot Lake, Ontario.

The sections are accompanied by, and to be read with, databases:

SR and MR water-sediment dB BASEss.xlsx

BIOTA db radionuclides-metals (narrative).doc

BIOTA radionuclides-metals dB (digital).xlsx

Sections in the report will be incorporated into one or more papers, on the recovery of the Serpent River watershed after uranium operations ceased, to be submitted for publication in the scientific literature.

Metal and radionuclide contributions from a watershed containing former U operations and an adjacent watershed with unexploited U deposits, to Lake Huron.

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EXECUTIVE SUMMARY

Assessment of environmental recovery requires knowledge of baseline contamination prior to initiation of activities (the *status quo ante*). At Elliot Lake, mining activities in the 1960s began without a compresensive minesite pre-operationl Environmental Impact Study (EIS) and with limited knowledge of baseline conditions. In this study, we present sedimentary core profiles that will be used to estimate background concentrations in Lake Huron that have been altered by the Uranium operations upstream. We also measured radionuclides and metals in water and sediment in the impacted (Serpent River) watershed and an adjacent non-impacted (Mississagi) watershed. These water and sediment concentrations ill be used to derive background concentrations at the time operations were closing down. This study demonstrates how sediment , water, and sediment analyses help in estimating historical background concentrations in an impacted watershed where no preoperational minesite EIS was carried out. The environmental concentrations presented in this study will help in evaluating the environmental recovery in the Serpent River Watershed.

1.0 Introduction

Uranium bearing ores have been mined and milled near the City of Elliot Lake, Ontario, for over sixty years. Industrial activity around Elliot Lake has resulted in about 180 x 10^6 tonnes of mixtures with varying amounts of mill 'tailings' (finely divided and **U**-depleted ore) and mine wastes spread over approximately 260 ha in 'management areas' behind retaining dams and berms. The management areas have been treated in several ways; some acid-producing and radium-rich tailings were revegetated while others were flooded. Materials, including radionuclides, escape from the tailings as a result of wind scouring of un-compacted deposits, as gaseous emissions (Radon), and in solution in leachates that result from chemical and microbial activities in the deposits. Drainage liquids are treated with lime and barium salts to precipitate, and so remove, metals, including radium, before being released to minimize or avoid risks to human and other life. The mining and milling operations ceased in 1996 and the sites were decommissioned. Environmental monitoring is being conducted to track recovery of the Serpent River Watershed (SRW) and can only be discontinued when the environment has recovered.

Environmental recovery objectives are difficult to determine at these sites because no pre-operational mine-site study was made prior to initiation of mining operations. This presents difficulties for regulators wishing for a return to the *status quo ante* (as those conditions are uncertain) following the end of mining and milling operations. In the absence of data from studies done before exploitation of an area, there are two approaches that can be used to determine if an impacted environment has returned to its natural state.

First, sedimentary core profiles represent direct evidence of historical contamination. If sediment cores are penetrated deep enough into sediments, they can also provide the contaminant concentration prior to operation (McKee *et al*. 1985; Ecometrix 2011). These concentrations can then serve as a basis to set recovery objectives for sediments.

A second method (the reference condition approach) can also be used to determine if an impacted site has likely recovered [1,2]. This approach consist of comparing levels of items of interest in water and sediments in an impacted area to a non-impacted area. Similarity in water and sediment contamination (when comparing the two) can be a indication of complete recovery if these approximate to each other.

The work reported here was in three steps:

a) An assessment of the spatial extent of contamination was performed by analysing radionuclides and other elements, especially metals, in water and sediments at various distances from the mine and mill sites (to examine spatial aspects) towards the end of the active life of the Elliot Lake operations in the SRW;

b) Analysis was carried out on radionuclides and other elements, especially metals, in the sediment from the bottom of Lake Huron (North Channel) at the mouth of the Serpent River. This sediment, deposited since the retreat of Laurentide ice sheet that scoured the area up to several thousand years ago (Wright, 1971) is of particular interest as it reflects, in its composition such events as the onset of industrial activity and atmospheric nuclear weapon testing. This aspect of the study provided insight into temporal aspects of industrial activity.

c) An examination of radionuclides and metals in the adjacent comparable, but unexploited, Mississagi River Watershed (MRW) was performed to assess the relative contributions of the industrialized and near-pristine watersheds to radionuclide (and metal) inputs to the Great Lakes. This examination provided an entry to the reference condition method mentioned above. In conjunction with the core profile approach described in c) this helped clarify the recovery of the SRW as industrial activities were closing down.

2.0 Site description

The Elliot Lake mining area is in the SRW that drains through the Serpent River to the North Channel of Lake Huron at Serpent Harbour (SH). The MRW immediately adjacent (to the west) of the SRW, drains via the Boland and Little White Rivers to the Mississagi River entering the North Channel near Blind River. This second watershed contains uraniferous deposits but has seen no uranium mining and milling activities (in contrast to those in the Serpent River catchment basin) and provides a useful baseline for comparative studies. The MRW has proven but unexploited uraniferous rocks, some occuring as outcrops on its surface. Robertson and Gould, 1983 report in their survey that in Little White River area of Albanel Township (in the MRW): *Radioactivity of 10 to 20 times the background is not uncommon. Locally this may rise to 40 times the background where quartz pebbles are present.* Selected samples of Mississagi quartzite assayed up to 0.04% U_3O_8 (0.8 lb/t) in the area.

As indicated above, both watersheds drain to the North Channel of Lake Huron. This channel is isolated to some degree from the main body of Lake Huron by Manitoulin Island and others islands to the west that contain it except for several gaps through which water moves in and out of the main waterbody. Although the circulation in the main body of Lake Huron is overwhelmingly counter clockwise (Beeton and Saylor, 2014), movement within the North Channel is predominantly West to East exiting, at several knots, to Georgian Bay at Little Current at the Northeast of the Island. Circulation varies according to winds and other variables and the direction of flow in the North Channel reverses from time to time (Forrester, 1961). These variations have implications for the distribution of waters and sediments entering the channel from the Mississagi and Serpent Rivers.

These accessible and adjacent systems provided a special and convenient opportunity to study the spatial, temporal (historical), and relative effects of industrial activity (uranium mining and milling) on the SRW, from inception to close-down, using the MRW as a convenient control and reference as required. Clearly, a comparison of the two watersheds provides both an estimate and comparison of the current and historical radionuclide (and metal) inputs into Lake Huron of the industrialized watershed SRW compared to the non-industrialized MRW. This is clearly useful in providing an approximation of the characteristics of the SRW (including radionuclide inputs to Lake Huron) before industrialization; such knowledge is of use in setting the objectives to be attained when operations have ceased.

3.0 Methods

3.1 Water sampling

Water pH values were taken in the field. Triplicate water and sediment samples were taken the length of each water course (starting at the exit from Quirke Lake in the SRW and at the exit of Semiwhite Lake in the MRW) every ~2 km down the watercourses into the North Channel and for 25 km (every 5 km) east and west of the entry points of the rivers into the channel (Figure 1) over several months during reduced flows in the rivers. Sample location coordinates, along with water depth, bottom characteristics, and other observations are presented in the associated database. Water samples were collected at each site from 50 cm below the surface using a Van Dorn bottle. Water was transferred from the sampler to plastic bottles that were previously rinsed in lake water. Half of the 2 L water samples were acidified with 20 mL of 1 N HCl in the field and and kept cool until radioanalysis. Water collected in the field but not acidifed was filtered at 45µm in order to analyse for dissolved radium and metal concentrations, acidified for stability and stored at 4°C until analysis.

3.2 Water flow rates

Water flow rates were obtained from the online databases of Environment Canada reachable at (for example):

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=02CC008&mode=Table&type=h2oArc&results_type=historical&dataType=Daily&parameterType=Flow&year=2011&y1Mean=1&scale=normal

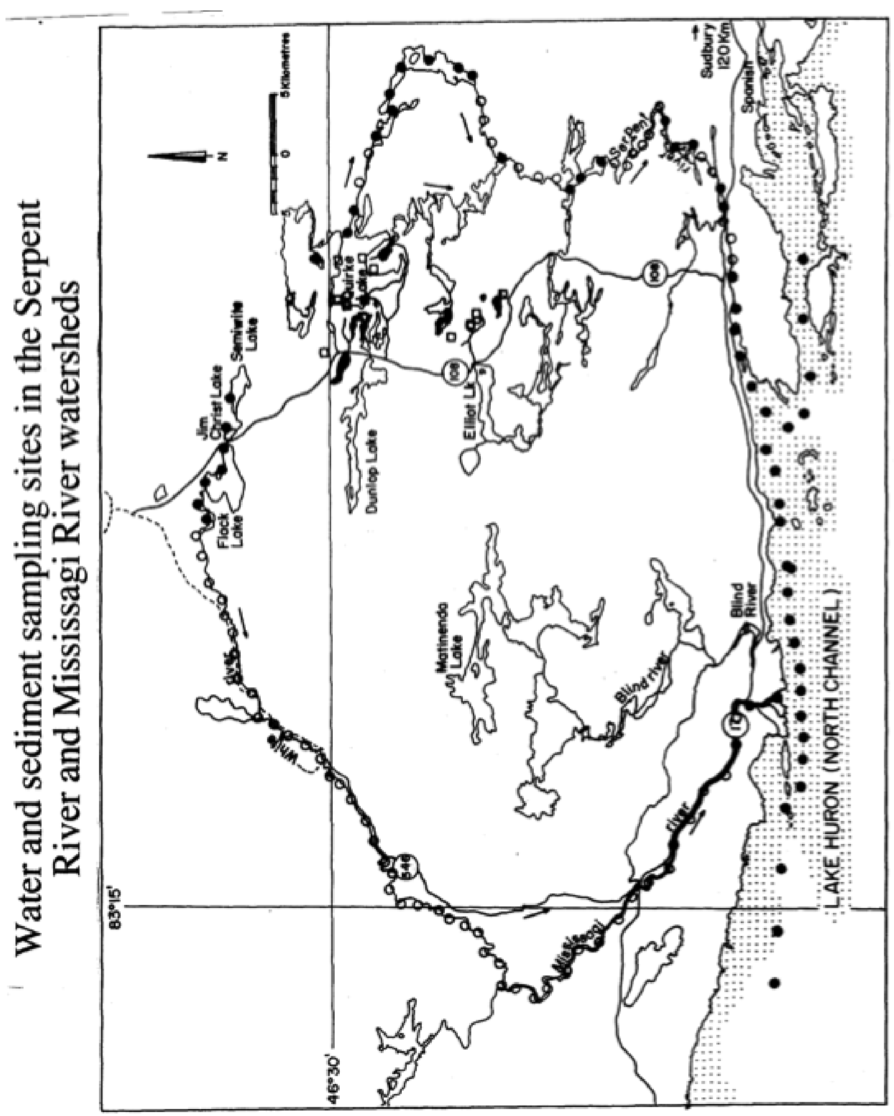
these records incorporate Ontario records from the Ministry of Energy and Environment.

3.3 Sediment Sampling

Sediment samples were taken at each site using an Eckman dredge, and were placed in clean plastic bags and placed on ice for transport to the laboratory. Once at the laboratory sediment samples were dried (110 °C for 24-48 h), crushed for 10 min in a SPEX Shatter Box 8500, and stored in air-tight plastic containers prior to radioanalysis.

Two sediment cores (SH2 and SH3) taken from the estuary of the Serpent River ('Serpent River Harbour'), at the sites indicated in the database, using a standard corer, chilled, sliced horizontally at 2mm and 10mm, then kept at 4°C until analyzed.

Figure 1. Site description with sampling sites indicated.



3.4 Analyses

Sediment samples were digested using standard methods and extracts were stored at 4°C until analysis. All samples were analyzed for radionuclides and metals at the Elliot Lake Research Field Station of Laurentian University. Ra-226, ^{232}Th, ^{230}Th, and ^{228}Th were measured using high-resolution α-spectrometry counting methods, described in detail elsewhere (Lim & Davé, 1981) with regard to methods, detection limits, quality assurance, and quality control; and metals and metalloids were analyses by atomic absorption. Radium-226 in sediment samples was determined, following complete digestion of solid samples, dissolution to a clear solution, and precipitation of Ra-Ba sulphate, by high-resolution α-spectrometry. The method gives very reliable measures down to 5 mBq g^{-1} and is usable below this level with less reliability. Analytic and measuring methods are described in detail elsewhere (Lim & Davé, 1981).

Radium-226 was separated from the thorium-isotope fraction by precipitation with $PbSO_4$. To the thorium-isotope fraction, 0.1 mL of a 0.5 mg ml^{-1} cerium carrier solution was added. After adding 2.5 ml of 10 N NaOH, the solution was heated for 15 min. then cooled for 15 min. Precipitate was collected with a 0.2 µm membrane filter. To minimize sample loss, analytical equipment and precipitate were rinsed with 80% methanol. After samples were allowed to dry, ^{232}Th, ^{230}Th, and ^{228}Th, activities were determined using high-resolution α-spectrometry, as in the detection of ^{226}Ra.

A barium-133 (^{133}Ba) tracer solution added to the starting solid sample allowed measurement of the overall chemical recovery of ^{226}Ra; recovery rates of ≥80% of the amount of ^{133}Ba added by spiking were usual in the study. Samples were typically counted for 6000 s or more to minimize counting variability to less than 10% at the 20 mBq g^{-1} range. Analytical results for a given sample specimen included propagated counting and radiochemical and analytical recovery factor errors. Several approaches were followed for quality assurance and quality control (QA/QC) of the radionuclide data reported here. First, routine procedure involved calibration of the analytical system itself by certified NBS calibration standards. Second, the standard method, involving recovery of ^{133}Ba added to samples prior to digestion to measure analytic recovery of the radiological procedure, when applied to samples of cow shank bone (NBS material) spiked with known amounts of ^{226}Ra and ^{133}Ba, showed a recovery rate of 98±10%. Third, the QA/QC program of the laboratory (ELRFS) includes check analyses, as a matter of routine, of: a) certified CANMET uranium tailings samples DL-1 and DL-2; b) standards and blanks analysed along with samples; and c) liquid, solid, and biological samples also analysed by other facilities, as cross-checks. These checks indicated ≤10% variation.

Quality Assurance information is included in the accompanying database.

4.0 Results

4.1 Water quality

With the exception of Kindle, Pecors and Whiskey lakes, where pH was below 5.0, water pH in the SRW and in the MRW are consistently around pH 6 even in Lake Huron. TDS, sulfate, Gross Alpha and Beta, Ra-226, and Uranium are higher in SRW than MRW. Generally, concentrations decline with distance but with evident elevations in concentrations at some sampling sites. For instance, the increase in total dissolved solids (TDS) and sulfates in the Missisagi River (Figures 5 & 7) is associated with proximity to roads. Also, the increase in Uranium in the Mississagi River, although still low (6 µg/l) could be attributed to mineralization areas. Zinc levels in the SRW and MRW are similar.

Figure 2. pH downstream of Quirke Lake in the Serpent River and Lake Huron.

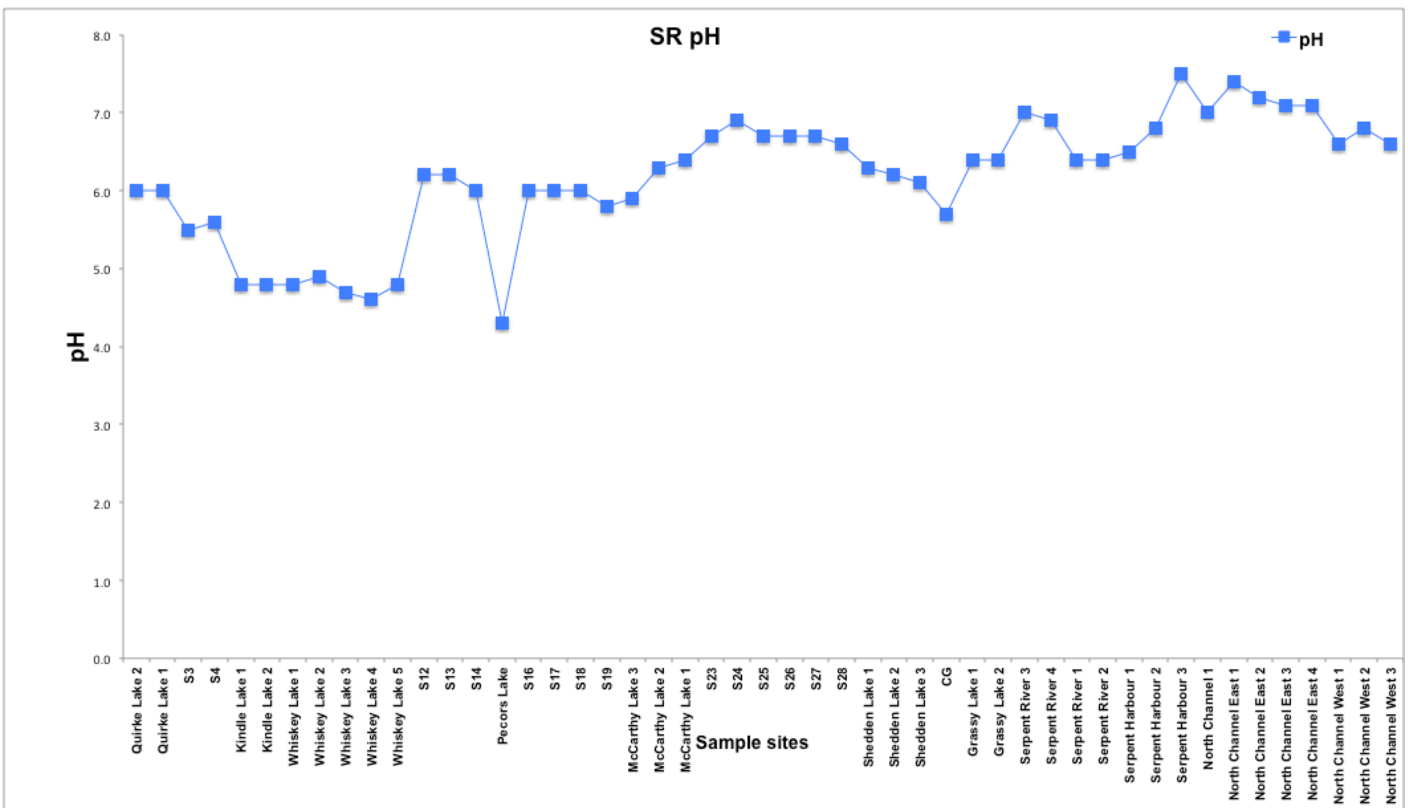


Figure 3. pH downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

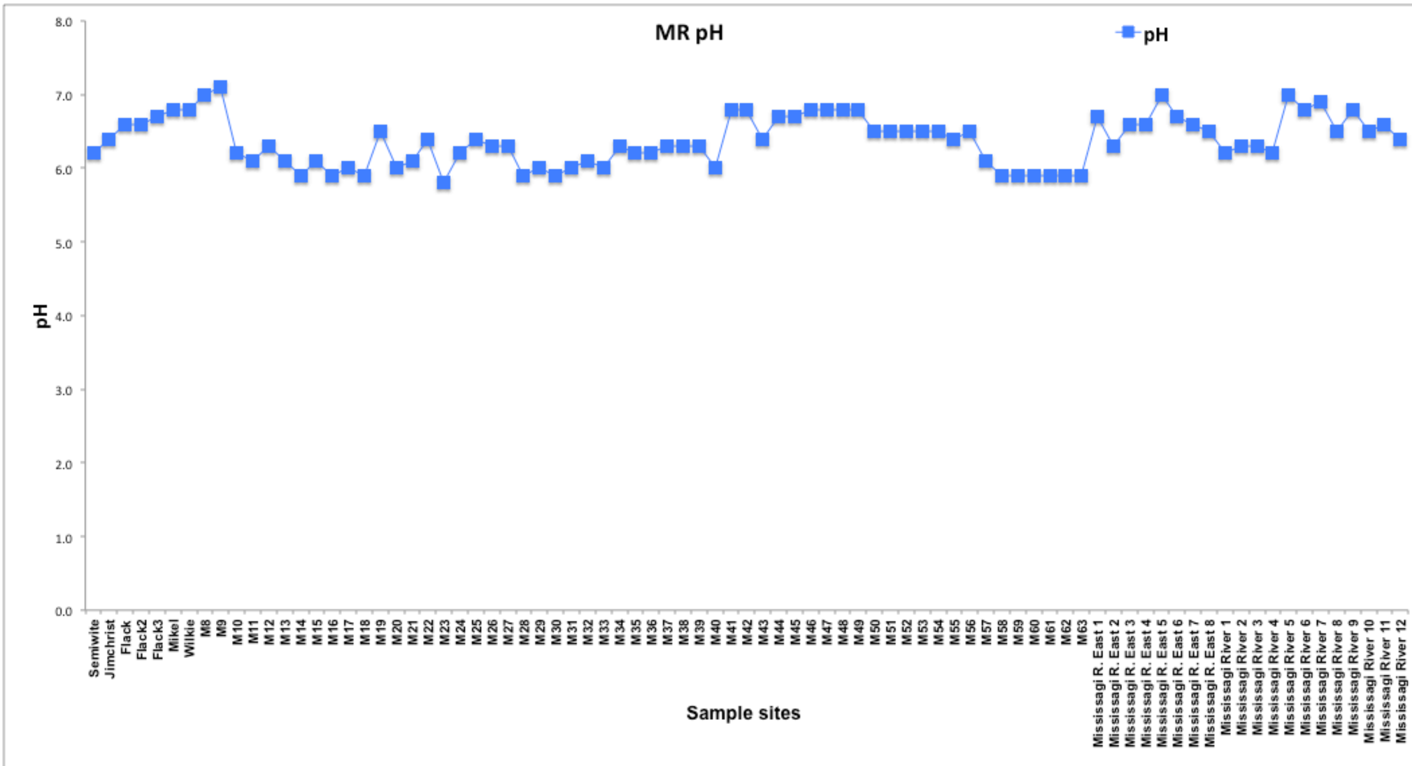


Figure 4. Total dissolved solids (TDS) downstream of Quirke Lake in the Serpent River and Lake Huron.

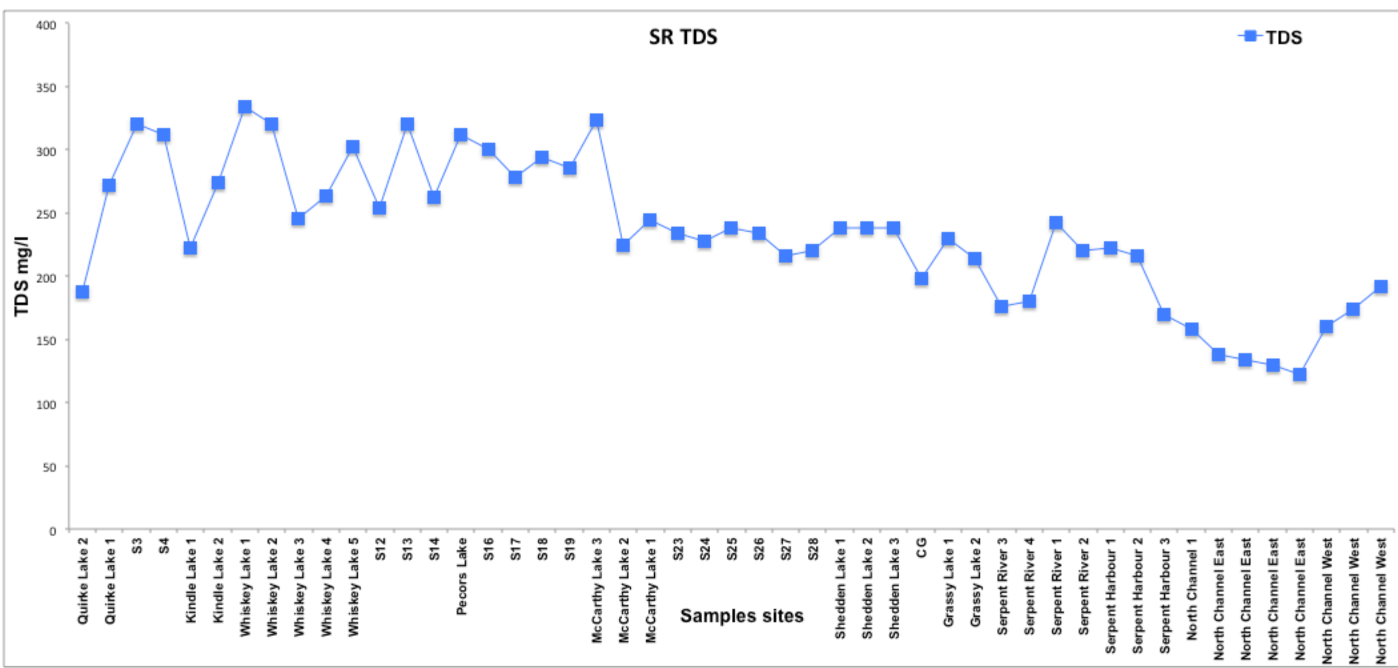


Figure 5. TDS downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

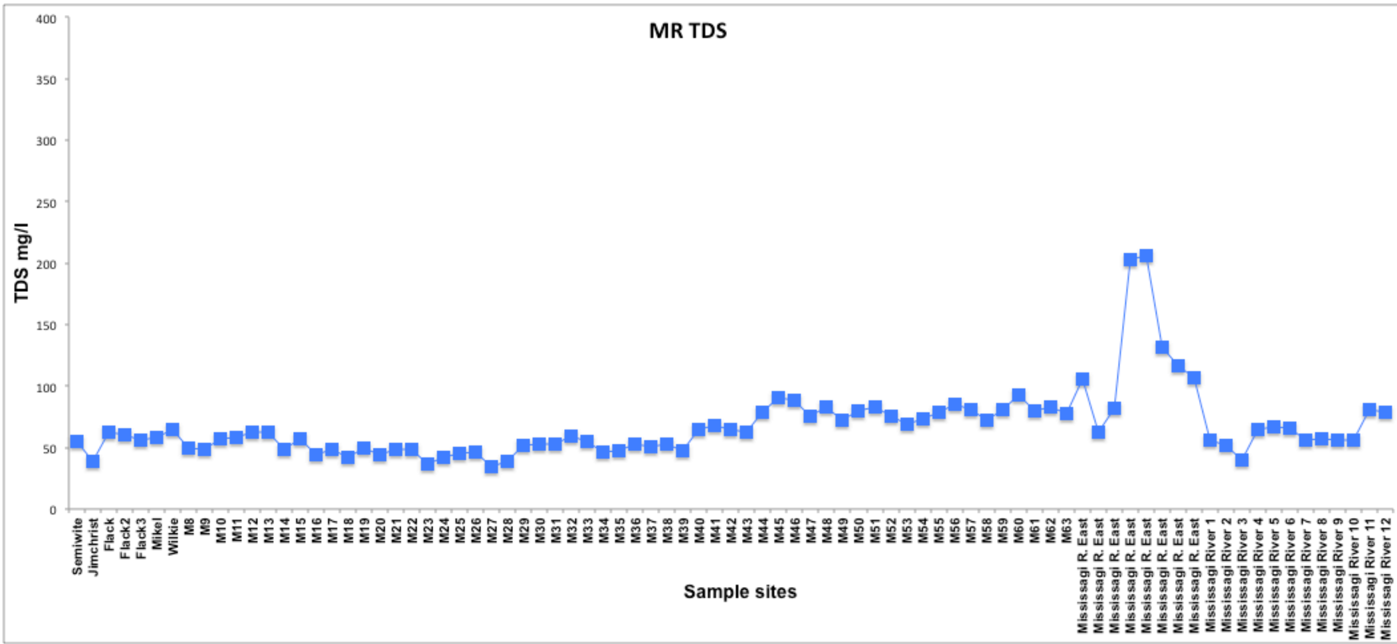


Figure 6. Sulfate downstream of Quirke Lake in the Serpent River and Lake Huron.

