Canada

Regional Geochemical Maps for Risk Assessors

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Abstract

Systematic regional geochemical mapping by the Government of Canada commenced in 1975 with the initial motivation being uranium mineral exploration. Stream and centre-bottom lake sediment surveys were undertaken at an approximate density of 1 site per 13 km^2 in areas considered to have increased uranium potential. After 1978 the program was broadened to include all metallic mineral resources and named the National Geochemical Reconnaissance (NGR). To date, almost 200,000 lake and stream sediment samples have been collected following consistent field and analytical protocols, representing some 2.6 million km^2 of Canada's 9.7 million km^2 landmass.

Since the early 1990s the Geological Survey of Canada has been called upon for geochemical data to support environmental studies. To meet the growing need and use of NGR data by risk assessors and to increase public awareness of the characteristics of Canada's surface environment, a series of maps, with tables and text, are being prepared for release through Canada's National Atlas website. In addition to traditional contoured geochemical maps the data are being presented as maps in the ecological and drainage basin spatial frameworks used by the risk assessors. Summary statistical tables for NGR data on the basis of the different spatial frameworks will be available so that users can import the geochemical information into their own GIS facilities to meet their own graphical needs. Text accompanying the maps will be aimed at the high school and general university level, with the objective of informing Canadians about their surface environment so that they can participate meaningfully in national debate concerning environmental issues. Examples of the new map products and tables are represented.

Introduction

The Geological Survey of Canada's systematic freshwater sediment regional geochemical mapping program commenced in 1975. These surveys at a sampling density of one site per 13 km^2 (5 mi^2) do not set out to directly discover potential ore deposits, but to recognize the halo of mineral occurrences that usually occur in a mining camp surrounding the one, or several, ore deposit(s). As such, they set out to map metallogenic provinces and provide extensive data on natural background levels.

Stream sediments are collected in mountainous and hilly terrain with well directed stream networks, e.g., the western Cordillera and eastern Appalachians. In the Canadian Shield, where the relief is low for the most part and the drainage networks are generally poorly directed, centre-lake bottom sediments are collected. The <177 μm fraction of sediments are analysed by ICP-ES, originally AAS, following an aqua regia dissolution for a wide range of trace and major elements. Additional trace elements, e.g., Hg and Au, are determined by more suitable procedures, e.g., cold vapour AAS (CV-AAS) and INAA, respectively. Since 1975 a rigorous QA/QC monitoring scheme has been in place to ensure that the data would be comparable over indefinite time periods. The development and protocols of the NGR program have been described by Friske and Hornbrook (1991).

In the almost 30 years of systematic mapping some 200,000 freshwater sediment samples have been collected and archived in Ottawa, representing some 2.6 million km^2 of Canada's 9.7 million km^2 landmass. The archive has proven invaluable, the NGR has been able to respond to new questions concerning mineral resource potential of already mapped areas by re-analysing the archived samples.

References

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New Maps for the National Geochemical Reconnaissance

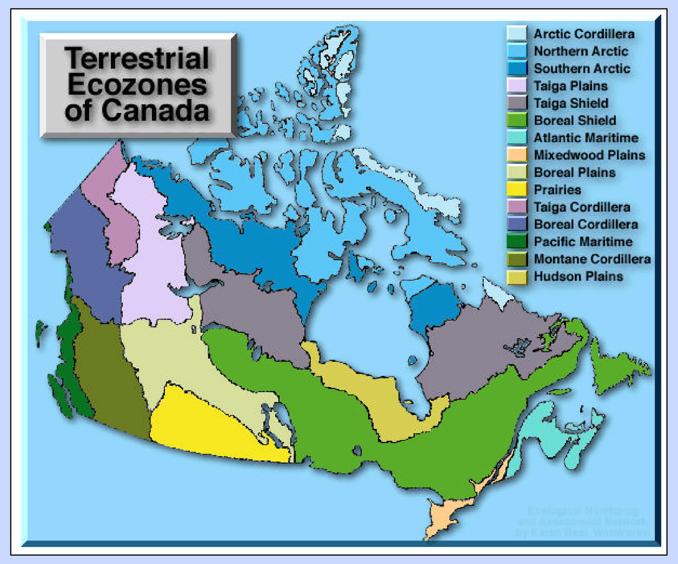
A major task today is compiling and presenting the accumulated NGR data into forms that facilitate their use beyond the original geoscience clients in government and industry. By the 1990s NGR data were being used by environmental agencies to provide information on the range of natural background levels in freshwater sediments. The practise of environmental risk assessment under the Canadian Environmental Protection Act (CEPA, 1988 and 1999) requires that background levels of natural occurring substances be taken into account. It is becoming current practice to regionalize these assessments, and the framework chosen by the Federal and Provincial Departments of Environment is the ecological classification of Canada (Marshall et al., 1996; see Ecoclassification map) and:

