Ein Vergleich der Sedimentverschmutzung im Erie- und Ontariosee

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Summary

Lake Erie and Lake Ontario have experienced considerable pollution of both water and sediment over the last century. There have been recent improvements in terms of total concentrations of major contaminants; however there are large areas within both lakes that still exceed Canadian federal guidelines for sediment contamination. The position of the lakes at the lower end of the Great Lakes system results in contamination from upstream sources in addition to those that enter through each lake's drainage basin. Mercury, Lead, Polychlorinated Biphenyls (PCBs), and Hexachlorobenzene are contaminants that have major environmental implications. A GIS-based kriging technique is used to predict their lakewide spatial distribution. The results show that Lake Erie has generally lower levels of sediment contamination and that considerable areas of the lake are now under the Threshold Effect Level (TEL), which relates to the impact that contaminants can have on lake ecosystems. Higher contamination levels in Lake Ontario can be partly attributed to its greater average depth and longer water retention time.

1 Introduction

The Great Lakes contain approximately 18% of the world's supply of fresh water. The Canadian and American Governments, in response to changing needs and the recognition that cooperation between the two countries was necessary, signed the amended Great Lakes Water Quality Agreement in 1987, with a purpose to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem" (LELMP, 2000). Among the recommendations in the agreement was the creation of a Lakewide Management Plan for each lake, adopting an ecosystem approach to address environmental issues (LELMP, 2000). Industrial development and urbanization in the Great Lakes Basin have brought a host of problems. Many industries located on major waterways to ease the transportation of their goods. Untreated effluent from steel mills and the production of pulp and paper has been directly discharged into waterways. Urban areas have also released untreated municipal wastes into the lakes (EPA, 1995). Along with industrialization came the development of new chemicals that could be used for agricultural purposes to control pests and as fertilizers. The runoff of these substances as well as many other toxic pollutants such as trace metals has had many negative effects on the ecosystem.

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While the use of some chemicals has been phased out, they can still be found in the environment due to their persistence and natural processes such as the re-suspension of sediment. Their presence, even in minute concentrations, has the ability to have negative consequences on the environment, as well as to bioaccumulate through the food chain (JAKUBEK and FORSYTHE, 2003). The Canadian federal government specifies Threshold Effect Level (TEL) and Probable Effect Level (PEL) guidelines for sediment contamination. These are outlined in Table 1.

Tab. 1: Selected Contaminants and Federal Guidelines (Source: after CCME, 1999)

Contaminant	TEL	PEL
Mercury	0.17 ug/g	0.486 ug/g
Lead	35 ug/g	91.3 ug/g
Polychlorinated Biphenyls (PCBs)	34.1 ng/g	277 ng/g
Hexachlorobenzene (HCB)	20 ng/g	480 ng/g

1.1 Kriging

Kriging methods utilize statistical models that incorporate autocorrelation among a group of measured points to create prediction surfaces (JOHNSTON et al., 2001). ISAAKS and SRIVASTAVA (1989) state that if the pattern of spatial continuity of the data can be described visually using a variogram model, it is difficult to improve on the estimates that can be derived in the kriging process. Given the statistical properties of this method, measures of certainty or accuracy of the predictions can be produced using a cross-validation process (JAKUBEK and FORSYTHE, 2003). Ordinary kriging is the most flexible kriging model because it functions under the assumption that the mean **u** is an unknown constant, and thus, the random errors at the data locations are unknown (JOHNSTON et al., 2001).

2 Study Area and Data

Lake Erie drains parts of the American States of Michigan, Ohio, Pennsylvania, New York, and Indiana, and the Canadian Province of Ontario. By volume, it is the smallest of the Great Lakes, at 484 km^3, which can be attributed to a shallow average depth of 19 m, and a small surface area of approximately 25700 km^2. Lake Erie has a water retention time of 2.6 years, shortest of all the Great Lakes (EPA, 1995). The main source of inflow to Lake Erie is from Lake Huron and Lake St. Clair via the Detroit River. The main outflow is to Lake Ontario via the Niagara River and the Welland Canal. Lake Ontario has an area of approximately of 19010 km^2 which is the smallest of the Great Lakes (LOLMP, 1998). It has a water retention time of 6 years and its drainage basin covers portions of the Canadian Province of Ontario and the American State of New York. It is fed primarily by the waters of Lake Erie through the Niagara River. Approximately 93 percent of the water in Lake Ontario is drained to the northeast by the St. Lawrence River (LOLMP, 1998).

