Environmental Radioactivity in Canada - Measurements

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ECOMatters Inc.

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ABSTRACT

Title: **Environmental Radioactivity in Canada - Measurements**
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Abstract
A recent review of background concentrations of radionuclides in surface waters and soils across Canada identified gaps in information. In particular, there were few data for ^{129}I and ^{36}Cl. Additionally, the degree of disequilibria in U and Th decay series was not well characterised. The present project involved sampling of 21 surface waters from New Brunswick to Saskatchewan. Analysis of ^{129}I and ^{36}Cl was by Accelerator Mass Spectroscopy and U and Th progeny by radiochemical methods. Trace elements and tritium were also measured. The observed concentrations of ^{129}I, ^{36}Cl and ^{3}H were consistent with expectations, and the present study increased by several fold the numbers of data available for Canadian waters. Concentrations of ^{232}Th, ^{235}U and ^{238}U were detectable in all locations, with substantial ranges. The U and Th decay series radionuclides were seldom detectable in water. Data were obtained for ^{129}I and several U and Th decay series radionuclides in a few soil and rock samples.

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1. INTRODUCTION AND OBJECTIVE

Low levels of radionuclides occur in surface water and soils, from primordial sources, current natural sources and human sources. As part of a project to develop a database of background concentrations in Canada, measurements were undertaken for selected radionuclides. The measurements are described in this report. The overall results of the project are described in Sheppard et al. (2011).

1.1 ANALYTES

The key analytes were ^{129}I and associated stable iodine. Analysis by accelerator mass spectroscopy (AMS) is required for ^{129}I, and the costs and scheduling of AMS limited the numbers of sites that were possible. Equally important analytes were ^{36}Cl and associated stable Cl. This also required AMS, but was further limited by scheduling because it required re-configuration of the AMS machine.

Tritium (^{3}H) was analysed in all water samples.

The primordial radionuclide analytes were chosen to be radionuclides in the U and Th decay series that are before and after radionuclide pairs known to be in disequilibrium. There were several radionuclides of particular interest:
   − In water, ^{224}Ra from the ^{232}Th decay series is prominent in terms of radioactivity, but is seldom measured, at least in part because there is no suitable reference standard for environmental concentrations (personal communication, Dr. E. Hoffman, ActLabs). However, it is reasonable to assume secular equilibrium with ^{228}Th, which can be measured. There is particular interest in ^{228}Th data (or ^{228}Ra, ^{228}Ac or ^{224}Ra, the others in that decay series) because of an assumed secular disequilibrium in water between ^{232}Th and ^{228}Ra. Thus to fully deal with the lack of ^{224}Ra data, it is relevant to measure ^{232}Th, ^{228}Ra and ^{228}Th.
   − The ^{235}U series has an assumed secular disequilibrium in water between ^{235}U and its progeny. Gamma spectroscopy may quantify this disequilibrium by analyses of ^{235}U and ^{223}Ra.
   − The ^{238}U decay series radionuclides are commonly measured, but data for these are generally useful and are good ancillary data for any environmental radioactivity measurements. The key radionuclides are ^{238}U and ^{226}Ra, with ^{210}Pb as the next most important, as there is often disequilibria between these pairs.

In addition to the primary analytes, ancillary data for water samples included pH, dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). All samples were also analysed for a suite of about 50 trace elements.

1.2 MEDIA AND SAMPLING DOMAIN

The majority of samples were of surface waters (21 samples), most drawn from rivers where there are flow-rate data. The spatial domain for the water samples placed emphasis on the nuclear provinces (Saskatchewan, Ontario, Quebec and New Brunswick), but a sample was

also drawn from the Mackenzie River in the far north. Site selection also took into account expected spatial trends:

- – For [129]I, it was important to sample a gradient away from West Valley NY because this is the closest emission source to Canada and has a notable [129]I signature in the order of hundreds of kilometres from the source (Rao and Fehn 1999). A latitudinal gradient was also important because cosmogenic [129]I (and cosmogenic ^{3}H and [36]Cl) is predominantly deposited in mid-latitudes.
- – For stable iodine (and to a lesser extent Cl), a transect with distance from the oceans was relevant because oceans are major sources of stable iodine on the continental scale.
- – For tritium, it was important to sample at several hundred kilometres distance from nuclear power plants.

In order to link the present results to previous studies, some of the surface waters sampled were among those sampled in 2007 (Sheppard et al. 2010, Sheppard et al. 2009).

In addition to water samples, there were 4 soil samples and 3 rock samples from Ontario and Saskatchewan.

2. METHODS

2.1 SITES SAMPLED AND IN-FIELD PROCEDURE

The water sampling sites are described in Table 1, along with notes related to the site selection and characteristics. Figure 1 shows the locations on a map of Canada and Table 2 gives flow statistics for locations at or near the sampling sites. Most samples were collected from the banks of the rivers at a point where there was sufficiently turbulent flow that the sample could be considered representative of the cross section of the river. In a few cases, the sample was drawn from a boat, bridge or dock. A reaching assist was used when required to collect a sample 1 to 2 m away from the edge of the bank. All sampling equipment was rinsed on site with water from the river prior to drawing samples.

Because of the large sample volumes needed, it was decided to not filter the large samples. However, to account for elements attached to suspended particulate matter, small additional sample pairs were collected. One of these was filtered in the field and the other not filtered. Both were subjected to stable iodine and trace element (including U and Th) analyses, and any differences could be attributed to suspended particulate matter. The corresponding filtered/unfiltered concentration ratio might be assumed to apply to the [129]I and other radionuclides. Similarly, there was a minor concern about volatilization of iodine from samples: previously water samples for iodine were frozen in the field and stored frozen, whereas that was not possible in this sampling campaign. To account for possible effects, small additional sample pairs were collected, one was kept on ice in the field and one was left at ambient temperature.

As a further precaution against loss of [129]I, it was decided to add the carrier stable iodine in the field. For AMS, the procedure is to first add a known amount of stable 'carrier' iodine to the sample. It is assumed the stable iodine and [129]I in the sample reach isotopic equilibrium in all possible chemical phases, including any iodine sorbed to bottles and bound in dissolved

organic matter. Thus the stable iodine 'carries' the [129]I by saturating any unknown sorption sites or other loss mechanisms. The AMS then measures the specific activity of the iodine (atoms of [129]I per atom of stable iodine). Because of the known addition of stable iodine in the sample, it is possible to compute the amount of [129]I originally in the sample. The decision to add the carrier in the field ensured the sample was robust against loss of [129]I during transport and storage, as well as in the lab (with the assumption that chemical speciation was in equilibrium). Note that the iodine carrier also contains [129]I (as does virtually all iodine materials), but the specific activity of the iodine carrier is known and is subtracted from the final [129]I sample results.

All sample bottles were pre-labelled, with specific instructions on the label regarding filtering, sample storage conditions and intended analytes. The sampling procedure was as follows.

1) Rinse all bottles and sampling equipment with site water, with the exception of bottles which are to contain filtered water, and these are rinsed with filtered site water.
2) Fill a 4-L 'U/Th series' plastic bottle nearly to brim, acidify to <pH2 (check with the pH-sensitive paper) and seal.
   a. Repeat above if the site is designated to have a duplicate sample for U/Th series analysis, seal.
3) Fill a 1-L 'archive' plastic bottle nearly to brim and seal (no duplicates).
4) Precisely measure 2 L of site water into a 2-L plastic bottle for [129]I, add precisely 1 mL of NaI solution (this stock solution is 1.1811 g NaI per 100 mL deionized water, resulting in 5 mg I L^{-1} in the collected sample[1]), seal.
   a. Repeat above if the site is designated to have a duplicate sample for [129]I analysis, seal.
   b. Repeat above if the site is designated to have a sample for [129]I sent to Prime Laboratories (Purdue University), seal.
5) If the site is designated for [36]Cl analysis, fill a 2-L bottle and seal.
6) Using syringe filter (0.45µm), fill a 60-mL plastic bottle with filtered water for trace element analyses, acidify to <pH2 and seal.
7) Without filtering, fill another 60-mL plastic bottle with site water for trace element analyses, acidify to <pH2 and seal.
8) Using same syringe filter, fill a 75-mL glass bottle with filtered water for stable I analysis, seal, and store at ambient temperature.
9) Without filtering, fill two 75-mL glass bottles for stable I and Cl, seal and keep one at ambient temperature and the other chilled or frozen.
10) Without filtering, fill to the brim with no headspace three 75-mL glass bottles labelled separately for ^{3}H, DOC and DIC analyses, seal.
    a. Repeat above two samples if the site is designated to have duplicate samples for ^{3}H, DOC and DIC analysis, seal.

After sampling, the pH of the water was measured from the archive sample, and a subsample of the [129]I samples was retained to confirm the intended carrier concentrations. The samples were taken by hand or shipped in batches to the respective analytical laboratories. These were:

− IsoTrace Laboratories at the University of Ottawa for [129]I, [36]Cl and [3]H (they also did stable I, DOC and DIC). The samples for [129]I and [36]Cl were chemically processed at the University of Ottawa to prepare AgI and AgCl targets for the AMS. These targets were then shipped to IsoTrace Laboratories at the University of Toronto for AMS of [129]I and

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[1] Note that the samples from 2 sites (Sylvia Lake and Mackenzie River) were not spiked in the field, and were spiked in the laboratory to achieve 1 mg I L^{-1}.

Prime Laboratories at Purdue University for AMS of ^{36}Cl. The ^{3}H was analysed at the University of Ottawa.
- Prime Laboratories for alternative-lab analysis of ^{129}I (3 water samples).
- Activation Laboratories in Ancaster for stable I (including the carrier-spiked subsamples) and Cl, U/Th series radionuclides, trace elements, DIC and DOC.
- ECOMatters Inc. laboratories for frozen storage of archive samples.

The sites for 3 mineral soil samples were from central and northern Ontario: two near Tiverton ON and one north of Lake Superior. At each site, a composite sample of the top 20 cm was collected. An organic soil near Black Lake, Nopiming Province Park, Manitoba was specifically chosen as the bottom peat (~1 m deep) in a wetland known to be enriched in uranium (U) because of a local mineralisation (Sheppard and Thibault 1984). The hypothesis was that U and geogenic ^{129}I carried by groundwater would accumulate in the peat, as both elements are especially sorbed by organic soils. To support this hypothesis, one of the rock samples was from the rock outcrop adjacent to the peat.

One of the remaining 2 rock samples was collected near the site in northern Ontario where a mineral soil sample was collected. The third rock sample was from northern Saskatchewan, from the outcrop nearest the water sampling site at Lac La Ronge.

Soil and rock samples were sent to IsoTrace Laboratories at the University of Ottawa for analysis of ^{129}I and ^{36}Cl, and to Activation Laboratories for analysis of stable I and Cl and trace elements. Soil samples were sent to ALS Laboratories in Saskatoon for texture and organic carbon analysis. The rock samples were examined under optical microscopy and classified by C. Galeschuk (P.Geo., Agassiz Geological Services).

2.2   PROBLEMS ENCOUNTERED AND MITIGATION

There was a problem caused by the breakage of 6 sample bottles during shipment to the University of Ottawa and 1 bottle broken in the laboratory at University of Ottawa. These were intended for ^{129}I analyses. The alternatives were to re-sample or to use the archive samples. Re-sampling was less desirable because most of the other analyses for these sites had already been done and would have to be re-done, or an assumption made that sampling time had no effect. In addition, the lost samples were from sites widely spread apart, so that it was not trivial to re-visit the sites. Preliminary analyses showed that reliable ^{129}I analyses could be obtained from samples as small as 400 mL, so that the archive samples could be used. The procedure was to thaw the archive sample and extract ~50 mL to be retained as an archive. The volume of sample to be sent for ^{129}I analyses was precisely measured, the appropriate amount of stable iodine carrier was added to achieve 5 mg I L^{-1}, and the sample was shipped (successfully) to the University of Ottawa. As before, a subsample of the carrier-spiked sample was analysed for stable iodine.

2.3   ANALYTICAL METHODS

2.3.1   Redox Extraction of ^{129}I in Water Samples

Unfiltered water samples were prepared for ^{129}I analysis by redox separation. The water samples were spiked with NaI carrier (see above). Most samples received a spike that had a ^{127}I/^{129}I atom ratio of (18.6 ± 0.7) x 10^{-14}, whereas for 2 sites (Sylvia Lake and Mackenzie River) the spike had a ^{127}I/^{129}I ratio of (2.0 ± 0.3) x 10^{-14}. These spikes contributed less than 10% of the total ^{129}I in the spiked samples and these additions of ^{129}I were accounted for in the calculations, so that these differences in spike amounts were not problematic. The bottles were then transported to University of Ottawa and stored in a dark, cool place until extraction.

Aliquots of 400 mL were used for ^{129}I analysis. Samples were pre-treated with 0.5 mL of 30% H_2O_2 in order to oxidize any humic and/or fulvic acids which may limit the recovery of iodine. The water was then acidified using 6-N HNO_3 and shaken for half an hour before all the iodine species in solution were reduced to I$^-$ (iodide) using 2 mL of 1-M $NaHSO_3$. The water was then left to stand for 16 hours.

To facilitate the extraction process, the sample was divided into two 200-mL portions and transferred into 250 mL separatory funnels. About 15 to 20 mL of hexane was added to the sample followed by 0.1-0.3 mL of 6-M $NaNO_2$ to oxidize all of the iodine to I_2 (elemental iodine), which has a strong affinity for hexane. The sample was then shaken for 15 minutes. The hexane containing I_2 turned dark pink to purple in colour and had clear separation from the water. The aqueous sample was decanted into a plastic bottle and the hexane was collected into a centrifuge tube. New hexane was added to the aqueous sample and the process was repeated until the hexane remained clear after being shaken, usually following 4-5 repetitions. Clear hexane indicated no further I_2 in the aqueous sample. The accumulated hexane was then poured back into the separatory funnels and 10 to 20 mL glacial water (low in ^{129}I, (10.3 ± 2.3) x 10^6 atoms ^{129}I L^{-1}) was added as well as sufficient 1-M $NaHSO_3$ (0.1 to 0.3 mL) so that the hexane appeared colourless. This indicated that all the I_2 was reduced to I$^-$ and was in the aqueous phase.

The hexane was then discarded and 15 mL of new hexane and 0.5 mL of 6-N HNO_3 was added to the aqueous phase along with 0.1 mL of 1-M $NaNO_2$ and the separatory funnel was shaken until the hexane turned dark pink. The aqueous phase was discarded and 10 mL of glacial water was added with 0.1 to 0.3 mL of 1-M $NaHSO_3$ and the separatory funnel was shaken until the hexane was clear. The aqueous layer was then drained into a 20-mL scintillation vial. An aliquot of 100 µL of 6-N HNO_3 was then added to the aqueous solution in the scintillation vial and the temperature was raised to 80-90°C.

An aliquot of 20 µL of 0.1-M $AgNO_3$ was added causing an immediate precipitation of AgI, which was allowed to settle in a 50°C drying oven. The precipitate and the remaining water were then transferred to a 2 mL round-bottomed vial and placed in a centrifuge for 15 minutes. The supernatant was then removed and a few drops of glacial water were added. This step was repeated up to three times to ensure that the precipitate was clean. The precipitate was then dried at 50°C. Once dry, the vial containing the precipitate was wrapped in aluminum foil to prevent photo-oxidation of the AgI and it was sent to IsoTrace Laboratories for AMS analysis.

The reproducibility of results within an AMS run was checked by duplicate measurements of ~10% of the samples during a run. The measurements were normalized with respect to the ISOT-2 reference material for which the $^{129}I/^{127}I$ atom ratio is $(1.313 \pm 0.017) \times 10^{-11}$, which is calibrated with the NIST 3230 I and II standard reference material[2]. In each ion source load, 2 ISOT-2A reference targets, 1 (or 0) NaI blanks, 1 pure Nb, and 5 (or 6) unknown samples were loaded. Each target was measured for the same length of time. The ^{129}I counts collected from the Nb target were used to estimate the cross-contamination level for all the samples in the load. The total collected ^{129}I counts from each target were first corrected by this number before further data analysis. The ratios obtained for the individual sample targets were normalized using the values obtained for the reference targets to provide the $^{129}I/^{127}I$ ratio for the target. The concentration of ^{129}I was obtained by multiplying this ratio by the quantity of ^{127}I (from carrier and natural sources) in the sample, determined by ICP-MS measurements on aliquots of the spiked samples.

2.3.2   Caustic Fusion Extraction of ^{129}I in Solid Samples

Caustic (alkali) fusion was used to extract ^{129}I from solid organic and inorganic materials. Approximately 5 g of sample was placed in the 50°C oven and dried. The sample was then transferred into a washed 100-mL iron crucible, 15 g of solid NaOH and 10 g of solid $NaNO_2$ were added to the crucible along with a few mL of glacial water. Quantities of a NaI carrier ($^{129}I/^{127}I$ ratio of $(2.0 \pm 1) \times 10^{-14}$) were added depending on the existing iodine concentration of the sample, 5 to 20 µL of carrier may be added. The mixture was then stirred gently and covered for a 24-h period.

The covered crucible was then placed in a furnace and heated in a stepwise fashion up to a maximum temperature of 600°C. The stepwise heating allowed for the gradual release of organic matter, preventing rapid oxidation and possible explosion of the sample. The sample was then removed from the oven and left to cool to room temperature. The appearance of the sample was that of a greenish-blue crust on the bottom of the crucible. An aliquot of 40 mL of glacial water was added to the crucible and stirred to loosen the crust. The mixture was then poured into a beaker and the washing process repeated until all the sample had been removed from the crucible. The soluble and insoluble fractions were separated by centrifugation. The insoluble fraction was saved for later treatment and the soluble fraction was put through an abbreviated form of aqueous redox extraction.