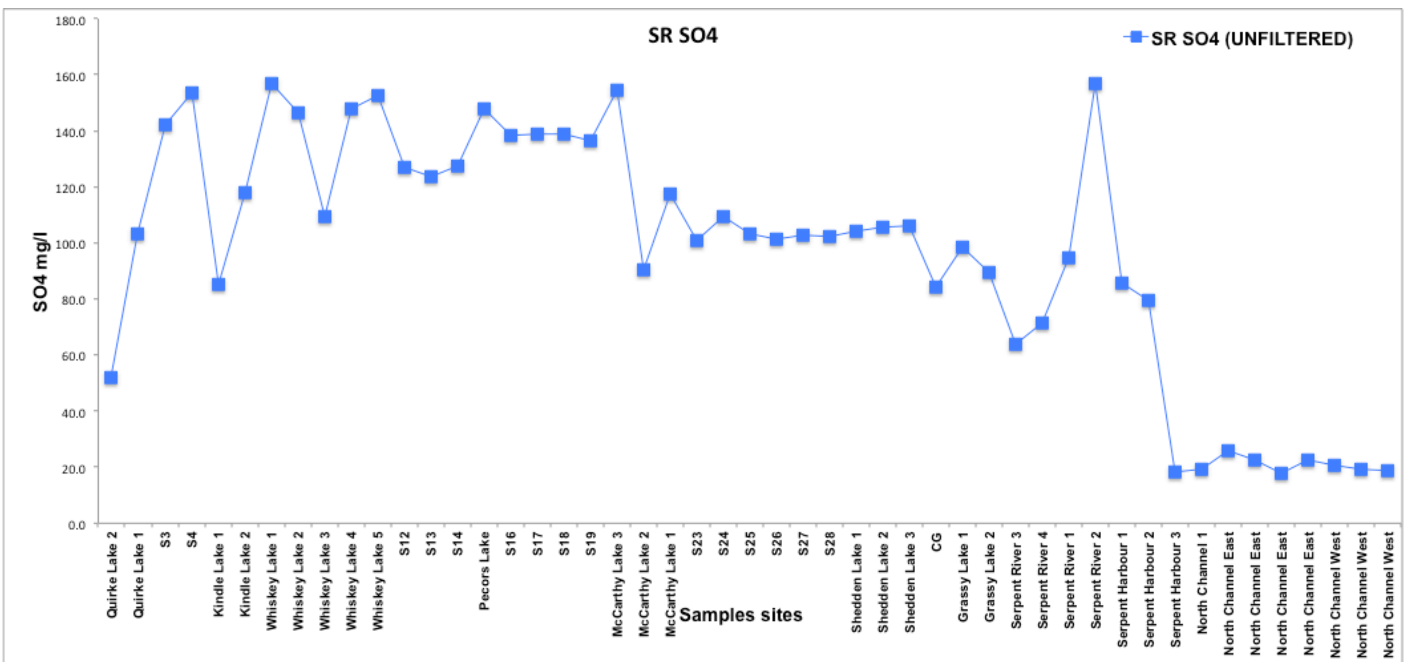
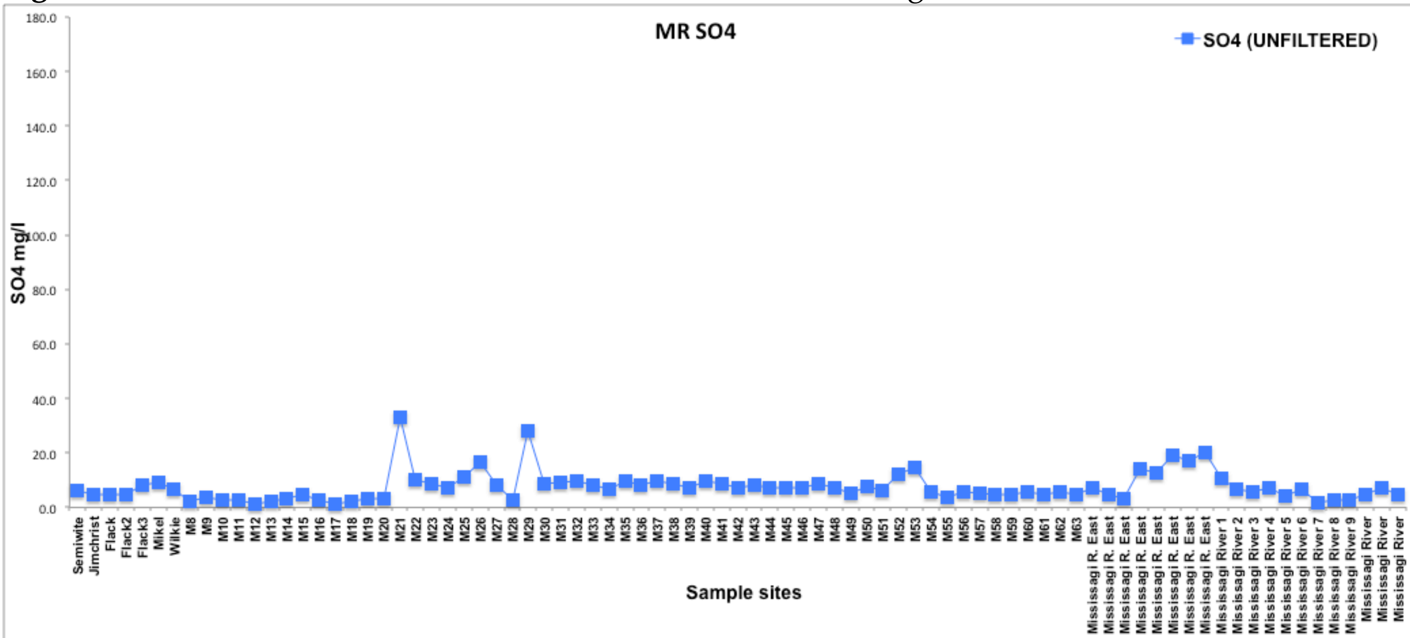


Figure 7. Sulfate downstream of Semiwhite Lake in the Mississagi River and Lake Huron.



4.2 Activity in water

Figure 8. Gross alpha downstream of Quirke Lake in the Serpent River and Lake Huron.

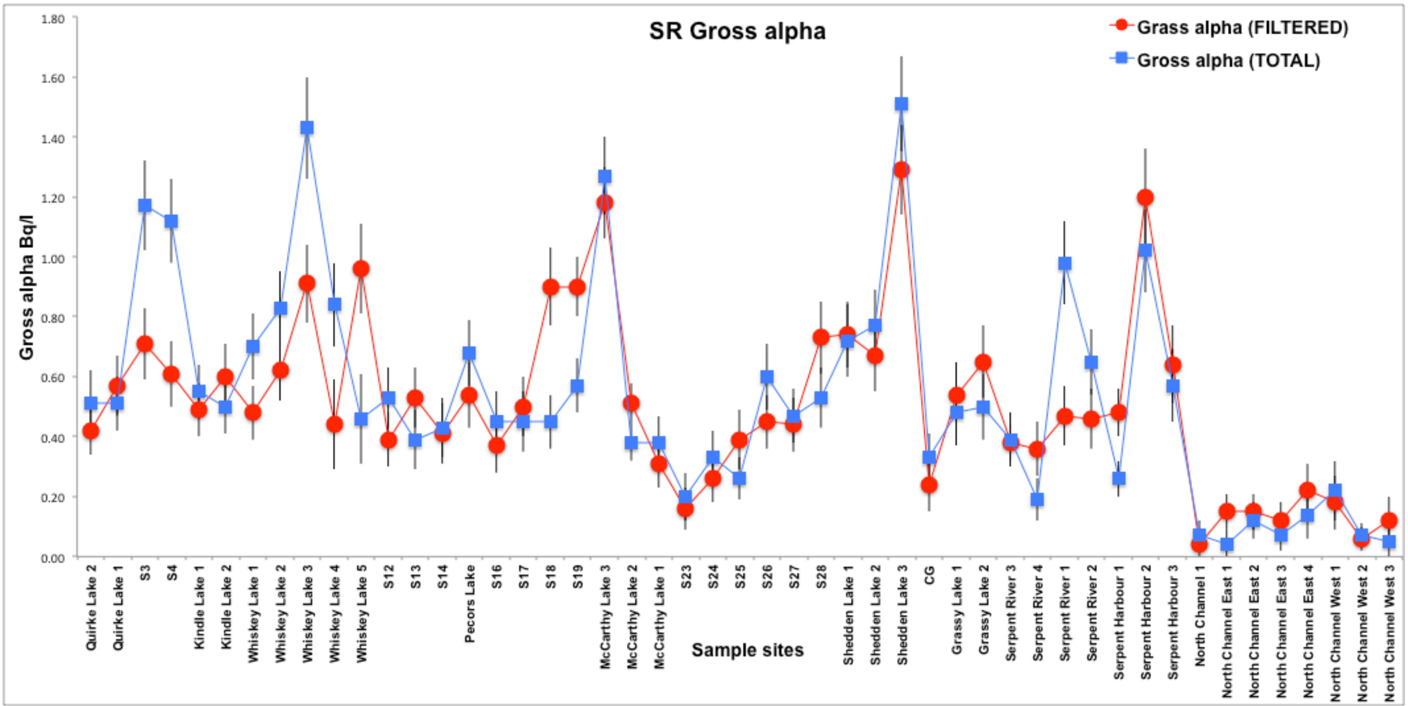


Figure 9. Gross alpha downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

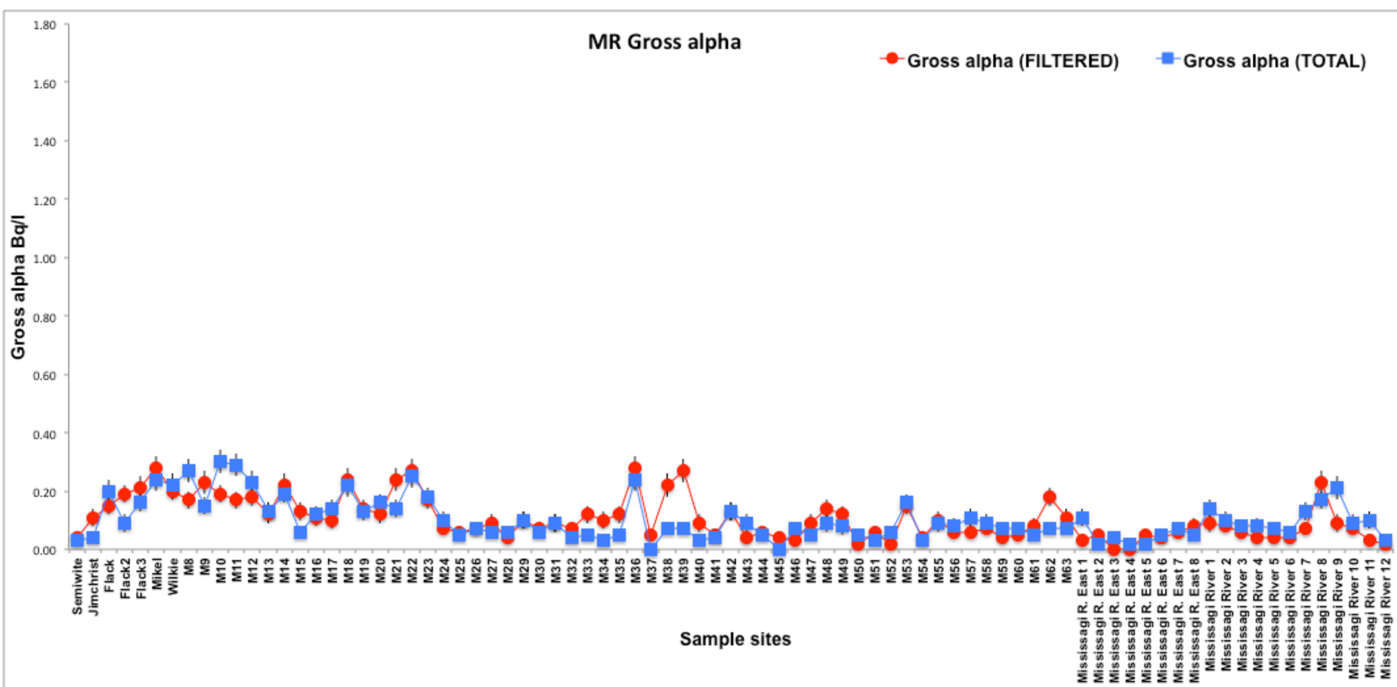


Figure 10. Gross beta downstream of Quirke Lake in the Serpent River and Lake Huron.

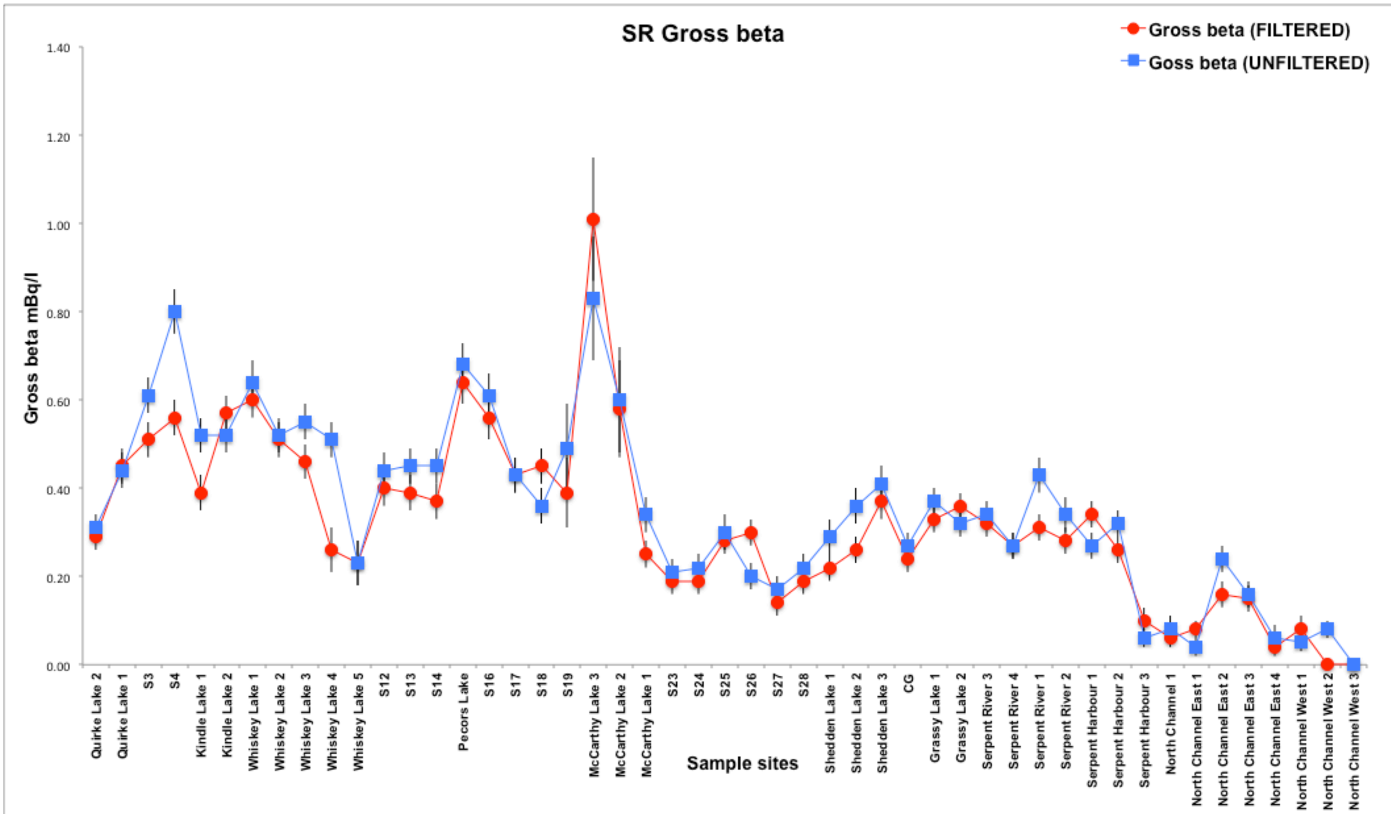


Figure 11. Gross beta downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

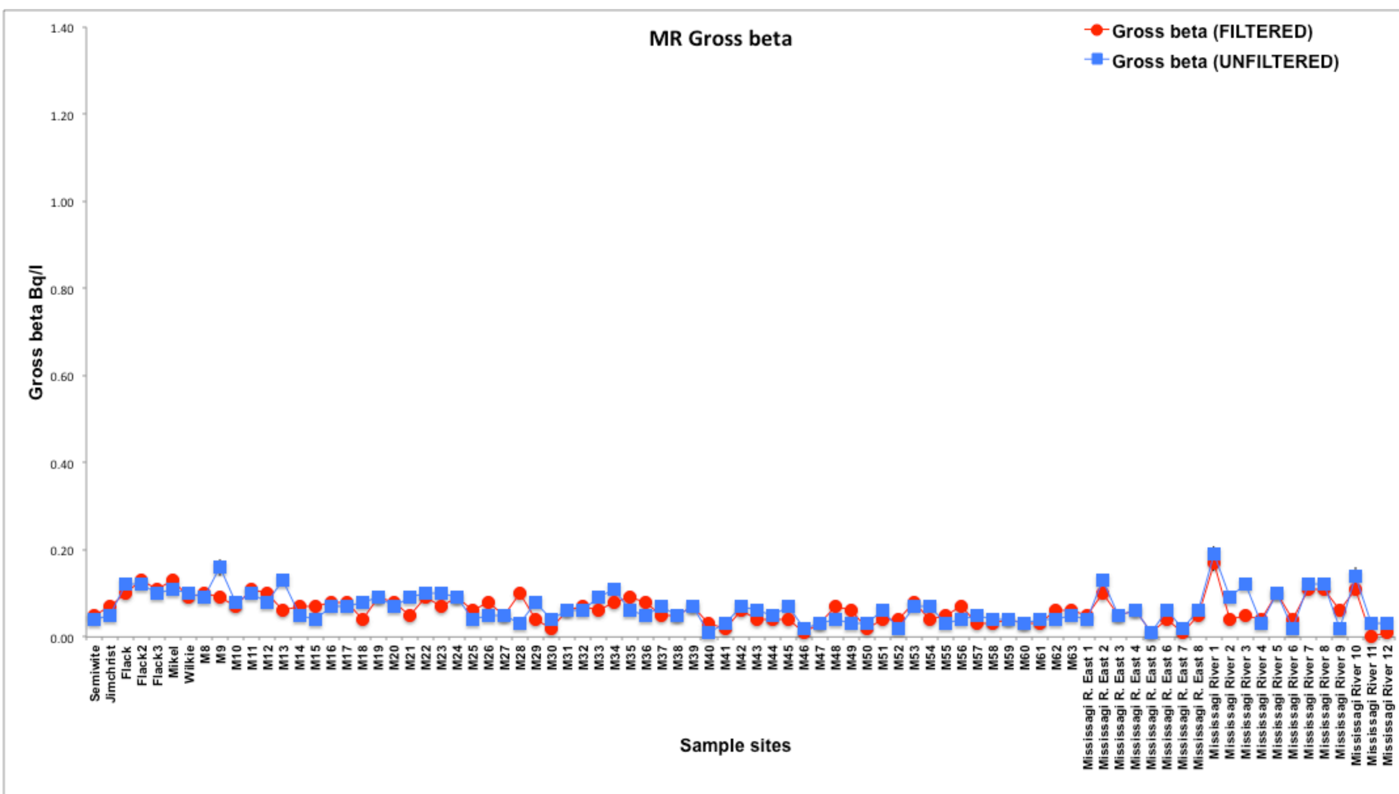


Figure 12. Radium downstream of Quirke Lake in the Serpent River and Lake Huron.

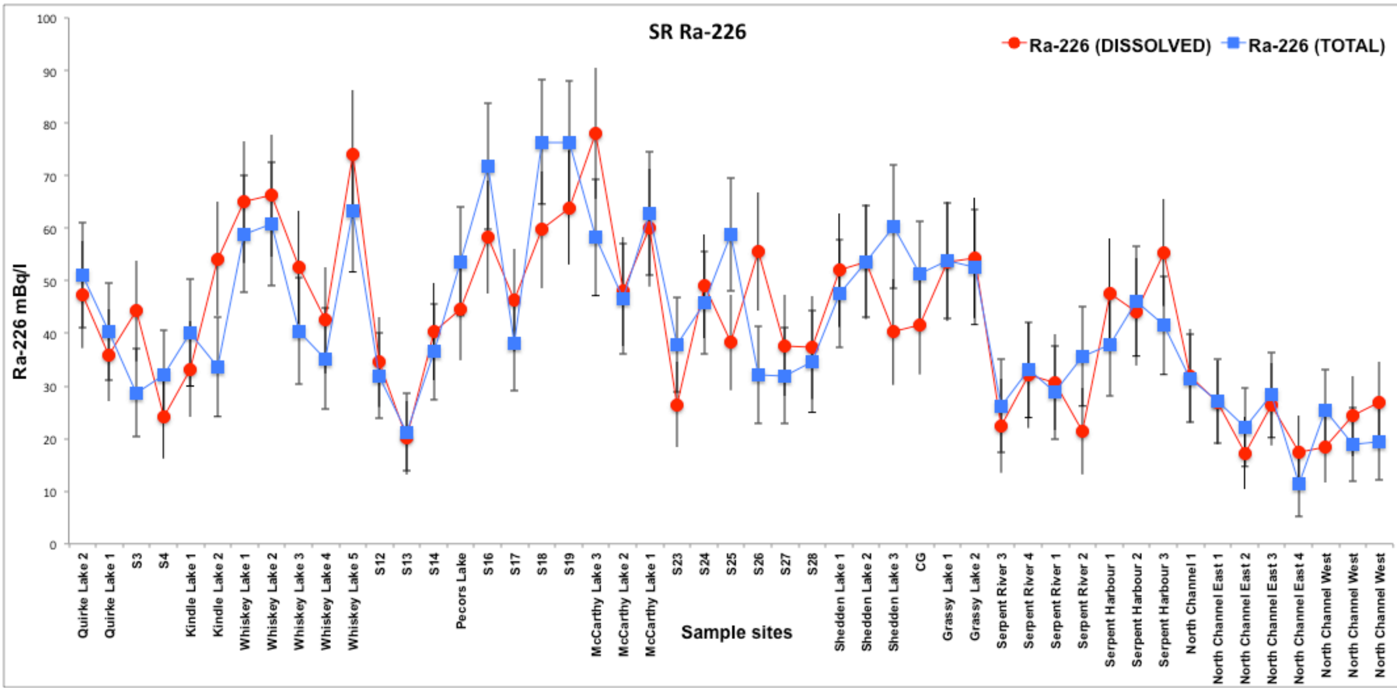
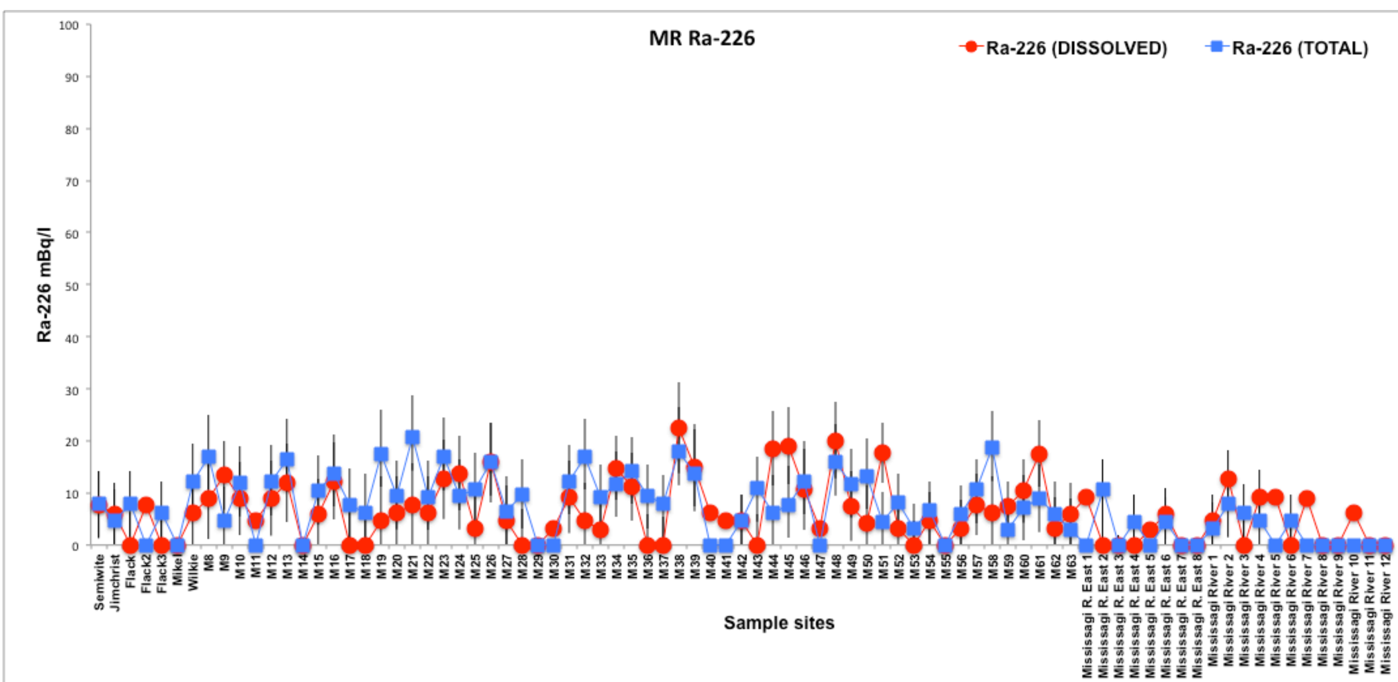


Figure 13. Radium-226 downstream of Semiwhite Lake in the Mississagi River and Lake Huron.



4.3 Metals in water

Figure 14. Zinc downstream of Quirke Lake in the Serpent River and Lake Huron.