Field research was conducted in 1997-98 under the Environment Canada Great Lakes Sediment Assessment Program that provided sediment contamination data for 62 sites in Lake Erie (Fig. 1) and 70 sites in Lake Ontario (Fig. 2). Some specific sites were sampled in order to assess certain Lake Ontario Areas of Concern (AOCs) including Hamilton Harbour and the mouth of the Niagara River (JAKUBEK and FORSYTHE, 2003). The sediment samples were collected using a mini-box core sampling procedure. The top 3 cm of the sediment were sub-sampled from the core for analyses that included contaminants and metals (MARVIN et al., 2002 as found in JAKUBEK and FORSYTHE, 2003).

3 Analysis and Results

The use of kriging on large-lake datasets allows for additional analysis and interpretation opportunities that are not available with more traditional interpolation methods (i.e. Inverse Distance Weighting - IDW) and map representations (i.e. proportional circles). The cross validation procedure provides measures of accuracy for the predictions made using the ordinary kriging method. The measures produced include the Mean Prediction Error (MPE), Average Standard Error (ASE), and Standardized Root-Mean-Squared Prediction Error (SRMSPE). Values calculated for these measures are documented for Lake Erie in Table 2 and Lake Ontario in Table 3. Statistically valid results should have ASE values that are <20 (otherwise predictions are straying quite far from the measured locations), with SRMSPE values approaching 1.

Tab. 2: Kriging Cross Validation Results for Lake Erie

Contaminant	MPE	ASE	SRMSPE
Mercury	0.0006	0.144	1.102
Lead	0.4266	18.26	1.165
Polychlorinated biphenyls (PCBs)	0.1522	42.30	1.056
Hexachlorobenzene (HCB)	0.0122	2.115	0.917

Tab. 3: Kriging Cross Validation Results for Lake Ontario

Contaminant	MPE	ASE	SRMSPE
Mercury	0.0107	0.36	0.9474
Lead	1.3490	39.77	0.9331
Polychlorinated biphenyls (PCBs)	2.5720	72.86	0.9336
Hexachlorobenzene (HCB)	0.4687	14.64	0.9748