The insoluble fraction was washed with glacial water and 5 mL of 6-N HCl were added to the beaker to dissolve the precipitate, then the supernatant was decanted to a separate beaker. This step was repeated until all of the precipitate was dissolved. The sample was then put through an abbreviated aqueous redox extraction.

The AgI was precipitated in the same manner as with aqueous samples for both the soluble and insoluble fractions of the sample.

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[2] National Institute of Standards and Technology - Standard Reference Material 3230 is an ^{129}I isotopic standard (low level), now discontinued but with an expiry of 2013.

2.3.3 ^{36}Cl in Water Samples

An aliquot of unfiltered sample containing sufficient Cl to produce between 5 and 25 mg of AgI was placed in a centrifuge tube. If the ^{36}Cl/^{35}Cl ratio was greater than 2×10^{-12} then the sample was diluted using a stable chloride carrier solution to decrease this ratio. An aliquot of 1 mL of 0.1-M AgNO$_3$ and 5 mL of concentrated HNO$_3$ was added to the sample and it was placed in the refrigerator to let the precipitated AgCl settle overnight. Once the AgCl was settled, the sample was dissolved and purified by column elution.

The ion exchange column was prepared with a 5-cm bed of Dowex 1X8 anion exchange resin. The column was preconditioned with 150 mL of 1.5-M HNO$_3$. Three drops of AgNO$_3$ were added to the last 5 mL of elutriate to test for chloride. If any turbidity was observed, more acid was passed through the column and the test was repeated until the elutriate remained clear. The column was then washed with 300 mL of 18 MΩ de-ionized water.

The centrifuge tubes containing the precipitated AgCl were then centrifuged and the supernatant was decanted. An aliquot of 5 mL of de-ionized water and 20 drops of concentrated NH$_4$Cl were added to the precipitate to dissolve it. The solution of ammoniacal silver chloride was then loaded onto the column and drained level to the top of the resin bed, the elutriate was collected in a 30-mL bottle. About 10 mL of 0.1-M NH$_4$OH was added to the centrifuge tube and then loaded onto the column and drained until it was level with the top of the resin bed. Then about 10 mL of 0.05-M HNO$_3$ was added to the centrifuge tube, loaded onto the column and drained level to the top of the resin bed. A further 5 mL of 0.15-M HNO$_3$ was added and drained to the top of the resin bed. The 30-mL sample bottle was then removed and replaced with the original sample centrifuge tube containing 3 drops of 0.1-M AgNO$_3$, and an additional 2 mL of eluant was added to the column and collected in the centrifuge tube. Another 15 mL of fresh 0.15-M HNO$_3$ was added to the column and drained into the collection tube. Finally, 3 drops of 1-M AgNO$_3$ were added to the centrifuge tube as well as 5 drops of 0.15-M HNO$_3$. The resulting AgCl precipitate was shaken to coagulate it and then placed in the refrigerator. This material was then analyzed by AMS by Prime Laboratories.

2.3.4 ^{3}H in Water Samples

For ^{3}H analysis in unfiltered water, a 10-mL aliquot of sample was weighed into a 20-mL scintillation vial. Ten mL of UltimaGold LLT scintillation cocktail (Perkin Elmer product number 6013371) was then pipetted into the scintillation vial. Scintillation vials were then loaded into a Wallac Quantalus 1220 Ultra Low-Level Liquid Scintillation Counter for analysis. Counts were made on batch samples with a total of 100 minutes of counting time, using a 35 to 280 channel window. Sample quench correction was made using a standard with pre-determined ^{3}H activity. Blank correction was made using a mid-Holocene glacier water. Repeat counts of the blank water produced a background activity concentration of approximately 1 Bq L^{-1}.

2.3.5   Stable I, Cl and Trace Elements in Water Samples

Iodine and trace elements other than Cl in water samples were analysed by inductively coupled plasma – mass spectrometry (ICP-MS). This method was applied to samples that were i) field-filtered, ii) unfiltered and iii) unfiltered and stored chilled. In ICP-MS, the sample is atomized in a high-temperature plasma and then the atoms are separated by mass

spectroscopy. Care was taken to minimize sample dilution so that the best available detection limit for each element was achieved.

Chlorine in (unfiltered) water samples was determined by anion chromatography on an AS9-HC (Anion Separator, column # 9 High Capacity) column and an AG9-HC (Anion Guard column # 9 High Capacity) column followed by suppressed conductivity detection (using an Anion Self Regenerating Suppressor).

2.3.6   Stable I, Cl and Trace Elements in Solid Samples

Iodine and Cl in mineral solid samples (soil and rock) were analysed by instrumental neutron activation analysis (INAA). In INAA, samples are exposed to a neutron flux in a nuclear reactor, the samples are allowed to rest for a specified time so that short-lived activation products decay away and then the long-lived activation products from the analytes of interest are measured by gamma spectroscopy. Iodine and Cl analysis by INAA was different from general INAA methods in that they were analysed by measuring short-lived activation products.

Trace elements other than I and Cl in solid samples were analysed by the combination of INAA and ICP-MS. A four-acid total digestion (using Aqua Regia, perchloric, and hydrofluoric) was used to fully dissolve the solid samples for ICP-MS. Trace elements were analysed by ICP-MS and INAA and the results for ~60 elements were reported using whichever method for each element (ICP-MS or INAA) had the better precision.

For gamma spectroscopy, both for nuclides in activated samples from INAA and for gamma-emitting natural radionuclides, samples were counted on a HPGe solid-state photon detector with a multiple channel analyzer. The background count rate was automatically assessed with each determination, and therefore the minimum detectable activity varied for each determination. Reference materials traceable to recognized standard agencies such as NIST or NRC were used to calibrate the detection equipment for energy and efficiency.

2.3.7 ^{232}Th, ^{235}U and ^{238}U by Mass

Measurements were performed by ActLab on unfiltered water samples using an Element 2 ICP-MS (i.e. HR-ICP-MS) equipped with a guard electrode to eliminate secondary discharge in the plasma and to enhance overall sensitivity. Iridium was used as the internal standard. For solid samples, a four-acid total digestion (using Aqua Regia, perchloric and hydrofluoric acids) was used and dilution was required. Note that ^{232}Th and ^{238}U were also determined on field-filtered and unfiltered water samples by ICP-MS, but this method had higher detection limits than HR-ICP-MS. Thus, the ICP-MS data were used only to compute the effect of filtration on ^{232}Th and ^{238}U concentrations, otherwise the mass concentration and computed activity concentration data from HR ICP-MS for unfiltered samples were reported for these isotopes. In addition, ^{232}Th was analysed by alpha spectroscopy, but also with higher detection limits than by HR-ICP-MS.

To convert mass concentrations to activity concentrations, the following conversions were used:
^{232}Th: 4.1 kBq per g ^{232}Th,
^{235}U: 80 kBq per g ^{235}U, and
^{238}U: 12.4 kBq per g ^{238}U.

2.3.8 ^{210}Pb

Lead-210 was determined indirectly by the precipitation and counting of its high energy beta emitting progeny, ^{210}Bi. Following a digestion (using nitric and perchloric acids) for the unfiltered water samples and a four-acid digestion (Aqua Regia, perchloric and hydrofluoric acids) for solid samples, Bi was isolated by solvent extraction and subsequently precipitated as bismuth oxychloride. The precipitate was collected on a filter paper/disk assembly and beta counted in a low background counting system (Berthold LB770 gas flow proportional counter). For each set of samples a blank, a control sample and a calibration check standard were analyzed. One of every ten samples (10% of all samples) was analyzed in duplicate. Each sample was spiked with a known quantity of stable (non-radioactive) Bi which was used to determine the recovery after sample processing. The Bi recovery was suspect if it was less than 25% or greater than 100%.

2.3.9 ^{223}Ra, ^{226}Ra and ^{228}Ra

Following a digestion (using nitric and perchloric acids) for the unfiltered water samples and a four-acid digestion (Aqua Regia, perchloric and hydrofluoric) for solid samples, all radium isotopes in the sample solution were separated by co-precipitation with lead sulfate. The precipitate was re-dissolved and the radium isotopes were separated by co-precipitation with barium sulfate. The precipitate was filtered and mounted on a plastic disk. It was then counted on an alpha spectrometer. The ^{226}Ra alpha energy is distinct and the peak could be clearly identified. For each set of samples a blank, a control sample, and a calibration check standard were analyzed. One of every ten samples was analyzed in duplicate. Each sample was spiked with a known quantity of ^{133}Ba, which was used to determine the recovery.

For ^{228}Ra, the precipitates were stored for at least 36 hours to allow for the ingrowth of ^{228}Ac. The ^{228}Ac progeny of ^{228}Ra was selectively separated and precipitated. Beta counting the sample yields the ^{228}Ac concentration which is directly related to the ^{228}Ra concentration.

For ^{223}Ra, the analysis was performed by gamma spectroscopy, using an HPGe solid-state photon detector with multiple channel analyzer.

2.3.10 ^{228}Th and ^{232}Th by Alpha Spectroscopy

Following a digestion (using nitric and perchloric acids) for the unfiltered water samples and a four-acid digestion (Aqua Regia, perchloric and hydrofluoric) for solid samples, thorium was isolated by precipitation with barium sulfate, with several cleanup steps and subsequent precipitation with ceric hydroxide. The precipitate was collected on a filter paper and the individual isotopes were determined by alpha spectrometry. This method was used with alpha spectroscopy to determine ^{228}Th and ^{232}Th. Note that ^{232}Th was also determined by HR-ICP-MS, with very comparable results when both were expressed as activity concentrations, although in several cases the HR-ICP-MS could determine lower concentrations than could alpha spectroscopy. For each set of alpha spectroscopy samples a blank, calibration check standard and a control sample were analyzed. One of every ten samples was analyzed in duplicate. Each sample was spiked with a known quantity of ^{234}Th which is used to determine

the recovery. The tracer recovery is suspect if it is less than 25% or greater than 100% than the original amount.

2.3.11 DIC, DOC and pH in Water Samples

Dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) and pH were determined in water samples that were filtered in the laboratory. The DOC (otherwise described as non-purgeable organic carbon) is measured by acidifying samples to about pH 2.0 with HCl and sparging with hydrocarbon free air. The acidification and sparging process removes inorganic carbon as carbon dioxide (CO_2) prior to measurement. The treated sample is injected into a combustion tube filled with oxidation catalyst, and heated to 680°C. This decomposes the sample organic carbon to CO_2. The combustion product is sent through an reaction vessel containing phosphoric acid (which would change inorganic carbon to CO_2 if it had not been removed by prior treatment), cooled, dried by a dehumidifier and then sent through a halogen scrubber. The CO_2 is then detected by a non-dispersive infrared gas analyzer (NDIR) that is specifically tuned to the absorptive wavelength of 4.26 µm. The resulting peak area is proportional to the DOC concentration of the sample and DOC concentration is calculated by comparing the peak area to a calibration curve using dilutions of potassium hydrogen phthalate (KHP).

Dissolved Inorganic Carbon (DIC) is done by the same method as DOC, except that the sample is not acidified and is not purged during analysis and the reference standard is a mix of sodium carbonate and sodium bicarbonate (carbonate) instead of KHP.

The pH was determined in the field and in the lab, but the laboratory data were used as they were considered more standardized.

2.3.12 Texture, Organic Matter and pH in Soil Samples

Physical properties and organic carbon content of soils were measured by ALS Laboratories. Particle size fractionation of the mineral material was categorized into clay, silt and sand fractions by the hydrometer method. Organic carbon analysis was by the Walkley Black wet oxidation method on the mineral soils and by loss on ignition for the organic soil. Soil pH was determined in water from saturated paste extracts of the soil.

Table 1: Water sampling sites, giving sample number, name, sampling date, rationale for the location and location details.

Site	Water body	Date sampled	Rationale	Location description	Deg N	Min	Sec	Deg W	Min	Sec
1	Winnipeg River (Sylvia Lake)	May 6	Sampled in 2007, noted to be highest in stable I, but low in I transfer to biota. Sampled in advance of the other sites to test protocols.	Sylvia Lake is a fore bay on the Winnipeg River, sampled from boat ~50m off-shore of Carter Island	50	8	28	95	52	7
2	Niagara River	June 11	Great Lakes drainage basin upstream of West Valley NY	From seawall in Niagara-on-the-Lake, southwestern shore ~1.2 km from the river mouth	43	15	22	79	3	44
3	Wabigoon River	June 7	Sampled Lake Wabigoon near the mouth of the Wabigoon River in 2007	Hwy 17 crossing of Wabigoon River	49	48	55	92	52	26
4	English River	June 7	Shield location in Ontario sampled in 2007	Hwy 17 crossing of English River	49	14	2	90	58	16
5	Black Sturgeon River	June 8	Shield location in Ontario sampled in 2007	Hwy 17 crossing of Black Sturgeon River	48	54	17	88	21	41
6	McLean's Creek	June 8	Shield location in Ontario sampled in 2007	Hwy 17 crossing of McLean's Creek	48	50	22	87	26	35
7	Quirke Lake	June 9	Shield location in Ontario sampled in 2007 (sampling in 2007 was further off shore), also near U mines	On Panel Mine Road, from dock in bay directly north of Roman Island	46	30	23	82	33	49
8	Spanish River	June 9	Shield location in Ontario sampled in 2007	From bank 0.9 km downstream of the bridge on Hwy 6	46	15	56	81	47	9
9	Sturgeon Falls	June 9	Near location sampled by Renaud et al. (2005)	From bank along Levert Drive, west end of causeway north of Evansville	46	23	35	79	53	48
10	French River	June 9	Flow data location, large river in north central Ontario	Off dock, in town of French River	46	1	17	80	34	26
11	Saugeen River	June 10	Flow data location, moderately sized river in north central Ontario	Near Port Elgin, Bruce Road 3 crossing of Saugeen River	44	27	23	81	19	36

Table 1: Continued

Site	Water body	Date sampled	Rationale	Location description	Deg N	Min	Sec	Deg W	Min	Sec
12	Lake Huron near Tiverton	June 10	Great Lakes drainage basin	From shore near Lake Street, about 100 m south of junction of Hwy 15 and Lake Street	44	17	12	81	35	31
13	Lake Huron/ St Clair River	June 10	Great Lakes drainage basin, near flow data location	Off government dock at end of Seaway Rd, Sarnia Bay, Point Edward	42	58	58	82	24	50
14	Grand River	June 11	Large river in south central Ontario	Near Brantford, on bank near Newport Road, 150 m north of junction with Hwy 18	43	6	3	80	14	29
15	Lac La Ronge	June 21	Shield location in Saskatchewan	From dock in camp/cottage development, English Bay, Lac La Ronge	55	13	27	105	18	17
16	Saskatchewan River	June 21	Large river in central Saskatchewan	From bank in Saskatoon, off Spadina Crescent E, downstream of most of the city	52	9	45	106	36	50
17	St Lawrence River	Sept. 14	Great Lakes drainage basin downstream of West Valley NY but upstream of the confluence with the Ottawa River	Off government dock in Repentigny, Quebec, off Rue Notre Dame and between Blvd Levesque and Bvld. d'Argenson	45	43	34	73	27	23
18	Ottawa River	Sept.	Large river in north central Ontario	1129 rue Jacques Cartier, Gatineau, QC	45	27	32	75	41	16
19	Mackenzie River	June 1	Large river in the far north, and near location sampled by Rao and Fehn (1999)	Near the ferry landing on the north side of the river in Tsiigehtchic NWT	67	27	22	133	45	27
20	Miramichi River	July 16	Large river in Atlantic Canada	From bank on east side of river at Blackville, opposite northern tip of Doctor's island.	46	44	2	65	49	27
21	Petitcodiac River	July 16	Moderately sized river in Atlantic Canada, at flow data location	From bank near Petitcodiac, just south of junction of Plantation Road and Renfrew Street	45	56	48	65	10	1

Sampling Sites 2010

1   Sylvia Lake
2   Niagara
3   Wabigoon River
4   English River
5   Black Sturgeon River
6   McLean's Creek
7   Quirke Lake
8   Spanish River
9   Sturgeon Falls
10   French River
11   Saugeen River
12   Tiverton
13   Sarnia
14   Grand River
15   La Ronge
16   Saskatchewan R
17   St Lawrence
18   Ottawa R
19   Tsiigehtchic
20   Miramichi
21   Petitcodiac
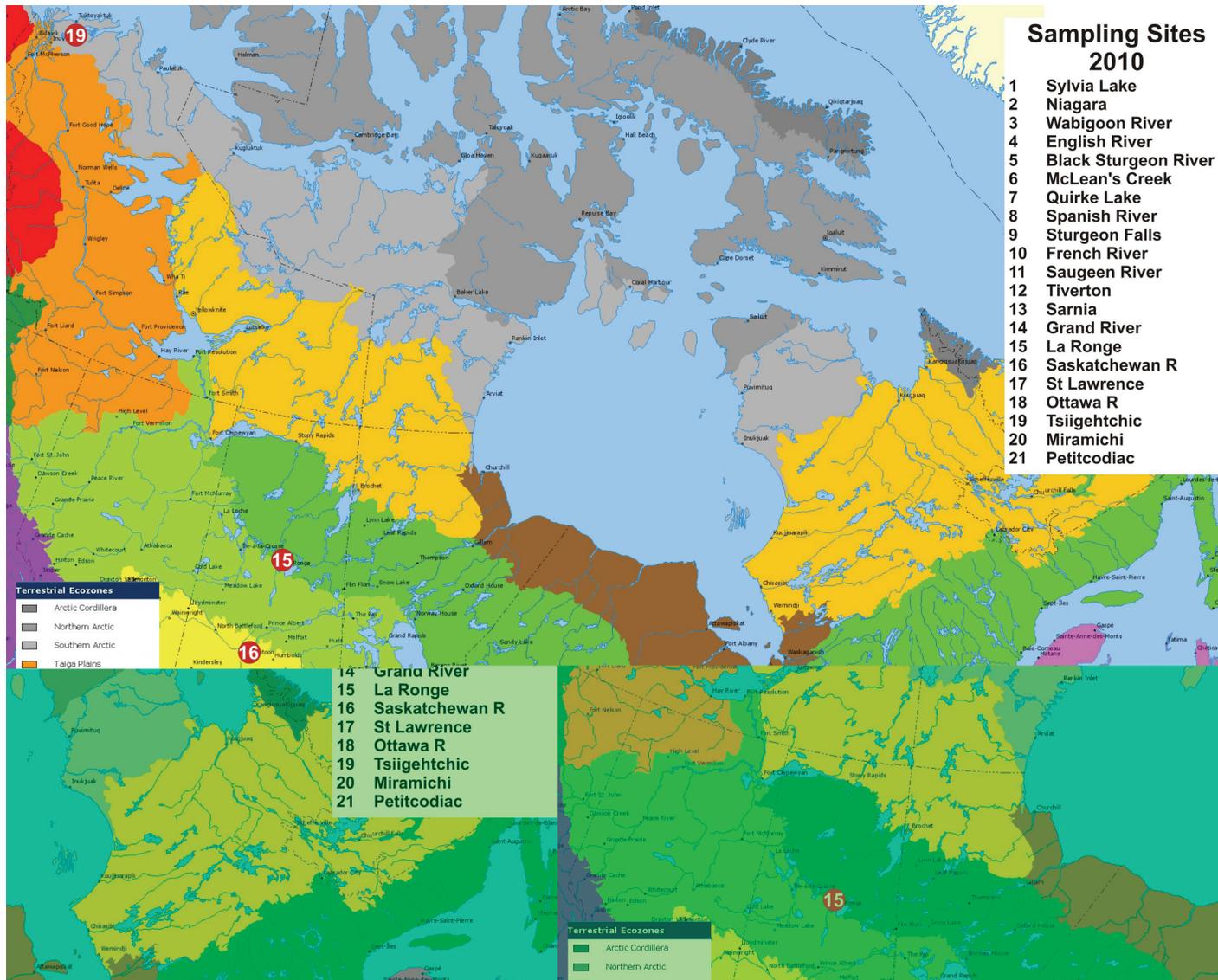
Figure 1: Map showing location of sampling sites, with Ecozone and Province boundaries indicated.