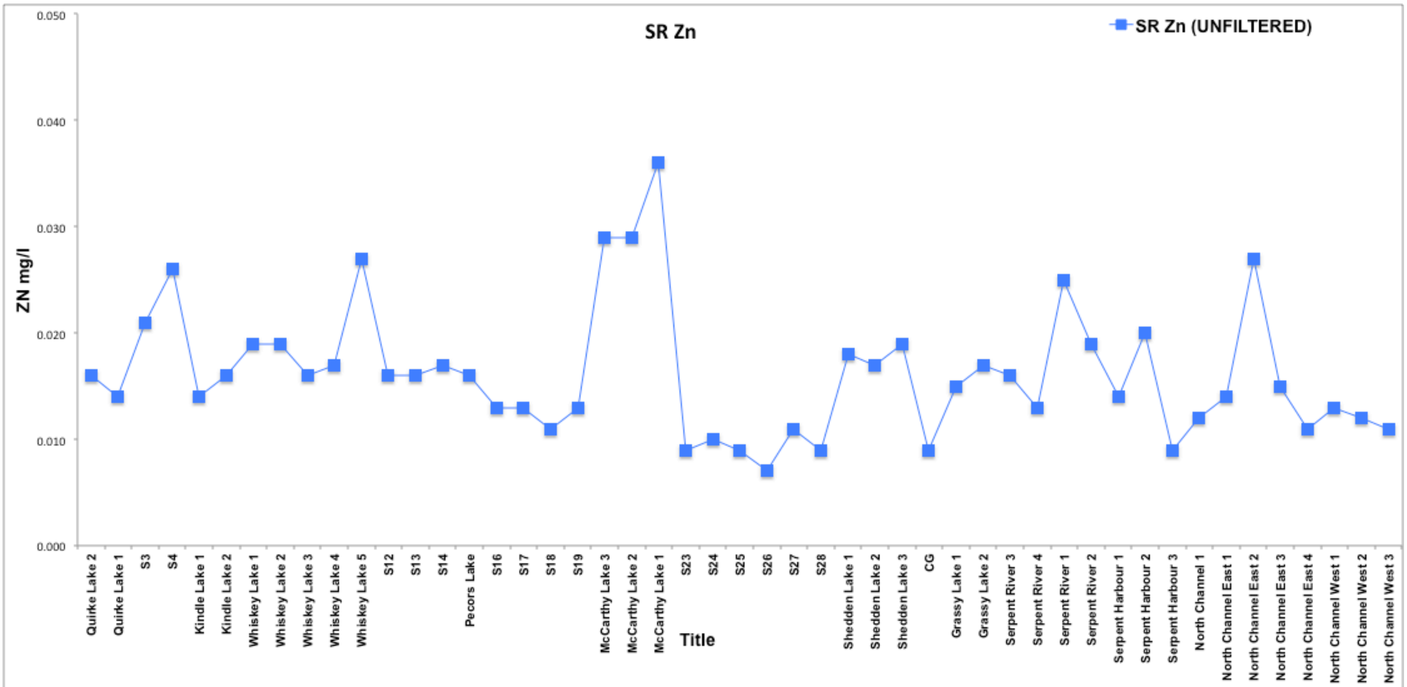


Figure 15. Zinc downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

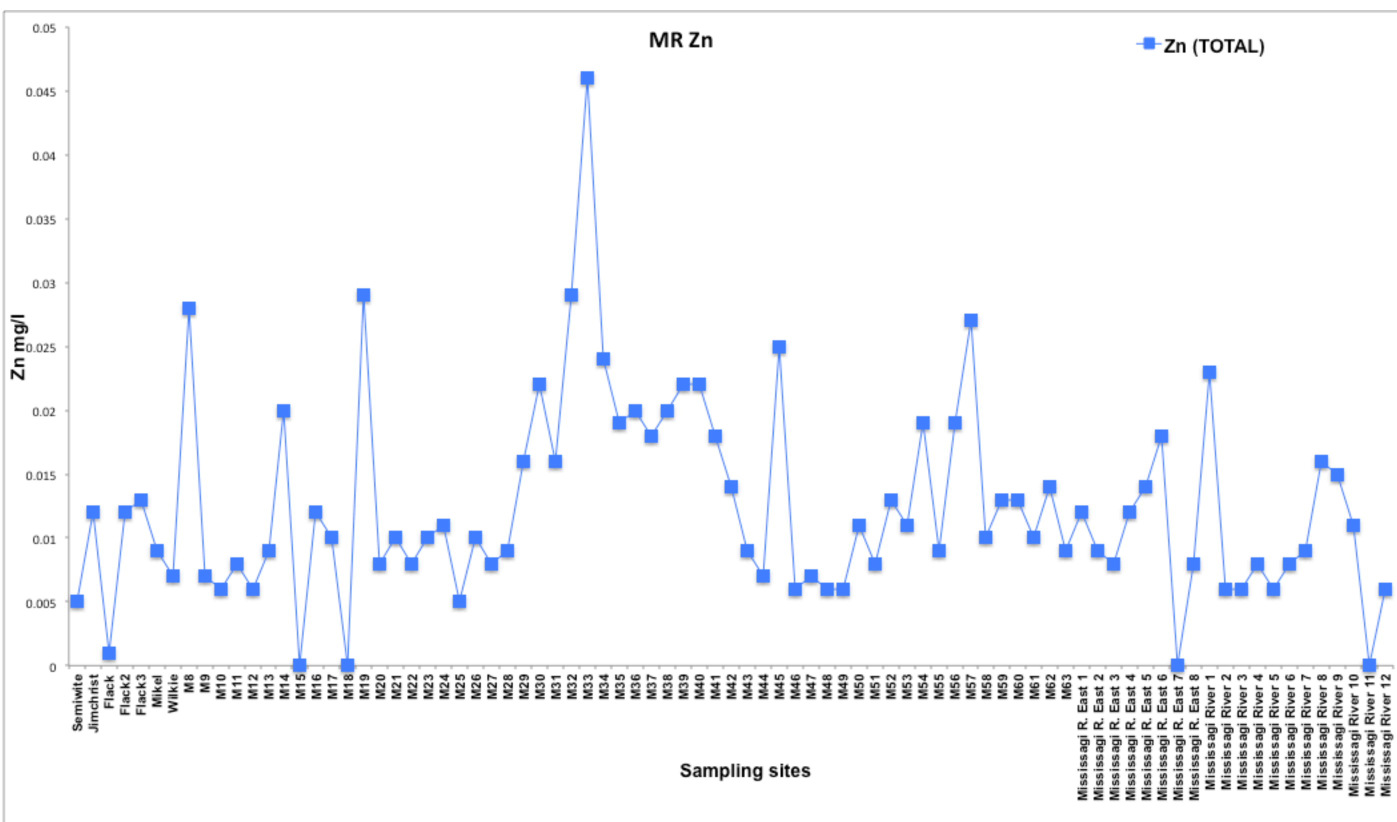


Figure 16. Uranium downstream of Quirke Lake in the Serpent River and Lake Huron.

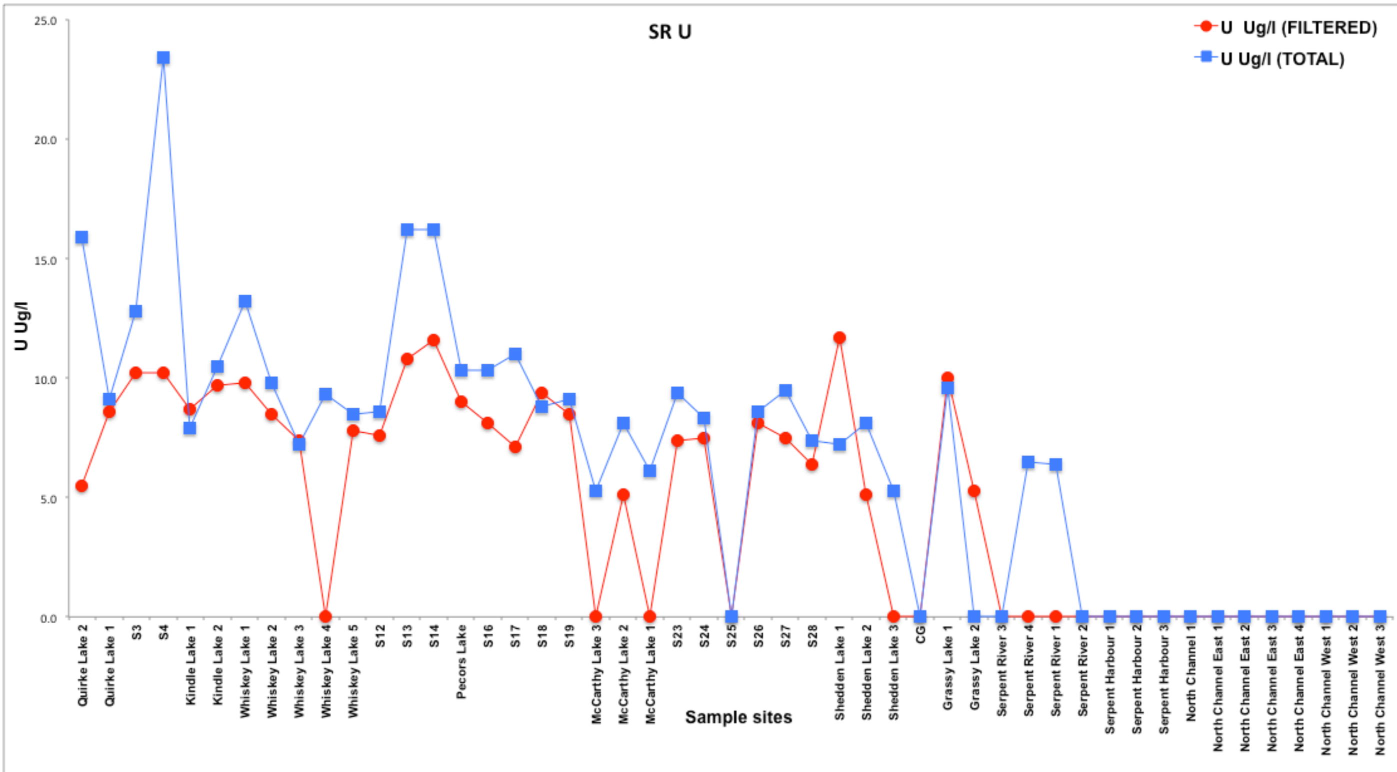
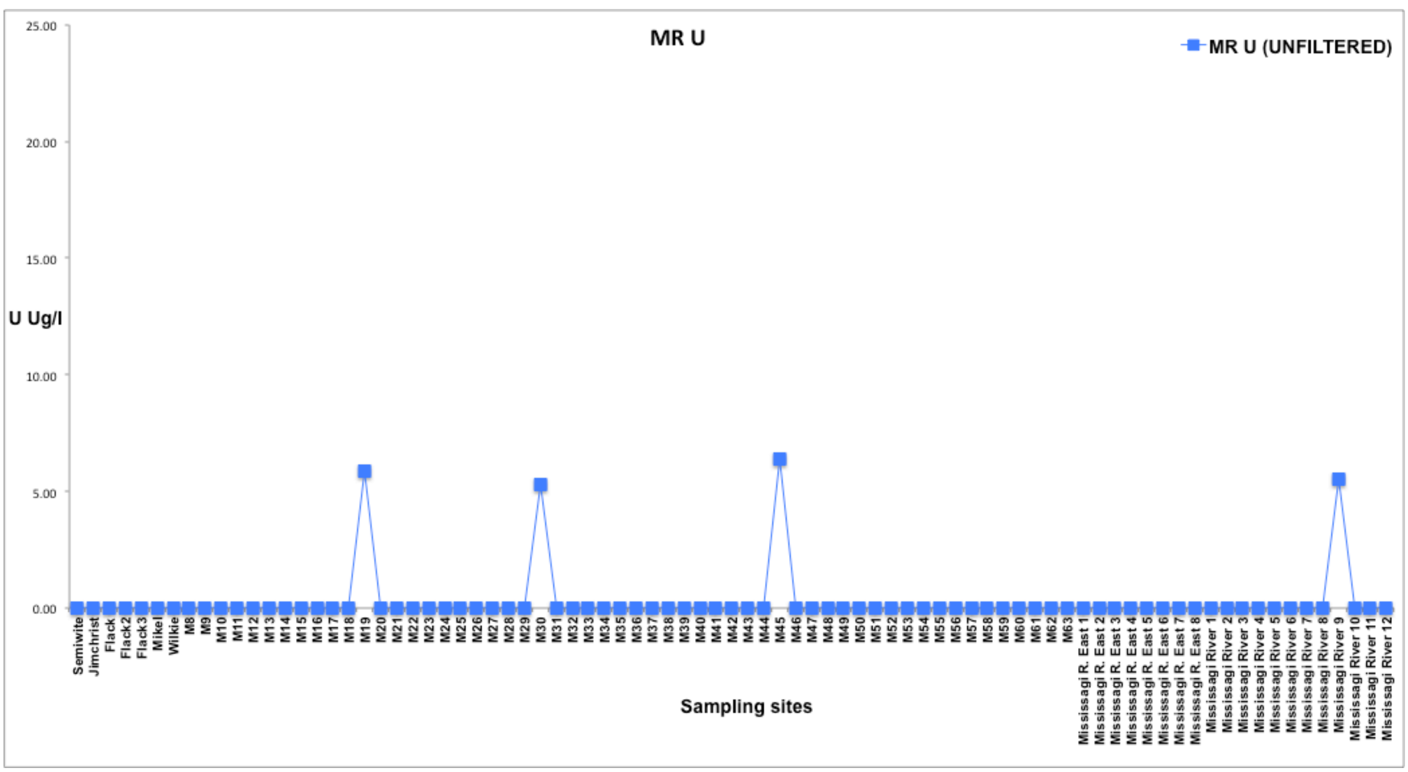


Figure 17. Uranium downstream of Semiwhite Lake in the Mississagi River and Lake Huron.



4.2. **Sediments - activity**

Figure 18. Gross alpha activity downstream of Quirke Lake in the Serpent River and Lake Huron.

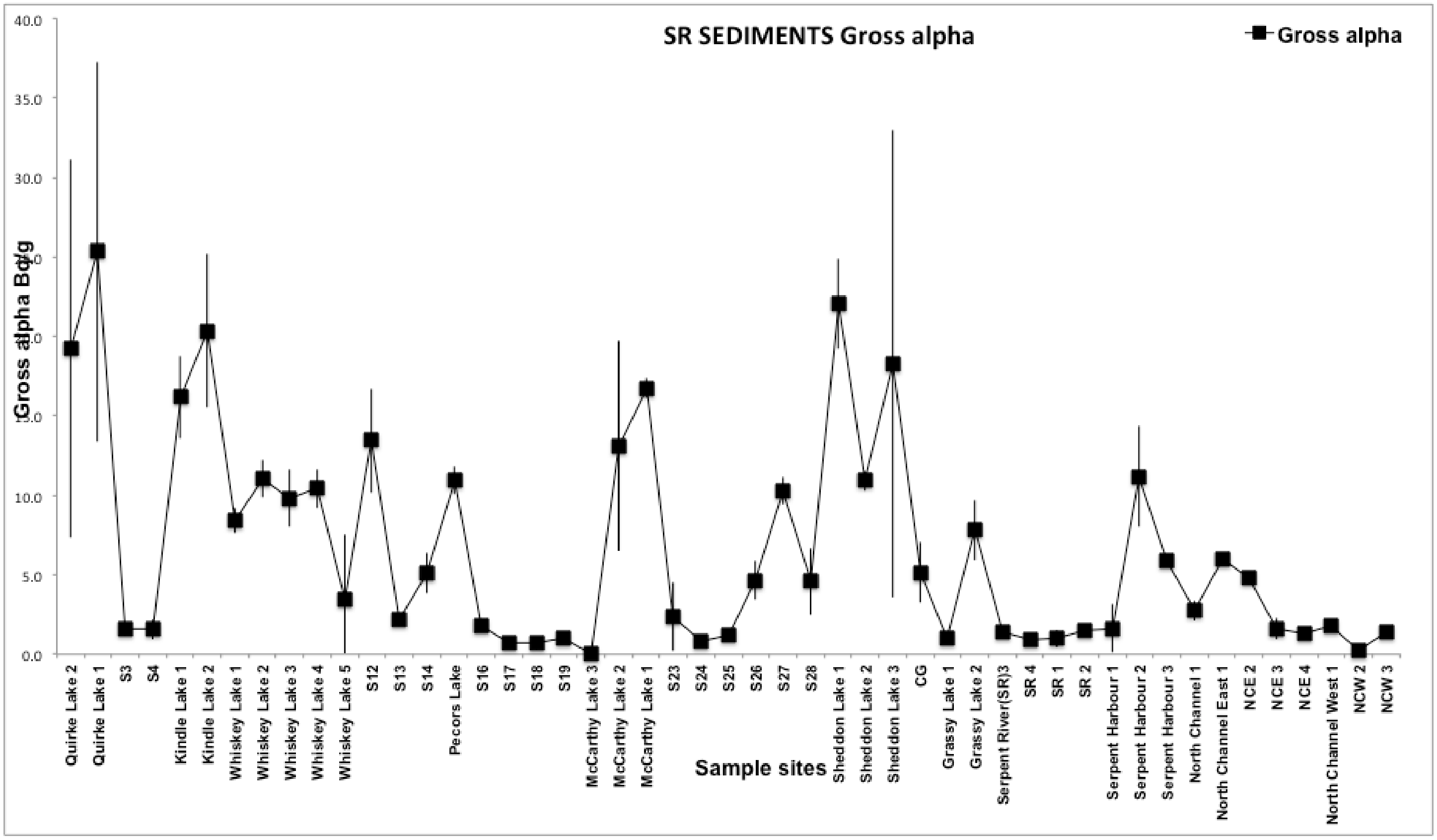


Figure 19. Gross alpha activity downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

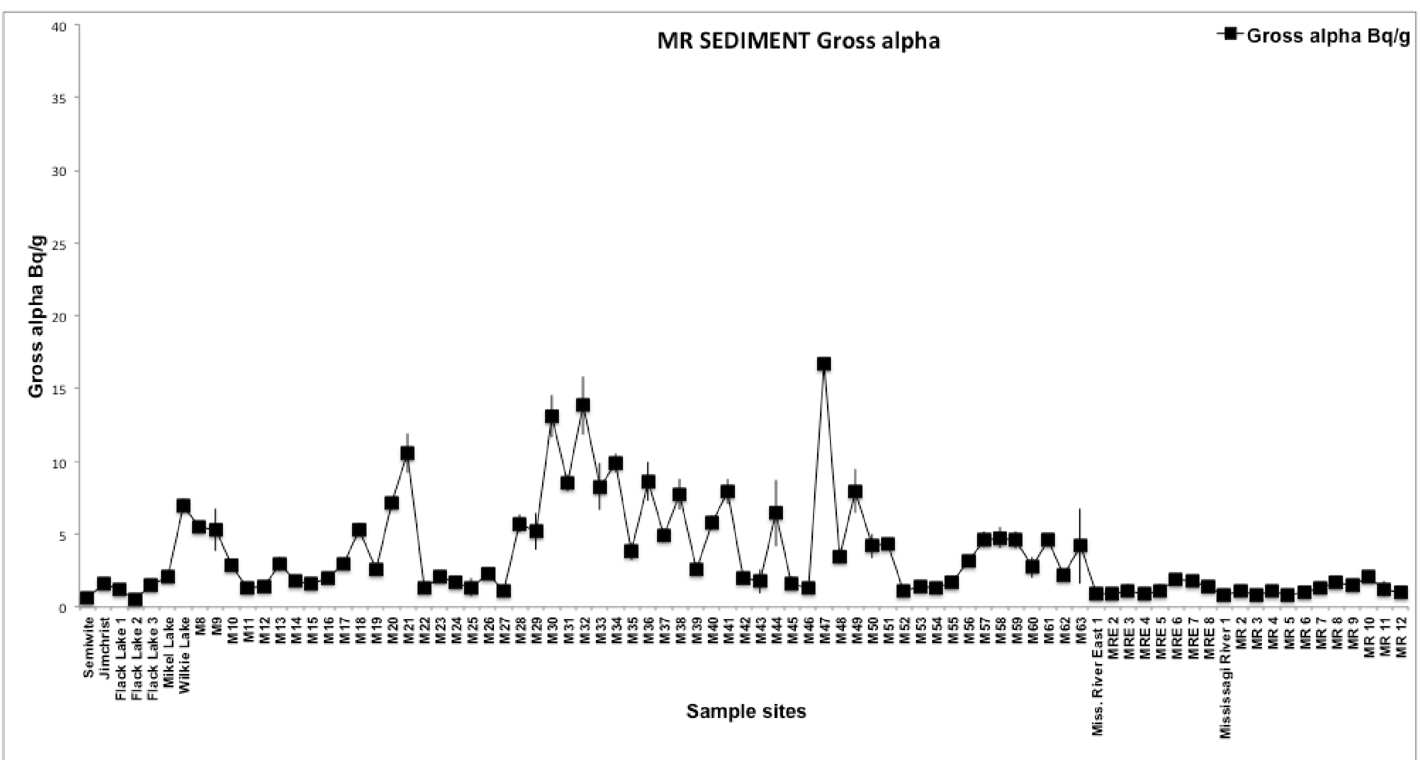


Figure 20. Gross beta activity downstream of Quirke Lake in the Serpent River and Lake Huron.

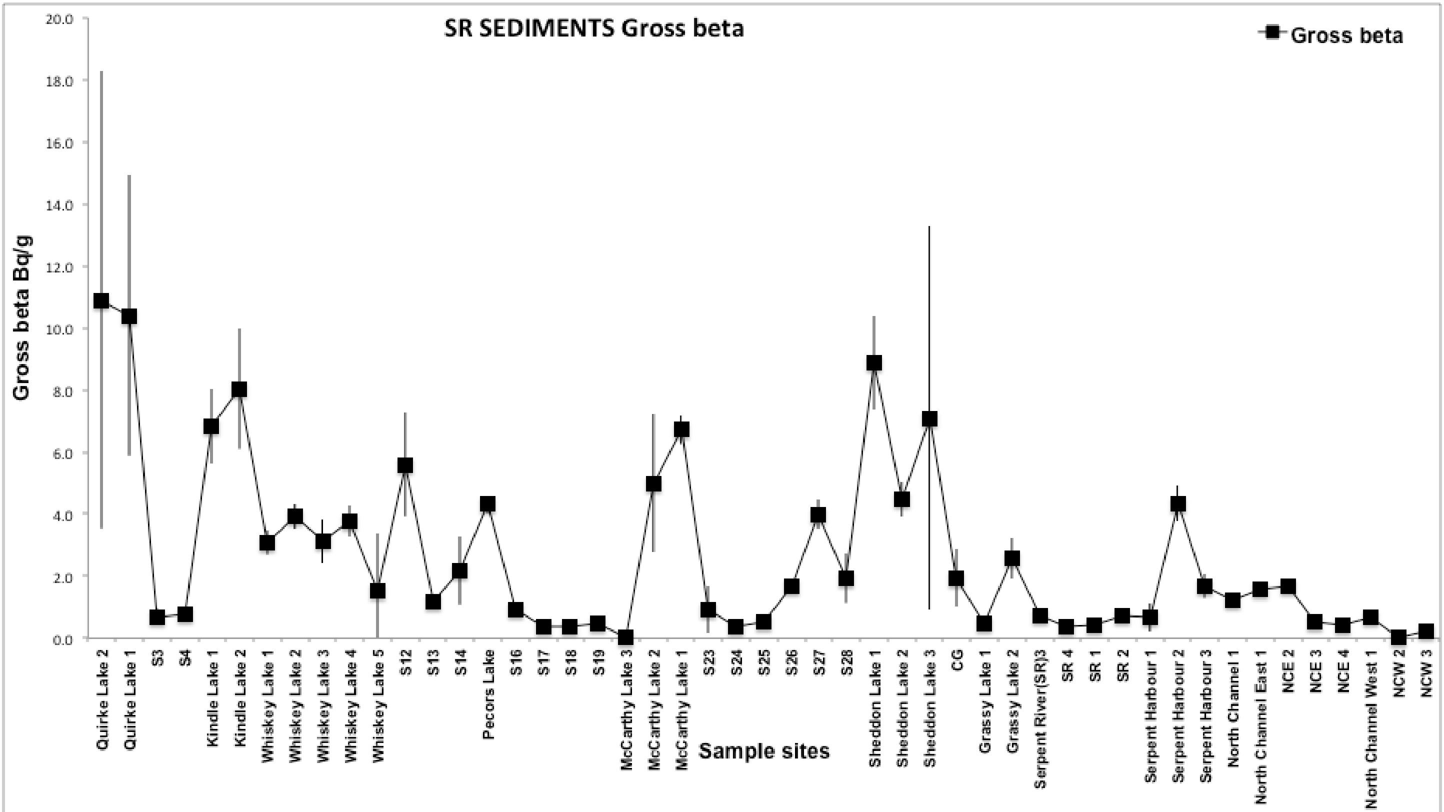


Figure 20. Gross beta activity downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

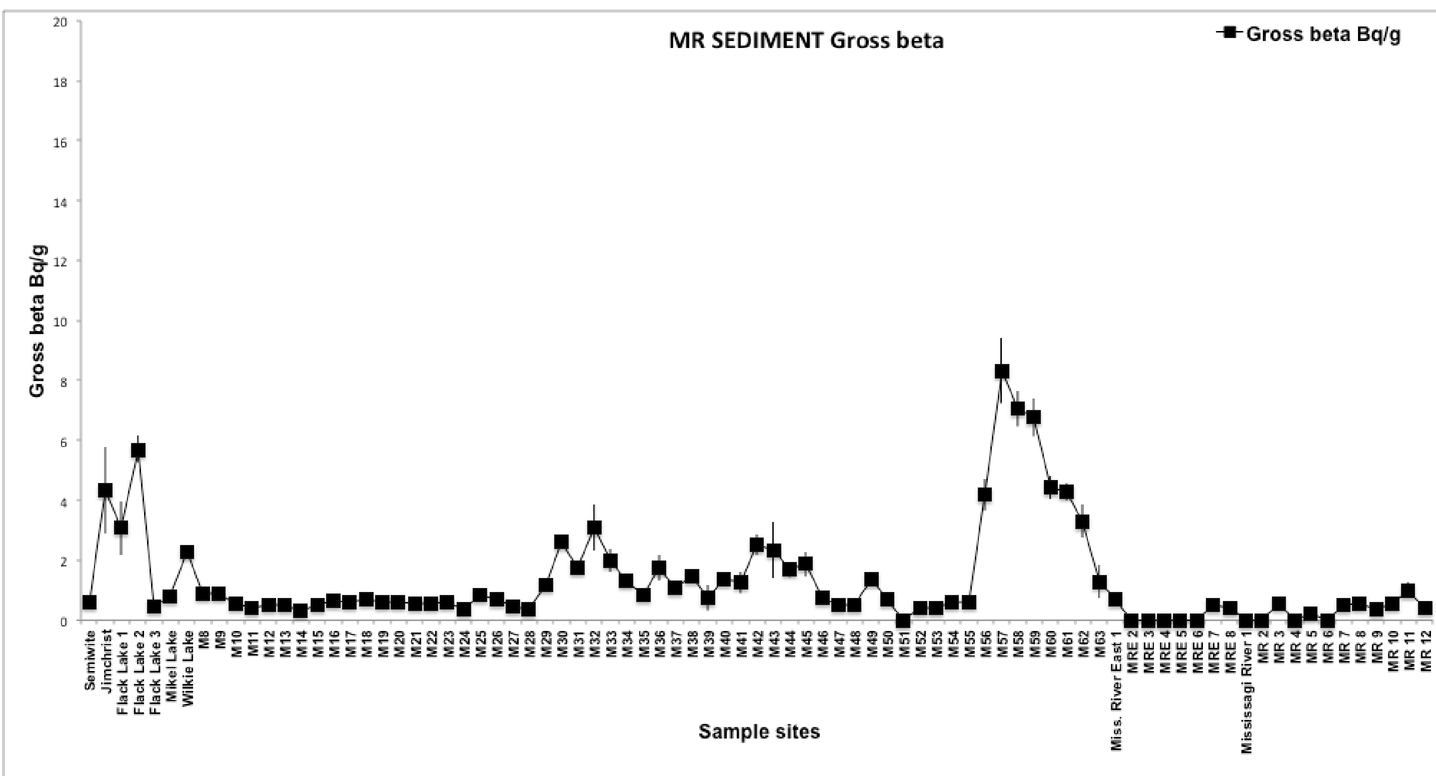


Figure 21. Gross gamma activity downstream of Quirke Lake in the Serpent River and Lake Huron.