http://www.ec.gc.ca/soer-ree/English/Framework/default.cfm

for greater detail with web maps and GIS framework files see:

http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html

Canada is divided into 15 Ecozones, which in turn consist of 194 Ecoregions. Within the 217 contiguous Ecoregion polygons are spatially nested 1021 Ecodistricts. This classification is widely accepted by physical scientists, e.g., geologists, pedologists, biologists, climatologists, etc., as they can see in it reflections of their own science.



Traditionally regional overviews of the NGR data have been presented as contoured maps. The ecological framework presents a new way to map regional geochemistry, where the Ecodistrict polygons are coloured in proportion to the median of the data falling within them. In addition to the ecological framework, Environment Canada has a drainage basin spatial framework that divides continental scale river basins into sub-basins and sub-sub-basins. This provides a further spatial framework for presentation of the NGR data for those involved in environmental and risk assessment and management functions. Each NGR sample site has been allocated to an Ecoregion, Ecodistrict, river drainage sub-basin and sub-sub-basin by a point-in-polygon GIS process. Summary statistics for the data falling within each polygon are generated (Insightful, 2001, 2002) as files for direct importation into a spreadsheet, e.g., Microsoft's Excel™ (see Table below).

The National Atlas of Canada maintains a website that provides spatially related information to Canadians, ranging from elementary school through to college and university students, the general public, and technical and policy decision makers.

http://www.atlas.gc.ca/site

The NGR team is working with the National Atlas in a pilot project for four metals of common interest to Canadians due to recent Canadian Environmental Protection Act ecosystem and human health risk assessments for: Ni, Cu, Zn and Hg. It is geochemists' responsibility to inform Canadians on the geochemistry of their surface environment as reflected by freshwater sediment data; and to demonstrate that Canada is not geochemically homogeneous and that the prime controlling factor is geology. Thus the public will be better informed when they engage in debate and decision making concerning environmental issues related to naturally occurring substances, e.g., metals such as Hg, Cd and Pb, and metalloids such as As, with species that can be detrimental to ecosystem or human health. The maps and summary statistics tables will be available for download by agencies and individuals for integration into their own GIS activities.

To demonstrate the new maps and compare them with the traditional contouring approach, maps of Ni in freshwater sediments are presented. To ensure the visualization is uninfluenced by polygons containing a few, maybe high or low level sample sites, only polygons for which the medians are based on >30 sites are plotted. The Canada-wide medians of elements in stream and centre-bottom lake sediments are different. Therefore the polygon medians were expressed as ratios to the appropriate Canada-wide median (see Darnley et al., 1995) prior to their compilation into a single map. The maps give an instant indication of how a particular polygon varies from the Canada-wide median in a form that is easy for non-geoscientists to appreciate.

Example of Ecoregion Summary Statistics Table

Elem	EcoReg	N	NA	Min	2 %ile	5 %ile	10 %ile	25 %ile	Median	75 %ile	90 %ile	95 %ile	98 %ile	Max	LCI	UCI	MAD	IQ SD	Mean	SD	CV %
Ni	5	13	0	14	18.08	24.2	31.4	35	39	51	58.4	64.6	69.64	73	33	56	11.86	5.786	43	14.85	34.55
Ni	7	530	0	9	14	18	21	33	51	77	130	160	200	360	47	54	32.62	22.84	63.46	46.55	73.66
Ni	23	1281	0	3	7	10	14	24	40	64	96	120	160.8	415	38	43	28.17	19.79	50.35	41.71	82.83
Ni	24	984	0	2	7	11	16	25	39	59	79	95.85	118	325	38	42	23.72	17.51	45.37	30.17	66.49
Ni	25	68	0	-2	-2	-2	3.4	17.5	27.5	35	52.3	57.3	61.3	73	23	31	12.6	18.35	27.03	16.5	61.04
Ni	30	1621	21	3	15	21	27	39	54	74	100	136	225	850	54	56	25.2	20.56	65.59	55.18	84.13
Ni	35	13	0	3	4.2	6	8.2	9	13	15	16	20	23.6	26	9	16	4.448	3.654	12.62	5.516	43.72