Table 2: Catchment areas and flow rates for water sampling sites, taken from Water Survey of Canada, Environment Canada[3].

Site	Water body[a]	Catchment area (km^2)	Median flow rate in sampling month[b] ($m^3\ s^{-1}$)	Median annual flow rate ($m^3\ s^{-1}$)	Years of flow data summarized	Flow on the day of sampling ($m^3\ s^{-1}$)
1	Winnipeg River (at Lac du Bonnet)	128000	806	805	1907-2008	(255.0 m)[c]
2	Niagara River	686000	6230	5890	1860-2009	(172.4 m)
3	Wabigoon River (near Quibell)	6370	61.8	43.7	1953-2009	90
4	English River (at Umfreville)	6230	99.7	57.2	1921-2009	63
5	Black Sturgeon River	2980	44.6	24.5	1971-2008	13
6	McLean's Creek	na	na	na		na
7	Quirke Lake (entry of Serpent River)	157	2.27	2.69	1967-2008	0.5
8	Spanish River	11400	121	130	1947-1994	na
9	Sturgeon Falls (Glen Afton)	2980	47.6	39.1	1941-1962, 1979-2008	15
10	French River	13900	166	194	1961-2009	33
11	Saugeen River	3960	28.9	55.0	1941-2008	65
12	Lake Huron near Tiverton	na	na	na		na
13	Lake Huron at St Clair River	576000	5500	(176.09 m)	1927-2009	na
14	Grand River	5210	18.4	35.2	1913-2008	65
15	Lac La Ronge	na	na	na		na
16	Saskatchewan River	141000	514	231	1911-2009	680
17	St Lawrence River (at Brockville)	774000	7860	7370	1958-1993	na
18	Ottawa River	90900	1290	1180	1960-2008	(52 m)
19	Mackenzie River (at Arctic Red River)	1680000	21300	9250	1972-2008	10000
20	Miramichi River	5050	96.2	111	1918-2008	(0.75 m)
21	Petitcodiac River	391	3.44	8.12	1961-2008	(0.6 m)

[a] flow rate data not always at same location as sampled, as notes in this column indicate.
[b] most rivers were sampled in June, see Table 1 for exact dates.
[c] for some rivers, only level (m) above mean sea level are recorded, these are indicated in brackets.

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[3] http://www.wsc.ec.gc.ca/staflo/flow_monthly.cfm and linked pages

2.4   REPLICATE SAMPLES AND REFERENCE MATERIALS

2.4.1   Collection and assignment of replicates

The sampling plan included duplicate sampling of about 10% of the sites for the radionuclide analyses. These replicate samples were assigned a different site number, so that they were 'blind' duplicates from the perspective of the analyst (i.e., the analyst may know there are replicates among the samples, but he/she has no way to identify the duplicate pairs).

For ^{129}I, it was considered important to obtain analyses on duplicate samples from a separate independent laboratory (Prime Laboratories, Purdue University). For this, 3 separate water samples (Sylvia Lake, Saugeen River and St. Lawrence River) were collected at the same time and place as those collected for analysis by IsoTrace Laboratories.

The laboratories do analyses of standard reference materials when they are available, as well as analyst-known duplicates, and these are done at the same time as each batch of research samples.

2.4.2   Results of replicates and reference materials

For ^{129}I, there were 3 blind duplicates, and the measured concentrations for the duplicates were within 4% for Lac La Ronge, 7% for the Miramichi River and 22% for the Saskatchewan River. There is no known reason the duplicates for the Saskatchewan River were so different, other than the sediment load was especially high and this made subsampling difficult. An interlaboratory comparison was done for paired samples collected at the same time from Sylvia Lake, Saugeen River and St. Lawrence River. The results as (atom ratio (^{129}I/^{127}I) x 10^{-14} IsoTrace versus Prime Laboratories) were:

	IsoTrace	Prime	Sample preparation
Sylvia L.	270	530	This was the first sample done by IsoTrace, and the peroxide step was not done, so that there may have been low recovery of organically bound iodine compared to the Prime Lab. Note that Prime Lab reported the value 270 as 'unpublishable'.
Saugeen R.	350	200	For these samples, IsoTrace used their newly developed aggressive peroxide treatment, and as a result probably had better recovery of organic iodine than did Prime Lab.
St. Lawrence R.	430	180	

These two laboratories have had very similar results in the past, especially when they analyse the same AgI targets, so the source of variation is almost certainly in sample preparation. Because of the high DOC content of the present samples, IsoTrace

developed and used a more extensive peroxide treatment, and it may be that IsoTrace achieved superior recovery of I compared to Prime Labs for the latter two samples.

For ^{3}H, there were 2 blind duplicates and these differed by 27% and 70%. Many of the ^{3}H data, including these 2 sites, were within twofold of the detection limit, so variation in the order of 25% to 50% is to be expected.

For the U and Th series radionuclides, duplicate samples were collected from Sylvia Lake and the Miramichi River. Differences between samples for both ^{235}U and ^{238}U were within 13%, whereas for ^{232}Th the differences averaged 34%. For ^{235}U and ^{238}U, the SLRS-5 River Water Reference Material for Trace Metals (National Research Council of Canada Certified Reference Material) was used for QA of all samples. The certified value is 0.1 mg L^{-1} and all results for SLRS-5 were 0.1 mg L^{-1}. The only reference material available for ^{232}Th was the calibration standard used in the analyses.

The duplicate analyses of ^{210}Pb, ^{223}Ra, ^{226}Ra, ^{228}Ra and ^{228}Th were all below or at the detection limits. From 6 to 18 reference materials were analysed, and the results were within 11% of the certified values except for ^{228}Th where agreement was only within 43%.

For stable I and Cl, there were duplicate samples taken from Sylvia Lake and the Miramichi River, and the samples taken from every site to be stored chilled are effectively duplicates for the unfiltered samples taken at every site. On average, the agreement was within 1.2% for I and 0.5% for Cl. No reference materials were reported for I and Cl.

For trace elements other than I and Cl, no replicate samples were collected. The reference materials SLRS-5 (above) and the National Institute of Standards and Technology material NIST 1643e (ICP-MS) were used, 3 times each. Not all elements in the ICP-MS suite are certified for these materials. Results for Al, Ba, Be, Ca, Cd, Co, Cu, K, Mg, Mn, Mo, Na, Rb, Sb, Sr and Tl were within 5% of the certified values, results for As, Bi, Fe, Li, Ni, Pb and Se were within 10%, and results for Ag, Cr, Te, V and Zn were within from 10% to 28%.

For DIC and DOC, one reference material was used, and agreement was within 3%.

3. RESULTS AND DISCUSSION

3.1   CONCENTRATIONS IN WATER

3.1.1 Water Chemistry

The concentrations of DOC, DIC, hardness and suspended sediment are shown in Table 3, along with pH. The concentrations of sediment are estimated from the effect of filtering on Ce concentrations[4], so the values can only be considered relative among this set of samples.

In general, DOC and DIC were relatively similar among sites, the coefficients of variation (CV, computed as standard deviation divided by arithmetic average, Table 3), were 27% and 38% respectively. Similarly, pH was fairly consistent. Hardness was more variable, with low values for some of the Shield sites (Wabigoon River, McLean's Creek, Quirke Lake, Sturgeon Falls) and high values for the Grand River which is underlain by calcareous deposits. Sediment load was quite variable, and the distribution was skewed (thus CV is not an appropriate statistic). The Saugeen, Grand, Saskatchewan, St. Lawrence and Mackenzie Rivers were notable turbid when sampled, and these data confirm the high sediment loads.

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[4] Because Ce is a rare earth element largely bound inside mineral structures, it is an effective tracer of inorganic suspended sediment. The material retained on the filter was assumed to be mineral suspended sediment was assumed to contain 50 mg Ce kg^{-1} dry sediment.

Table 3: Water chemistry for the waters sampled.

Site	Water body	Dissolved organic carbon (mg L^{-1})	Dissolved inorganic carbon (mg L^{-1})	Hardness[a] (mg L^{-1})	pH	Estimated sediment load[b] (mg L^{-1})
1	Winnipeg River	22	28	85	6.5	3
2	Niagara River	8	32	11	7.5	2
3	Wabigoon River	28	36	26	6.5	0.0
4	English River	26	30	130	5.0	6
5	Black Sturgeon River	26	53	79	7.5	2
6	McLean's Creek	31	26	15	5.0	2
7	Quirke Lake	21	24	16	5.5	1
8	Spanish River	26	32	95	6.5	1
9	Sturgeon Falls	20	31	20	5.5	2
10	French River	33	26	62	5.5	2
11	Saugeen River	34	73	55	8.5	11
12	Lake Huron near Tiverton	25	29	91	7.5	1
13	Lake Huron/St Clair River	18	41	130	7.0	1
14	Grand River	25	58	130	8.0	13
15	Lac La Ronge	26	38	61	6.5	1
16	Saskatchewan River	29	54	50	7.0	17
17	St Lawrence River	33	43	28		18
18	Ottawa River	32	48	43		3
19	Mackenzie River	38	77	89		19
20	Miramichi River	15	31	56	5.5	0.4
21	Petitcodiac River	31	30	86	6.0	2
	Coefficient of variation (%)	27	38	59	16	skewed

[a] Hardness as $CaCO_3$ equivalent, computed from Ca and Mg concentrations.
[b] Sediment load estimated from the difference in Ce concentrations between filtered and unfiltered samples, assuming the filtered material contained on average 50 mg Ce kg^{-1}. Data were skewed so a coefficient of variation is not appropriate.

3.1.2 Iodine and ^{129}I

The concentrations of stable element and the radionuclides ^{129}I and ^{36}Cl are shown for each site in Table 4. The stable I concentrations ranged 7-fold and were somewhat skewed towards a lognormal frequency distribution. Despite the relatively broad range, there is no readily apparent explanation for the high and low concentrations. Differences could result from: the I concentrations in the underlying soil and bedrock, human sources of I, effects of watershed size and water flow rate, varying sediment load and differences in water chemistry. The Petitcodiac River was expected to be high in stable I because of proximity to the ocean and relative to most other sites it was high. However, the Miramichi River is similarly close to the ocean and I concentration there was not as high as the Petitcodiac. This may be because the Miramichi has a 13-fold larger catchment than the Petitcodiac, and so the oceanic effect on I may be more diluted.

The ranges in ^{129}I specific activities and concentrations (Table 4) were similar to that of stable I: about 10-fold for specific activity and 4-fold for ^{129}I concentrations. The sources of ^{129}I include atmospheric deposition of cosmogenic and global source ^{129}I, and this would tend to deliver more ^{129}I to mid-latitude locations, such as Lac La Ronge. Another source is geogenic ^{129}I resulting from natural fission of U series radionuclides, and this source would be more prevalent near U mineralizations such as the Quirke River and watersheds on granites of the Canadian Precambrian shield. Finally, point-source releases of ^{129}I from West Valley NY and perhaps Chalk River Laboratories may affect a large radius, and this will include upstream locations because some of this ^{129}I may be volatile after release.

The Niagara River had the highest specific activity and concentration of ^{129}I, and this may relate to the historic releases from West Valley. However, further downstream the St. Lawrence River had moderate concentrations and low specific activity. The high concentration and specific activity in the Niagara River upstream of West Valley does contradict West Valley as the source. On the other end of the range, the Mackenzie, Saskatchewan, Grand, Petitcodiac and Saugeen Rivers all had low specific activities, and all have catchments dominated by clay soils with little granitic bedrock and no known point sources of ^{129}I. The concentration at Lac La Ronge was moderately high, as expected. Quirke Lake had a low specific activity but relatively high concentration, it is not clear if this is related to the U mineralization in the watershed.

Table 4: Concentrations of stable I and ^{129}I, stable Cl and ^{36}Cl and ^{3}H in unfiltered water.

Site	Water body	Stable I concentration	^{129}I specific activity	^{129}I concentration	Stable Cl concentration	^{36}Cl specific activity	^{36}Cl concentration	^{3}H concentration
		µg L^{-1}	Bq (g I)$^{-1}$	µBq L^{-1}	mg L^{-1}	Bq (kg Cl)$^{-1}$	µBq L^{-1}	Bq L^{-1}
1	Winnipeg River	2.2	0.082	0.18	3.3			1.6
2	Niagara River	1.7	0.16	0.28	17			2.2
3	Wabigoon River	1.3	0.11	0.14	9.9	0.38	3.8	1.3
4	English River	0.9	0.14	0.12	2.1			1.1
5	Black Sturgeon River	1.1	0.095	0.10	37			<0.7
6	McLean's Creek	0.7	0.11	0.080	0.42			<1
7	Quirke Lake	2.1	0.067	0.14	3.3			<0.6
8	Spanish River	1.3	0.057	0.074	18			2.4
9	Sturgeon Falls	1.0	0.11	0.11	1.2			2.4
10	French River	1.0	0.11	0.11	3.9			4.0
11	Saugeen River	2.4	0.044	0.11	11	0.079	0.90	6.3
12	Lake Huron near Tiverton	0.9	0.093	0.083	7.6			5.0
13	Lake Huron/ St Clair River	0.9	0.093	0.083	8.8	0.34	3.0	3.5
14	Grand River	4.1	0.021	0.087	61			1.7
15	Lac La Ronge	1.8	0.12	0.22	1.2	7.3	8.5	1.1
16	Saskatchewan River	4.4	0.016	0.069	9.4			2.0
17	St Lawrence River	3.9	0.031	0.12	17	0.68	11.0	4.2
18	Ottawa River	1.2	0.15	0.15	1.7	4.5	7.6	4.4
19	Mackenzie River	1.5	0.023	0.034	6.1			1.8
20	Miramichi River	1.6	0.051	0.085	2.1			1.9
21	Petitcodiac River	4.9	0.039	0.19	42			1.1
	Median	1.7	0.079	0.11	7.6	0.53	5.7	2.2

3.1.3   Chlorine and ^{36}Cl

Stable Cl concentrations in water are often linked to human activities, both because of Cl in urban and industrial waste water and because of Cl from road salt. For example, Cl concentrations increase downstream in the Great Lakes system. The data in Table 4 reflect this to some extent: the Grand River is high and there is a lot of road salt used in this region. Several of the more remote northern rivers, such as the English River and McLeans Creek, had quite low concentrations. The Petitcodiac was high in Cl, just as it was high in I, and this is probably an oceanic effect. Overall, the range in Cl concentrations is 145-fold.

Chlorine-36 was measured in only 6 samples, and the concentrations varied by about 10-fold and the specific activities varied about 100-fold (Table 4). For the same 6 samples the stable concentration varied about 10-fold. This implies the stable Cl and ^{36}Cl concentrations were not correlated. For example, of the 6 sites, Lac la Ronge had the lowest stable Cl concentration and the highest ^{36}Cl concentration. A working hypothesis might be that where stable Cl concentrations are increased because of mined salt, this Cl will have a low specific activity. Across sites with and without the influence of mined salt, one would expect ^{36}Cl concentrations to be less variable than specific activities.