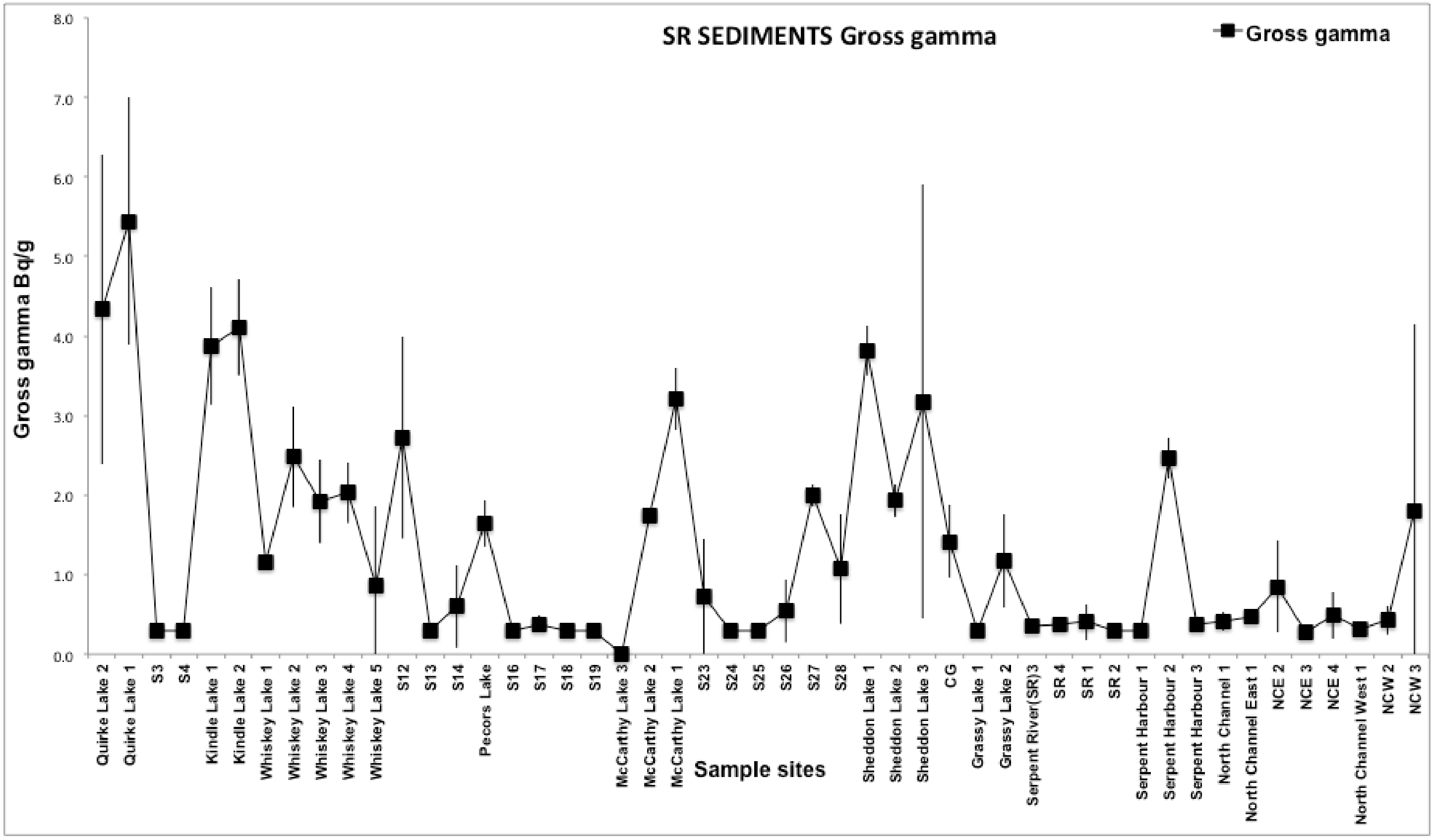
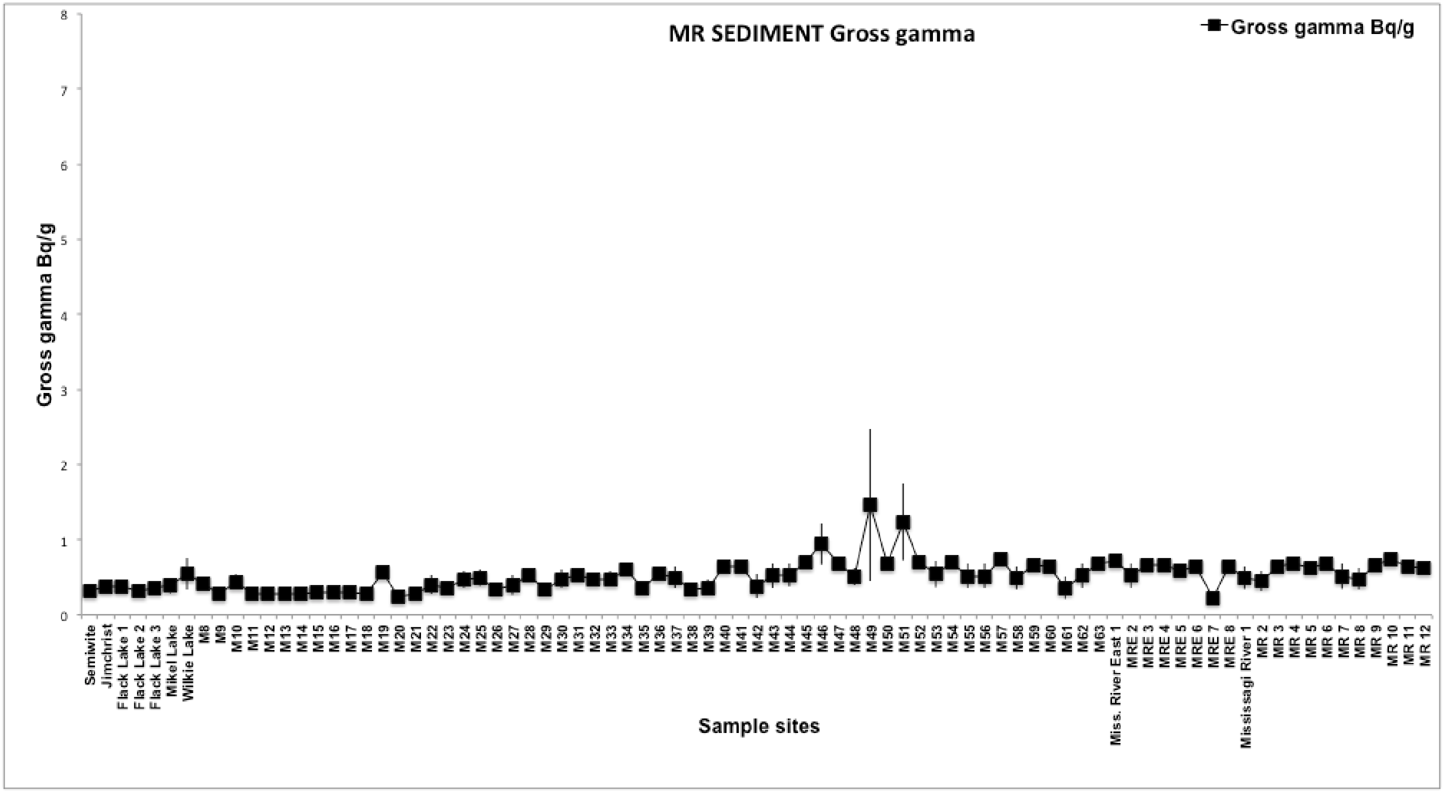


Figure 22. Gross gamma activity downstream of Semiwhite Lake in the Mississagi River and Lake Huron.