First seven Ecoregion summary statistics records of the 60 records for Ni in lake sediments

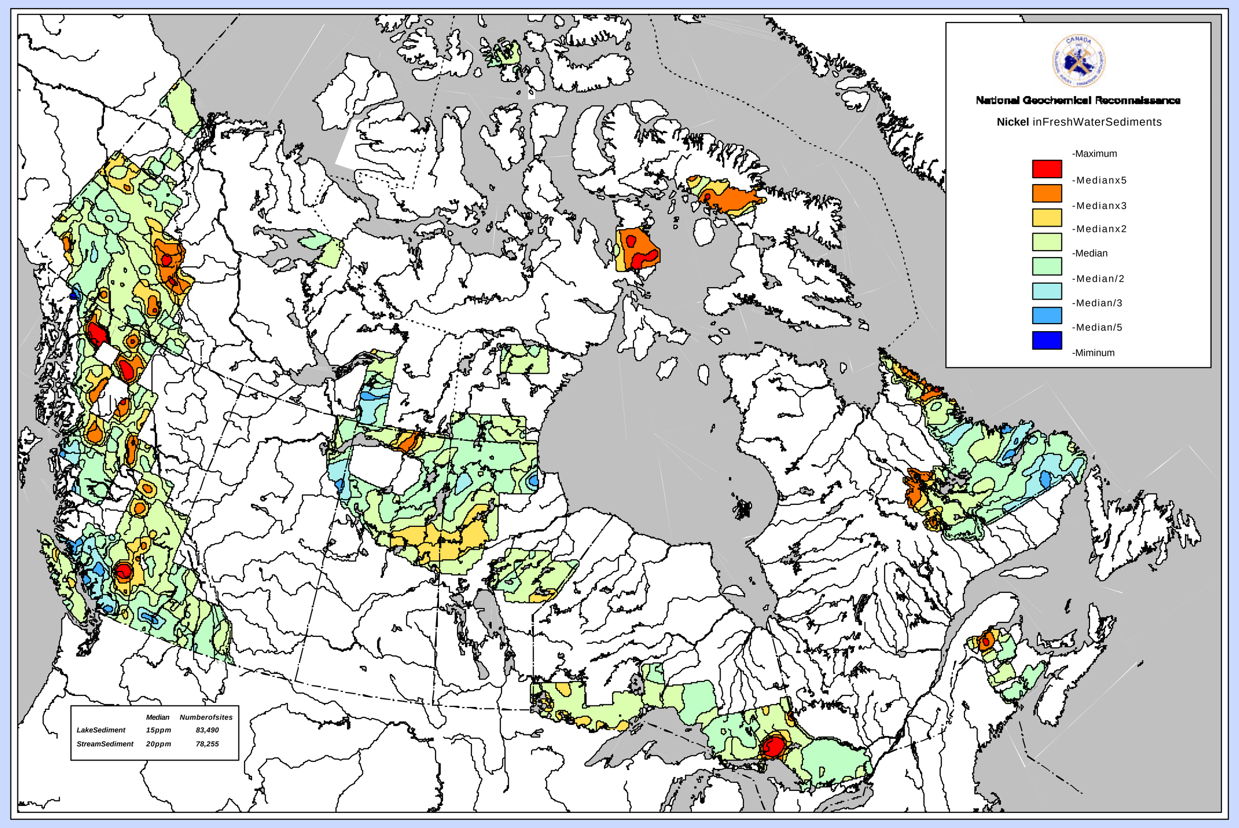
Notes: Group = unique Ecoregion polygon identifier; N = number of sample sites with data; NA = number of missing data; Min to Max = minimum and maximum values and intermediate percentiles and median; LCI & UCI = lower and upper 95% confidence bounds on the median respectively; MAD = median absolute deviation, a robust estimate of standard deviation, IQ SD = interquartile range based robust estimate of standard deviation; Mean = arithmetic mean; SD = standard deviation; CV% = coefficient of variation.

Summary and the Future

New styles of regional geochemical maps and summary statistics tables that meet the requirements of environmental risk assessors and managers have been prepared: Ni, Cu, Zn and Hg. These will become available for public access on the National Atlas of Canada website in Summer 2005.