3.1.4   Tritium

Tritium concentrations are also shown in Table 4. There are both cosmogenic and man-made sources of ^{3}H, the latter dominated now in Canada by power reactors. Thus concentrations might be expected to be higher for samples from near Bruce Power (i.e., the Tiverton sample of Lake Huron and the Saugeen River) and the St. Lawrence and Ottawa Rivers. These were indeed the highest concentrations. Notably, Lake Huron was 5.0 Bq L^{-1} at Tiverton and 3.5 Bq L^{-1} downstream at Sarnia, an effect expected from dilution and diffusion of tritiated water (HTO) into the atmosphere. The Niagara River is further downstream but also possible subject to emissions from the US: the concentration in the Niagara River was lower again at 2.2 Bq L^{-1}. The sites well outside the range of point-source emissions had a range from <0.6 to 2.4 Bq L^{-1}.

3.1.5   Trace Elements

The elemental concentration data are summarized in Table 5. Not all elements were detectable in all samples, and non-detectable values were handled as missing data (i.e. N<21). For Ca and Mg, the non-detectable values were because of concentrations in water above the upper detection limits: the upper non-detectable concentrations for these elements were >20 mg L^{-1}, indicating considerable water hardness. For all other elements, non-detectable values were below their lower detection limit. Most of the data were not normally distributed, most of these were skewed and most were approximately lognormal. As a result, the median, geometric mean (GM) and geometric standard deviation (GSD) best summarize the data. Most GSD values were in the range of 1.4 to 3.2, which implies that 95% of the data were within 2- to 10-fold of the GM.

Filtration of the water samples had no significant effect on concentrations of about half the elements, and it decreased concentrations by 50% for the other half. As can be seen in Figure 1, filtration did not affect elements that were at concentrations above about 100 µg L^{-1}, and affected most elements that were at concentrations below about 0.1 µg L^{-1}. In part, this is related to solubility: the more soluble elements are at higher concentrations in water because they have been dissolved from soils and rocks, and relatedly they are not retained on the particles that would be trapped on the filters. Filtration of the water samples significantly decreased concentrations of Al, Ce, Co, Cs, Dy, Er, Fe, Gd, La, Ho, K, La, Lu, Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Sm, Tb, Ti, Th, Tl, V, Y and Yb, which implies that some portion of these elements were associated with suspended sediment. These elements include rare earth elements (REE) that are usually bound inside mineral particles and cations that are usually strongly sorbed onto mineral particles, and so the observed effect of filtration is not surprising for these elements. It should be noted that filtration to pass a 0.45 µm filter is commonly accepted as the operational definition of soluble, but finer particles will pass through the filter and will carry particle-reactive elements. Thus, the concentrations of Al, Ce, Co, Cs, Dy, Er, Fe, Gd, La, Ho, K, La, Lu, Mn, Mo, Na, Nd, Ni, Pb, Pr, Rb, Sm, Tb, Ti, Th, Tl, V, Y and Yb in the filtered samples may still include species that are not dissolved by the strict chemical definition, but are clearly very mobile and are associated with particles that will not tend to sediment out of the water column by gravity.

Correlations among the water concentrations were generally among two groups. One group of inter-correlated elements were the relatively soluble elements, and Cl was used as a representative of this group. Another group were relatively insoluble elements, often associated with recalcitrant minerals, and Ce was used as a representative of this group. In Table 6, the correlation of (log) concentrations of each element versus log Cl and Ce concentrations are shown, for both unfiltered and filtered water. The concentrations in unfiltered water are shown for reference. Very few elements were correlated to both Cl and Ce, and in those cases the correlations were mostly positive. Among the isotopes, it is notable that ^{235}U and ^{238}U were correlated to soluble Cl, whereas ^{232}Th was correlated to insoluble Ce, both occurrences consistent with the expected behaviour of these elements.

In general, the correlations are similar for unfiltered and filtered water, with a few exceptions. Most notably is that correlations between Ce and hardness, K, Mg, Sb and Sr were not significant in unfiltered water but became significant and negative in filtered water. These elements (K, Mg, Sb and Sr) tend to occur as cations that would sorb by cation exchange to particle surfaces. It is expected that higher concentrations of Ce in the unfiltered or filtered water was indicative of a larger sediment load, so it may be that during filtration the sediments entrained by the filter removed cations from the water passing through the filter, resulting in lower concentrations of K, Mg, Sb and Sr in the filtrate.

Another effect of filtration was that positive correlations between (log) concentrations of Ce versus DOC, Co, Cu, Eu, Ga, Ge, Nb, Tm and V in unfiltered water become non-significant in filtered water. Many of these are REE, as is Ce, and REE are expected to be present in the mineral structure of particles. Thus their concentrations are expected to be correlated in unfiltered water, and it may be that once many of the mineral particles were removed, the residual concentrations were more random and hence less correlated.

Table 5: Summary of concentrations in unfiltered water (µg L^{-1} unless indicated).

Variable	N	Median	Arithmetic mean	Standard Deviation	P[b]	Geometric mean	Geometric Standard Deviation
DIC (mg L^{-1})	21	32	40	15		38	1.4
DOC(mg L^{-1})	21	26	26	7	ns	25	1.4
Hardness[a] (mg L^{-1})	21	61	65	39	ns	51	2.1
Al	21	80	130	129		75	3.5
As	21	0.53	0.64	0.46		0.55	1.7
Ba	21	20	29	24		22	2.0
Br	21	13	22	17		16	2.3
Ca	11	7100	10000	5900	ns	8400	1.9
Cd	12	0.025	0.031	0.028		0.023	2.2
Ce	21	0.33	0.44	0.38		0.27	3.0
Cl	21	7600	13000	16000		6200	3.7
Co	17	0.061	0.13	0.15		0.079	2.8
Cr	6	0.85	0.83	0.19	ns	0.81	1.3
Cs	21	0.012	0.024	0.035		0.012	3.2
Cu	21	1.2	1.4	0.9		1.1	2.0
Dy	21	0.021	0.033	0.033		0.020	3.0
Er	21	0.013	0.017	0.014		0.011	2.8
Eu	21	0.0070	0.012	0.010		0.0083	2.4
Fe	21	160	250	250		140	3.4
Ga	19	0.020	0.041	0.045		0.025	2.7
Gd	21	0.033	0.053	0.047		0.035	2.8
Ge	9	0.01	0.016	0.0073		0.014	1.5
Hf	17	0.0050	0.0072	0.0091		0.0046	2.5
Ho	18	0.0055	0.0068	0.0054		0.0052	2.1
I	21	1.5	2.0	1.3		1.6	1.8
K	21	1100	1300	810		1000	2.0
La	21	0.20	0.26	0.22		0.16	2.9
Li	15	3.0	3.9	2.9		3.0	2.1
Lu	18	0.0025	0.0027	0.0015	ns	0.0023	1.8
Mg	19	3700	5400	4700		3700	2.5
Mn	21	21	24	19		16	2.8
Mo	18	0.30	0.44	0.38		0.30	2.6
Na	20	5700	10000	11000		6000	2.9
Nb	12	0.010	0.016	0.011		0.013	1.9
Nd	21	0.19	0.25	0.20	ns	0.16	3.0
Ni	19	0.70	1.68	3.27		0.92	2.4
Pb	21	0.15	0.25	0.34		0.14	3.0
Pd	4	0.010	0.013	0.0058		0.012	1.4
Pr	21	0.052	0.064	0.052		0.041	3.0
Rb	21	1.3	1.8	1.4		1.5	1.7

Variable	N	Median	Arithmetic mean	Standard Deviation	P[b]	Geometric mean	Geometric Standard Deviation
Re	14	0.006	0.021	0.048		0.0077	3.5
Sb	20	0.050	0.104	0.159		0.065	2.3
Se	8	0.45	0.46	0.21	ns	0.42	1.7
Si	21	2200	1900	1200	ns	1500	2.2
Sm	21	0.030	0.053	0.046		0.034	3.0
Sr	16	39	59	48		44	2.2
Ta	4	0.0015	0.0015	0.00058		0.0014	1.5
Tb	19	0.0050	0.0072	0.0064		0.0052	2.3
Ti	20	3.1	5.3	7.0		2.7	3.4
Tl	20	0.0050	0.010	0.018		0.0064	2.2
Tm	14	0.0025	0.0030	0.0019		0.0026	1.8
V	19	0.70	0.69	0.47		0.53	2.2
W	4	0.04	0.035	0.01		0.034	1.4
Y	21	0.13	0.19	0.18		0.12	2.7
Yb	21	0.012	0.015	0.011	ns	0.011	2.6
Zn	19	2.1	3.5	2.9		2.6	2.2
Zr	21	0.10	0.20	0.28		0.11	3.1
^{235}U (ng L^{-1})	20	1.2	2.5	2.9		1.3	3.1
^{238}U (ng L^{-1})	20	170	350	400		180	3.2
^{232}Th (ng L^{-1})	20	80	110	82		85	2.3

[a] Hardness is as $CaCO_3$ equivalent, computed from Ca and Mg concentrations.
[b] Most data distributions were significantly different from normal and most were approximately lognormal. The P column is a Shapiro-Wilk normality test where the probability was P<0.05 (blank) except where ns indicates the distribution was not significantly different from normal.
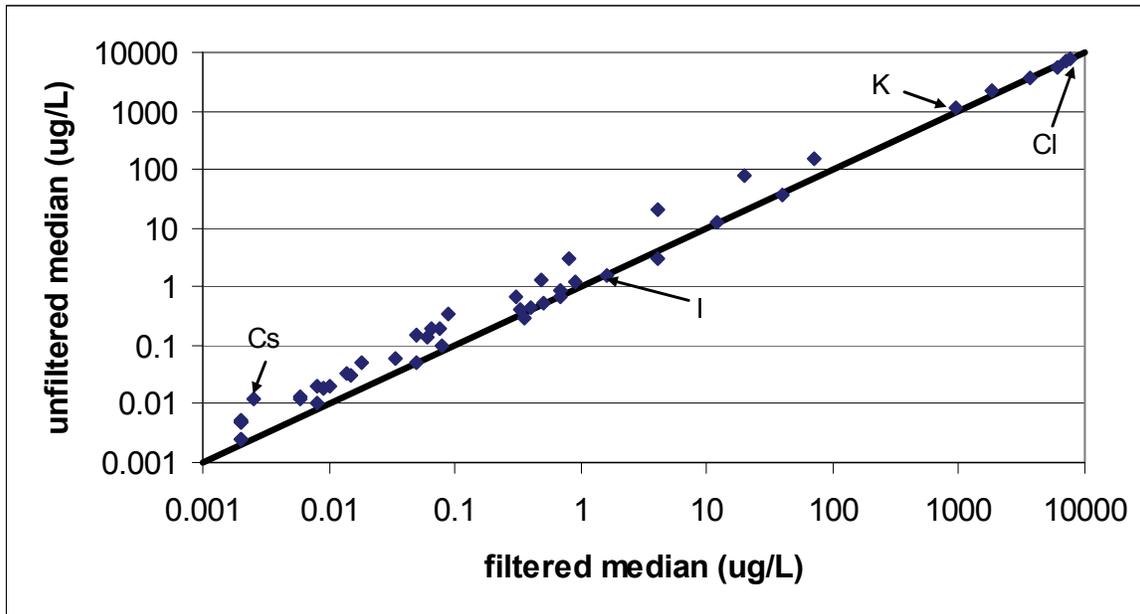
Figure 2: Effect of filtration on median water concentrations. Each point is a different element, and 4 elements are identified. The line is the 1:1 line and elements above the line had lower concentrations after filtration.

Table 6: Correlations among log concentrations in unfiltered and filtered water. Pearson correlation coefficients are shown when they are statistically significant (P<0.05, otherwise ns).

Variable	N	Unfiltered			Filtered	
		Median Concentration ($\mu g\ L^{-1}$)	Correlation with Cl[a]	Correlation with Ce[a]	Correlation with Cl	Correlation with Ce
DIC (mg L^{-1})	21	32	ns	ns	ns	ns
DOC(mg L^{-1})	21	26	ns	0.53	ns	ns
Hardness (mg L^{-1})	21	61	0.70	ns	0.56	-0.62
Al	21	80	ns	0.89	ns	0.90
As	21	0.53	0.66	ns	0.59	ns
Ba	21	20	0.48	ns	ns	ns
Br	21	13	0.86	ns	0.86	ns
Ca	11	7100	0.74	ns	0.67	ns
Cd	12	0.025	ns	ns	ns	ns
Ce	21	0.33	ns	1.00	ns	1.00
Cl	21	7600	1.00	ns	1.00	ns
Co	17	0.061	ns	0.75	ns	ns
Cr	6	0.85	ns	ns	ns	ns
Cs	21	0.012	ns	0.43	ns	0.54
Cu	21	1.2	ns	0.52	ns	ns
Dy	21	0.021	ns	0.86	ns	0.88
Er	21	0.013	ns	0.87	ns	0.86
Eu	21	0.0070	ns	0.90	ns	ns
Fe	21	160	ns	0.86	ns	0.79
Ga	19	0.020	ns	0.77	ns	ns
Gd	21	0.033	ns	0.92	ns	0.88
Ge	9	0.01	ns	0.69	ns	ns
Hf	17	0.0050	ns	0.73	ns	0.80
Ho	18	0.0055	ns	0.81	ns	0.79
I	21	1.5	0.55	ns	0.53	ns
K	21	1100	0.65	ns	0.70	-0.48
La	21	0.20	ns	0.96	ns	0.98
Li	15	3.0	ns	ns	ns	ns
Lu	18	0.0025	ns	0.82	ns	0.78
Mg	19	3700	0.57	ns	0.54	-0.66
Mn	21	21	ns	0.61	ns	0.63
Mo	18	0.30	0.62	ns	0.67	ns
Na	20	5700	0.92	ns	0.91	ns
Nb	12	0.010	ns	0.80	ns	ns
Nd	21	0.19	ns	0.97	ns	0.97
Ni	19	0.70	ns	ns	ns	ns

| Variable | N | Median Concentration ($\mu g\ L^{-1}$) | Unfiltered | | Filtered | |
			Correlation with Cl[a]	Correlation with Ce[a]	Correlation with Cl	Correlation with Ce
Pb	21	0.15	0.50	0.80	ns	0.73
Pd	4	0.010	ns	ns	ns	ns
Pr	21	0.052	ns	0.98	ns	0.98
Rb	21	1.3	ns	ns	0.62	ns
Re	14	0.006	ns	ns	ns	ns
Sb	20	0.050	0.54	ns	0.46	-0.64
Se	8	0.45	ns	ns	ns	ns
Si	21	2200	ns	0.49	ns	0.66
Sm	21	0.030	ns	0.94	ns	0.94
Sr	16	39	0.53	ns	0.58	-0.61
Ta	4	0.0015	ns	ns	---[b]	---
Tb	19	0.0050	ns	0.85	ns	0.78
Ti	20	3.1	0.49	0.79	ns	0.64
Tl	20	0.0050	ns	ns	ns	ns
Tm	14	0.0025	ns	0.59	ns	ns
V	19	0.70	0.54	0.75	0.58	ns
W	4	0.04	ns	ns	ns	ns
Y	21	0.13	ns	0.87	ns	0.87
Yb	21	0.012	ns	0.85	ns	0.83
Zn	19	2.1	ns	ns	ns	ns
Zr	21	0.10	ns	0.72	ns	0.67
^{235}U (ng L^{-1})	21	1.2	0.52	ns	---[c]	---
^{238}U (ng L^{-1})	21	170	0.52	ns	---[c]	---
^{232}Th (ng L^{-1})	21	80	ns	0.71	---[c]	---

[a] Correlations are shown versus Cl as representative of highly soluble elements and Ce as representative of strongly particle-reactive elements and as indicative of sediment load.
[b] non-detectable in any filtered samples
[c] not measured in filtered water

3.1.6   Radionuclides of U and Th Series

The concentrations of ^{232}Th, ^{235}U and ^{238}U were well within detection range for all samples, and are reported in Table 7 both as mass concentrations and activity concentrations (both based on HR-ICP-MS analyses). The ranges were 13-fold for ^{232}Th and 45-fold for ^{235}U and ^{238}U. These data were not strongly correlated to water chemistry. The high U concentrations in Quirke Lake, near Elliot Lake, are not surprising given the U mineralization in the area. There was a similarly high U concentration in the Saskatchewan River, and although Saskatchewan clearly has U mineralization in the north, the Saskatchewan River drains the sedimentary basin of southern Saskatchewan.

The mass ratio of ^{235}U/^{238}U was consistent and nearly the same as the assumed ratio of 0.72%. Deviation from this ratio is generally only observed in areas where enriched (or depleted) U is processed or used.

The ratios between filtered and unfiltered water (by ICP-MS instead of HR-ICP-MS) were nearly unity for U, confirming that U is quite soluble in water, especially at the pH range observed here. For Th, the ratios were generally less than unity, suggesting some Th was entrained as attached to suspended sediment. There were two ratios for Th that were greater than unity, and these may be artefacts because Th was near the detection limit of ICP-MS.

Concentrations of ^{210}Pb, ^{228}Ra, ^{228}Th and ^{223}Ra were non-detectable or detectable only at the detection limit in all samples (Table 6). There were detectable concentrations of ^{226}Ra in 4 samples, and among these the ^{226}Ra/^{238}U activity ratios ranged from 0.8 to 2. This activity ratio is expected to be unity at secular equilibrium, but deviation from secular equilibrium for this pair is not uncommon in open environmental systems. Here, the 4 values for the ratio cluster around unity as expected.

Table 7: Concentrations and ratios of concentrations for U and Th series radionuclides in unfiltered water[a].