4.3 Metals in sediments

Figure 23. Uranium in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

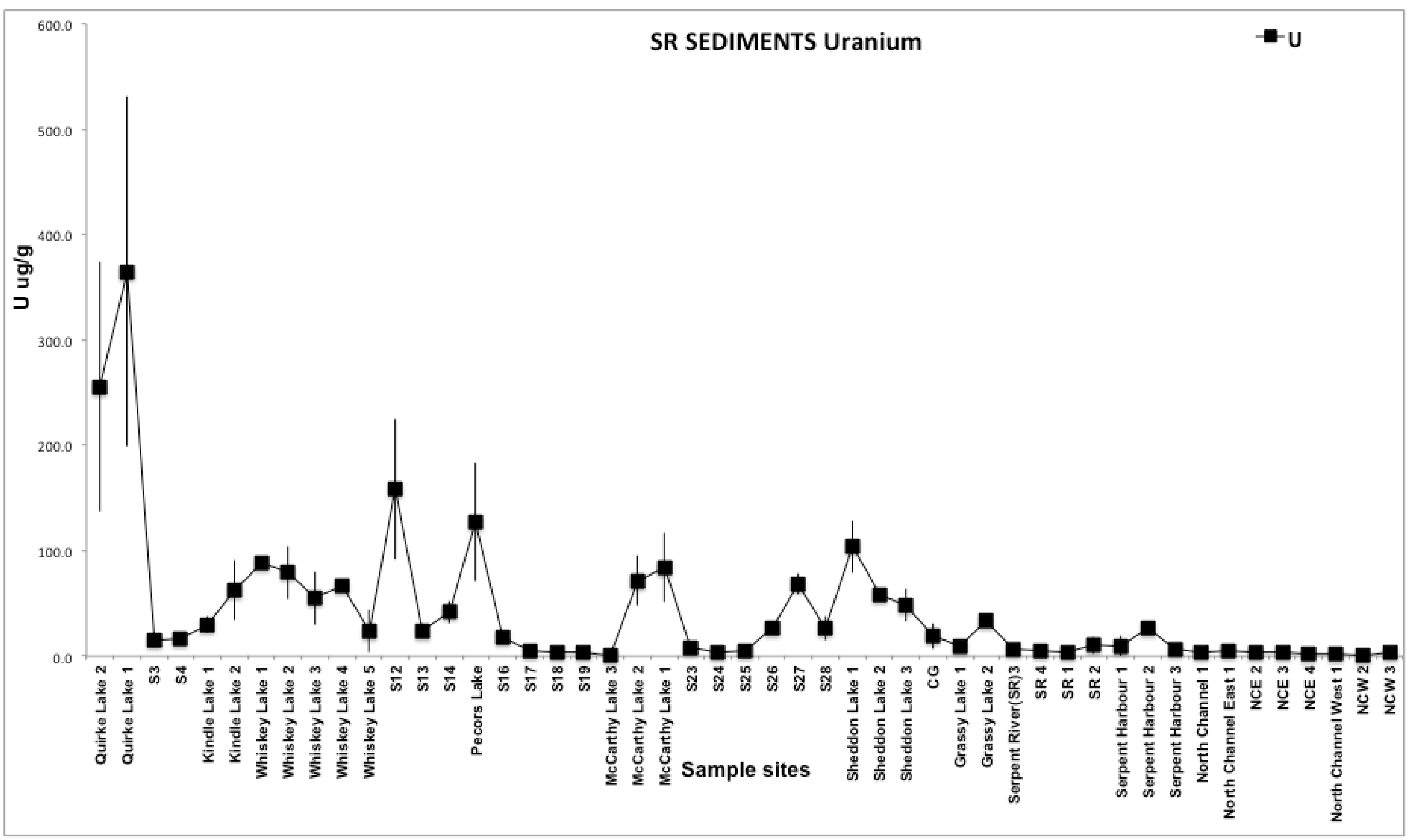


Figure 24. Uranium in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

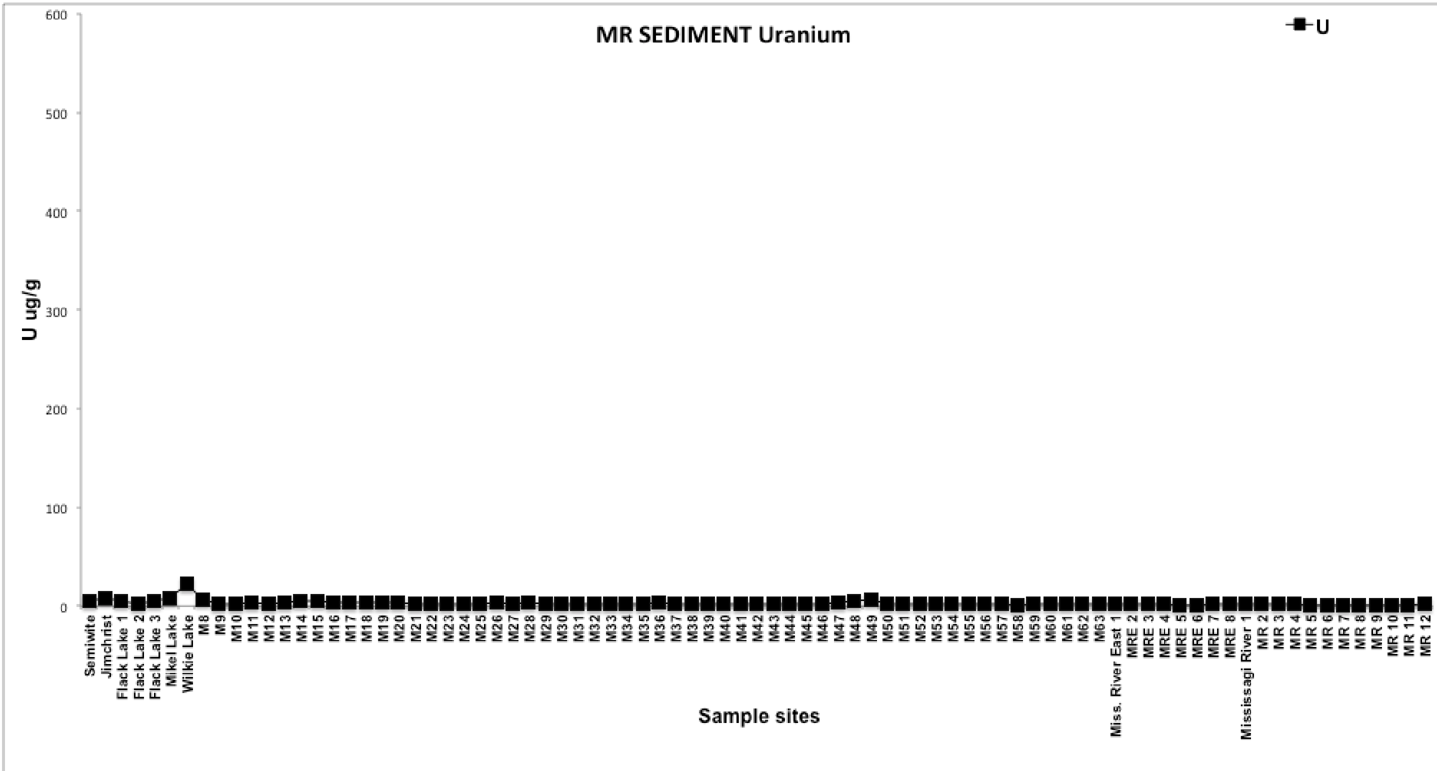


Figure 25. Thorium in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

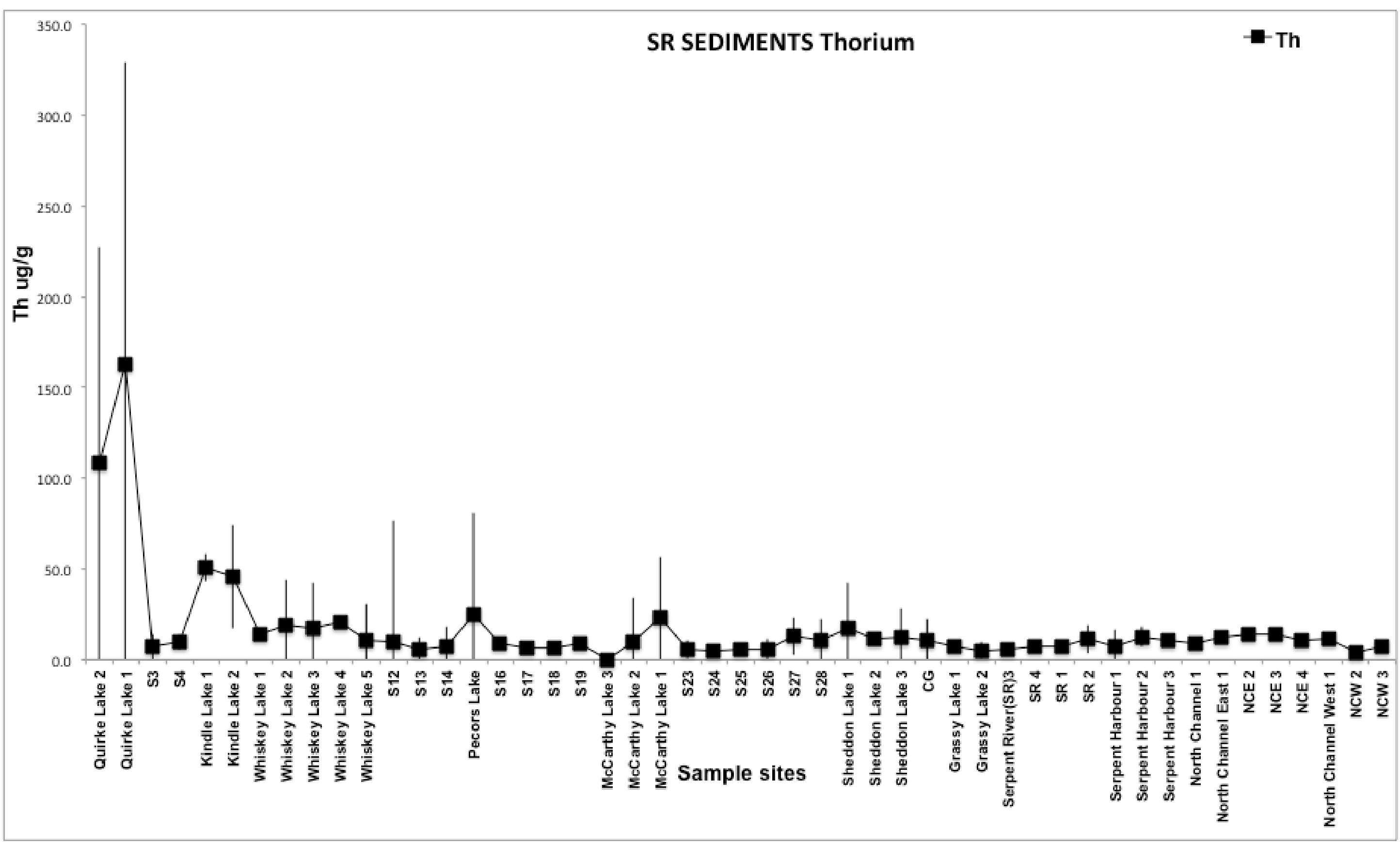


Figure 26. Thorium in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

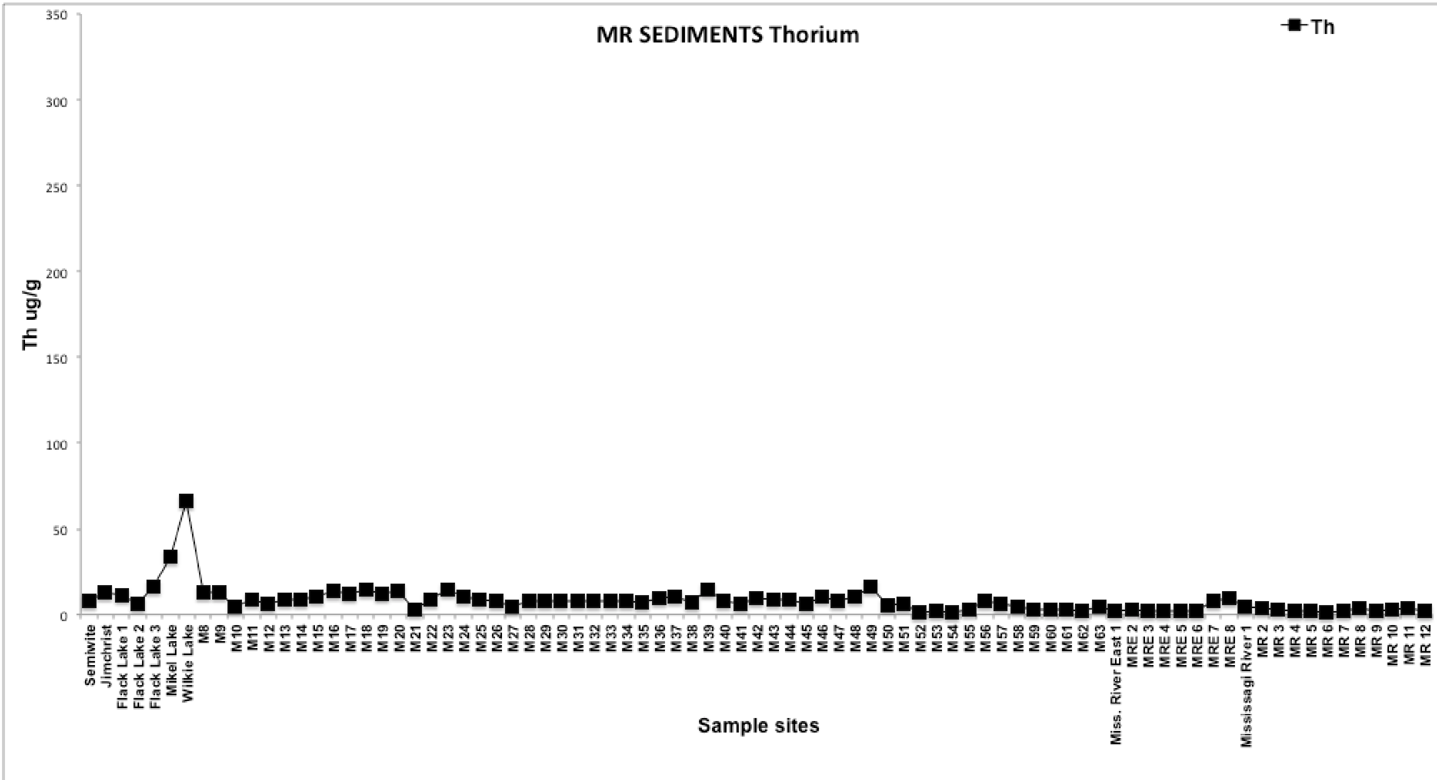


Figure 27. Lead in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

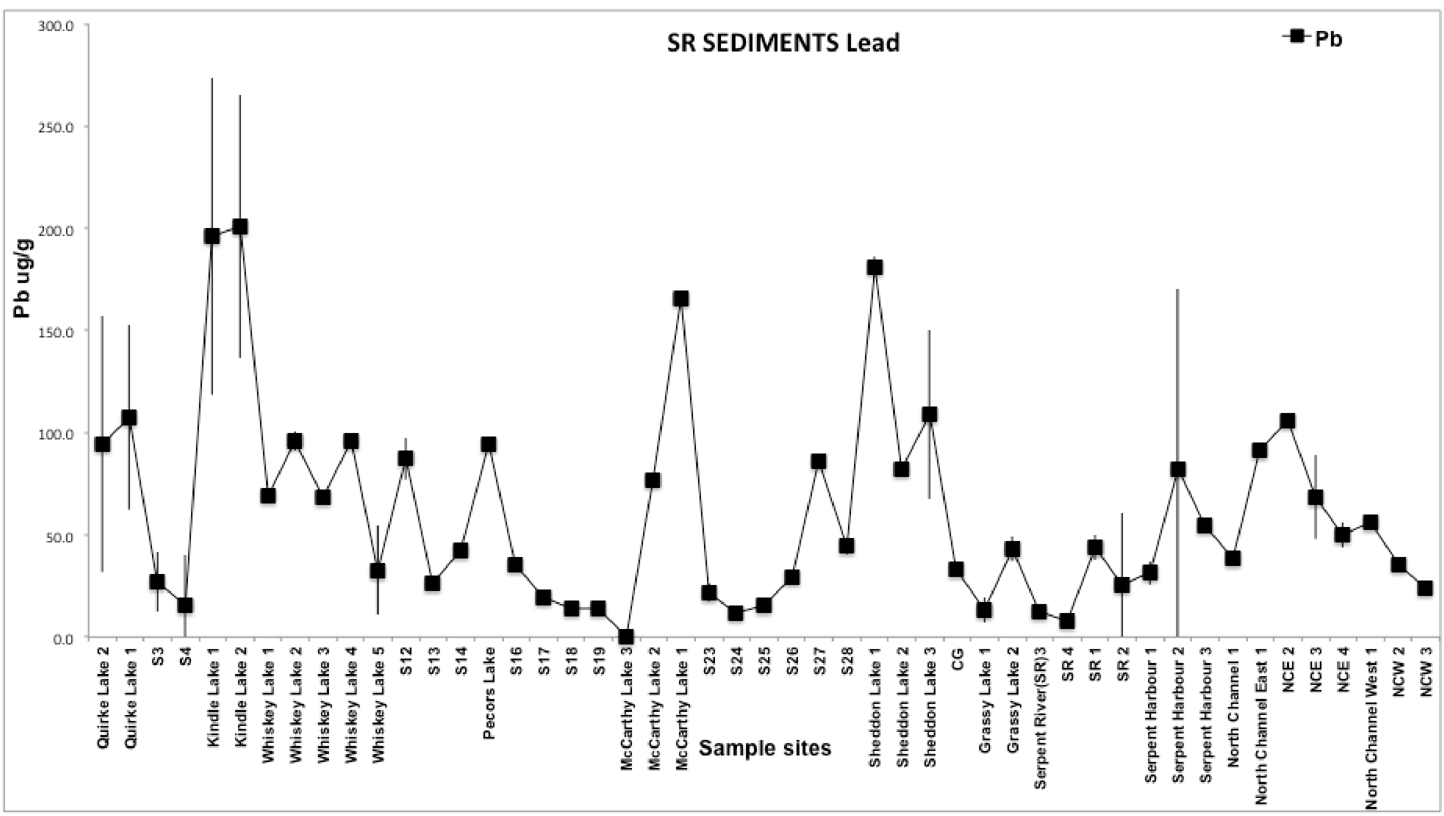


Figure 28. Lead in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

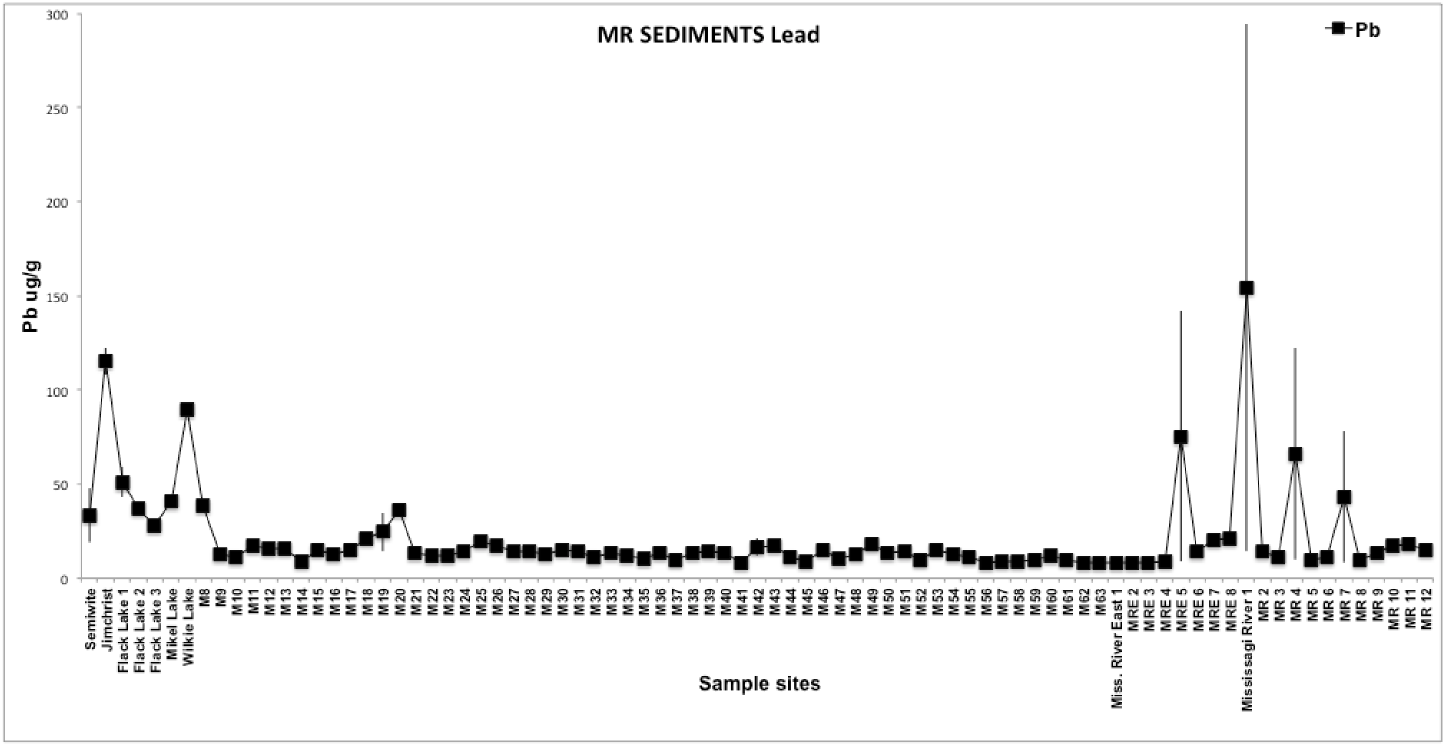


Figure 29. Nickel in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

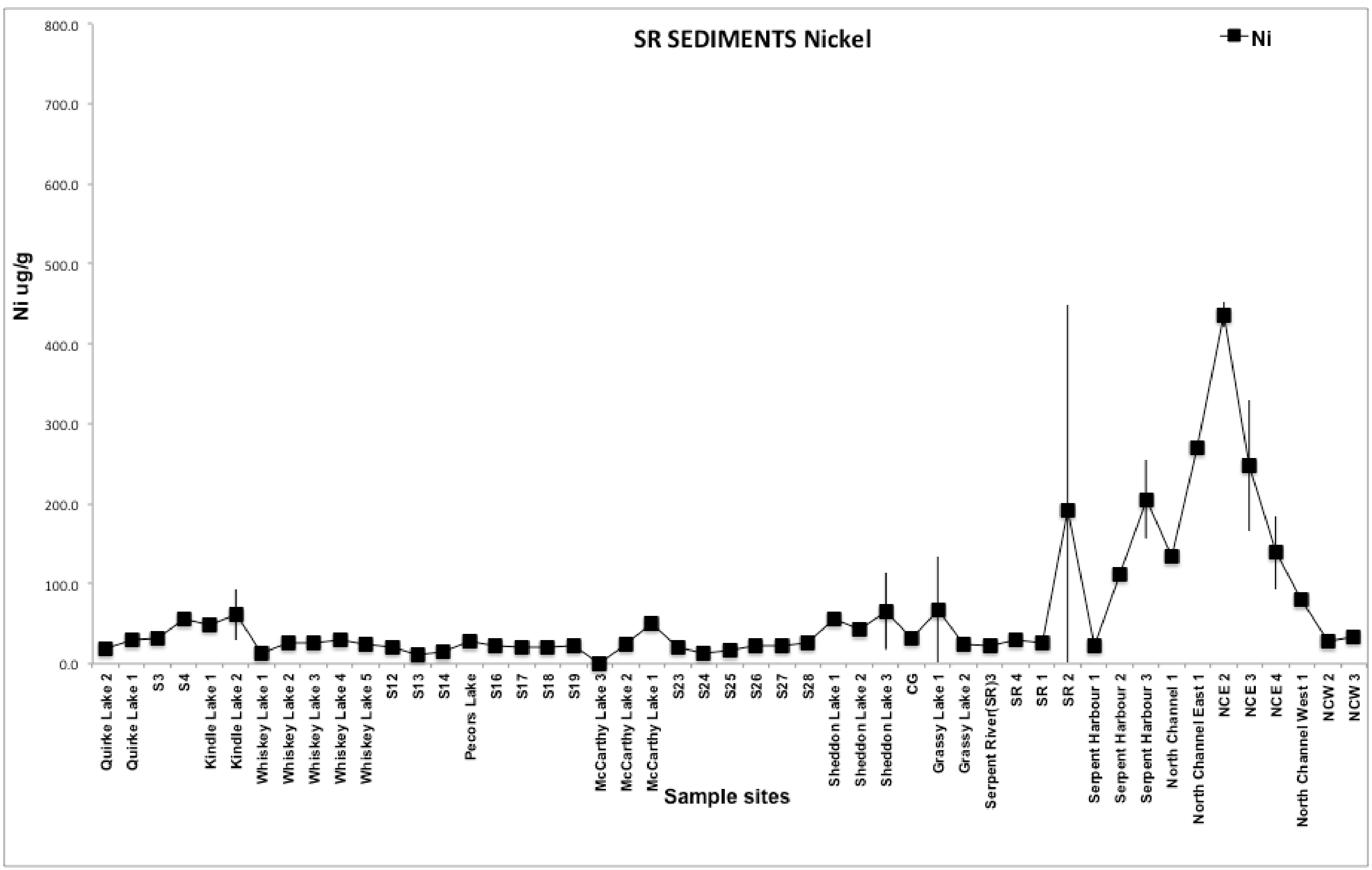


Figure 30. Nickel downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

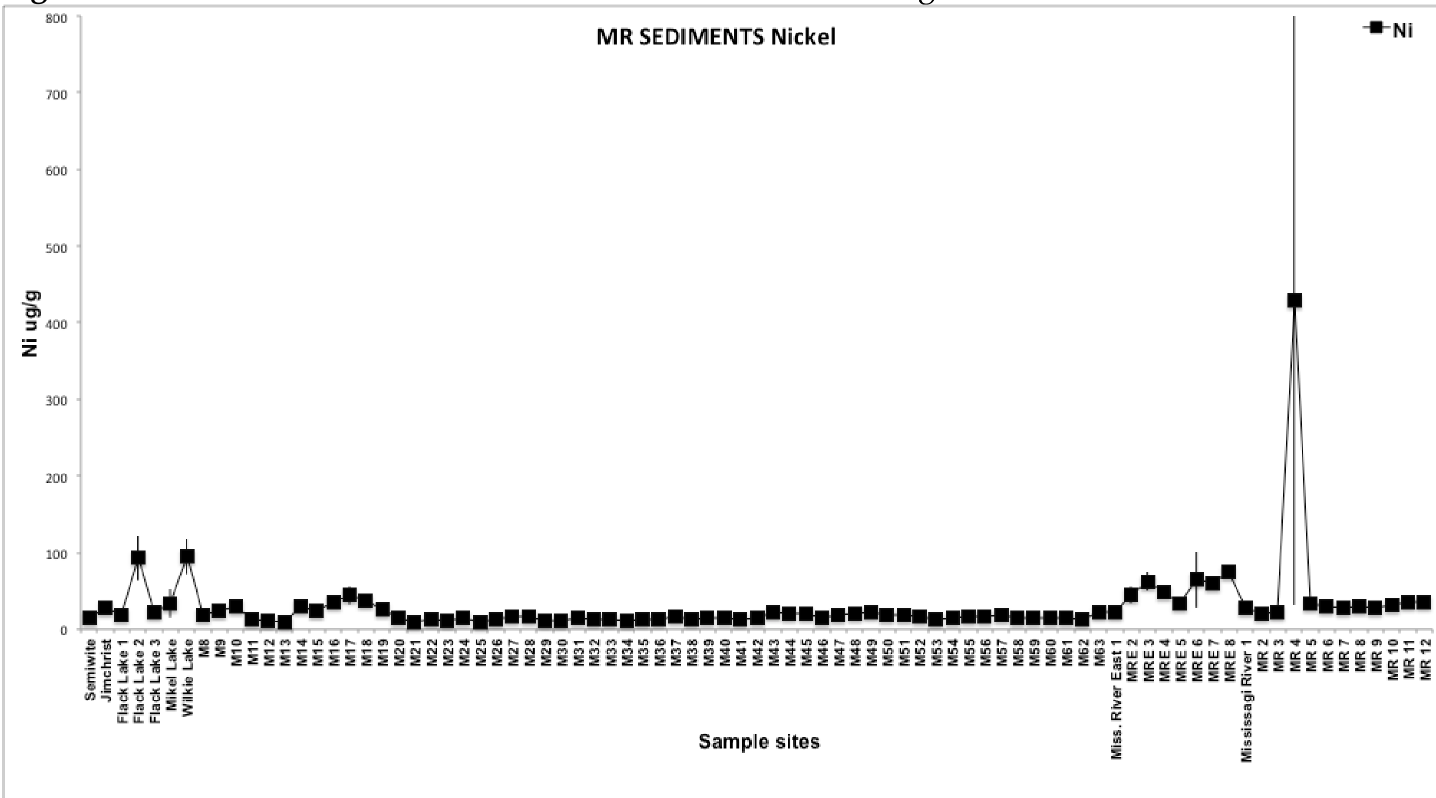


Figure 31. Copper in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

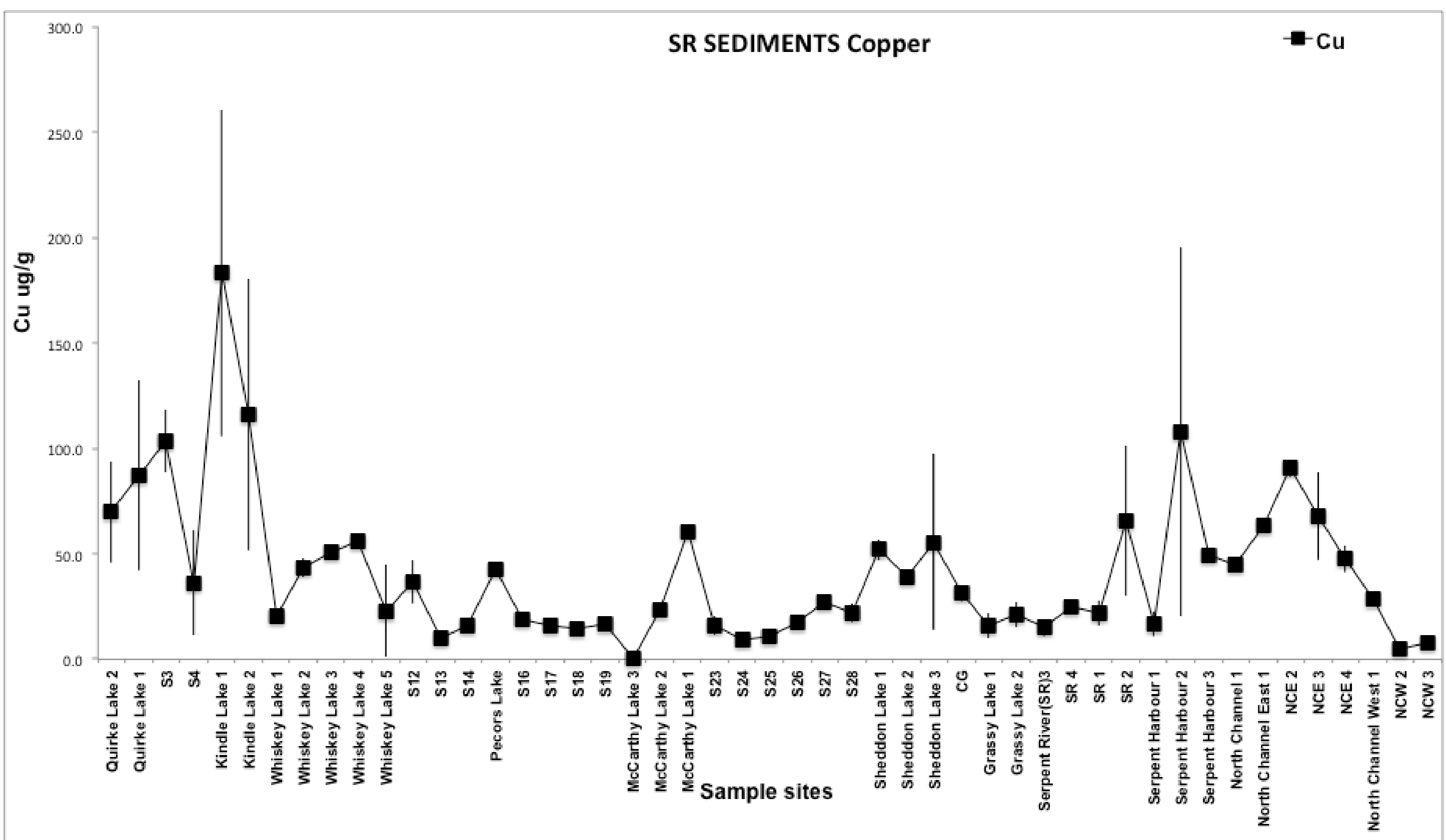


Figure 32. Copper downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

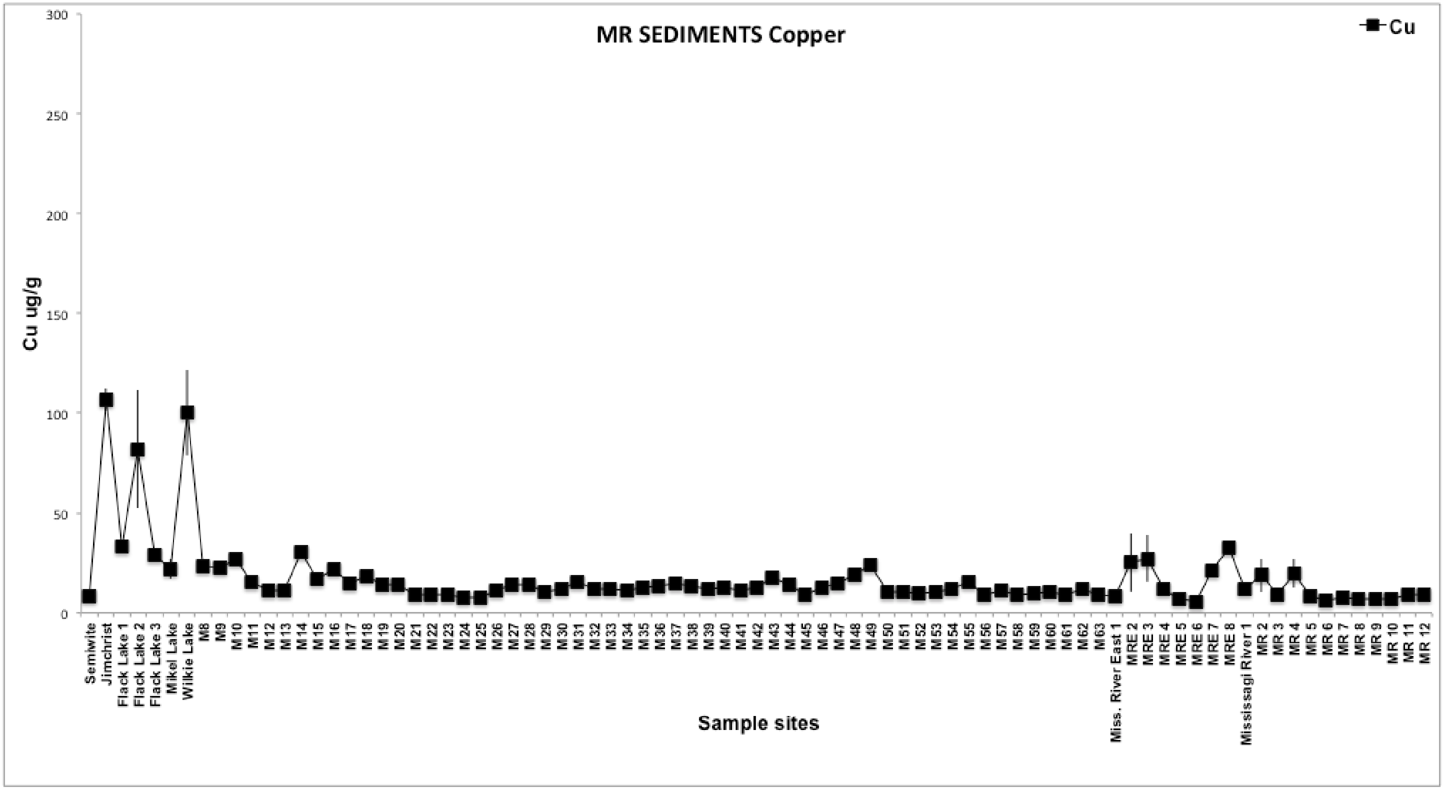


Figure 33. Zinc in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

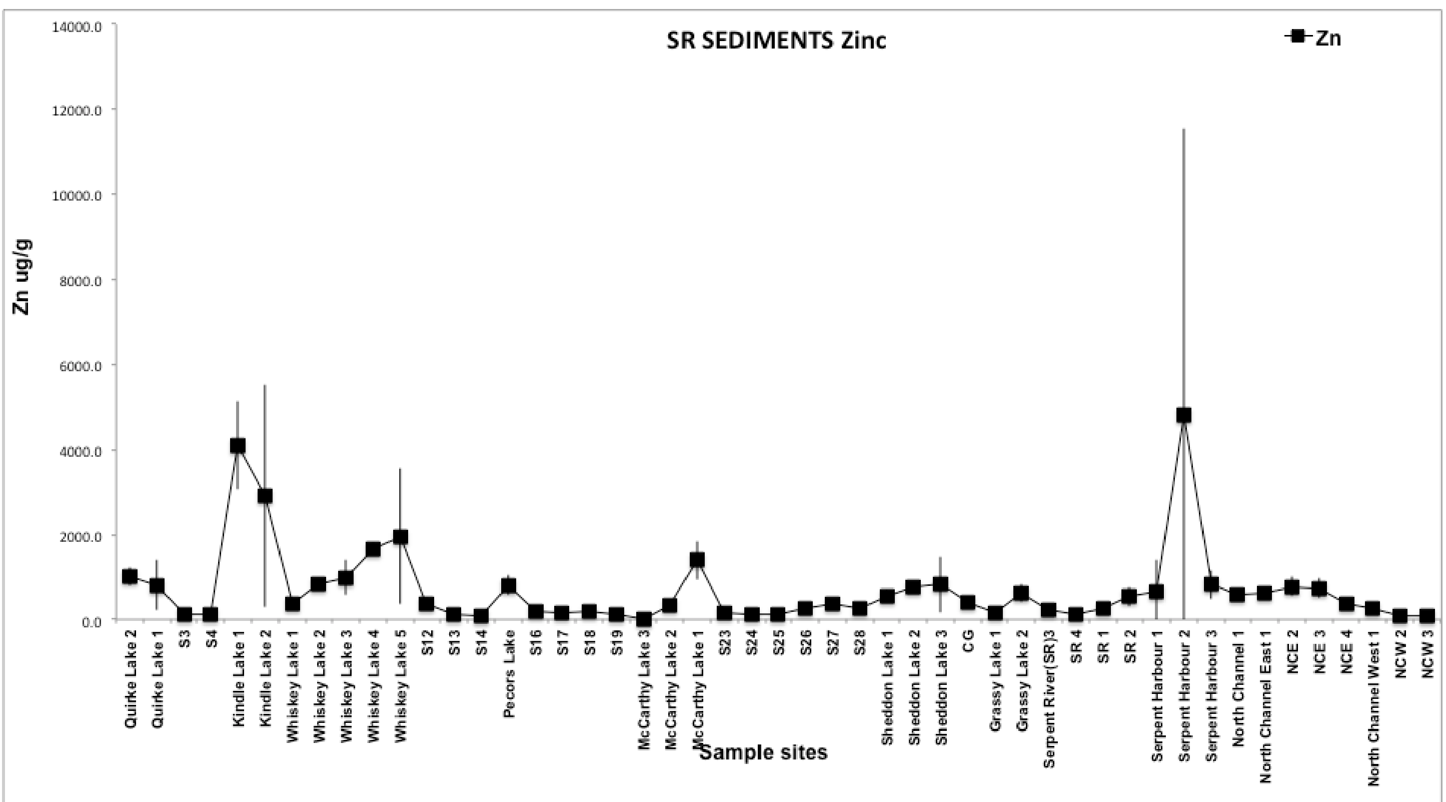


Figure 32. Zinc downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

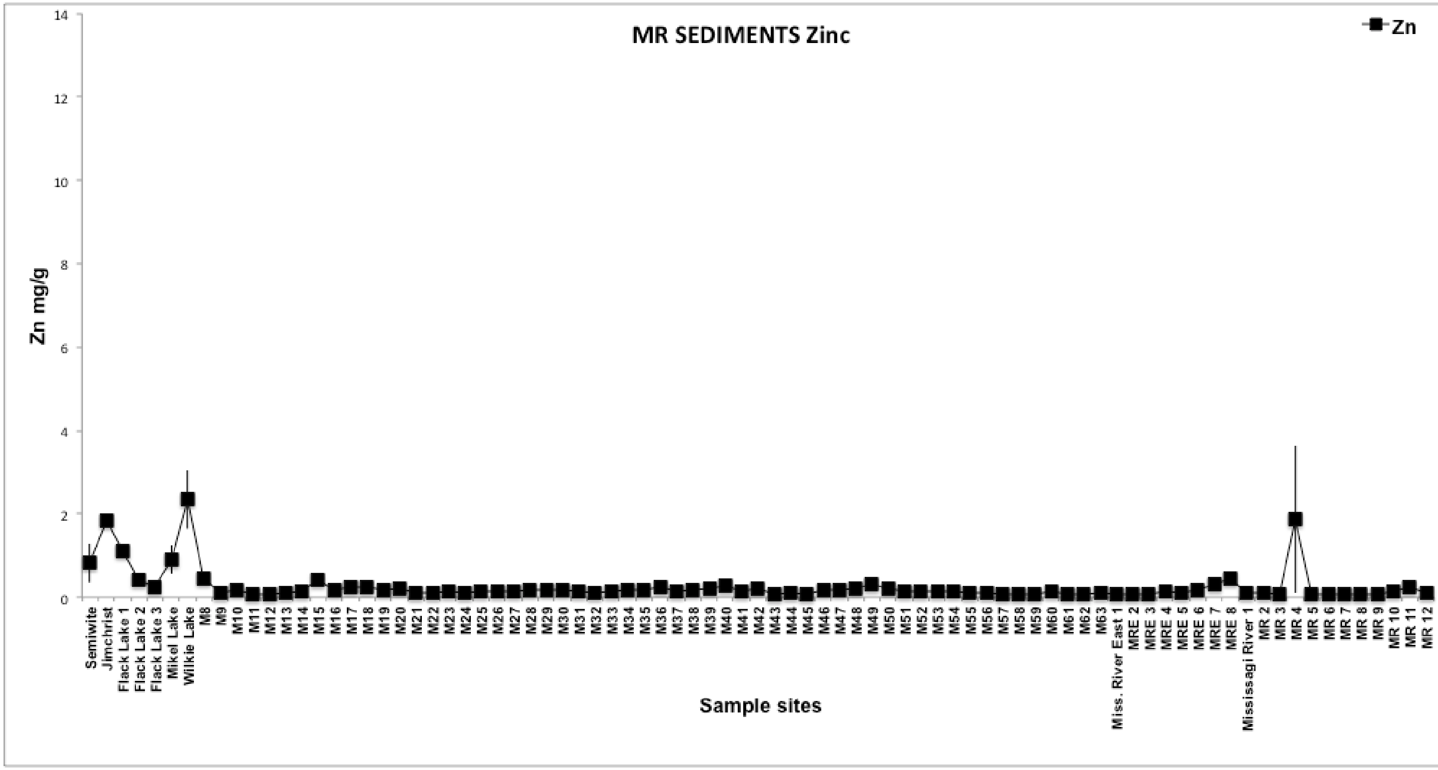


Figure 33. Manganese in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

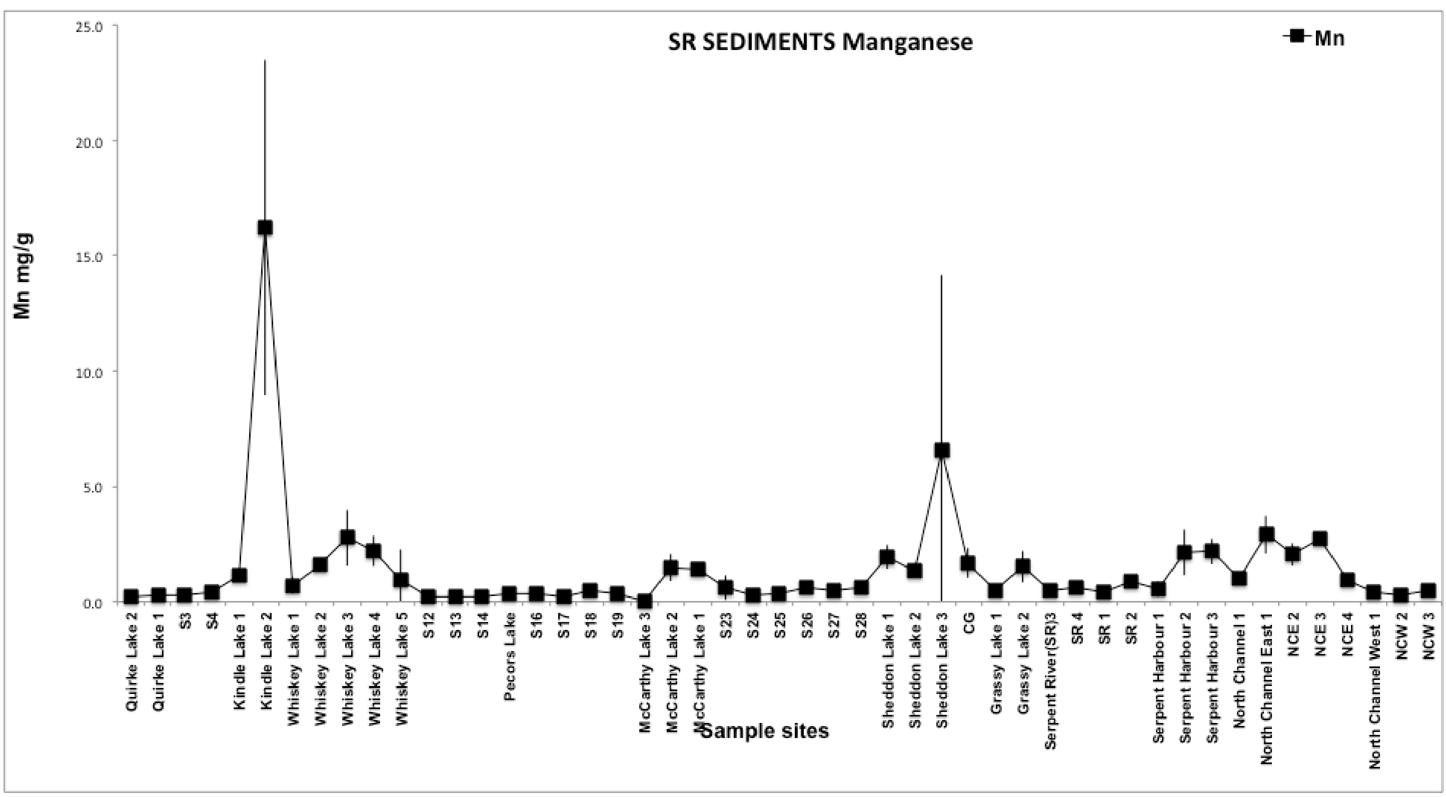


Figure 34. Manganese in sediments downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