Subsequently, other elements, e.g., As and Pb, will be added. In order to demonstrate the fundamental link between geology and geochemistry a simple lithological map of Canada is being developed. This task is non-trivial as the map, covering 9.6 million km^2, must accommodate a range of sedimentary, igneous and metamorphic rocks spanning from the Archean to the present, and distil the lithology down to between 10 and 15 units. This spatial framework will be particularly useful in demonstrating to students and the public that the primary control on surficial geochemistry is the underlying geology.

Contour Map

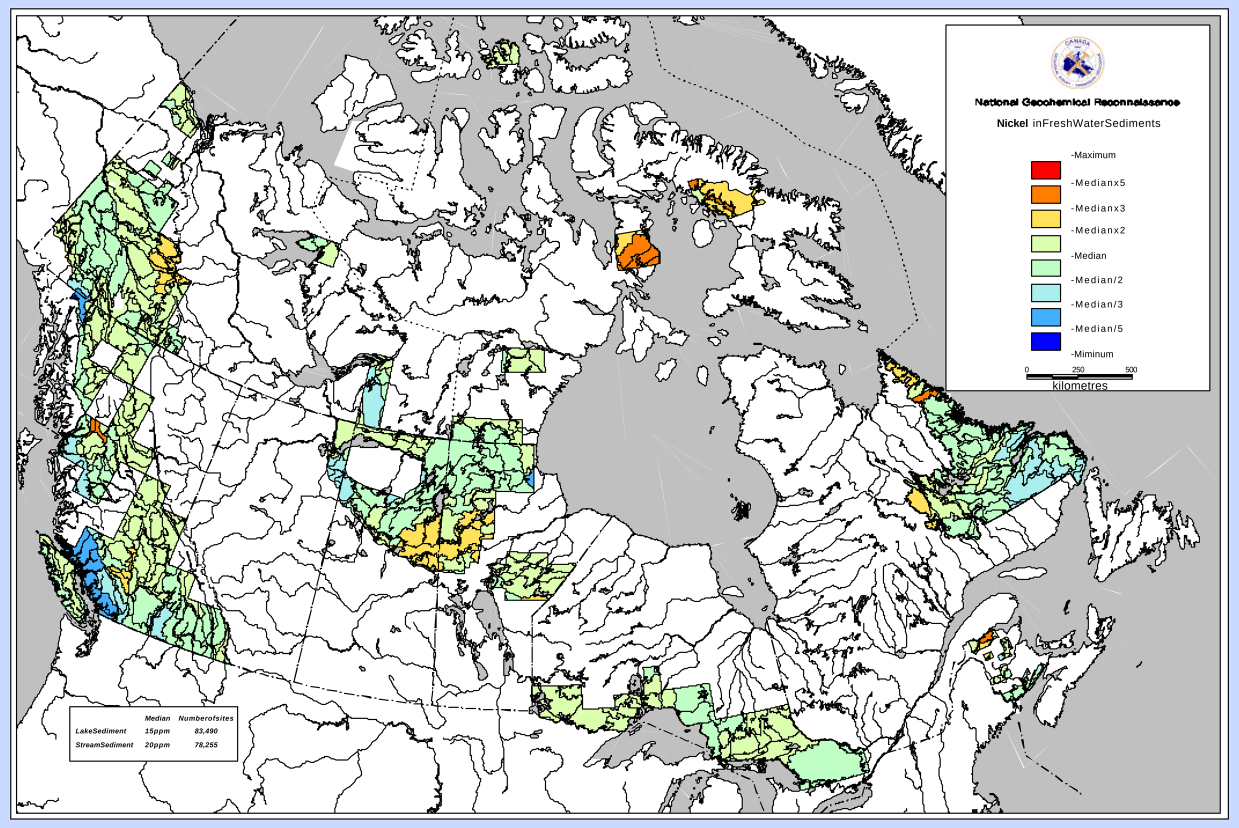


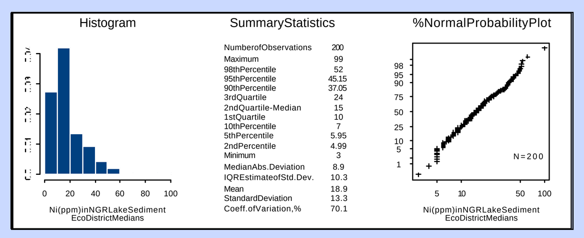
The map was prepared using an inverse distance squared function with a search radius of 50 km to interpolate data to a 2x2 km grid, which is displayed for all points within 13 km of a sample site. The colour scheme ranges from green around median levels, with yellow and increasing redness towards higher levels and increasing blueness towards lower levels. The ratio intervals reflect that the range of geochemical background often spans about half an order of magnitude, i.e. from half to twice average background. Beyond these limits there is often evidence for different geochemical processes.