Site	Water body	^{232}Th (ng L^{-1})	^{235}U (ng L^{-1})	^{238}U (ng L^{-1})	Th filtered/ unfiltered	U filtered/ unfiltered	^{235}U/^{238}U by mass	^{232}Th[b] (Bq L^{-1})	^{235}U[b] (Bq L^{-1})	^{238}U[b] (Bq L^{-1})	^{210}Pb (Bq L^{-1})	^{226}Ra (Bq L^{-1})
1	Winnipeg River	140	0.7	99	0.52	0.98	0.74%	5.7E-04	5.9E-05	1.2E-03	<0.02	<0.005
2	Niagara River	56	2.6	350	0.25	0.97	0.74%	2.3E-04	2.1E-04	4.3E-03	<0.02	<0.005
3	Wabigoon River	260	0.8	100	1.79	1.06	0.78%	1.1E-03	6.2E-05	1.2E-03	<0.02	<0.005
4	English River	220	0.3	40	0.99	0.88	0.73%	9.0E-04	2.3E-05	5.0E-04	<0.02	<0.005
5	Black Sturgeon River	110	1.8	250	0.60	1.01	0.73%	4.5E-04	1.5E-04	3.1E-03	<0.02	<0.005
6	McLean's Creek	190	0.9	120	1.10	0.99	0.77%	7.8E-04	7.4E-05	1.5E-03	<0.02	<0.005
7	Quirke Lake	88	10.2	1400	0.75	0.66	0.73%	3.6E-04	8.2E-04	1.7E-02	<0.02	0.04
8	Spanish River	130	1.0	130	0.79	1.11	0.74%	5.3E-04	7.7E-05	1.6E-03	<0.02	<0.005
9	Sturgeon Falls	71	0.2	33	0.75	0.88	0.75%	2.9E-04	2.0E-05	4.1E-04	<0.02	<0.005
10	French River	72	0.2	31	0.78	0.90	0.70%	3.0E-04	1.7E-05	3.8E-04	<0.02	<0.005
11	Saugeen River	150	4.6	630	0.14	0.99	0.73%	6.2E-04	3.7E-04	7.8E-03	<0.02	0.006
12	Lake Huron near Tiverton	35	1.4	200	nd[c]	1.05	0.72%	1.4E-04	1.1E-04	2.5E-03	<0.02	<0.005
13	Lake Huron/ St Clair River	22	1.7	230	nd	1.01	0.74%	9.0E-05	1.4E-04	2.9E-03	<0.02	<0.005
14	Grand River	120	4.7	650	0.04	1.00	0.73%	4.9E-04	3.8E-04	8.1E-03	<0.02	0.008
15	Lac La Ronge	38	0.6	85	nd	1.05	0.73%	1.6E-04	4.9E-05	1.1E-03	<0.04	<0.01
16	Saskatchewan River	210	9.0	1300	nd	0.95	0.69%	8.6E-04	7.2E-04	1.6E-02	<0.04	0.02
17	St Lawrence River	69	0.9	120	0.29	1.01	0.76%	2.8E-04	7.3E-05	1.5E-03	<0.02	<0.005
18	Ottawa River	26	0.4	48	0.50	0.56	0.74%	1.1E-04	2.8E-05	6.0E-04	<0.02	<0.005
19	Mackenzie River	290	5.1	710	0.05	0.92	0.72%	1.2E-03	4.1E-04	8.8E-03	<0.02	<0.005
20	Miramichi River	20	0.8	100	0.85	1.04	0.76%	8.2E-05	6.1E-05	1.2E-03	0.04	<0.005
21	Petitcodiac River	54	3.3	450	0.84	0.96	0.73%	2.2E-04	2.6E-04	5.6E-03	<0.02	<0.005

[a] Concentrations of ^{228}Ra, ^{228}Th and ^{223}Ra were non-detectable or detectable only at the detection limit in all samples, the detection limits were generally <0.01, <0.01 and <0.1 Bq L^{-1}, respectively.
[b] Activity concentrations of ^{232}Th, ^{235}U and ^{238}U were computed from the mass concentrations also given in this table.
[c] The ratio could not be computed for these samples because Th was below detection limits in the filtered sample.

3.2   CONCENTRATIONS IN SOILS AND ROCKS

The Plainsfield Sand and the Perth Clay Loam soils were near Tiverton Ontario, both under forest. Although clearly mapped as Perth Clay Loam, the texture analysis (Table 8) indicates it was probably a transitional phase between the Plainsfield Sand and the Perth Clay Loam. The podzol from near Barret Ontario was an early-development podzol with a weak Ae (eluviated white sand) horizon and a very strong Bf (illuviated reddish horizon enriched in iron oxides). The Black Lake peat was the bottom horizon of a 1-m-deep sphagnum peat bog, with fairly complete humification to black muck at the base of the bog. The Black Lake rock was a garnet porphyroblastic white granite to syenite (quartz syenite) about 70% feldspar, 20-25% quartz and 10% biotite with some garnet and muscovite. The rock from near Barret was a granite with about 60% potassium feldspar, 30% quartz, 8% albite feldspar with some biotite and hornblende. The rock from near Lac la Ronge was a meta-arkose fine-grained sandstone with 75% quartz, 15% feldspar, and 10% biotite and oxides.

There were few samples of soils and rocks, so detailed interpretation is not possible. Furthermore, stable I and stable Cl were not detectable in several of the soil and rock samples (Table 8).

There was detectable ^{129}I in all the samples, with a 31-fold range among the 4 soil samples and a 2.8-fold range among the 3 rock samples. It was anticipated that the specific activity of ^{129}I would be high in the peat sample, because it was affected by a U mineralization, and geogenic ^{129}I might have leached to the peat. This does not appear to be the case, as it had low ^{129}I concentrations and specific activities compared to the other samples.

Concentrations of ^{232}Th, ^{235}U and ^{238}U were readily detectable by mass spectroscopy in all the soils and rocks, and the corresponding activity concentrations were calculated (Table 9). As expected, the peat soil was strongly enriched in U (0.078% U by mass), and the corresponding Black Lake granite was also relatively high (0.0021% U). The mass ratio of ^{235}U/^{238}U was very consistent in all the samples with the global mass ratio of 0.72%

In the ^{238}U decay series, ^{226}Ra was detectable in all samples and ^{210}Pb in the soil samples. The largest deviation from a unity activity ratio for ^{226}Ra/^{238}U was in the peat soil, and here this may be because the peat probably has a specific affinity to accumulate U by chemical reduction: a roll-front process (Min et al. 2005, Spirakis 1996). The ^{210}Pb/^{226}Ra activity ratio is expected to be greater than unity in surface soils where there will be ^{210}Pb deposition from the atmosphere as a result of decay of radon in the atmosphere. This was apparent especially in the Plainsfield sand soil.

In the ^{232}Th and ^{235}U decay series, conclusions about activity ratios are severely limited by the number of non-detectable results. In soils and rocks, the ^{228}Ra/^{232}Th, ^{228}Ra/^{228}Th and ^{223}Ra/^{235}U activity ratios are expected to be near unity, and the results in Table 9 are not inconsistent with that.

Table 8: Soil properties and concentrations of ^{129}I, stable I and stable Cl in soils and rocks.

	Units or notes	Black Lake peat	Plains-field sand soil	Perth clay loam soil	Podzol near Barret, ON soil	GM soil	Black Lake rock	Barret rock	Lac La Ronge rock	GM rock
Clay	%	---	3.6	9.3	<1					
Sand	%	---	77	54	98					
OM	%	100	31	9.7	1.3					
pH		5.5	6.0	5.5	5.0					
Ca	g kg^{-1}	2.5	49	19	24	15	6.1	1.2	26	5.7
Mg	g kg^{-1}	0.8	20	7.9	7.8	5.6	1.9	0.60	5.5	1.8
Stable I	mg kg^{-1}	12	16	<0.5	<0.5		<0.5	1.3	<0.5	
^{129}I	mBq kg^{-1}	0.022	0.70	0.34	0.055	0.13	0.0071	0.0042	0.012	0.0072
^{129}I specific activity	Bq (kg^{-1} I)	1.9	43	>670	>110		>14	3.2	>25	
Stable Cl	mg kg^{-1}	200	400	200	<100	200	<100	200	<100	

Table 9: Concentrations and ratios of concentrations for U and Th series radionuclides in soils and rocks.

	Units or notes	Black Lake peat	Plains-field sand soil	Perth clay loam soil	Podzol near Barret, ON soil	GM/ aver.[b] soil	Black Lake rock	Barret rock	Lac La Ronge rock	average rock
^{232}Th	µg kg^{-1}	4900	5000	6300	2900	4600	5200	18000	710	
^{235}U	µg kg^{-1}	5800	12	14	5.3	48	150	23	4.9	
^{238}U	µg kg^{-1}	780000	1700	1900	730	6500	21000	3200	670	
^{235}U/^{238}U	~0.72%[a]	0.74%	0.72%	0.73%	0.72%	0.73%	0.73%	0.73%	0.73%	
^{232}Th	Bq g^{-1}	0.020	0.020	0.026	0.012	0.019	0.021	0.074	0.0029	
^{235}U	Bq g^{-1}	0.46	0.00098	0.0011	0.00042	0.004	0.012	0.0019	0.00039	
^{238}U	Bq g^{-1}	9.7	0.021	0.023	0.0091	0.081	0.26	0.039	0.0083	
^{210}Pb	Bq g^{-1}	0.31	0.14	0.05	<0.04	0.13	<0.04	<0.04	<0.04	
^{223}Ra	Bq g^{-1}	<0.01	<0.004	<0.003	<0.003		0.03	<0.005	<0.004	
^{226}Ra	Bq g^{-1}	0.35	0.03	0.04	0.02	0.05	0.09	0.02	0.02	
^{228}Ra	Bq g^{-1}	<0.02	0.02	0.04	<0.02	0.03	<0.02	0.03	<0.02	
^{228}Th	Bq g^{-1}	0.02	<0.02	<0.02	<0.02	0.02	<0.02	0.05	<0.02	
^{226}Ra/^{238}U	~1[a]	0.036	1.4	1.7	2.2	1.3	0.35	0.51	2.4	1.1
^{210}Pb/^{226}Ra	>1 in soil	0.89	4.7	1.3	<2	2.3	<0.5	<2	<2	---
^{228}Ra/^{232}Th	~1[a]	<1.0	0.98	1.56	<1.7	1.3	<0.95	0.41	<6.9	0.41
^{228}Ra/^{228}Th	~1[a]	<1	>1	>2	---	---	---	0.60	---	0.60
^{223}Ra/^{235}U	~1[a]	<0.02	<4	<3	<7	---	2.5	<3	<10	2.5

[a] Expected values of the mass or activity ratios.
[b] Geometric means are used for concentration data, arithmetic averages for ratios.

4. SUMMARY AND CONCLUSIONS

The present project involved sampling of 21 surface waters from New Brunswick to Saskatchewan. Analysis of ^{129}I and ^{36}Cl was by Accelerator Mass Spectroscopy, and of U and Th progeny by radiochemical methods. Trace elements and ^{3}H were also measured. A few soil and rock samples were also analysed.

The observed concentrations of ^{129}I, ^{36}Cl and ^{3}H in water were consistent with general expectations, and the present study increased several fold the numbers of data for these radionuclides in Canadian waters.

Concentrations of ^{232}Th, ^{235}U and ^{238}U were detectable in all locations, with substantial ranges. The ^{235}U/^{238}U agreed very closely with the assumed global average, in the absence of emissions from enrichment facilities or the used of depleted U metals. Concentrations of ^{235}U and ^{238}U were high near a known U mineralization, as expected.

The U and Th decay series radionuclides were seldom detectable, and so there was little opportunity to confirm activity ratios assumed based on secular equilibrium or disequilibrium.

ACKNOWLEDGEMENTS

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APPENDIX A: TRACE ELEMENT ANALYSIS

CONTENTS

A.1   INTRODUCTION

Table 5 gave the summary statistics for the trace element analyses of the 21 water samples collected in 2010. In Appendix A.2, the data are given for each individual sample. Note that I and Cl are not included in Appendix A.2 because these data are given for each site in Table 4.

In 2007, 20 lakes were sampled across Northern Ontario in a project designed to measure transfer of I and other element from water to fish. As these data are not presented site by site in any other document, they are presented here in Appendix A.3. In several of these lakes, the metalimnion and hypolimnion were sampled separately. In general the metalimnion was more dilute, the exceptions were for Mn and Fe where, probably because of lack of oxygen and reducing conditions at depth, the hypolimnion was more concentrated.

A.2   TRACE ELEMENT ANALYSIS OF SITES SAMPLED IN 2010

Trace element analysis of water samples collected in 2010 and summarized in the text of this report.

	1	2	3	4	5	6	7	8
Element	Winnipeg River	Niagara River	Wabigoon River	English River	Black Sturgeon River	McLean's Creek	Quirke Lake	Spanish River
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	20	10	597	103	13	137	2	44
As	0.82	0.84	0.51	0.37	0.63	0.3	0.3	0.62
Au	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ba	146	321	58.6	291	124	196	286	265
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	11	38	10	4	39	6	8	41
Ca	11100	> 20000	16000	3200	> 20000	4100	19400	17100
Cd	0.02	0.02	0.02	0.01	< 0.01	0.02	< 0.01	0.08
Ce	0.171	0.018	1.1	0.622	0.108	0.526	0.016	0.119
Co	0.029	< 0.005	0.144	0.089	0.023	0.024	< 0.005	0.041
Cr	0.7	< 0.5	0.9	< 0.5	0.7	< 0.5	< 0.5	< 0.5
Cs	0.002	0.002	0.037	< 0.001	0.001	< 0.001	0.004	0.007
Cu	2	1.1	1.9	0.5	2.6	0.9	0.9	2.4
Dy	0.017	0.003	0.042	0.025	0.015	0.033	0.008	0.011
Er	0.008	0.002	0.025	0.017	0.008	0.022	0.005	0.007
Eu	0.007	0.018	0.02	0.02	0.007	0.023	0.014	0.019
Fe	60	20	450	520	80	70	< 10	60
Ga	< 0.01	< 0.01	0.13	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Gd	0.025	0.007	0.076	0.051	0.017	0.063	0.008	0.019
Ge	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hf	0.003	0.001	0.027	0.007	0.003	0.007	0.001	0.002
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.003	< 0.001	0.007	0.005	0.003	0.007	0.001	0.002
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	710	1490	1450	220	1020	110	1550	1880
La	0.148	0.015	0.622	0.416	0.078	0.424	0.022	0.146
Li	2	4	4	2	4	< 1	3	1
Lu	0.001	< 0.001	0.003	0.003	0.002	0.003	< 0.001	0.001
Mg	3330	11000	3600	984	8590	1040	1810	3950
Mn	1.3	2	41.2	16.8	15.7	3.5	3.7	51.8
Mo	0.1	1.1	0.2	< 0.1	0.2	0.1	0.1	0.2
Na	2760	13000	16900	3350	33200	1650	3740	25000
Nb	< 0.005	< 0.005	0.055	0.007	< 0.005	< 0.005	< 0.005	< 0.005
Nd	0.118	0.013	0.465	0.334	0.076	0.392	0.022	0.098
Ni	0.5	0.7	0.9	< 0.3	0.7	0.4	0.5	13.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.45	0.03	0.25	0.19	0.03	0.05	< 0.01	0.13
Pd	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	0.01

Element	1 Winnipeg River	2 Niagara River	3 Wabigoon River	4 English River	5 Black Sturgeon River	6 McLean's Creek	7 Quirke Lake	8 Spanish River
Pr	0.033	0.003	0.139	0.091	0.019	0.102	0.004	0.027
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.222	0.489	2.07	0.062	0.64	0.031	1.63	2.72
Re	< 0.001	0.006	< 0.001	< 0.001	< 0.001	0.002	0.004	0.184
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.05	0.15	0.04	0.04	0.03	0.05	0.04	0.04
Sc	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Se	< 0.2	< 0.2	< 0.2	< 0.2	0.4	< 0.2	0.3	0.2
Si	< 200	300	3000	3000	5000	2900	1100	2200
Sm	0.02	0.003	0.082	0.062	0.017	0.077	0.008	0.021
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sr	22.7	162	29.1	13.4	41.9	19	30.6	51.6
Ta	< 0.001	< 0.001	0.004	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tb	0.003	< 0.001	0.01	0.006	0.002	0.007	0.001	0.002
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti	0.7	0.5	18.9	2	1.5	0.8	< 0.1	1.3
Tl	0.002	< 0.001	0.006	< 0.001	0.001	0.003	0.001	0.002
Tm	0.001	< 0.001	0.003	0.002	0.001	0.003	< 0.001	< 0.001
V	0.5	0.3	1.1	0.6	1.5	0.2	< 0.1	0.3
W	< 0.02	0.04	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.05
Y	0.098	0.024	0.242	0.157	0.099	0.217	0.054	0.077
Yb	0.007	0.001	0.022	0.016	0.009	0.019	0.003	0.006
Zn	61.3	43.8	53.3	148	69.4	95.5	22.8	126
Zr	0.15	0.06	0.85	0.22	0.15	0.14	0.02	0.08