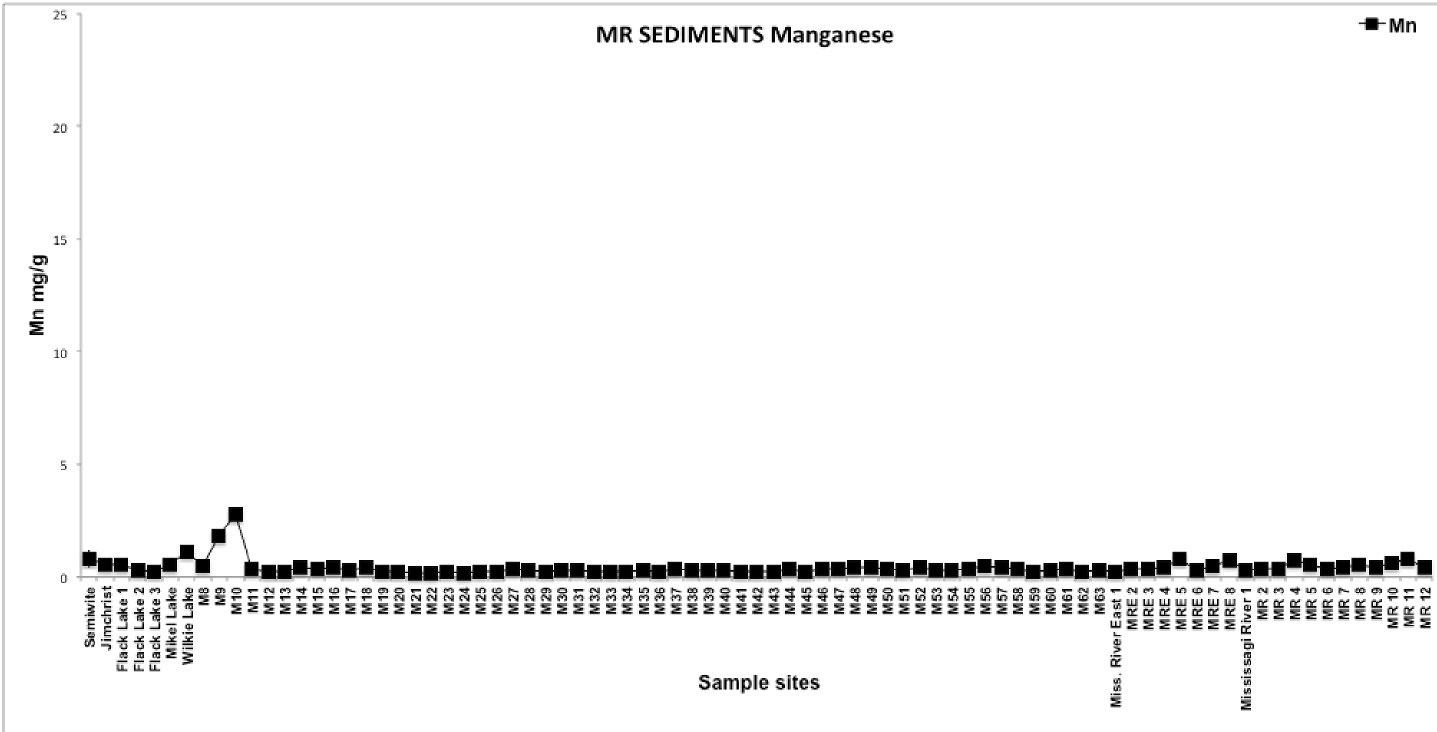


Figure 35. Iron in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

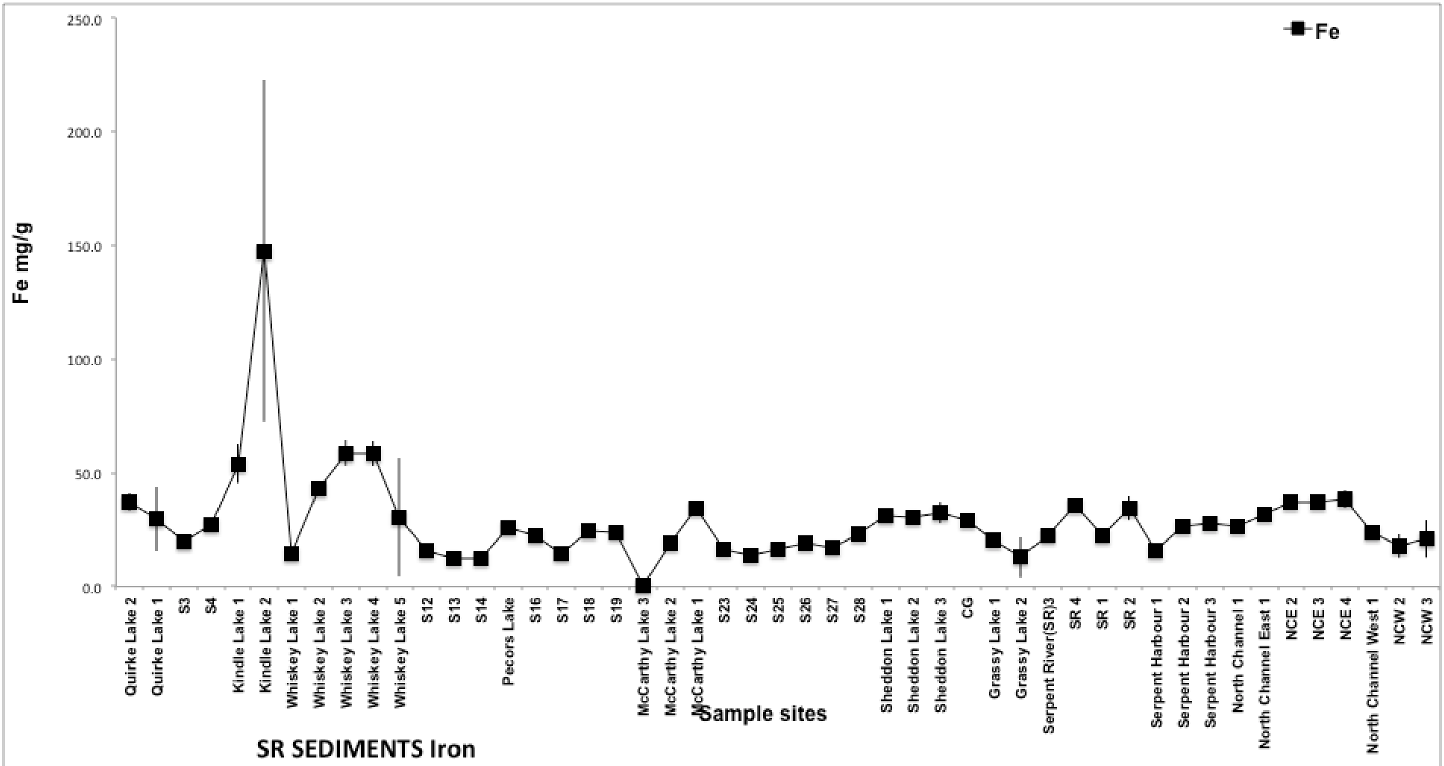
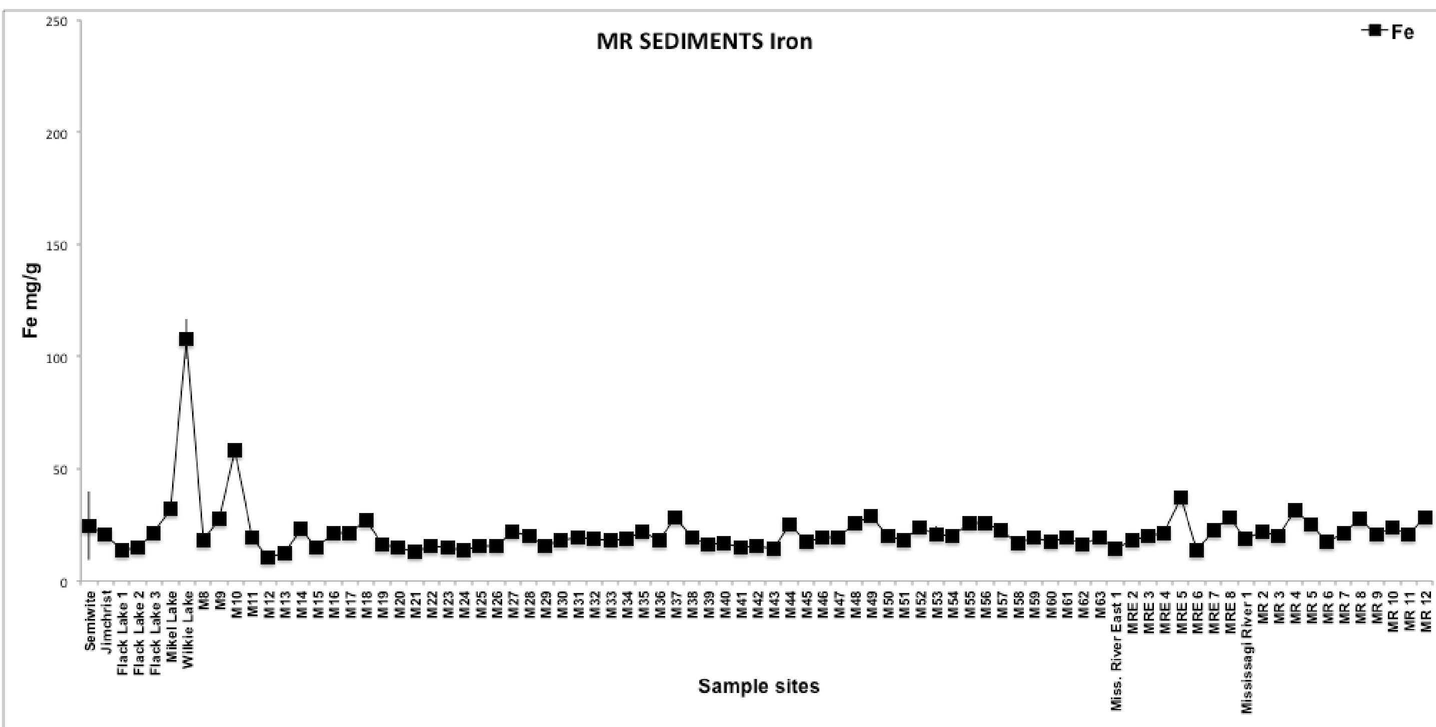


Figure 36. Iron in sediments downstream of Semiwhite Lake in the Mississagi River and Lake Huron.



4.4 Radionuclides in sediments

Figure 37. Ra-226 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

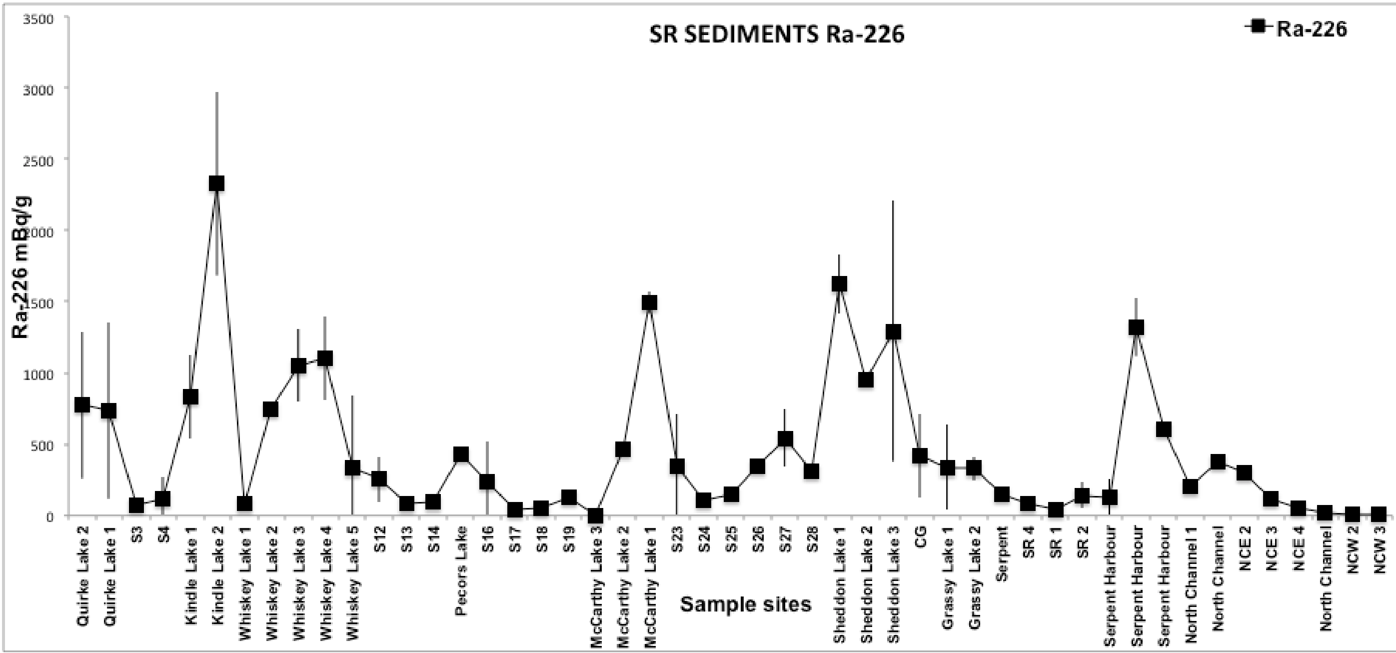


Figure 38. Ra-226 in sediments downstream of Semiwhite Lake in the Mississagi River and Lake Huron.