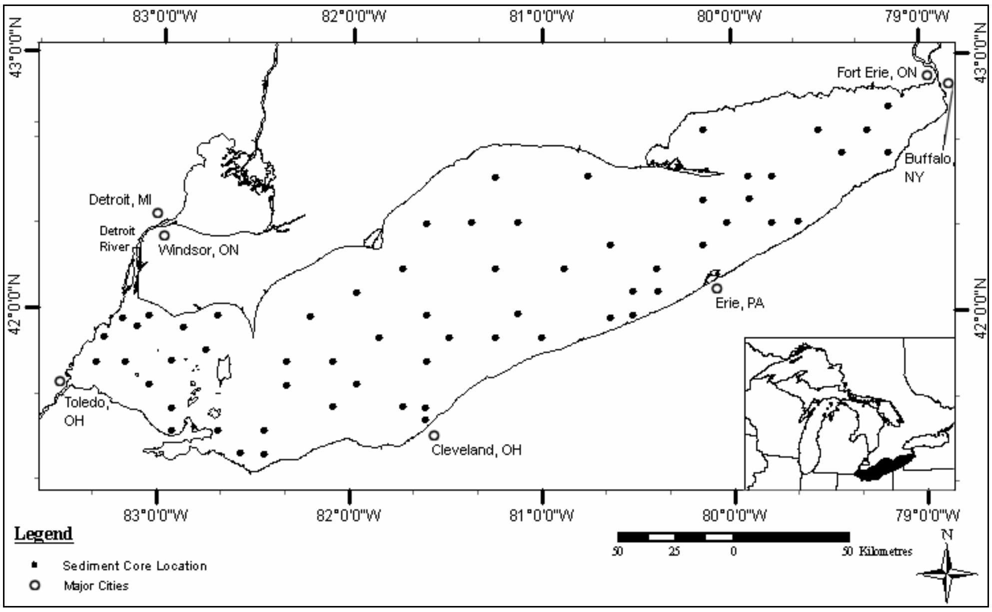

Fig. 1: Sediment Core Locations and Major Cities for Lake Erie

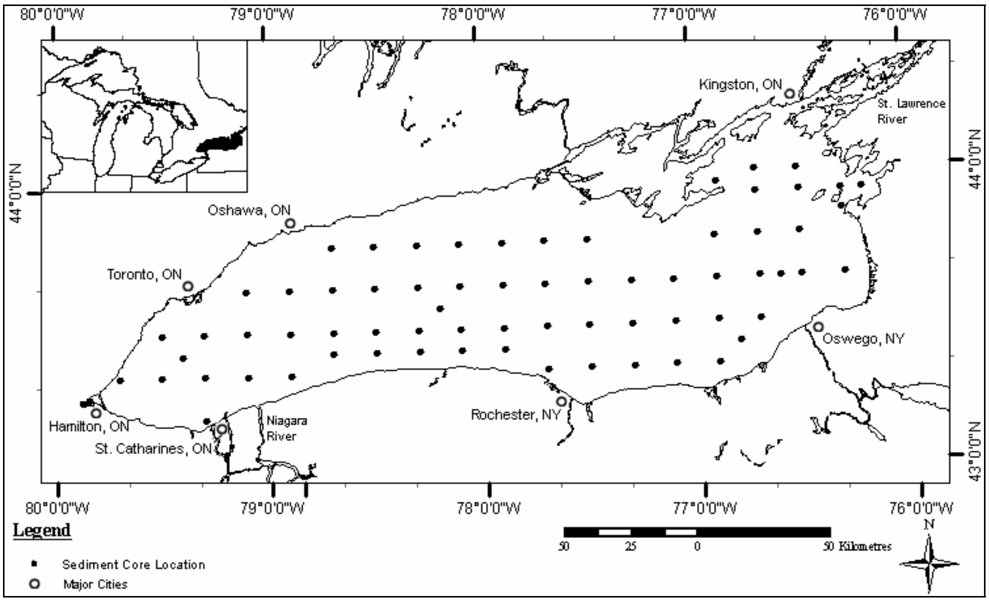

Fig. 2: Sediment Core Locations and Major Cities for Lake Ontario

3.1 Mercury and Lead

Mercury is classified as a critical pollutant by the Lake Erie and Lake Ontario Lakewide Management Plans. Mercury is a naturally occurring metal, however, its concentrations are now well in excess of those expected from natural sources. PIRRONE et al. (1998) estimate that increasing mercury emissions from waste incineration now account for up to 40% of current anthropogenic emissions to the atmosphere in North America, followed closely by the burning of fossil fuels. The kriging results for Lake Erie (Fig. 3) are very good with ASE and SRMSPE values that are very close to the optimum. Areas of high contamination still exist and these are mostly found directly downstream from the Detroit-Windsor area.