Element	9 Sturgeon Falls	10 French River	11 Saugeen River	12 Lake Huron near Tiverton	13 Lake Huron/ St Clair River	14 Grand River	15 Lac La Ronge	16 Saskat- chewan River
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	13	28	8	5	8	4	< 2	< 2
As	0.5	0.38	0.6	0.54	0.51	0.65	0.4	0.74
Au	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ba	258	244	90.9	284	229	288	94.1	312
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	5	6	25	23	25	74	12	23
Ca	7000	6200	> 20000	> 20000	> 20000	> 20000	> 20000	> 20000
Cd	< 0.01	0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	0.03
Ce	0.074	0.089	0.05	0.007	0.013	0.024	0.013	0.01
Co	0.017	0.009	< 0.005	< 0.005	< 0.005	0.038	< 0.005	0.054
Cr	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.7	< 0.5	< 0.5
Cs	< 0.001	< 0.001	0.001	< 0.001	0.001	0.003	0.001	0.002
Cu	1.1	1.5	0.9	0.6	0.6	1.6	0.3	0.8
Dy	0.007	0.008	0.007	0.002	0.002	0.005	0.002	0.004
Er	0.005	0.005	0.004	0.001	0.002	0.004	0.001	0.004
Eu	0.014	0.016	0.006	0.011	0.014	0.019	0.01	0.028
Fe	80	20	50	< 10	< 10	30	20	40
Ga	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.01
Gd	0.013	0.014	0.009	0.003	0.004	0.009	0.001	0.008
Ge	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	0.03
Hf	0.001	0.005	0.002	0.002	0.002	0.002	0.002	0.001
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.001	0.002	0.002	< 0.001	< 0.001	0.001	< 0.001	< 0.001
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	170	430	1340	960	950	3350	1520	3110
La	0.065	0.076	0.037	0.008	0.01	0.018	0.009	0.009
Li	< 1	< 1	< 1	< 1	< 1	8	5	13
Lu	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	< 0.001
Mg	2460	2510	> 20000	9400	9650	> 20000	7070	18900
Mn	4.1	2.8	3.7	0.4	1.4	6.5	2.1	10.4
Mo	< 0.1	< 0.1	0.4	0.5	0.5	1.3	0.2	1.4
Na	2400	4260	7760	6030	6980	> 35000	3690	28500
Nb	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Nd	0.061	0.082	0.034	0.007	0.009	0.018	0.004	0.005
Ni	1.1	1.3	0.5	0.3	0.4	0.9	< 0.3	1.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.04	0.05	0.03	0.02	0.02	0.09	< 0.01	0.02
Pd	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Pr	0.015	0.018	0.008	0.002	0.002	0.005	0.002	0.002
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.053	0.122	0.299	0.297	0.297	1.1	0.41	1.04
Re	0.015	0.011	0.004	0.004	0.004	0.004	< 0.001	0.013

Element	9 Sturgeon Falls	10 French River	11 Saugeen River	12 Lake Huron near Tiverton	13 Lake Huron/ St Clair River	14 Grand River	15 Lac La Ronge	16 Saskat- chewan River
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.04	0.05	0.06	0.11	0.11	0.19	< 0.01	0.12
Sc	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Se	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.4	0.5	1.3
Si	1600	1200	3300	900	900	2600	300	600
Sm	0.014	0.015	0.009	0.002	0.004	0.005	0.002	0.004
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sr	24.2	27.8	> 200	103	111	> 200	66.4	> 200
Ta	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tb	0.002	0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti	0.2	0.3	0.8	< 0.1	< 0.1	0.6	< 0.1	1
Tl	0.001	< 0.001	0.001	< 0.001	< 0.001	0.002	< 0.001	0.001
Tm	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
V	0.2	0.2	0.5	0.2	0.2	0.8	< 0.1	0.6
W	< 0.02	< 0.02	0.03	< 0.02	< 0.02	0.05	< 0.02	< 0.02
Y	0.05	0.055	0.05	0.014	0.017	0.038	0.015	0.03
Yb	0.004	0.005	0.006	0.002	0.002	0.008	0.001	0.003
Zn	52.6	61.1	40	47.2	42.2	77.1	45.9	50.9
Zr	0.06	0.14	0.13	0.04	0.06	0.08	0.06	0.06

Element	17 St Lawrence River	18 Ottawa River	19 Mackenzie River	20 Miramichi River	21 Petitcodiac River
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	40	20	7	32	51
As	0.49	0.21	0.33	0.58	2.37
Au	< 0.002	< 0.002	0.002	< 0.002	< 0.002
Ba	19.1	11.1	56.1	79	106
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	37	8	10	11	42
Ca	13800	6200	> 20000	4900	> 20000
Cd	0.02	< 0.01	0.03	0.01	0.02
Ce	0.183	0.164	0.011	0.102	0.33
Co	0.038	0.008	< 0.005	0.03	0.084
Cr	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Cs	0.006	0.004	0.004	0.001	0.003
Cu	1.4	0.8	1.2	0.2	0.8
Dy	0.011	0.008	0.008	0.022	0.045
Er	0.007	0.006	0.006	0.015	0.024
Eu	0.003	0.002	< 0.001	0.01	0.021
Fe	70	90	< 10	140	560
Ga	0.03	< 0.01	< 0.01	0.01	0.02
Gd	0.017	0.015	0.012	0.027	0.069
Ge	0.01	0.01	0.01	0.01	0.01
Hf	0.002	< 0.001	< 0.001	0.003	0.007
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.002	0.002	0.002	0.004	0.009
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	1410	570	870	410	890
La	0.113	0.128	0.016	0.051	0.153
Li	1	< 1	5	1	5
Lu	0.002	< 0.001	< 0.001	0.002	0.003
Mg	3680	1270	8240	743	2990
Mn	10.2	6.1	0.1	19.4	40.6
Mo	0.6	0.1	0.9	0.3	1
Na	10900	1800	5940	2900	32400
Nb	< 0.005	< 0.005	< 0.005	< 0.005	0.008
Nd	0.104	0.123	0.018	0.104	0.26
Ni	0.7	0.4	1.4	< 0.3	0.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.12	0.04	0.03	0.05	0.18
Pd	< 0.01	< 0.01	< 0.01	0.02	< 0.01
Pr	0.025	0.029	0.005	0.022	0.059
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	2.23	1.34	0.788	0.26	0.877
Re	0.03	0.007	0.003	< 0.001	< 0.001

	17	18	19	20	21
Element	St Lawrence River	Ottawa River	Mackenzie River	Miramichi River	Petitcodiac River
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.07	0.03	0.11	0.03	0.07
Sc	< 1	< 1	< 1	< 1	1
Se	0.3	0.3	0.6	< 0.2	0.5
Si	1600	1900	1700	2500	2200
Sm	0.017	0.021	0.009	0.028	0.069
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sr	149	36.3	> 200	64	> 200
Ta	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tb	0.002	0.002	0.002	0.004	0.01
Te	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Ti	1.6	0.8	0.3	1	2.3
Tl	0.006	0.006	0.006	0.002	0.026
Tm	0.001	< 0.001	< 0.001	0.002	0.003
V	0.8	0.2	0.2	0.2	0.7
W	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Y	0.068	0.06	0.078	0.12	0.262
Yb	0.006	0.006	0.006	0.011	0.022
Zn	2.4	4.8	4.6	80	52.6
Zr	0.04	0.02	0.04	0.09	0.25

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A.3 TRACE ELEMENT ANALYSIS OF SITES SAMPLED IN 2007

Trace element analysis of water samples collected in 2007, sites and elements ordered alphabetically except that I results are first. For some sites, separate samples were collected from two depths: the hypolimnion (deep, below the mixing zone) and the metalimnion (mid to shallow and mixed by wind action). Analytical methods the same as in this report. Universal Transverse Mercator (UTM) coordinates indicate location.

Date	21-Jul-07	21-Jul-07	18-Jul-07	18-Jul-07	28-Jul-07
Location	Agnew Lake	Agnew Lake	Aguasabon R. (mouth)	Black Sturgeon R.	Blue Lake
Sample Type	Hypo	Meta	Meta (mixed)	Meta (mixed)	Hypo
UTM	17T 433607 5132256	17T 433607 5132256	16U 491438 5402080	16U 399007 5417787	15U 464394 5528231
I	0.6	2.3	1.3	1.3	1.2
Ag	< 2	0.2	< 0.2	< 0.2	< 0.2
Al	423	155	248	175	160
As	3.13	3.34	12.4	9.24	4.29
Au	< 0.02	0.018	0.022	0.015	0.008
Ba	1020	> 400	> 400	286	325
Be	< 1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 3	< 0.3	< 0.3	< 0.3	< 0.3
Br	80	90	183	200	84
Ca	< 7000	2700	> 20000	17500	7400
Cd	< 0.1	0.02	0.02	1.11	0.03
Ce	0.325	0.422	0.207	0.206	0.075
Co	< 0.05	0.395	0.041	0.058	0.035
Cr	21.9	17.6	43	46.9	26.2
Cs	< 0.01	0.002	0.001	0.003	0.002
Cu	< 2	1	1.8	4	1.3
Dy	0.023	0.016	0.018	0.024	0.003
Er	0.016	0.011	0.012	0.016	0.002
Eu	0.062	0.013	0.015	0.013	0.003
Fe	< 100	410	40	120	40
Ga	0.13	0.08	0.13	0.14	0.07
Gd	0.035	0.033	0.027	0.034	0.006
Ge	< 0.1	0.08	0.21	0.22	0.08
Hf	0.063	0.017	0.03	0.037	0.014
Hg	< 2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	< 0.01	0.003	0.004	0.005	< 0.001
In	< 0.01	< 0.001	< 0.001	< 0.001	< 0.001
K	< 300	190	120	750	150
La	0.267	0.272	0.161	0.158	0.03
Li	< 10	1	2	2	2
Lu	< 0.01	0.002	0.004	0.004	0.001
Mg	1090	689	4560	5290	1990
Mn	3.5	333	2.6	3.8	1.8
Mo	< 1	0.2	0.4	0.4	0.3

Date	21-Jul-07	21-Jul-07	18-Jul-07	18-Jul-07	28-Jul-07
Location	Agnew Lake	Agnew Lake	Aguasabon R. (mouth)	Black Sturgeon R.	Blue Lake
Sample Type	Hypo	Meta	Meta (mixed)	Meta (mixed)	Hypo
UTM	17T 433607 5132256	17T 433607 5132256	16U 491438 5402080	16U 399007 5417787	15U 464394 5528231
Na	7150	7760	6140	15600	5960
Nb	< 0.05	0.006	0.008	0.008	< 0.005
Nd	0.233	0.224	0.148	0.138	0.019
Ni	< 3	1.1	0.8	1.2	< 0.3
Os	< 0.02	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.28	0.41	0.16	0.16	0.69
Pd	< 0.1	0.02	0.04	0.02	0.01
Pr	0.058	0.064	0.036	0.038	0.006
Pt	< 3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.104	0.101	0.059	0.223	0.088
Re	0.011	0.004	< 0.001	< 0.001	0.001
Ru	< 0.1	< 0.01	< 0.01	< 0.01	< 0.01
Sb	< 0.1	0.14	0.31	0.24	0.12
Sc	< 10	< 1	< 1	< 1	< 1
Se	5.6	24.4	60.1	58.7	25
Si	5000	800	2100	4100	700
Sm	0.046	0.04	0.032	0.032	0.008
Sn	< 1	0.6	0.3	0.1	1.1
Sr	19.1	13.8	23.4	29.7	20
Ta	< 0.01	0.002	0.002	0.002	0.002
Tb	< 0.01	0.004	0.004	0.005	< 0.001
Te	< 1	< 0.1	< 0.1	< 0.1	< 0.1
Th	< 0.01	0.016	0.017	0.015	< 0.001
Ti	5.2	2.3	3	3.7	2.7
Tl	< 0.01	0.01	0.007	0.006	0.006
Tm	< 0.01	0.001	0.002	0.003	< 0.001
U	0.179	0.119	0.12	0.162	0.012
V	5.4	4.8	11.6	13.8	7.3
W	< 0.2	< 0.02	0.03	0.02	0.06
Y	0.178	0.105	0.129	0.219	0.028
Yb	0.029	0.011	0.017	0.017	0.004
Zn	25.6	82.9	44.2	102	32
Zr	2.13	0.85	1.41	1.63	0.85

Date	28-Jul-07	28-Jul-07	17-Jul-07	17-Jul-07	17-Jul-07
Location	Blue Lake dup	Blue Lake	Dog Lake	Dog Lake dup	Dog Lake
Sample Type	Hypo	Meta	Hypo	Hypo	Meta
UTM	15U 464394 5528231	15U 464394 5528231	15U 313951 5395236	15U 313951 5395236	15U 313951 5395236
I	1.2	1.4	1.2	1.2	1.2
Ag	< 2	< 0.2	< 0.2	< 2	< 0.2
Al	880	98	353	760	317
As	5.7	1.29	5.7	9.5	3.94
Au	< 0.02	< 0.002	0.012	< 0.02	0.01
Ba	147	176	> 400	784	> 400
Be	< 1	< 0.1	< 0.1	< 1	< 0.1
Bi	< 3	< 0.3	< 0.3	< 3	< 0.3
Br	60	25	121	90	91
Ca	< 7000	4300	9600	< 7000	8000
Cd	< 0.1	0.01	0.01	< 0.1	0.01
Ce	0.42	0.026	0.25	0.38	0.182
Co	0.26	0.012	0.084	0.11	0.045
Cr	37	9.7	28	51	21.8
Cs	< 0.01	0.002	0.001	< 0.01	0.002
Cu	3	0.5	2.7	4	2.9
Dy	0.02	< 0.001	0.024	0.02	0.018
Er	< 0.01	0.001	0.015	0.02	0.013
Eu	< 0.01	0.002	0.031	0.05	0.024
Fe	< 100	< 10	120	< 100	90
Ga	0.2	0.03	0.11	0.2	0.08
Gd	0.02	0.003	0.039	0.06	0.037
Ge	0.1	0.02	0.14	0.1	0.1
Hf	0.01	0.011	0.038	0.09	0.046
Hg	< 2	< 0.2	< 0.2	< 2	< 0.2
Ho	< 0.01	< 0.001	0.005	< 0.01	0.004
In	< 0.01	< 0.001	< 0.001	< 0.01	< 0.001
K	< 300	80	290	< 300	280
La	0.18	0.012	0.184	0.2	0.14
Li	< 10	1	2	< 10	2
Lu	< 0.01	< 0.001	0.005	< 0.01	0.004
Mg	1450	1160	3160	1920	2650
Mn	3	0.4	13.9	10	1.5
Mo	< 1	0.1	0.5	1	0.4
Na	10200	3460	12900	13100	12800
Nb	< 0.05	< 0.005	< 0.005	< 0.05	< 0.005
Nd	0.13	0.008	0.163	0.14	0.127
Ni	6	< 0.3	1	< 3	0.8
Os	< 0.02	< 0.002	< 0.002	< 0.02	< 0.002
Pb	0.9	0.06	0.24	0.4	0.26
Pd	< 0.1	< 0.01	0.02	< 0.1	0.01

Date	28-Jul-07	28-Jul-07	17-Jul-07	17-Jul-07	17-Jul-07
Location	Blue Lake dup	Blue Lake	Dog Lake	Dog Lake dup	Dog Lake
Sample Type	Hypo	Meta	Hypo	Hypo	Meta
UTM	15U 464394 5528231	15U 464394 5528231	15U 313951 5395236	15U 313951 5395236	15U 313951 5395236
Pr	0.04	0.002	0.041	0.05	0.031
Pt	< 3	< 0.3	< 0.3	< 3	< 0.3
Rb	0.17	0.05	0.101	0.15	0.097
Re	< 0.01	< 0.001	< 0.001	< 0.01	0.001
Ru	< 0.1	< 0.01	< 0.01	< 0.1	< 0.01
Sb	< 0.1	0.05	0.12	< 0.1	0.12
Sc	< 10	< 1	< 1	< 10	< 1
Se	23	6.7	35.6	31	24.5
Si	5000	300	3300	6000	2300
Sm	< 0.01	0.003	0.033	0.03	0.029
Sn	< 1	0.5	0.3	< 1	0.4
Sr	18.6	11.4	16.6	11.6	14.7
Ta	< 0.01	0.002	0.006	< 0.01	0.012
Tb	< 0.01	< 0.001	0.004	< 0.01	0.004
Te	< 1	< 0.1	< 0.1	< 1	< 0.1
Th	0.02	< 0.001	0.014	0.02	0.014
Ti	6	1.6	3.3	7	2.9
Tl	< 0.01	0.004	0.005	< 0.01	0.003
Tm	< 0.01	< 0.001	0.002	< 0.01	0.002
U	0.03	0.007	0.102	0.09	0.103
V	9	2.8	8	14	6.2
W	< 0.2	< 0.02	0.04	< 0.2	0.03
Y	0.12	0.015	0.195	0.22	0.156
Yb	0.02	0.003	0.024	0.02	0.022
Zn	33	26.1	28.8	41	31.2
Zr	0.6	0.51	1.52	2.6	1.56

Date	28-Jul-07	28-Jul-07	28-Jul-07	27-Jul-07	26-Jul-07
Location	Eagle Lake	Eagle Lake dup	Eagle Lake	English River	Lac Des Mille Lacs
Sample Type	Hypo	Hypo	Meta	Meta	Meta
UTM	15U 472522 5521386	15U 472522 5521386	15U 472522 5521386	15U 648132 5454940	16U 697255 5421703
I	1.9	1.9	1.5	0.4	1.9
Ag	< 0.2	< 2	< 0.2	< 0.2	< 0.2
Al	226	750	191	226	424
As	3.61	7	5.56	6.04	17
Au	0.007	< 0.02	0.003	0.002	0.004
Ba	> 400	371	> 400	> 400	> 400
Be	< 0.1	< 1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 3	< 0.3	< 0.3	< 0.3
Br	83	70	62	65	183
Ca	4400	< 7000	3800	8700	6400
Cd	0.02	< 0.1	0.06	0.03	0.05
Ce	0.137	0.33	0.21	0.117	0.793
Co	0.106	0.16	0.095	0.033	0.252
Cr	18.9	40	23.4	25.5	63
Cs	0.003	< 0.01	0.002	0.005	0.004
Cu	1.3	3	1.2	1	2
Dy	0.007	0.02	0.007	0.005	0.046
Er	0.006	< 0.01	0.004	0.006	0.03
Eu	0.024	0.02	0.032	0.036	0.045
Fe	90	< 100	60	50	1070
Ga	0.08	0.2	0.08	0.08	0.22
Gd	0.018	0.03	0.015	0.01	0.077
Ge	0.11	< 0.1	0.07	0.08	0.26
Hf	0.031	0.03	0.032	0.022	0.079
Hg	< 0.2	< 2	< 0.2	< 0.2	< 0.2
Ho	0.001	< 0.01	0.002	0.001	0.01
In	< 0.001	< 0.01	< 0.001	< 0.001	< 0.001
K	370	300	460	1370	400
La	0.077	0.14	0.054	0.055	0.398
Li	2	< 10	1	3	4
Lu	0.003	< 0.01	0.002	0.002	0.008
Mg	1460	1250	1230	2090	2160
Mn	56.6	53	0.9	1.2	67.5
Mo	0.3	1	0.3	0.5	0.5
Na	12200	15800	10900	33700	12300
Nb	< 0.005	< 0.05	< 0.005	< 0.005	0.018
Nd	0.062	0.1	0.045	0.038	0.351
Ni	0.7	< 3	0.8	0.4	1.2
Os	< 0.002	< 0.02	< 0.002	< 0.002	< 0.002
Pb	0.2	0.5	0.17	0.15	0.39
Pd	< 0.01	< 0.1	0.03	0.02	0.04