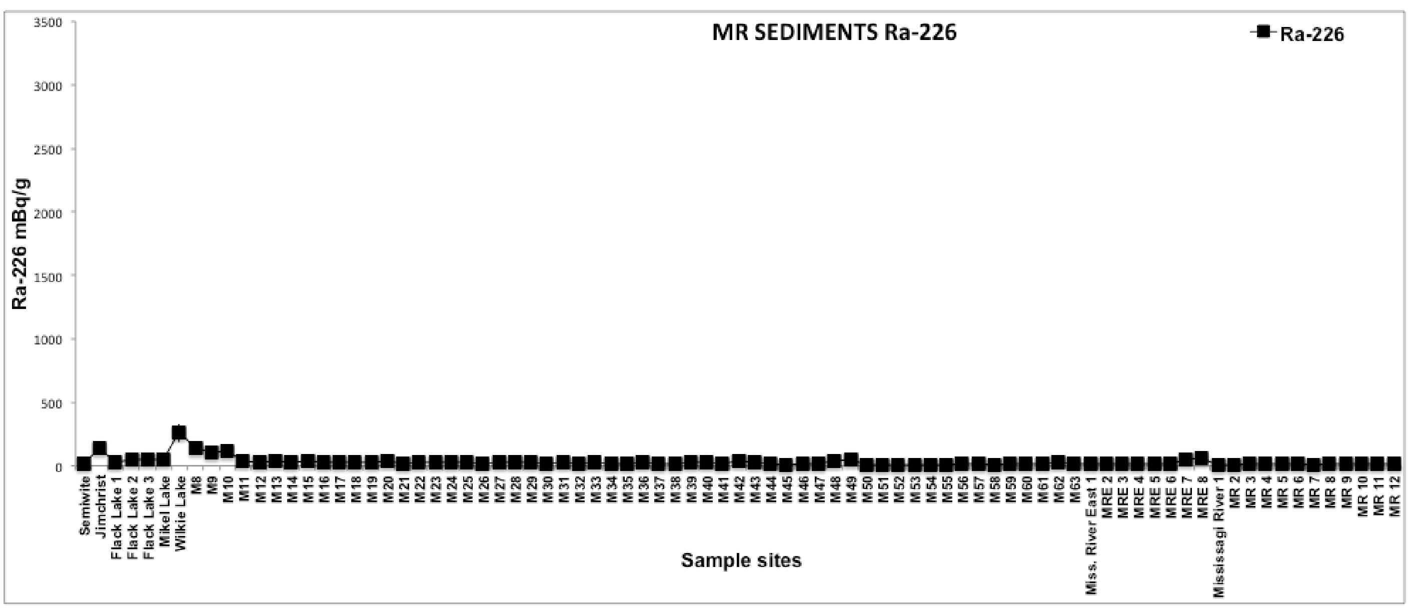


Figure 39. Thorium-232 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

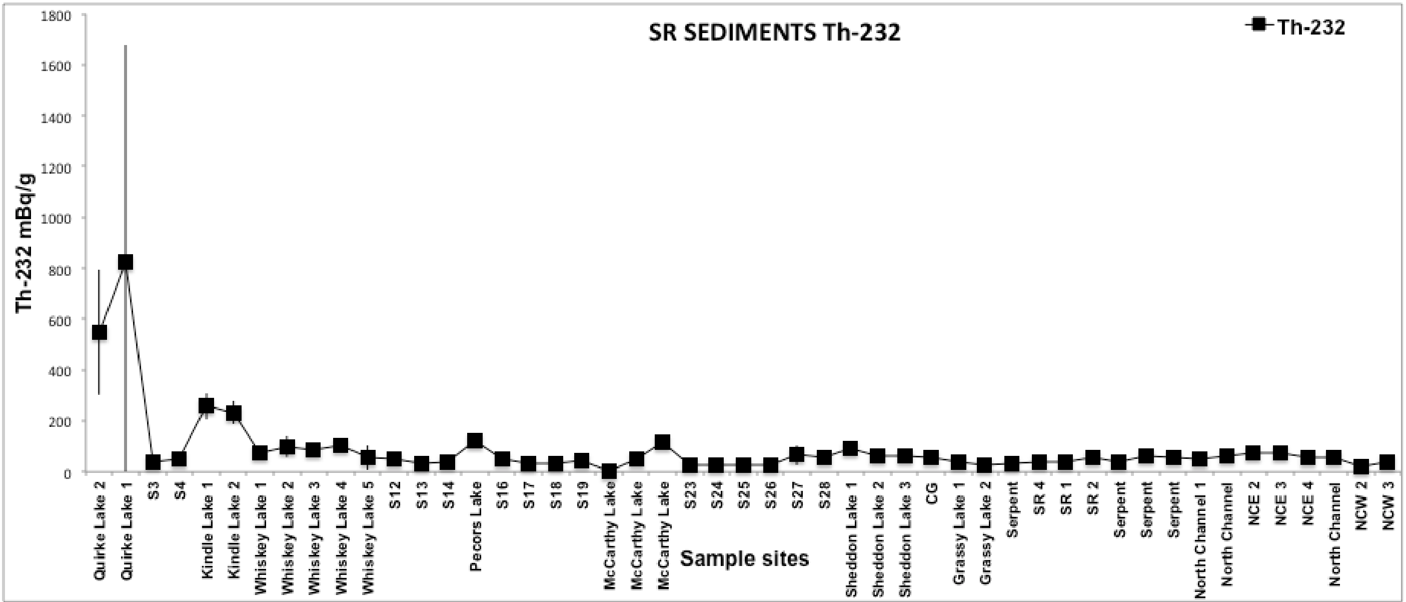


Figure 40. Thorium-232 in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

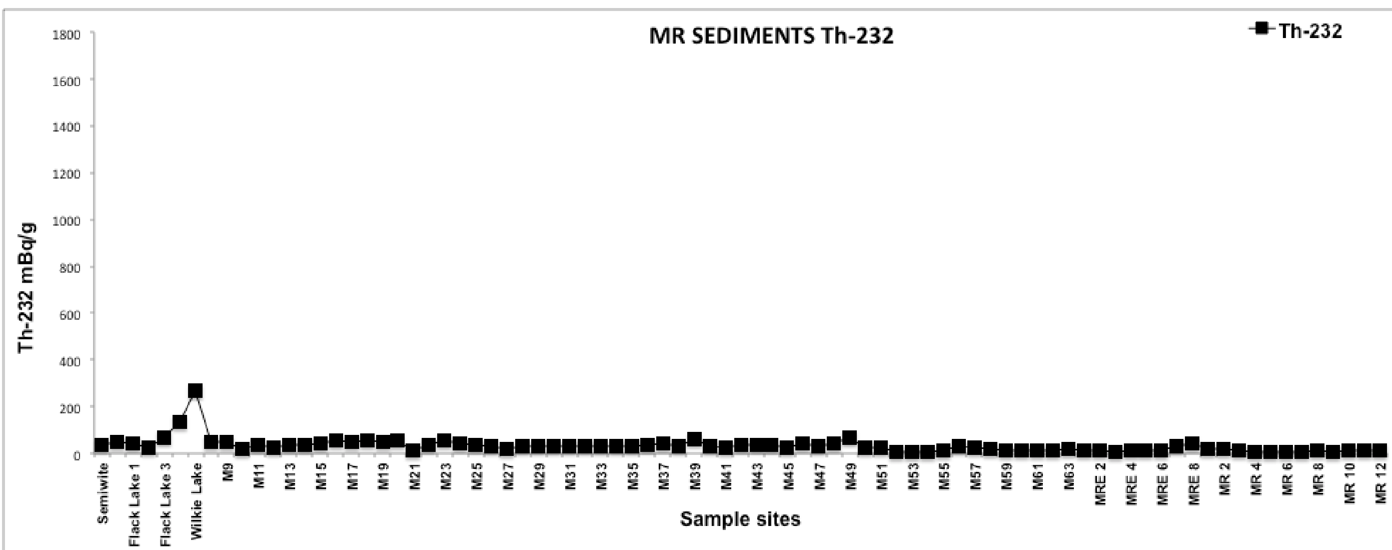


Figure 41. Thorium-230 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

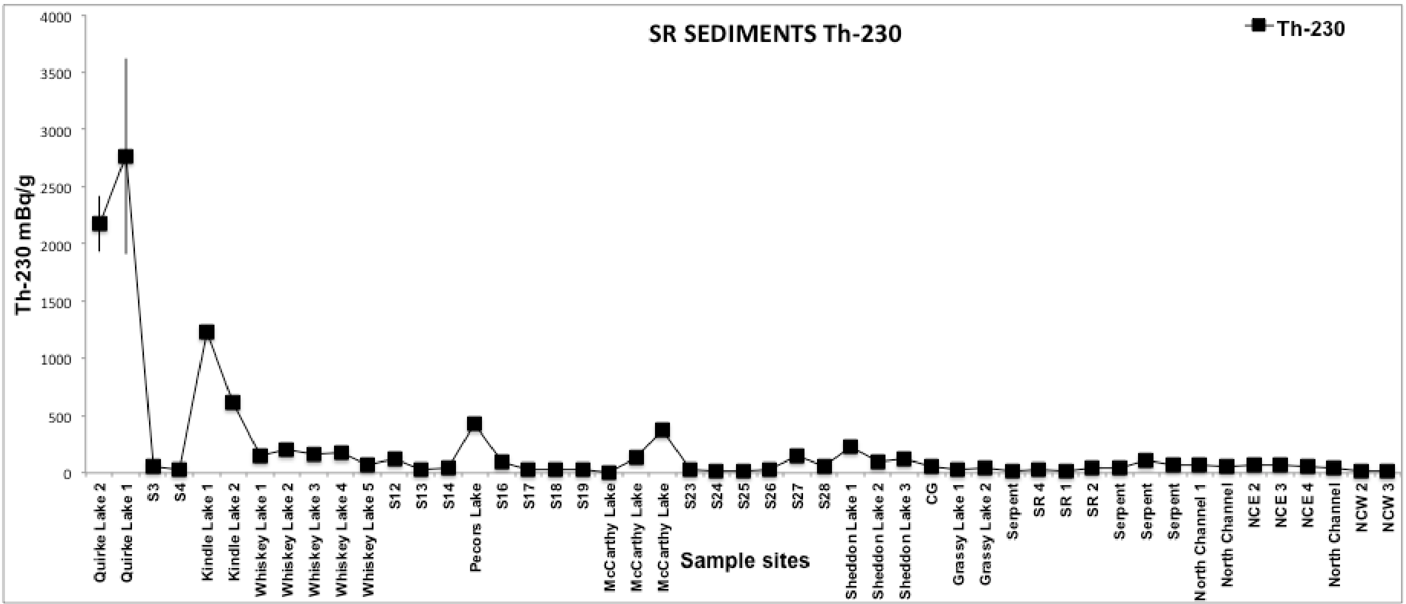


Figure 42. Thorium-230 in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

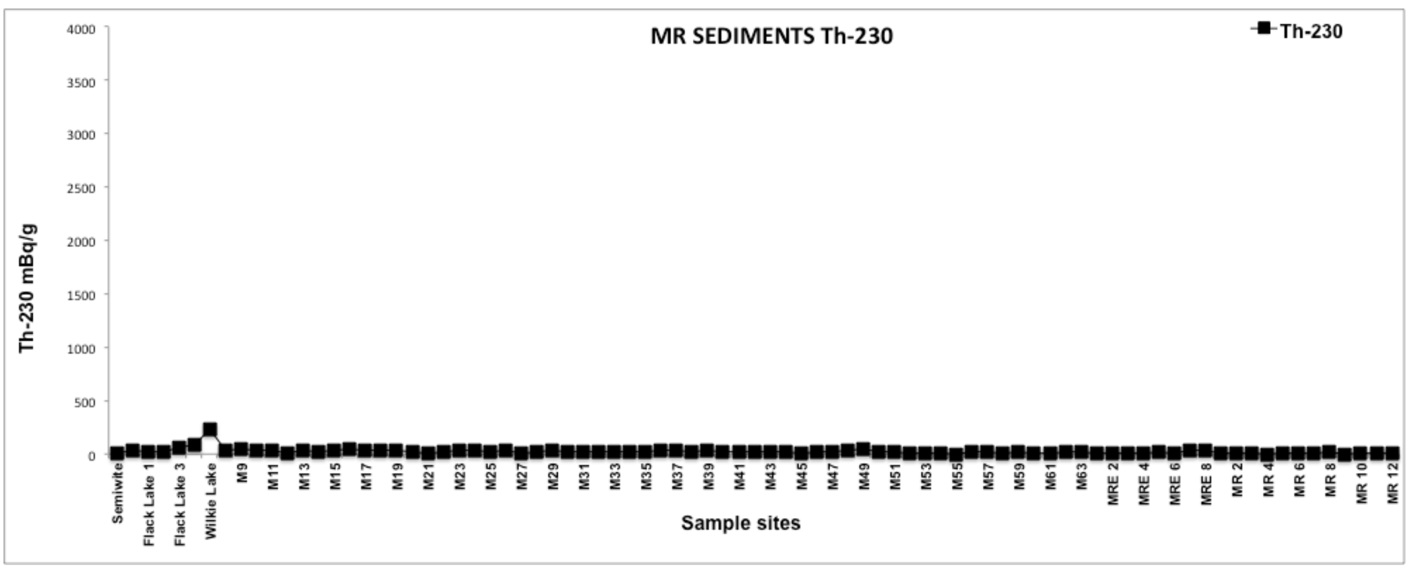


Figure 43. Thorium-228 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

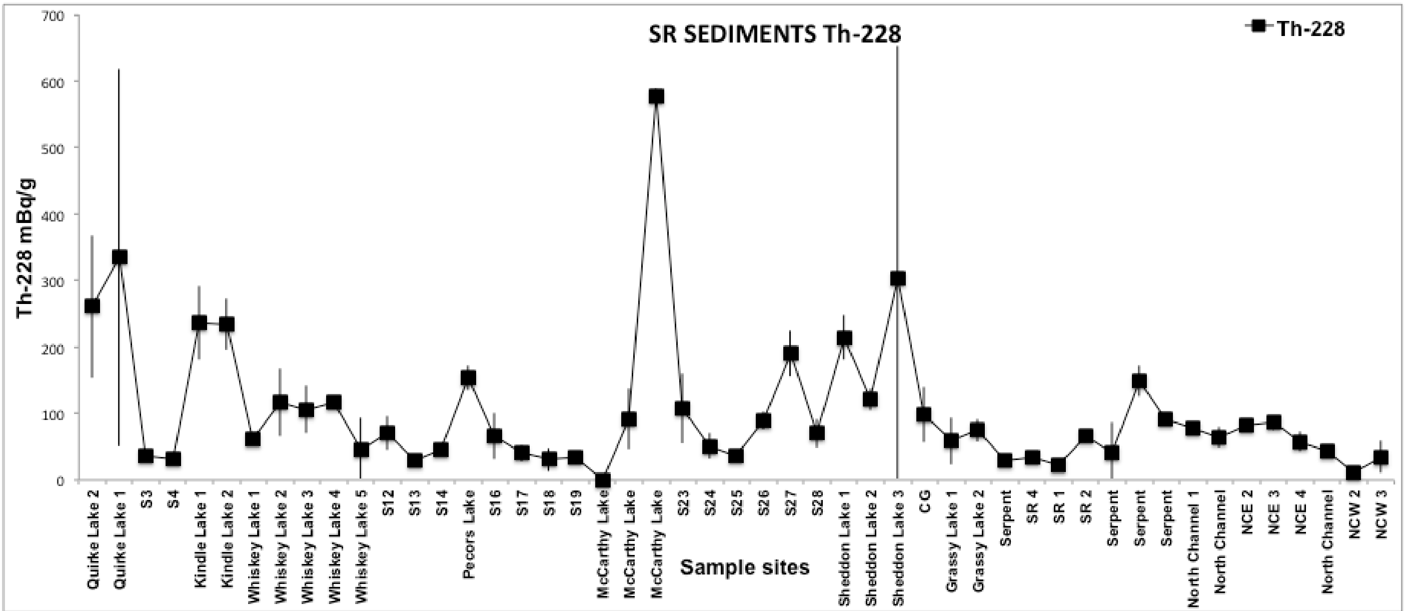


Figure 44. Thorium-228 in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

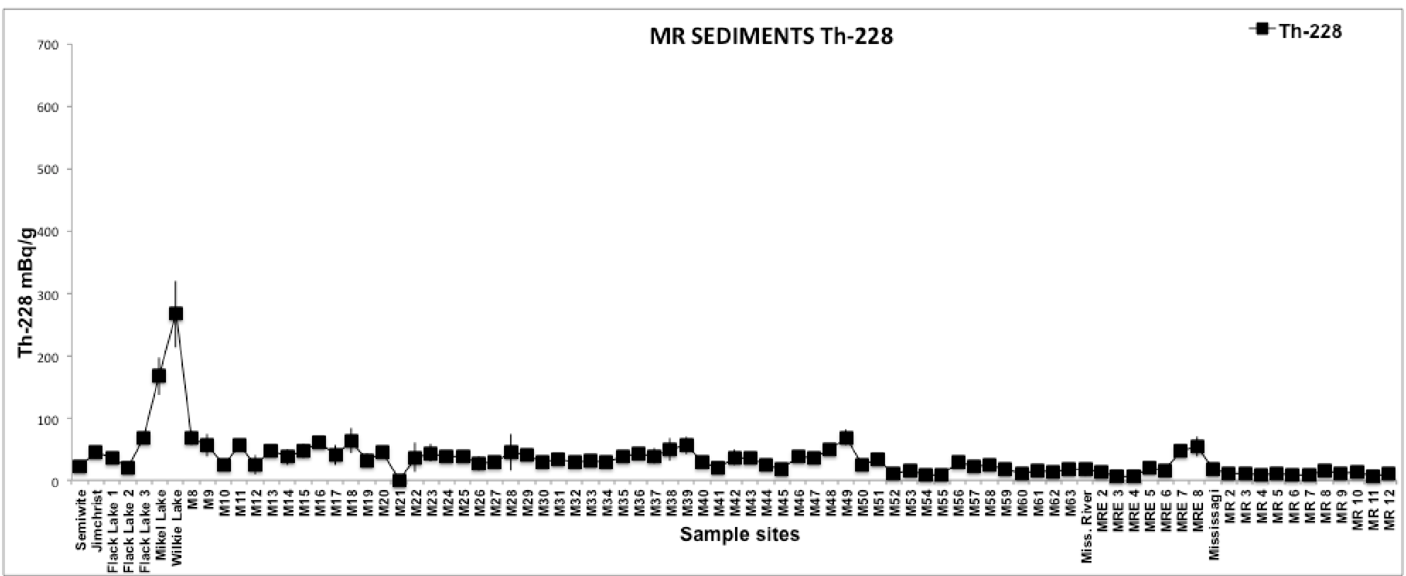


Figure 45. Polonium-210 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

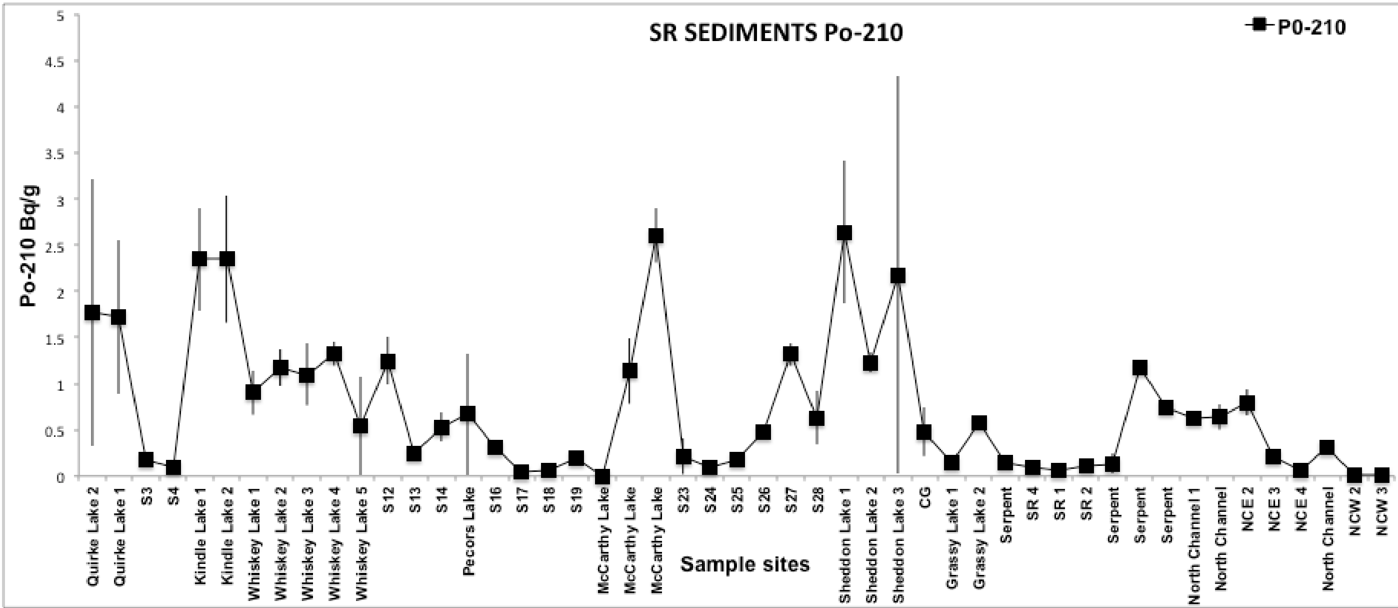


Figure 46. Po-210 in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

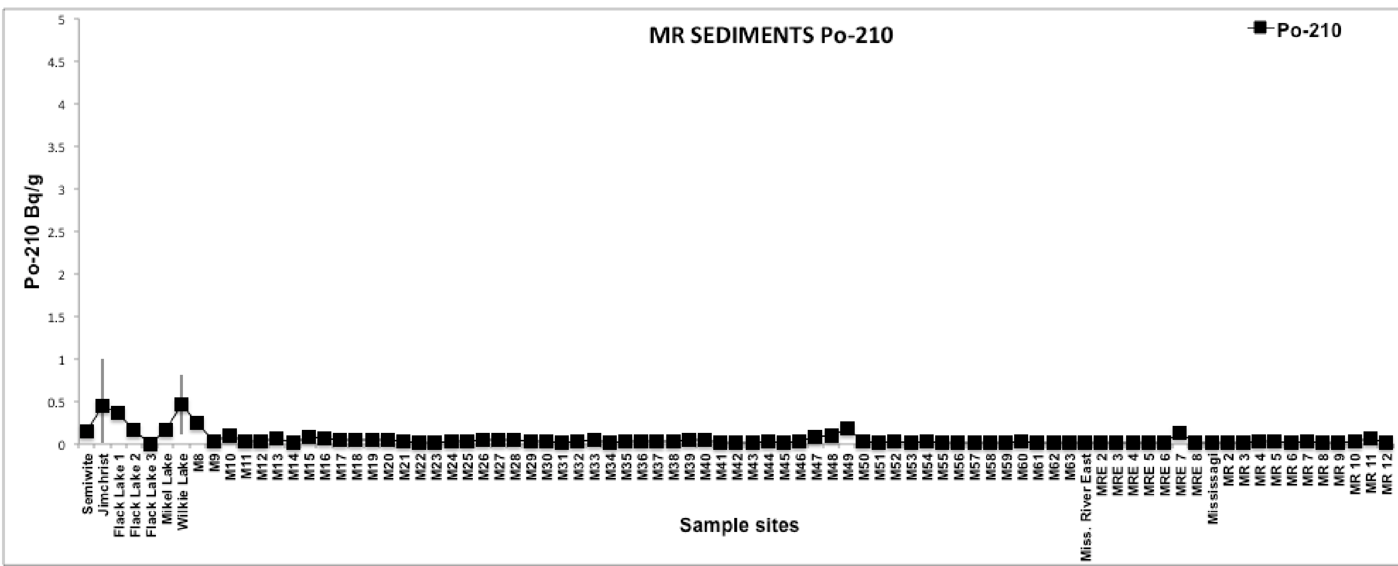


Figure 47. Pb-210 in sediments downstream of Quirke Lake in the Serpent River and Lake Huron.

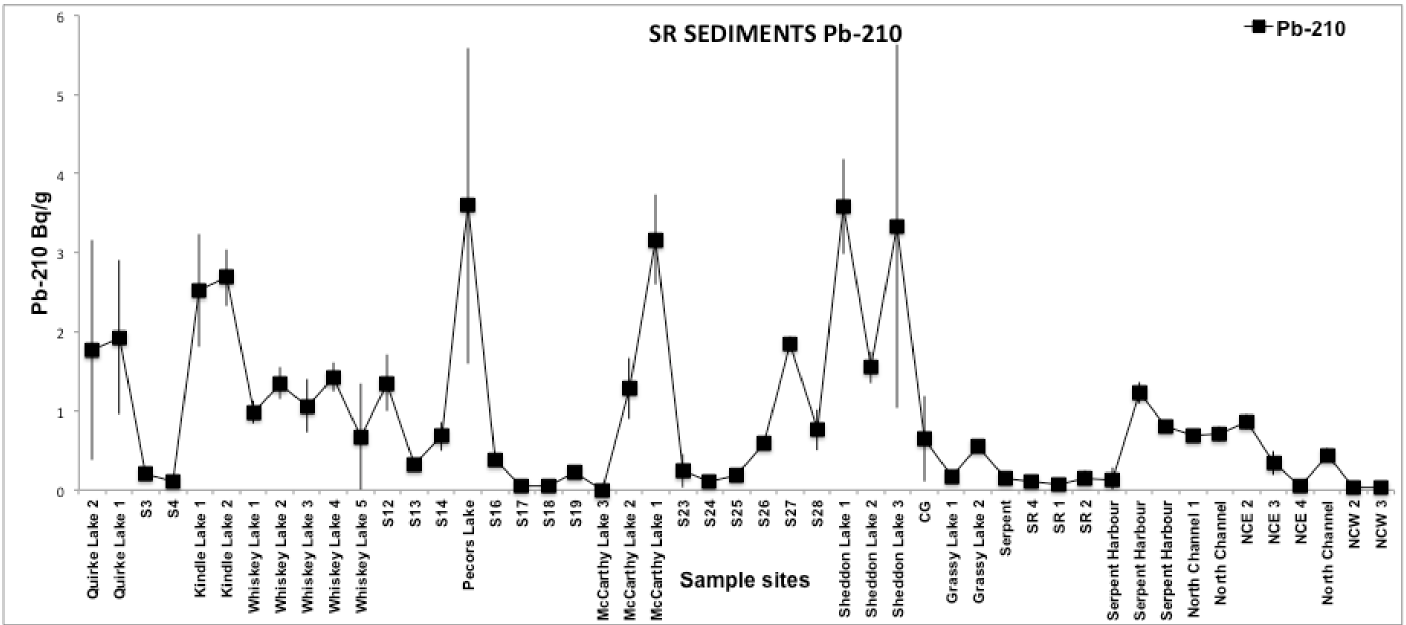
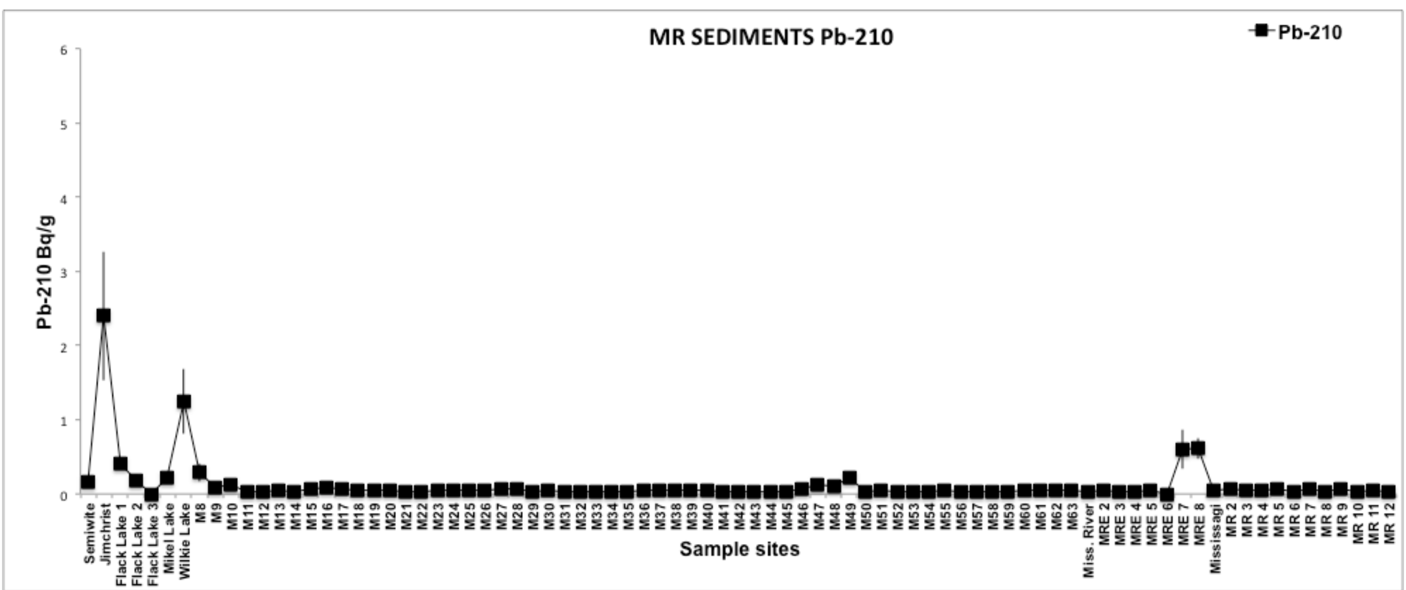


Figure 48. Pb-210 in sediments downstream of Semiwite Lake in the Serpent River and Lake Huron.

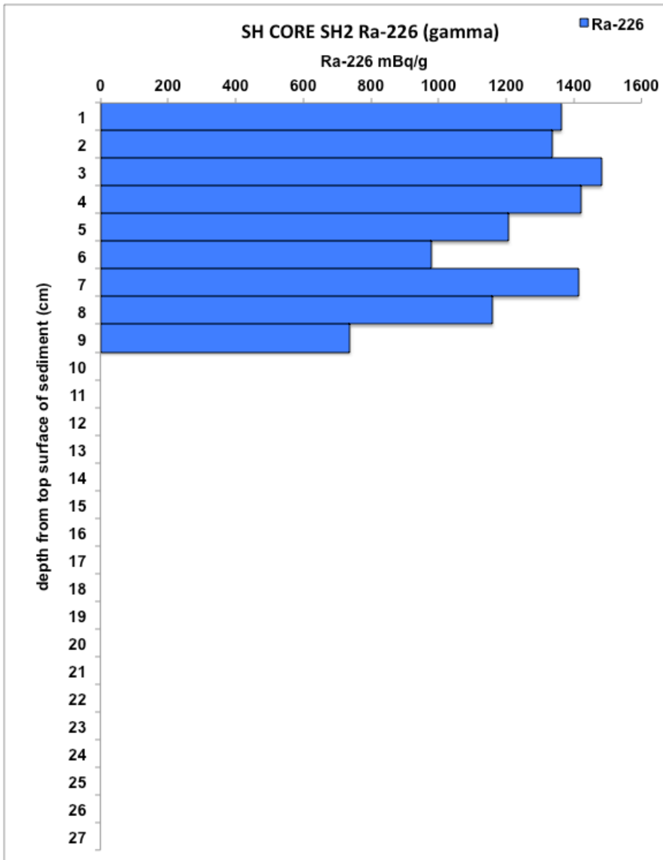


Radium-226 and other contaminant levels are higher in Serpent River sediments (downstream from **U** mining areas around Elliot Lake) than in samples from the Mississagi River (the control area with undisturbed **U** deposits) and generally decline with distance from mining activities (Figures

19&20). However, Nickel levels (Figures 29, 30) are similarly low down both watercourses but show elevation in the North Channel. The explanation for this is uncertain.

4.5 Sediment core profiles

Figure 49. Ra-226 (gamma) in Serpent Harbour cores SH2 (left) and SH3 (right)



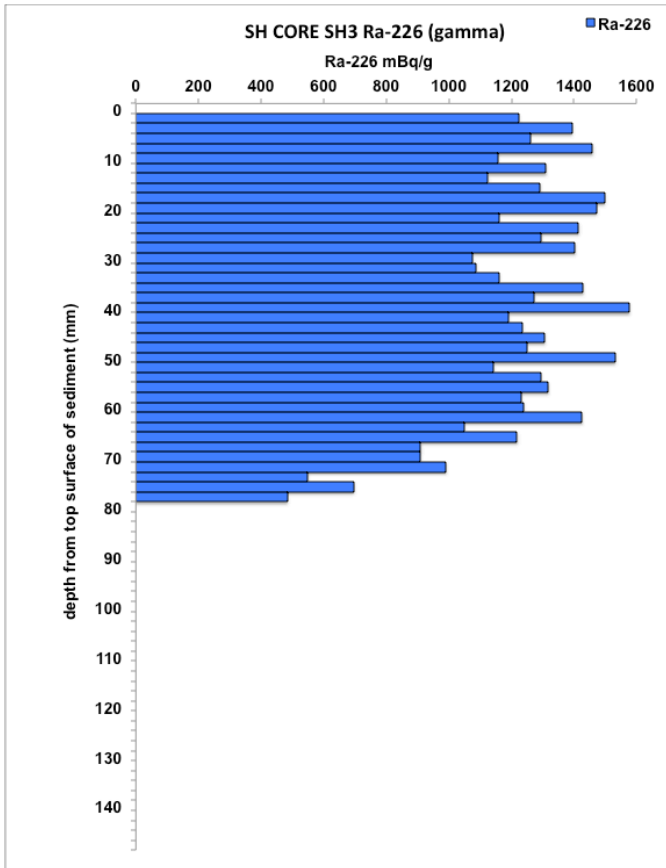


Figure 50. Ra-226 Gross gamma activity in Serpent Harbour cores SH2 (left) and SH3 (right)

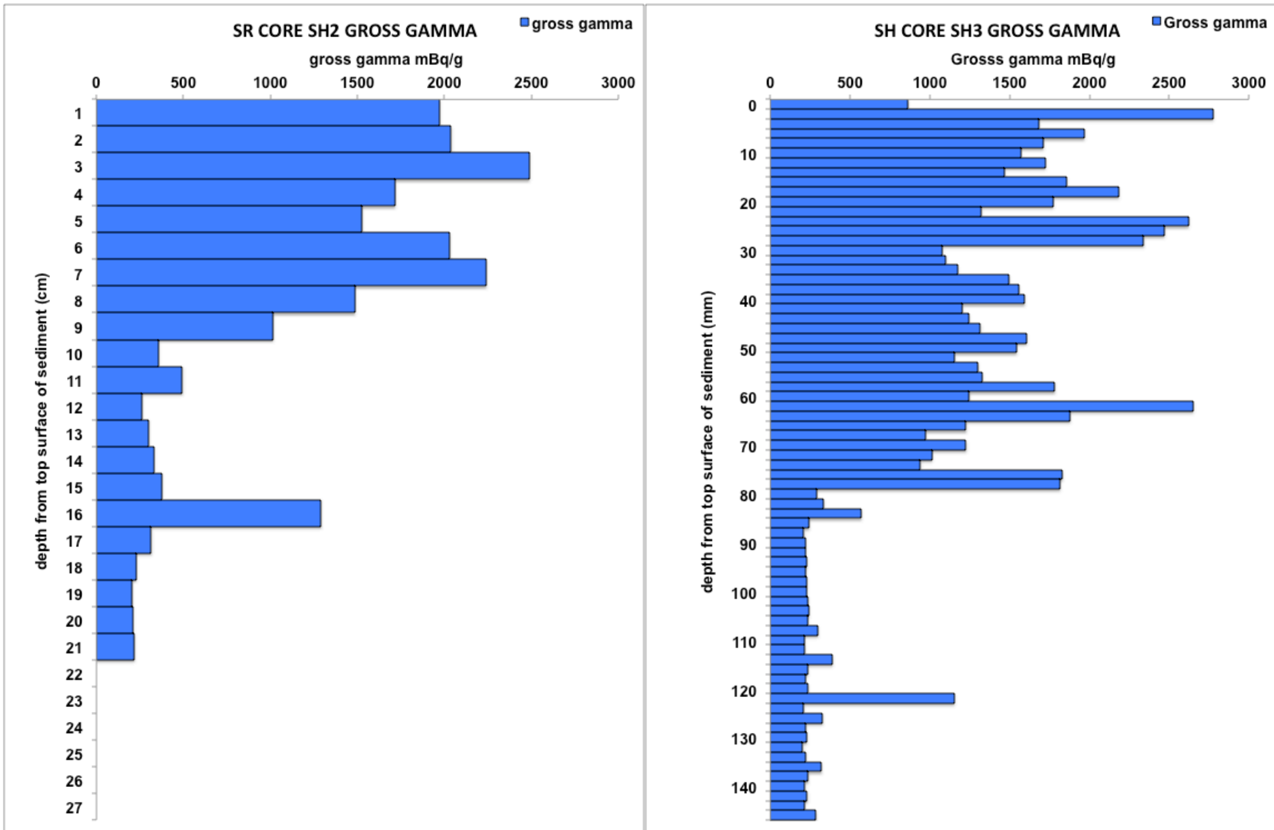


Figure 51. Ra-226 in Serpent Harbour cores SH2 (left) and SH3 (right)

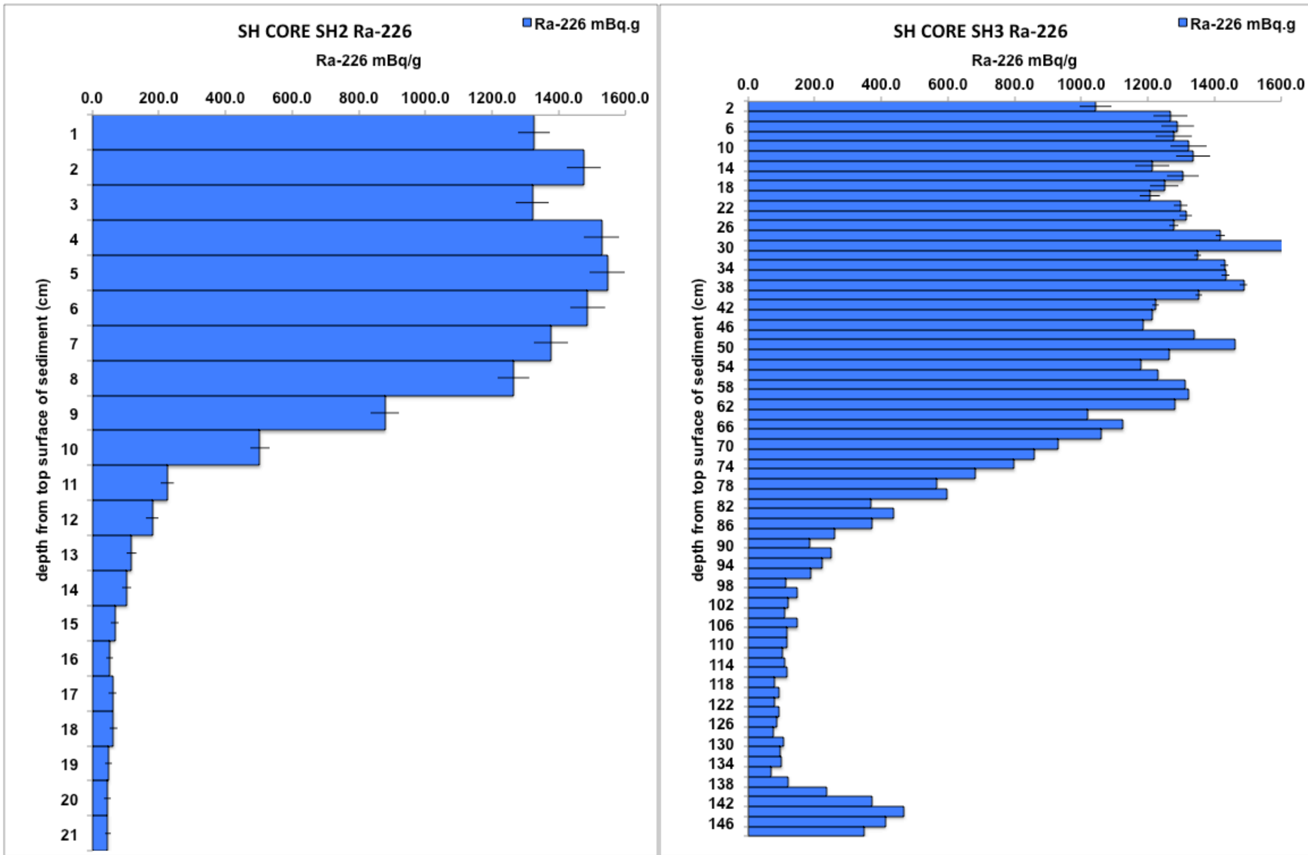


Figure 52. Cs-137 in Serpent Harbour cores SH2 (left) and SH3 (right)

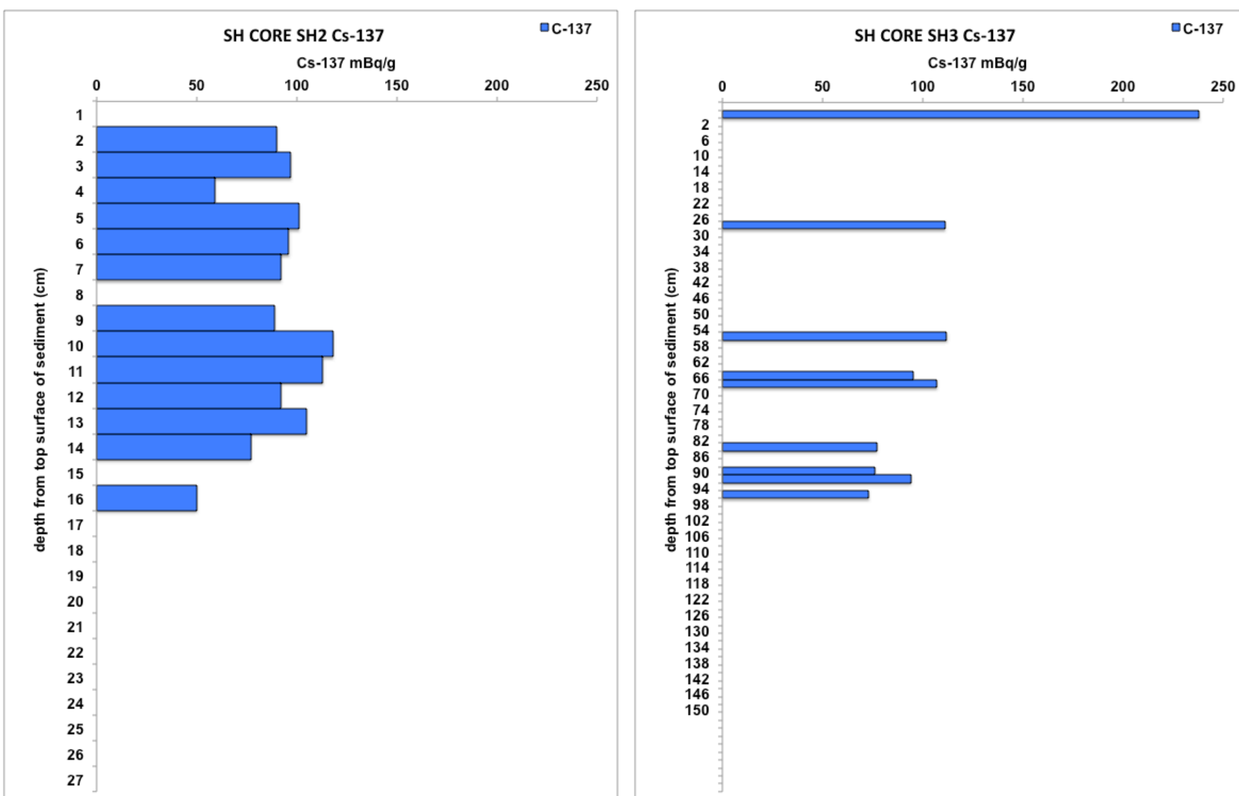


Figure 53. Metals in Serpent Harbour core SH2.