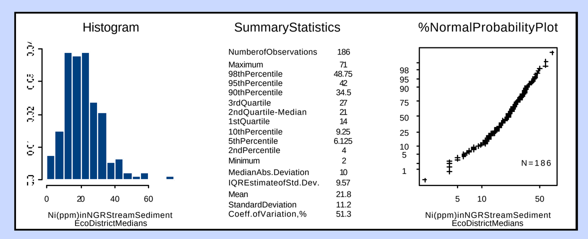
Low Ni levels, deeper blues, relate to geological features. In southern Labrador the areas underlain by anorthosites and the trans-Labrador batholith to the north are clearly identified. In northern Manitoba an area influenced by Wisconsin ice retreat marine clays around Hudson Bay is apparent, other low areas in the western Shield relate to felsic batholiths and gneisses. In the western Cordillera the Coast Range batholith and other belts of felsic intrusives and metasediments are clearly identified. In contrast the high Ni levels, oranges and reds, may be related to both natural and anthropogenic sources. The most important and obvious anthropogenic source is the Sudbury mining and smelting complex in Ontario, but even here the anthropogenic input is superimposed on naturally higher Ni levels due to the presence of the ultramafic rocks hosting the Ni-Cu deposits. All other high Ni levels are of natural origin. Sources range from sedimentary sequences in northern New Brunswick, the Labrador Trough, the Piling Group in Nunavut and the Selwyn Basin in the Yukon, to mafic and ultramafic rocks in greenstone belts in the Precambrian Shield, especially in Labrador, Manitoba and Saskatchewan, and to intrusive belts in the western Cordillera.

The natural background medians for freshwater sediments in the Ecodistricts vary in excess of 25-fold on the map, and in excess of 30-fold in the actual data. This is an essential feature to be recognized in ecological risk assessments where biotic communities may be specialized for, and acclimated to, the local geochemical reality.