Date	28-Jul-07	28-Jul-07	28-Jul-07	27-Jul-07	26-Jul-07
Location	Eagle Lake	Eagle Lake dup	Eagle Lake	English River	Lac Des Mille Lacs
Sample Type	Hypo	Hypo	Meta	Meta	Meta
UTM	15U 472522 5521386	15U 472522 5521386	15U 472522 5521386	15U 648132 5454940	16U 697255 5421703
Pr	0.015	0.03	0.012	0.01	0.095
Pt	< 0.3	< 3	< 0.3	< 0.3	< 0.3
Rb	0.158	0.21	0.192	0.471	0.183
Re	0.001	< 0.01	0.001	0.001	0.001
Ru	< 0.01	< 0.1	< 0.01	< 0.01	< 0.01
Sb	0.12	< 0.1	0.07	0.05	0.19
Sc	< 1	< 10	< 1	< 1	1
Se	22.6	20	19.5	20.7	58.7
Si	900	6000	1100	2600	4500
Sm	0.016	0.02	0.01	0.011	0.071
Sn	0.4	< 1	1	< 0.1	0.8
Sr	21.1	20.1	23.9	43.8	22.3
Ta	0.005	< 0.01	0.002	0.003	0.002
Tb	0.002	< 0.01	0.001	< 0.001	0.009
Te	< 0.1	< 1	< 0.1	< 0.1	< 0.1
Th	0.004	0.01	0.004	0.003	0.035
Ti	3.2	8	2.7	3.1	9.1
Tl	0.004	< 0.01	0.003	0.004	0.003
Tm	< 0.001	< 0.01	< 0.001	< 0.001	0.004
U	0.054	0.08	0.039	0.134	0.053
V	5.6	12	5.9	7	18
W	0.02	< 0.2	0.12	0.04	0.03
Y	0.128	0.23	0.063	0.083	0.319
Yb	0.009	0.01	0.009	0.012	0.037
Zn	99.6	112	225	21	161
Zr	1.23	2	1.3	1.15	3.25

Date	18-Jul-07	27-Jul-07	27-Jul-07	23-Jul-07	18-Jul-07
Location	Little Pic R.	Little Vermillion Lake	Little Vermillion Lake	Little Wawa	McCleans Creek-
Sample Type	Meta (mixed)	Hypo	Meta	Meta	Meta (mixed)
UTM	16U 527252 5404705	15U 562360 5538892	15U 562360 5538892	17T 287640 5303635	16U 467490 5409699
I	1.4	1.5		0.4	0.6
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	331	240	266	233	386
As	20.3	9.49	10.3	5.63	15.1
Au	0.003	< 0.002	< 0.002	< 0.002	0.004
Ba	> 400	> 400	> 400	> 400	> 400
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	167	80	87	47	145
Ca	> 20000	> 20000	> 20000	11700	3000
Cd	0.04	0.16	0.05	0.06	0.05
Ce	0.807	0.196	0.087	0.081	0.892
Co	0.116	0.164	0.084	0.083	0.069
Cr	82.4	44.8	47.1	29.7	64.2
Cs	0.009	0.002	0.002	0.002	0.002
Cu	2.6	1	1.1	2.1	1.5
Dy	0.043	0.008	0.006	0.006	0.048
Er	0.026	0.007	0.006	0.004	0.03
Eu	0.053	0.026	0.034	0.027	0.047
Fe	180	50	50	30	70
Ga	0.22	0.11	0.1	0.08	0.19
Gd	0.075	0.014	0.011	0.013	0.086
Ge	0.23	0.11	0.1	0.08	0.22
Hf	0.064	0.046	0.063	0.026	0.036
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.008	0.002	0.002	0.001	0.009
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	300	350	390	290	250
La	0.483	0.054	0.045	0.035	0.527
Li	7	6	6	3	7
Lu	0.008	0.003	0.003	0.002	0.006
Mg	4610	4080	4150	1960	711
Mn	8.6	303	2	29.9	3.6
Mo	0.6	0.5	0.5	0.4	0.5
Na	11300	13000	12200	11000	10900
Nb	0.021	< 0.005	0.005	< 0.005	0.006
Nd	0.418	0.036	0.038	0.028	0.513
Ni	1	0.5	3.4	< 0.3	0.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.24	0.16	0.14	0.16	0.17
Pd	0.04	0.03	0.03	0.01	0.03

Date	18-Jul-07	27-Jul-07	27-Jul-07	23-Jul-07	18-Jul-07
Location	Little Pic R.	Little Vermillion Lake	Little Vermillion Lake	Little Wawa	McCleans Creek-
Sample Type	Meta (mixed)	Hypo	Meta	Meta	Meta (mixed)
UTM	16U 527252 5404705	15U 562360 5538892	15U 562360 5538892	17T 287640 5303635	16U 467490 5409699
Pr	0.109	0.012	0.009	0.006	0.139
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.249	0.148	0.158	0.134	0.11
Re	0.002	< 0.001	0.001	0.002	0.002
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.14	0.08	0.08	0.08	0.12
Sc	1	< 1	< 1	< 1	< 1
Se	71.1	33.2	35.5	18.9	52.7
Si	3700	2200	1900	1200	3100
Sm	0.08	0.012	0.008	0.008	0.091
Sn	0.4	0.1	0.3	0.3	< 0.1
Sr	39.9	41.7	42.2	26.4	18.5
Ta	0.001	< 0.001	< 0.001	0.002	< 0.001
Tb	0.009	< 0.001	< 0.001	< 0.001	0.01
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.036	0.001	0.002	< 0.001	0.036
Ti	8.9	4.9	4.7	3.4	5.3
Tl	0.003	0.002	0.002	0.002	0.004
Tm	0.003	0.001	< 0.001	< 0.001	0.004
U	0.141	0.037	0.042	0.019	0.128
V	22.1	12.5	12.5	8.8	17.7
W	0.02	0.57	0.08	0.56	0.06
Y	0.28	0.058	0.062	0.046	0.303
Yb	0.029	0.01	0.01	0.006	0.032
Zn	62.3	62.6	39	22.5	45.4
Zr	2.82	2.43	3.06	1.21	1.65

Date	21-Jul-07	21-Jul-07	21-Jul-07	22-Jul-07	22-Jul-07
Location	Panache Lake	Panache Lake	Pinawa Dam	Quirke Lake	Quirke Lake
Sample Type	Hypo	Meta	Meta	Hypo	Meta
UTM	17T 473298 5123306	17T 473298 5123306	15U 295140 5560393	17T 381806 5150285	17T 381806 5150285
I	1.3	1.3	3.3	2.6	2.5
Ag	< 0.2	< 0.2	< 0.2	0.3	< 0.2
Al	227	279	363	275	238
As	25.5	18.1	8.28	6.61	7.6
Au	0.004	0.002	< 0.002	0.003	< 0.002
Ba	151	172	24.6	285	332
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	240	155	64	64	70
Ca	6200	5800	< 700	> 20000	> 20000
Cd	0.03	0.03	< 0.01	0.02	0.02
Ce	0.095	0.115	0.13	0.097	0.075
Co	0.04	0.02	0.01	0.054	0.039
Cr	105	81.1	35.7	25.5	29.5
Cs	0.002	0.002	0.002	0.002	0.004
Cu	5.9	5.5	1.9	1.1	1
Dy	0.01	0.008	0.005	0.016	0.011
Er	0.007	0.008	0.006	0.012	0.01
Eu	0.01	0.008	0.002	0.014	0.015
Fe	20	< 10	30	< 10	< 10
Ga	0.33	0.2	0.13	0.09	0.08
Gd	0.012	0.013	0.005	0.015	0.011
Ge	0.42	0.2	0.11	0.08	0.08
Hf	0.034	0.035	< 0.001	0.016	0.012
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.002	0.002	0.001	0.003	0.002
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	700	550	70	610	650
La	0.064	0.061	0.04	0.056	0.048
Li	12	11	2	9	10
Lu	0.002	0.002	0.001	0.002	0.002
Mg	1930	1860	4	1740	1760
Mn	5.8	0.5	0.5	2.6	6.3
Mo	0.6	0.4	0.4	0.6	0.4
Na	8950	9290	7000	14500	13500
Nb	< 0.005	< 0.005	< 0.005	0.005	< 0.005
Nd	0.055	0.063	0.033	0.057	0.039
Ni	10.2	10.8	< 0.3	1.7	1
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.18	0.13	0.24	0.07	0.05
Pd	0.04	0.03	< 0.01	0.04	0.03

Date	21-Jul-07	21-Jul-07	21-Jul-07	22-Jul-07	22-Jul-07
Location	Panache Lake	Panache Lake	Pinawa Dam	Quirke Lake	Quirke Lake
Sample Type	Hypo	Meta	Meta	Hypo	Meta
UTM	17T 473298 5123306	17T 473298 5123306	15U 295140 5560393	17T 381806 5150285	17T 381806 5150285
Pr	0.015	0.015	0.009	0.015	0.011
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.217	0.174	0.067	0.196	0.239
Re	0.055	0.051	< 0.001	0.004	0.005
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.23	0.13	0.04	0.08	0.07
Sc	< 1	< 1	< 1	< 1	< 1
Se	90.1	60.8	29.7	22.8	26.9
Si	2900	2700	2800	1900	1600
Sm	0.013	0.013	0.011	0.018	0.012
Sn	0.5	0.5	< 0.1	0.2	0.2
Sr	21.4	21.1	0.61	35.7	37.3
Ta	< 0.001	< 0.001	< 0.001	< 0.001	0.001
Tb	0.002	0.002	0.001	0.003	0.002
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.002	0.002	0.002	0.004	0.003
Ti	7	6.9	3.9	3	3.6
Tl	0.003	0.003	< 0.001	< 0.001	< 0.001
Tm	< 0.001	0.001	0.001	0.002	0.002
U	0.017	0.021	0.01	1.12	0.912
V	28.6	22.3	9.6	6.7	8.1
W	0.03	0.04	0.02	0.03	0.04
Y	0.095	0.071	0.046	0.133	0.11
Yb	0.01	0.009	0.011	0.015	0.011
Zn	168	236	23.5	16.9	40.2
Zr	1.74	1.52	0.05	1	0.97

Date	22-Jul-07	22-Jul-07	27-Jul-07	27-Jul-07	22-Jul-07
Location	Ranger Lake	Ranger Lake	Sandbar Lake	Sandbar Lake	Semiwite lake
Sample Type	Hypo	Meta	Hypo	Meta	Hypo
UTM	17T 309439 5198975	17T 309439 5198975	15U 603945 5480861	15U 603945 5480861	17T 370672 5159820
I	1.1	1.1	1.1	1	1
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	288	220	237	194	341
As	9.54	7.29	13.1	11	10.5
Au	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ba	> 400	162	> 400	195	> 400
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	89	67	126	91	90
Ca	3100	3900	7600	5600	2300
Cd	0.02	0.01	0.02	< 0.01	0.02
Ce	0.127	0.113	0.137	0.092	0.207
Co	0.025	0.031	0.075	0.023	0.172
Cr	40.9	33.8	58.8	49.6	45.7
Cs	0.003	0.002	0.002	0.002	0.002
Cu	1.1	1.6	1.3	0.8	1.7
Dy	0.007	0.006	0.009	0.007	0.011
Er	0.007	0.006	0.006	0.007	0.009
Eu	0.028	0.01	0.065	0.008	0.028
Fe	50	50	80	20	110
Ga	0.12	0.09	0.15	0.11	0.13
Gd	0.014	0.012	0.02	0.009	0.018
Ge	0.11	0.08	0.16	0.11	0.12
Hf	0.027	0.027	0.04	0.028	0.019
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.002	0.002	0.002	0.001	0.003
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	240	100	460	390	270
La	0.065	0.071	0.086	0.046	0.106
Li	6	6	10	8	8
Lu	0.002	0.001	0.004	0.002	0.003
Mg	887	1040	1560	1200	580
Mn	1.6	4.5	47.2	1.3	176
Mo	0.4	0.3	0.8	0.4	0.4
Na	11900	5000	15800	6160	11900
Nb	< 0.005	< 0.005	0.005	< 0.005	< 0.005
Nd	0.066	0.059	0.075	0.049	0.107
Ni	0.4	0.6	0.6	< 0.3	0.5
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.22	0.2	0.18	0.24	0.69
Pd	0.04	0.02	0.04	0.03	0.02

Date	22-Jul-07	22-Jul-07	27-Jul-07	27-Jul-07	22-Jul-07
Location	Ranger Lake	Ranger Lake	Sandbar Lake	Sandbar Lake	Semiwite lake
Sample Type	Hypo	Meta	Hypo	Meta	Hypo
UTM	17T 309439 5198975	17T 309439 5198975	15U 603945 5480861	15U 603945 5480861	17T 370672 5159820
Pr	0.015	0.016	0.017	0.01	0.026
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.132	0.07	0.181	0.144	0.118
Re	0.003	0.002	< 0.001	< 0.001	0.004
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.08	0.06	0.1	0.07	0.11
Sc	< 1	< 1	< 1	< 1	< 1
Se	33.8	24.6	48.9	39.1	35.3
Si	2000	1700	3200	2800	2300
Sm	0.014	0.011	0.024	0.012	0.024
Sn	< 0.1	0.6	0.5	1.1	< 0.1
Sr	20.4	17.5	24.1	16.2	18.3
Ta	0.003	0.001	0.006	0.002	0.001
Tb	0.001	0.002	0.002	0.001	0.002
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.004	0.005	0.003	0.003	0.003
Ti	4.1	3.6	5.7	4.4	5.1
Tl	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tm	0.002	0.001	0.001	0.001	0.002
U	0.148	0.158	0.247	0.161	0.039
V	10.9	8.9	15.8	13.7	12.8
W	0.02	0.02	< 0.02	< 0.02	0.04
Y	0.065	0.06	0.083	0.057	0.088
Yb	0.01	0.009	0.018	0.008	0.012
Zn	52	13.6	239	174	35.2
Zr	1.43	1.04	2.2	1.19	1.16

Date	22-Jul-07	21-Jul-07	27-Jul-07	27-Jul-07	04-Jul-07
Location	Semiwite lake	Spanish River	Sturgeon Lake	Sturgeon Lake	Sylvia Lake
Sample Type	Meta	Meta (mixed)	Hypo	Meta	Hypo
UTM	17T 370672 5159820	17T 439930 5124138	15U 633499 5525946	15U 633499 5525946	15U 295123 5557716
I	1	1.7	1.1	1.2	1.9
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	271	272	244	198	264
As	21.9	17.7	5.74	3.59	6.93
Au	0.005	< 0.002	< 0.002	< 0.002	< 0.002
Ba	> 400	> 400	245	252	278
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	208	167	51	29	55
Ca	3000	11400	15300	10600	11100
Cd	< 0.01	0.06	0.02	0.02	0.01
Ce	0.098	0.28	0.09	0.077	0.38
Co	0.025	0.13	0.009	0.051	0.053
Cr	95	78.7	31.2	19.9	33
Cs	0.001	0.003	0.001	0.001	0.006
Cu	1.6	6.5	1.6	1.5	1.7
Dy	0.006	0.017	0.004	0.005	0.022
Er	0.006	0.013	0.004	0.004	0.015
Eu	0.044	0.049	0.01	0.011	0.017
Fe	20	210	< 10	< 10	130
Ga	0.25	0.19	0.07	0.06	0.09
Gd	0.013	0.033	0.006	0.006	0.039
Ge	0.32	0.19	0.06	0.04	0.06
Hf	0.045	0.072	0.025	0.02	0.027
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.001	0.003	0.001	< 0.001	0.005
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	230	840	140	220	260
La	0.051	0.217	0.043	0.038	0.231
Li	10	11	5	3	4
Lu	0.005	0.006	0.001	< 0.001	0.003
Mg	752	2270	2710	1830	3260
Mn	0.5	19.2	6.7	86.2	3.7
Mo	0.5	0.6	0.3	0.2	0.4
Na	10400	19400	5540	4420	5840
Nb	< 0.005	0.008	< 0.005	< 0.005	0.007
Nd	0.039	0.198	0.045	0.024	0.209
Ni	0.4	11.5	0.3	0.4	0.9
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.15	0.29	0.1	0.15	0.16
Pd	0.06	0.05	0.01	< 0.01	0.01