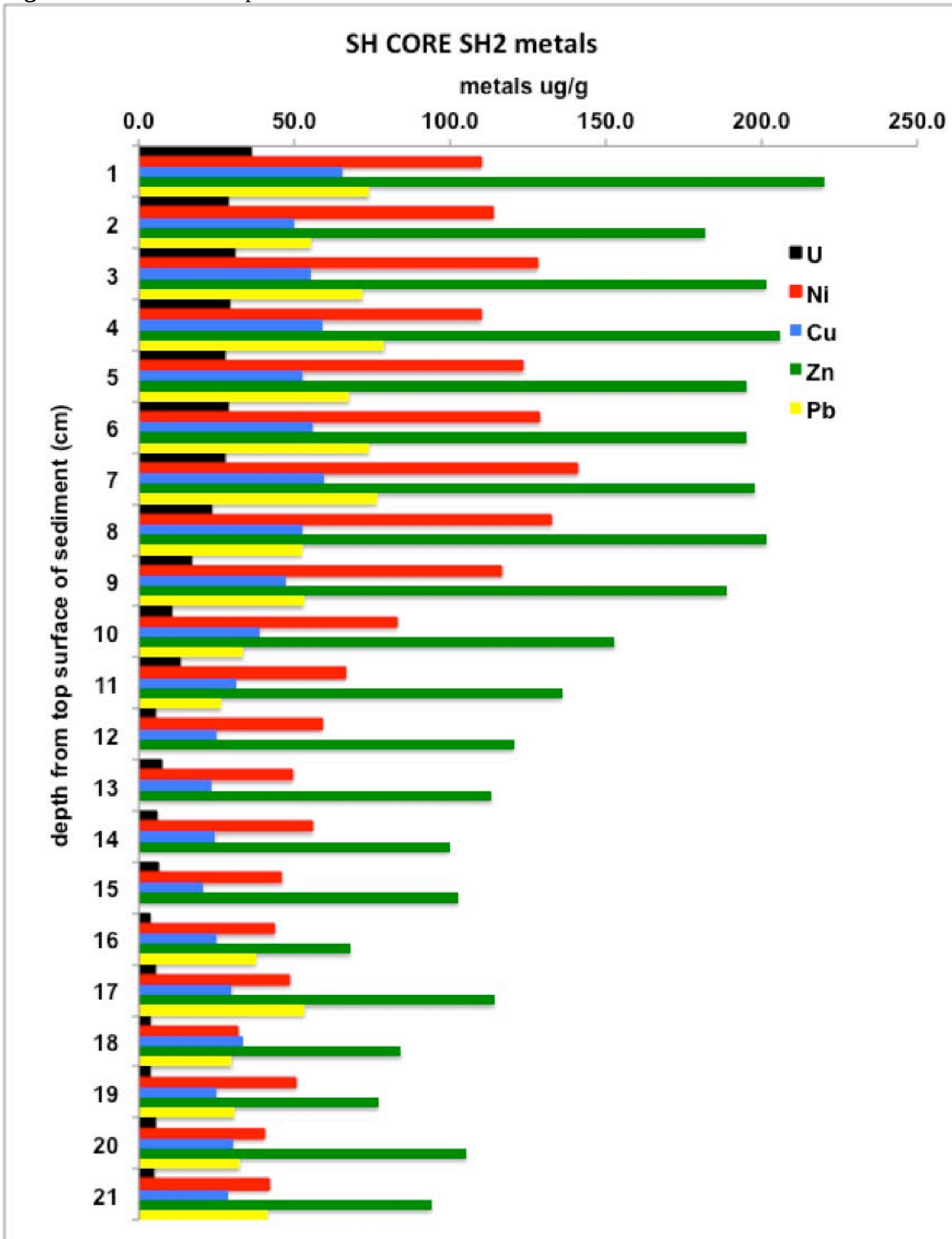
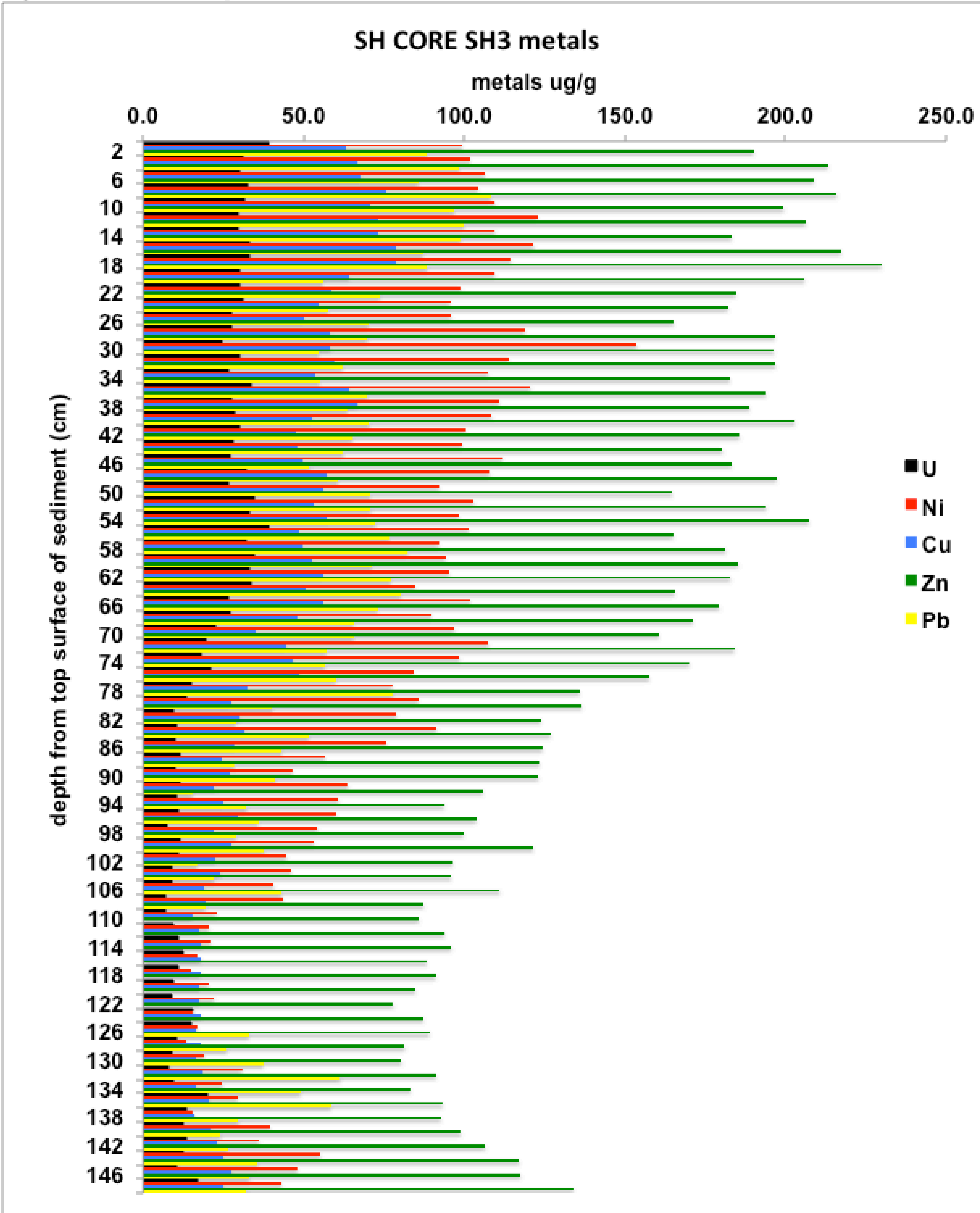


Figure 54. Metals in Serpent Harbour core SH3.



As seen in Figure 53, levels of ^{226}**Ra**, **U**, other metals, and **gamma** – activity, increase greatly about 80 - 90 mm below the sediment/water interface in the mouth of the Serpent River and remain relatively constant until within 6 - 8 mm from the top where some tend to decline. **Ra**-226 increases 30 times from background levels (more than 100 mm deep) with a subsequent decline of 15 - 20% near the surface. Core profiles suggest that background concentrations of Ra-226 are likely around 48 mBq/g suggested by the stable concentrations 19 cm below the sedment surface. Similarly, the background concentration in Lake Huron appears to around 5 µg U/g. These background levels are below the lowest effect level of 600 mBq/g and 104 µg/g derived by Thompson et al. 2005.

Radionuclide and metal level increases coincide with detectable levels of ^{137}**Cs** in the sediment column and are interpreted as reflecting the onset of mining activity in the Elliot Lake region in the 1950s and a concurrent increase in atmospheric nuclear bomb testing. The small but significant declines in contaminant levels near the surface probably reflect improved tailings management along with a decline in **U** production over the last decade of mining activity in Elliot Lake.

Results provide insight to the spatial extent of historical contamination of the **U** industry. Sediment cores also provide background concentrations of metals and radium-226 in Serpent River Harbor.

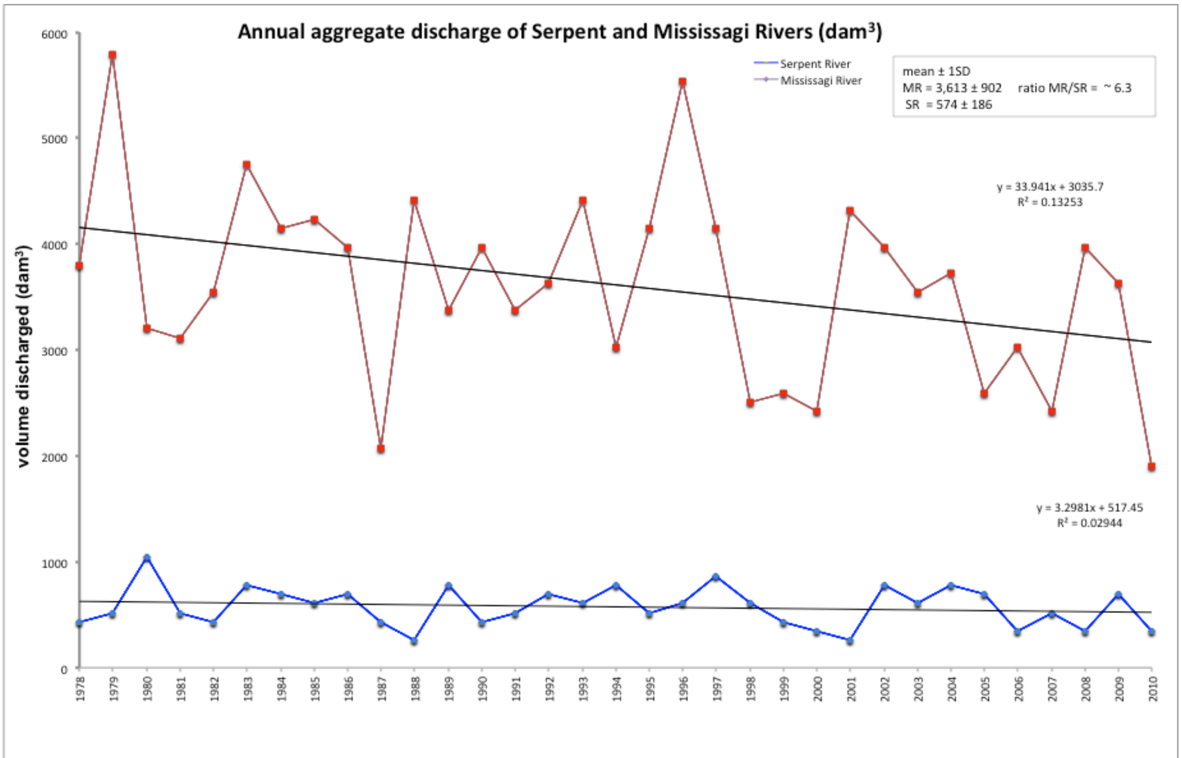
Studies to extend the range and precision of core analyses, and to collect seasonal and annual sediment depositions (to calculate current river loadings and input to the Great Lakes and to allow more precise interpretation of historical information in core profiles) are also described.

4.6 Flow rates of the two rivers into North Channel of Lake Huron

Figure 55 shows the separate total discharge of the Serpent and Mississagi Rivers for the 32 year period 1978 - 2010 to the North Channel of Lake Huron (measured at MOEE station 001 - on the left bank of the Serpent River 333 m upstream of Hwy. 17 bridge on the Serpent River Band Territory, about 3.2 km west of Cutler, and at MOEE station 008 - on the bank of the Mississigi River, 0.8 km upstream of CPR bridge near the town of Mississauga, just west of Blind River[1].

[1] Discharge Data Available for Serpent River at Hwy 17 (02CD001) and Mississiagi River at Chute (02CC008) at: https://wateroffice.ec.gc.ca/report/historical_e.html?stn=02CD001&mode=Table&type=h2oArc&results_type=historical&dataType=Daily&parameterType=Flow&year=2010&y1Mean=1&scale=normal

Figure 55. Annual discharge of Serpent River and Mississagi River to North Channel.



Using the mean annual discharge of each river and the known concentrations of the radionuclides and metals in the contained water the contribution of each can be calculated: e.g. for Ra-226 (assuming that concentration remains constant through the year, and with approximations):

The mean Serpent River discharge is 574 ± 186 $dam^3 \bullet y^{-1}$ or 574 x 10^6 (± 186 x 10^6) litres per year. Taking the Ra-226 content of water at the point of discharge to approximate 40 $mBq.l^{-1}$ the **Serpent River** annual contribution of Ra-226 to the North Channel (and hence Lake Huron) would be

574 x 10^6 x 40 = 22,960 x 10^6 mBq = **22.96** MBq in total

(range, allowing for ± 1SD = 15.52 to 30.4 MBq in total).

https://wateroffice.ec.gc.ca/report/historical_e.html?stn=02CC008&mode=Table&type=h2oArc&results_type=historical&dataType=Daily&parameterType=Flow&year=2011&y1Mean=1&scale=normal

For the Mississagi River, the discharge volume is more than six times greater: 3,613 ± 902 $dam^3 \bullet y^{-1}$ or 3,613 x 10^6 (± 902 x 10^6) litres per year. Taking the Ra-226 content of water at the point of discharge to approximate 5 $mBq.l^{-1}$ the **Mississagi River** annual contribution of Ra-226 to the North Channel (and hence Lake Huron) would be

3,613 x 10^6 x 5 = 18,065 x 10^6 mBq = 18.07 MBq in total

(range, allowing for ± 1SD = 13.56 to 22.58 MBq in total).

5.0 **Conclusions**

The data indicate, as expected, that there have been increases in the levels of radionuclides, and some metals, in the waters and sediments downstream from the Uranium operations at Elliot Lake. These changes are reflected in the sediment profiles of the radionuclides and metals in the estuary of the river where it enters the North Channel. These profiles indicate the historical changes that have occurred in concentrations, the water and sediment values upstream indicate the geographic extent and current status of the contaminants of interest. There are signs of decline in sediment levels as the surface (most recent) deposits are considered. Analysis of current profiles is reccommended to see if improvement has continued.

Comparison of the SRW and MRW values in water and sediments suggests that natural weathering of surface uraniferous rocks (in the MRW) contributes to the inflow of radionuclides to Lake Huron (via the North Channel) and that the contribution of such contaminants, in the case of Ra-226, is comparable between the two watersheds. This is a reflection of the much greater volume of water entering the North Channel from the Mississagi River than the Serpent River, although the relative concentrations are greater in the latter.

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Human intake of radionuclides from biota near Elliot Lake, Ontario.

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P3E 2C6

General approaches.

In order to assess risk to human consumers of dietary radionuclides (or other items of interest such as elements or compounds) the concentrations of such components in food items must be known. When these are known, there are two approaches possible:

a) **The first** is to calculate the mass of the food item that needs to be consumed to match or exceed the oral 'annual limits on intake' (ALI). All that is required is the radionuclide concentration in a particular food item - it is then simple to calculate the mass of that food item that would have to be consumed in order to meet or exceed the ALI. This approach has the ***advantage that only one variable (the radionuclide concentration) needs to be known and no further assumptions need to be made. Furthermore, it provides the public with a more tangible measure of safety.***

Davé *et al.*, 1985, used this approach when calculating that with concentrations of ^{226}Ra in blueberries growing at different distances from U tailings at Elliot Lake varying from 2 to 6 mBq.g^{-1} dry weight (background, taken more than 1,000 m from the tailings), through 20 to 290 mBq.g^{-1} d.w. within 500m of the tailings, to ~285 mBq.g^{-1} d.w. on a tailings spill, the amounts (wet weight) of fresh berries to be consumed *per annum* to reach the ICRP dose limits on oral consumption of berries from each area would need to be 3,350 kg.a^{-1}, 160 kg.a^{-1}, and 47 kg.a^{-1} respectively. To put these consumption rates into perspective, people living in Uranium City in Northern Saskatchewan consume 1.68 kg.a^{-1} of local blueberries (Cameco 2011 Beaverlodge Project: Uranium City Country Food Study – Year 1).

b) **A second** approach allowing comparison to be made among consumers with different dietary habits in different locations, is to use known radionuclide concentrations in specific dietary intakes (of fruit, fish, flesh, and so on) to calculate (with several assumptions on amounts consumed per unit time) the annual intakes and to calculate the received doses; these of course are per radionuclide and need to be summed for the array of known radionuclides in the food eaten.

So, if the radionuclide concentration in a particular food item ***and*** the annual consumption of such food item is known then the ***actual intake of such radionuclide can be calculated*** (and compared to published ALI). This approach clearly requires knowledge of the concentrations of radionuclides (and other elements of interest from the tailings effluents accumulating in biota) – as in the first approach just described. We have considerable information on such concentrations in biota from the SRW gathered over the last fifty or so years. ***The second, additional, requirement*** for this approach is ***knowledge or estimate of the quantity of each food item being consumed***; this second variable is measured or estimated by social scientists and depends on a number of assumptions which introduce uncertainties into the calculation. A precaution that can be implemented that gives confidence is to adopt ***worst-case-scenario*** assumptions of concentrations (if there is variation) and intakes that will err of the side of overestimating risk to an unknown degree. With concentration information and dietary estimates in hand it is then possible to calculate received doses and compare to the annual oral ALI.

In the case of consumers of food items from around the Elliot Lake mining and milling area the literature contains the following examples of assumptions concerning dietary intake of food items:

a) Swanson, 1985 assumed a weekly meal of 375 g of fresh fish per person per week in her studies of uptake of radioactive material.

b) Clulow et al., (beaver paper) used Goldfarb, 1977 as the source for a value of local (Elliot Lake) hunters consuming wild game at the rate of 46 kg per family per year; he calculated an intake of 175 g per day per person per year those taking all their meat requirements (71 kg per person per year according to Health and Welfare Canada, 1975 for a Canadian male 20 – 29 years old) from the wild, and in this case consuming beaver.

c) Perhaps the gold-standard for knowledge of human consumption of fish and game by people around the Great Lakes is the EAGLE Eating patterns survey (Anon., 2001) conducted in partnership with the Assembly of First Nation, Chiefs of Ontario, Health Canada, and First Nations Communities in Ontario.

This study, on individuals who likely consume more wild fish and game in their diets than the Canadian population at large, involved conducting interviews using life-like mock-ups of portions of cooked food (fish and meat - cooked pickerel fillet of 418 g and cooked venison steak of 246 g) and recording statements on portion size and frequency of consumption from some 1,658 individuals in 35 communities. Overall consumption of fish (on average) was 19.8 g of fish per day; consumers aged

18 years or older consumed on average 22.8 g per day. The Lake Superior Region consumers ate almost twice as much at 35.8 g per day. Overall the three most frequently consumed fish were pickerel, whitefish, and lake trout.

For consumption of game meat the average portion was 261.4 g eaten 49.9 time per year. The Lake Huron Region and SE Ontario Region reported similar consumption rates, each with a daily consumption level roughly twice that of the SW Ontario Region, but only half the rate observed in the Lake Superior Region. Moose and deer were the most frequently consumed species of wild game, as they accounted for 53.2% and 26.2% of all wild game consumed by weight, respectively. Smaller wild game such as duck, rabbit, and partridge were less consumed and made up the balance of the wild meat diet.

In this report the EAGLE survey is used as the basis for conclusions as it is detailed (looking at individual intakes by age and sex), recently performed, and the area of interest (North Shore) of Lake Huron falls within its boundaries of study. The Swanson, Goldfarb, and the Health and Welfare Canada data do not share all of these qualities and are merely mentioned for completeness.

Biological information

Extent and quality of data – general observations

Radionuclide and metal concentrations in biota is patchy by organism, tissue, time, and place. The extent of this information is summarized in Table 1 and in the Annexes that contain known biota concentrations in both digital and narrative form. Published values fall within the range of values reported in the literature for other nuclear locations, when comparable figures are available, except for a few fish values that are higher than others reported in Canada.

Plant levels were generally the first to be reported, with most animal data being produced after 1985. Much biota information has in fact been produced after the peak of mining and milling activity in the area.

There is great variability in the form of reporting: this ranges from data on specified tissues or parts, of animals or plants to reports on mixtures of tissues or whole organisms, sometimes with adherent particles or gut contents included, sometimes peeled or washed. In addition, the manner of reporting ranges from ash through dry and fresh weight-based values.

The final observation is that biota data were not always reported in conjunction with environmental (water, substrate, or, as appropriate, diet) levels.

Available data have allowed calculation of several transfer parameters (concentration ratios (CRs), and in one case, a transfer coefficient) among components of the ecosystems of the area. Several human food items, used by residents of the area, have been studied; these include blueberries, fish (trout and whitefish in particular), grouse and some other game birds, hare, muskrat, beaver, and moose, and have been used to calculate intakes of human consumers of the items. Transfer parameters obtained in these studies have fallen within ranges published for other systems and localities (it is not possible to find comparable values in all cases as some of the Elliot Lake studies are the only ones of their kind). Although CRs greater than unity have been reported to some tissues (especially for ^{226}**Ra** from environmental compartments to bone) they are mostly less than unity to muscle (flesh) from all compartments except water, that in any case is only one of several possible sources of environmental radionuclides.

Conservative calculations of human intake, with generous dietary assumptions on consumption amounts, indicate that in the worst case only a fraction of the (ALI) would come from consumption of game or plants in the area, for those radionuclides studied.

In order to summarize the risks, if any, to human consumers of wild foods taken near Elliot Lake, the following process should be followed in eventual peer-reviewed publications:

a) The biota database (digital and narrative) is inspected and species not consumed by humans removed from further consideration.

b) Representative values, and extreme values, of radionuclides and metals in tissues that enter the human diet are selected; other data should not be considered further.

c) Using the ALIs the quantity of material required to meet (or exceed) the ALIs should be calculated and presented in table form.

d) Quantities of food items required to exceed the ALI should be compared to consumption values reported by EAGLE for Lake Huron (Lake Superior) First Nation band members.

e) CNSC should assume that First Nations consumers in the area eat more wild plant, fish, and game material than the general population of the area; by extension the risk (if any) to the general population will be less than the First Nations people may experience.

Annex 1 BIOTA radionuclides-metals dB (narrative)

Annex 2 BIOTA radionuclides-metals dB (digital)

Table 1. Sources of Elliot Lake biota radionuclide level information.

	................................organism................................			source
General				
plankton				Morris 1994
Plants				
wetland				
	Typha lattifolia		cattail	Kalin 1983, 1988; Mirka 1988
	Carex spp., Cyperus spp.		sedge	Kalin 1983, 1988
	Scirpus cyperinus		sedge	Kalin 1983, 1988
Terrestrial				
fungi	***Amanita sp., Fomes sp., Hydnum sp., Stereum sp., Polyporus sp., Trametes sp., Trichaptum sp.***			Clulow et al., 1992
lichens	***Cladonia rangiferina, Cladonia mitis Stereocaulon spp., Umbilicaria spp.***			Beckett *et al.*, 1982 (and Boileau *et al.*, 1982; Nieboer *et al.*, 1982)
mosses	***Pleurozium schreberi, Dicranium spp. Polytrichum commune, Sphagnum spp.***			
ferns	unidentified		'ferns'	MacLaren, 1978
grasses	***Festuca rubra***		creeping red fescue	
	Phalaris arundinacea		reed canary grass	Moffet & Tellier 1977
	Agrostis alba		redtop	Davé *et al.*, 1984a,b;1985
	Pleum pratensis		climax timothy	
woody plants	***Vaccinium angustifolium***		blueberry	Davé *et al.*, 1985
	Myrica gale		**sweet** gale	Clulow *et al.*, 1989, 1991
	Ilex verticillata		wine berry	Clulow *et al.*, 1989, 1991
	Populus tremuloides		trembling aspen	
	Populus grandidentata		largetooth aspen	Kalin 1983,1988,
	Betula papyrifera		white birch	Davé *et al.*, 1984a,b, 1985;
	Salix sp.		willow	Clulow *et al.*, 1989, 1991
	Alnus rugusa		speckled alder	
Animals				
invertebrates				
molluscs	***Hexagenia sp., Sagittaria sp., Unionidae***		clams	BEAK 1985
crustaceans	***Cambarus bartoni, Oronectes virilis***		crayfish	Alikhan, 1994
insects	***Agrotis ipsilon***		black cutworm	Clulow *et al.*, 1988
vertebrates				
fish	***Coregonus artedii***		cisco	
	Salvelinus namaycush		lake trout	
	Esox lucius		northern pike	
	Prosopium cylindraceum		round whitefish	BEAK 1987; Pyle 1993
	Acipenser fluvescens		sturgeon	Owen 1993, Clulow 1994b,c;
	Catostomus commersoni		sucker	
	Stizostedion vitreum		walleye	
	Coregonus clupeaformis		lake whitefish	
birds	***Bonasa umbellus***		ruffed grouse	Clulow *et al.*, 1989,1992
	Anas platyrhynchus		mallard	MacLaren 1978
	Mergus merganser		c. merganser	MacLaren 1978
mammals	***Microtus pennsylvanicus***	(rodent)	meadow vole	Cloutier et al., 1983 - 1986
	Ondatra zibethicus	(rodent)	muskrat	Mirka 1988
	Castor canadensis	(rodent)	beaver	Clulow *et al.*, 1989, 1991
	Lepus americanus	(lagomorph)	hare	Clulow *et al.*, 1986; Davé *et al.*, 1989
	Alces alces	(ungulate)	moose	BEAK 1987
	Lutra canadensis	(carnivore)	otter	Wren *et al.*, 1987 Clulow *et al.*, 1994
	Mustela vison	(carnivore)	mink	Clulow *et al.*, 1994

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