Ecodistricts Map





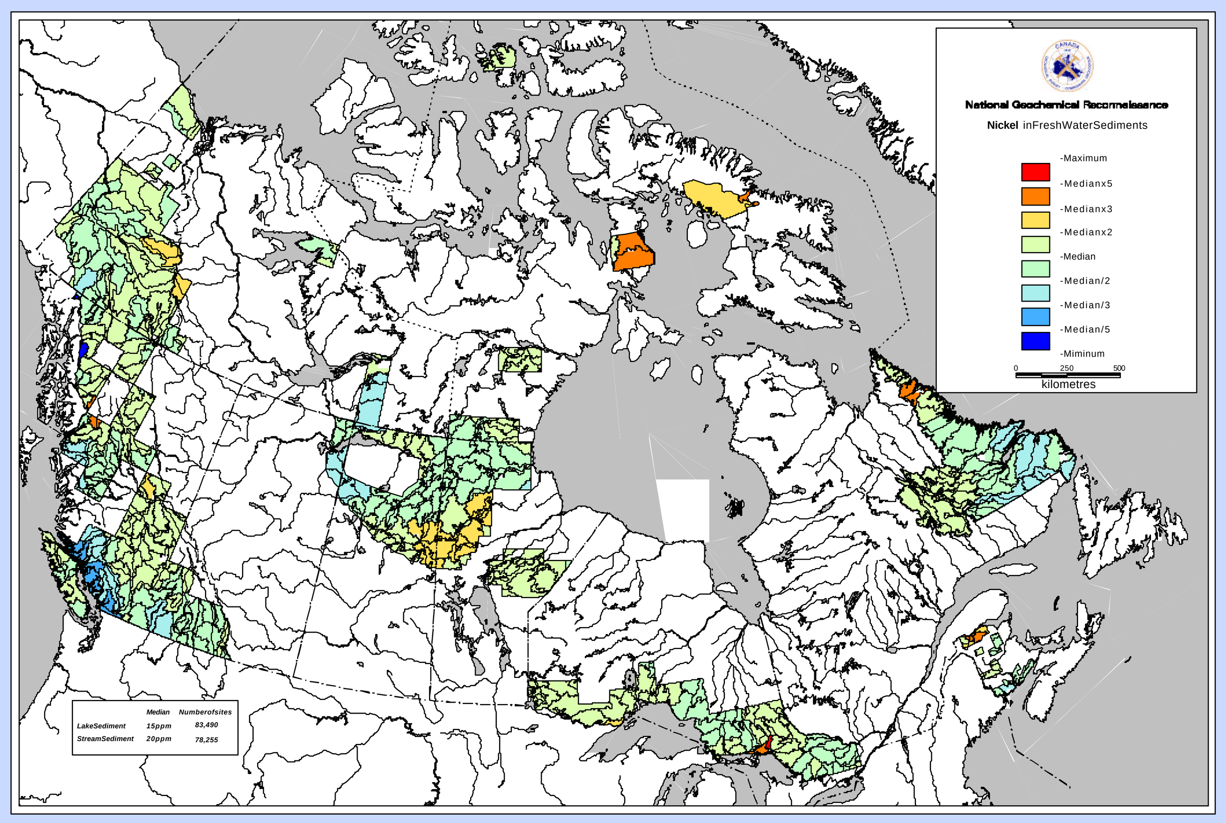


The same colour scheme is used as for the contoured map. It is immediately noticeable that the range of colours is reduced, there are no Ecodistrict polygons with levels greater than 5-fold the appropriate Canada-wide media median. The use of Ecodistrict medians results in major smoothing of the data as they are unaffected by any very high or low values. The benefit is that medians are stable estimators of Ecodistrict average backgrounds, which makes them good indicators of shifts in regional background.

Most of the Ecodistricts in Ontario fall into either the high or low background range. Low background Ecodistricts correspond to the Grenville tectonic province in the southeast and an area of the Superior province northeast of Lake Superior dominated by felsic intrusives and gneisses. In contrast, the high background Ecodistricts in northwestern Ontario contain greenstone belts, Proterozoic metal-rich sediments, and Nipigon basic lavas. The Sudbury complex lies in the higher background Southern tectonic province north of Lake Huron. These lithological and tectonic differences reflected in subtle geochemical features indicate the robustness of regional geochemical mapping. In Labrador, low levels are associated with the extensive areas of anorthosites in the south and the trans-Labrador batholith to the north. Further north, elevated levels reflect the presence of mafic and ultramafic rocks; slightly elevated levels of Ni in western Labrador reflect the presence of Archean rocks remarkably accurately. Higher Ni levels are associated with sediments in the Selwyn basin, Yukon, the Piling Group in Nunavut, and in northern New Brunswick. Similarly, elevated Ni levels reflect the Glennie and Kisseynew-Flin Flon tectonic domains in Saskatchewan and Manitoba containing greenstone belts and associated metallic mineral occurrences and mines. In the western Cordillera the Ni-poor Coast Range granitoid batholith is clearly visible, as are local areas of higher-Ni mafic and ultramafic rocks.

The Ecodistrict map clearly reflects the geochemistry of major underlying geological features. This demonstrates why unique and acclimated biotic assemblages can be established in different Ecoregions and Ecodistricts. For ecological risk assessments to be relevant to the natural environment these features need to be recognized in environmental risk assessments and ecotoxicity tests designed appropriately.

Drainage Basins Map



The same colour scheme is used as for the contoured map. This presentation is an extension to the national scale of the first order geochemical drainage basin mapping procedure presented by Bonham-Carter et al. (1987).

In contrast to the Ecodistrict based map the full range of the data display is used. This is due to the influence of anthropogenic contamination from the Sudbury mining and smelting complex in Ontario on drainages flowing into Lake Huron. The five-fold increase in median Ni contents is due to atmospheric deposition into the small headwater lakes that are the focus of the lake sediment sampling program. In other respects the map is quite similar to the Ecodistrict map. However, with a sharper spatial focus in some regions, and a poorer one in others, in part due to the way the drainage basins are aggregated, with greater detail in the more populated areas of Canada.

Again this mode of data presentation indicates the importance of accounting for natural background variations in ecological risk assessments and the ecotoxicological studies that support them. The supporting NGR summary data tables will provide risk assessors and managers with drainage basin specific knowledge of the background ranges for freshwater sediment geochemistry.