Date	22-Jul-07	21-Jul-07	27-Jul-07	27-Jul-07	04-Jul-07
Location	Semiwite lake	Spanish River	Sturgeon Lake	Sturgeon Lake	Sylvia Lake
Sample Type	Meta	Meta (mixed)	Hypo	Meta	Hypo
UTM	17T 370672 5159820	17T 439930 5124138	15U 633499 5525946	15U 633499 5525946	15U 295123 5557716
Pr	0.011	0.048	0.009	0.007	0.053
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.103	0.301	0.063	0.084	0.182
Re	0.003	0.158	< 0.001	< 0.001	0.001
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.16	0.12	0.08	0.05	0.09
Sc	< 1	< 1	< 1	< 1	< 1
Se	78.6	59.6	20.3	12.4	21.7
Si	2900	2900	1700	1100	800
Sm	0.012	0.037	0.008	0.005	0.04
Sn	0.4	0.9	0.9	4	1
Sr	14	44.1	27	18.8	22.5
Ta	0.002	0.002	0.001	0.001	< 0.001
Tb	0.001	0.004	< 0.001	< 0.001	0.004
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.004	0.009	0.002	0.002	0.013
Ti	6.7	6.4	3.7	2.5	4
Tl	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tm	0.001	0.002	0.001	< 0.001	0.002
U	0.04	0.138	0.013	0.011	0.1
V	25.3	21.6	8.4	5.6	9.6
W	0.02	0.04	< 0.02	< 0.02	0.02
Y	0.059	0.148	0.04	0.034	0.151
Yb	0.017	0.02	0.009	0.005	0.015
Zn	16.2	156	27.5	50.8	23.4
Zr	2.17	2.71	1.24	0.91	1.45

Date	29-Jun-07	04-Jul-07	29-Jun-07	16-Jul-07	16-Jul-07
Location	Sylvia Lake	Sylvia Lake	Sylvia Lake	Thunder Lake	Thunder Lake
Sample Type	Hypo	Meta	Meta	Hypo	Meta
UTM	15U 295123 5557716	15U 295123 5557716	15U 295123 5557716	15U 525017 5513052	15U 525017 5513052
I	1.8	1.8	1.8	1.4	1.5
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	288	366	324	305	285
As	9.81	6.27	5.38	6.98	5.22
Au	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ba	342	> 400	267	> 400	> 400
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	77	52	41	64	50
Ca	11500	10400	11000	14100	13700
Cd	0.02	0.01	0.01	0.02	0.01
Ce	0.394	0.374	0.387	0.159	0.12
Co	0.054	0.077	0.048	0.03	0.031
Cr	41.5	28.9	23.8	33.2	24.6
Cs	0.004	0.006	0.005	0.003	0.002
Cu	1.7	1.7	1.7	2	1.7
Dy	0.021	0.024	0.023	0.008	0.008
Er	0.015	0.014	0.017	0.007	0.006
Eu	0.025	0.057	0.017	0.051	0.045
Fe	110	160	110	30	< 10
Ga	0.11	0.09	0.08	0.09	0.07
Gd	0.038	0.05	0.043	0.017	0.018
Ge	0.08	0.06	0.06	0.07	0.06
Hf	0.031	0.064	0.045	0.042	0.043
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.005	0.004	0.004	0.002	0.002
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	220	280	200	320	320
La	0.229	0.221	0.23	0.088	0.063
Li	3	3	2	4	3
Lu	0.003	0.003	0.002	0.004	0.002
Mg	3230	3130	3130	3210	3040
Mn	4.2	3.3	3.5	1.6	0.4
Mo	0.4	0.6	0.4	0.5	0.5
Na	5750	12100	6550	13600	13000
Nb	0.008	0.007	0.006	< 0.005	< 0.005
Nd	0.2	0.188	0.192	0.068	0.047
Ni	0.8	1.1	0.9	0.5	0.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.82	0.28	0.2	0.18	0.17
Pd	0.02	0.02	0.01	0.02	0.02

Date	29-Jun-07	04-Jul-07	29-Jun-07	16-Jul-07	16-Jul-07
Location	Sylvia Lake	Sylvia Lake	Sylvia Lake	Thunder Lake	Thunder Lake
Sample Type	Hypo	Meta	Meta	Hypo	Meta
UTM	15U 295123 5557716	15U 295123 5557716	15U 295123 5557716	15U 525017 5513052	15U 525017 5513052
Pr	0.05	0.052	0.053	0.016	0.012
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.169	0.212	0.169	0.146	0.131
Re	< 0.001	0.001	< 0.001	< 0.001	0.001
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.11	0.08	0.07	0.09	0.06
Sc	< 1	< 1	< 1	< 1	< 1
Se	31.5	18.5	17.1	24.7	17.6
Si	1500	800	1400	1700	1100
Sm	0.043	0.041	0.038	0.016	0.014
Sn	2.6	1.2	1.1	0.2	0.5
Sr	22	22.7	21.8	30.7	28.9
Ta	< 0.001	0.003	0.001	0.005	0.002
Tb	0.005	0.004	0.005	0.001	0.002
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.012	0.014	0.015	0.003	0.004
Ti	4.8	4.2	3.7	3.9	3
Tl	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tm	0.002	0.003	0.002	0.002	0.001
U	0.107	0.104	0.104	0.032	0.048
V	11.4	8	7	8.8	6.5
W	0.02	0.03	< 0.02	0.03	0.04
Y	0.155	0.163	0.16	0.067	0.076
Yb	0.018	0.021	0.016	0.012	0.012
Zn	28.1	24.3	29.3	21.4	16.3
Zr	1.4	2.54	1.87	1.98	1.86

Date	16-Jul-07	23-Jul-07	23-Jul-07	28-Jul-07	28-Jul-07
Location	unnamed (0.5 km west of Mahree Lake)	unnamed (Nebskwashi River)	unnamed (Nebskwashi River)	Wabigoon Lake	Wabigoon Lake
Sample Type	Meta (mixed)	Hypo	Meta	Hypo	Meta
UTM	15U 423034 5515036	17T 308596 5294431	17T 308596 5294431	15U 511793 5511966	15U 511793 5511966
I	1.3	1.2	1.1	1.6	1.6
Ag	0.4	< 0.2	< 0.2	< 0.2	< 0.2
Al	199	244	227	634	587
As	1.6	4.42	10.9	4.85	7.48
Au	0.013	< 0.002	< 0.002	< 0.002	< 0.002
Ba	316	389	237	> 400	200
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	56	47	100	43	62
Ca	3900	11400	9300	14500	12500
Cd	0.06	0.01	0.02	0.03	0.02
Ce	0.276	0.751	0.436	0.867	0.755
Co	0.035	0.22	0.061	0.235	0.182
Cr	5.9	17.2	46	24.3	33.3
Cs	0.003	0.003	0.001	0.031	0.029
Cu	1.1	0.8	1.5	19.5	2.4
Dy	0.015	0.031	0.029	0.029	0.028
Er	0.009	0.022	0.019	0.019	0.015
Eu	0.01	0.027	0.02	0.052	0.02
Fe	110	3800	290	500	440
Ga	0.05	0.09	0.11	0.19	0.19
Gd	0.024	0.062	0.041	0.073	0.052
Ge	0.04	0.07	0.1	0.05	0.07
Hf	0.036	0.027	0.046	0.044	0.034
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.003	0.006	0.006	0.005	0.004
In	< 0.001	< 0.001	< 0.001	0.001	< 0.001
K	940	830	380	480	510
La	0.197	0.467	0.333	0.525	0.455
Li	2	2	3	4	4
Lu	0.002	0.004	0.003	0.005	0.002
Mg	647	2170	2120	2950	2520
Mn	23.9	402	38.9	13.4	6
Mo	0.3	0.3	0.3	1.2	0.4
Na	34800	6660	6280	12900	6520
Nb	0.006	0.01	0.008	0.015	0.015
Nd	0.149	0.382	0.3	0.367	0.353
Ni	0.3	0.6	0.4	1.2	0.8
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.16	0.28	0.21	0.87	0.3
Pd	0.04	0.01	0.02	0.02	0.01

Date	16-Jul-07	23-Jul-07	23-Jul-07	28-Jul-07	28-Jul-07
Location	unnamed (0.5 km west of Mahree Lake)	unnamed (Nebskwashi River)	unnamed (Nebskwashi River)	Wabigoon Lake	Wabigoon Lake
Sample Type	Meta (mixed)	Hypo	Meta	Hypo	Meta
UTM	15U 423034 5515036	17T 308596 5294431	17T 308596 5294431	15U 511793 5511966	15U 511793 5511966
Pr	0.04	0.104	0.079	0.108	0.098
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.37	0.378	0.134	0.797	0.763
Re	< 0.001	0.002	0.001	0.001	< 0.001
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.07	0.06	0.05	0.07	0.08
Sc	< 1	< 1	< 1	< 1	< 1
Se	8.5	13.6	40.4	16	24.9
Si	500	1800	2800	1600	2000
Sm	0.031	0.068	0.048	0.069	0.057
Sn	0.1	0.5	0.4	0.3	1.1
Sr	20.6	28.2	22.4	36.9	25.1
Ta	0.002	< 0.001	0.001	0.002	0.001
Tb	0.003	0.006	0.006	0.006	0.006
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.02	0.028	0.024	0.069	0.052
Ti	1.7	3.8	4	14.9	15.4
Tl	0.007	< 0.001	< 0.001	< 0.001	0.001
Tm	< 0.001	0.003	0.002	0.002	0.002
U	0.131	0.047	0.038	0.063	0.057
V	1.6	9.6	12.6	7.4	9.7
W	0.05	0.03	0.04	0.04	< 0.02
Y	0.094	0.212	0.183	0.201	0.167
Yb	0.01	0.019	0.02	0.023	0.019
Zn	22	> 250	112	43.5	44.9
Zr	1.52	1.37	1.93	2.18	1.58

Date	20-Jul-07	20-Jul-07	25-Jul-07	25-Jul-07	18-Jul-07
Location	Wanapitei Lake	Wanapitei Lake	White Lake	White Lake	White Sand Lake
Sample Type	Hypo	Meta	Hypo	Meta	Hypo
UTM	17T 516403 5181856	17T 516403 5181856	16U 600332 5399692	16U 600332 5399692	16U 471428 5409963
I	0.7	0.8	1.6	1.2	0.6
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	231	324	151	123	281
As	37.8	28.3	11.1	4.82	16.6
Au	0.005	0.003	< 0.002	< 0.002	< 0.002
Ba	262	> 400	193	77.4	276
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	311	224	79	36	134
Ca	8100	6900	14600	8000	4800
Cd	0.03	< 0.01	0.05	< 0.01	0.04
Ce	0.137	0.155	0.153	0.046	0.512
Co	0.033	0.048	0.187	0.01	0.15
Cr	152	126	53.8	27.6	70.1
Cs	0.002	0.001	0.001	0.001	< 0.001
Cu	3.4	3.3	0.8	0.4	2.1
Dy	0.014	0.015	0.01	0.004	0.039
Er	0.01	0.009	0.006	0.004	0.026
Eu	0.017	0.056	0.008	0.004	0.025
Fe	50	50	480	10	170
Ga	0.49	0.32	0.1	0.05	0.17
Gd	0.02	0.025	0.013	0.004	0.061
Ge	0.61	0.39	0.09	0.03	0.19
Hf	0.052	0.054	0.02	0.017	0.032
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.003	0.003	0.001	< 0.001	0.008
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	150	300	180	50	200
La	0.109	0.097	0.072	0.025	0.366
Li	7	11	6	3	5
Lu	0.004	0.008	0.002	< 0.001	0.005
Mg	1900	1720	3530	1970	926
Mn	0.9	1.7	128	0.5	68.9
Mo	0.7	0.6	0.4	0.1	0.5
Na	4710	12300	2700	2490	5550
Nb	0.007	< 0.005	0.005	< 0.005	0.006
Nd	0.102	0.091	0.057	0.015	0.377
Ni	6.1	5.9	0.8	< 0.3	0.6
Os	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pb	0.23	0.16	0.12	0.07	0.21
Pd	0.05	0.05	0.01	< 0.01	0.02

Date	20-Jul-07	20-Jul-07	25-Jul-07	25-Jul-07	18-Jul-07
Location	Wanapitei Lake	Wanapitei Lake	White Lake	White Lake	White Sand Lake
Sample Type	Hypo	Meta	Hypo	Meta	Hypo
UTM	17T 516403 5181856	17T 516403 5181856	16U 600332 5399692	16U 600332 5399692	16U 471428 5409963
Pr	0.027	0.021	0.015	0.005	0.093
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.077	0.121	0.088	0.05	0.084
Re	0.018	0.016	< 0.001	< 0.001	0.002
Ru	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.23	0.14	0.05	0.02	0.08
Sc	1	1	< 1	< 1	< 1
Se	134	105	39.3	16.7	59.8
Si	4300	3400	2200	1100	3000
Sm	0.021	0.022	0.012	0.006	0.082
Sn	1.9	0.3	0.5	0.4	0.8
Sr	21	19.1	16.3	8.61	16
Ta	0.001	0.004	< 0.001	< 0.001	0.001
Tb	0.002	0.003	0.002	< 0.001	0.009
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.008	0.006	0.004	0.003	0.017
Ti	7.3	8	4.5	2.4	4.5
Tl	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Tm	0.002	0.002	0.001	< 0.001	0.003
U	0.053	0.053	0.047	0.03	0.099
V	40.4	33.7	14.8	7.8	19.7
W	< 0.02	0.03	0.65	< 0.02	0.05
Y	0.108	0.113	0.062	0.031	0.284
Yb	0.017	0.024	0.009	0.006	0.027
Zn	113	17.1	198	88.6	169
Zr	2.24	2.42	1.32	0.63	1.64

Date	18-Jul-07	23-Jul-07	23-Jul-07	29-Jun-07	29-Jun-07
Location	White Sand Lake	Whitefish Lake	Whitefish Lake	Winnipeg River	Winnipeg River
Sample Type	Meta	Hypo	Meta	Hypo	Meta
UTM	16U 471428 5409963	16T 685957 5318639	16T 685957 5318639	15U 295046 5558617	15U 295046 5558617
I	0.7	0.8	0.9	1.8	1.8
Ag	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Al	752	190	242	321	284
As	22.1	9.38	9.31	3.75	3.46
Au	0.003	< 0.002	< 0.002	< 0.002	< 0.002
Ba	> 400	261	> 400	388	> 400
Be	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Bi	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Br	190	75	75	30	30
Ca	5800	9500	7500	11300	10400
Cd	0.05	0.02	0.02	0.02	0.01
Ce	0.673	0.151	0.214	0.383	0.318
Co	0.303	0.023	0.08	0.056	0.058
Cr	94.9	40.7	43.9	15.8	14.4
Cs	0.005	0.001	0.002	0.006	0.005
Cu	2.5	1	1.7	1.7	1.5
Dy	0.066	0.013	0.014	0.025	0.019
Er	0.045	0.011	0.011	0.013	0.013
Eu	0.314	0.016	0.036	0.024	0.052
Fe	120	40	90	120	110
Ga	0.34	0.09	0.11	0.07	0.06
Gd	0.128	0.028	0.026	0.037	0.043
Ge	0.29	0.09	0.09	0.05	0.04
Hf	0.05	0.026	0.045	0.046	0.052
Hg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Ho	0.014	0.003	0.004	0.004	0.004
In	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
K	2520	110	290	210	240
La	0.518	0.143	0.162	0.234	0.191
Li	8	2	2	2	1
Lu	0.03	0.003	0.003	0.003	0.003
Mg	891	1850	1600	3210	3060
Mn	88.7	3.1	2.7	4.5	3.2
Mo	0.6	0.3	0.4	0.6	0.4
Na	28100	4480	10100	6750	10400
Nb	0.005	< 0.005	0.006	0.008	0.009
Nd	0.476	0.123	0.124	0.187	0.146
Ni	2.2	0.4	1.3	0.9	0.8
Os	0.005	< 0.002	< 0.002	< 0.002	< 0.002
Pb	1.62	0.09	0.6	0.22	0.26
Pd	0.06	0.02	0.02	0.01	0.02

Date	18-Jul-07	23-Jul-07	23-Jul-07	29-Jun-07	29-Jun-07
Location	White Sand Lake	Whitefish Lake	Whitefish Lake	Winnipeg River	Winnipeg River
Sample Type	Meta	Hypo	Meta	Hypo	Meta
UTM	16U 471428 5409963	16T 685957 5318639	16T 685957 5318639	15U 295046 5558617	15U 295046 5558617
Pr	0.125	0.034	0.037	0.052	0.04
Pt	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Rb	0.811	0.061	0.131	0.182	0.172
Re	0.001	0.001	0.002	< 0.001	< 0.001
Ru	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sb	0.12	0.05	0.07	0.05	0.07
Sc	< 1	< 1	< 1	< 1	< 1
Se	78.5	31.9	32.4	9.5	9.6
Si	3000	2100	2100	1000	500
Sm	0.119	0.03	0.029	0.037	0.037
Sn	0.3	0.8	0.6	< 0.1	< 0.1
Sr	33.1	20.8	25	22.1	22.3
Ta	0.015	0.001	0.002	0.001	0.002
Tb	0.014	0.003	0.003	0.005	0.004
Te	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Th	0.021	0.009	0.011	0.02	0.017
Ti	5.6	3	3.6	2.7	2.4
Tl	0.016	< 0.001	< 0.001	< 0.001	< 0.001
Tm	0.009	0.002	0.002	0.002	0.002
U	0.116	0.067	0.074	0.102	0.097
V	25	11.5	11.9	4.7	4
W	0.02	0.03	0.03	0.02	0.03
Y	0.57	0.107	0.115	0.153	0.144
Yb	0.108	0.012	0.014	0.015	0.014
Zn	> 250	42.2	30.8	83.9	22.3
Zr	1.63	1.35	2.11	1.98	2.53