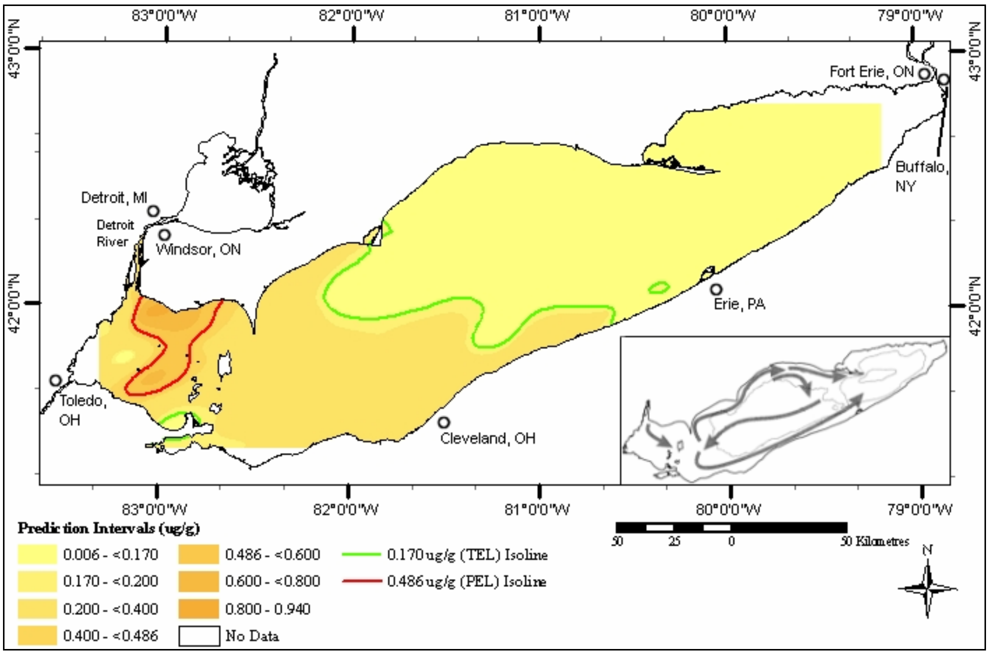

Fig. 3: Mercury Kriging Results for Lake Erie (Inset: Annual Circulation in Lake Erie - Isobaths at 20 m and 50 m - Source: modified after BELETSKY et al., 1999)

Fig. 4 estimates the locations for the highest mercury concentrations in the central deep lake regions of Lake Ontario. The predicted surface produced very reliable cross validation results, which were relatively unbiased and rendered a low ASE value.

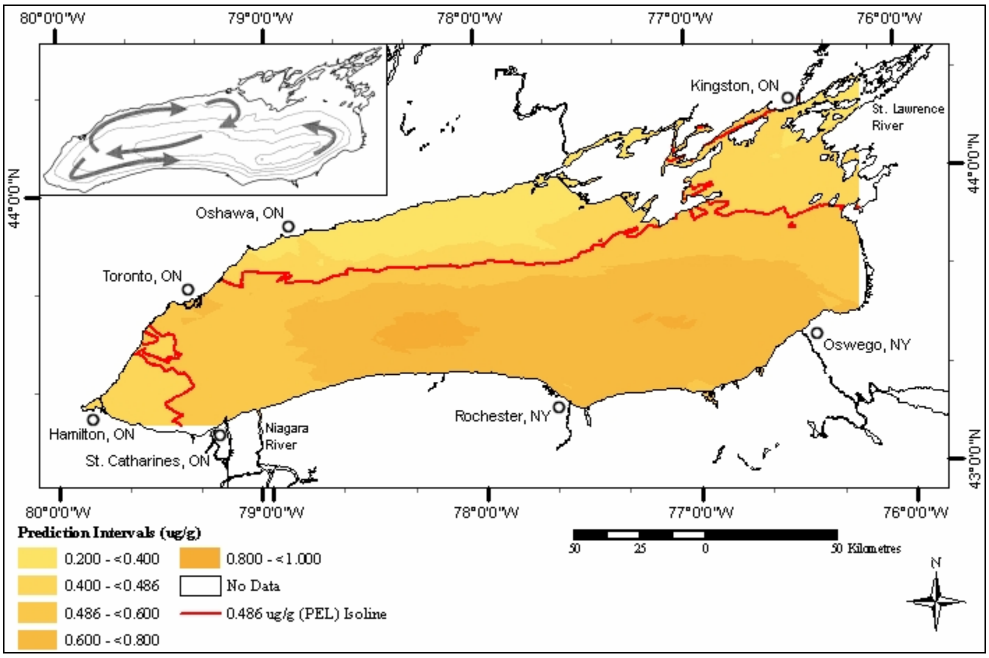

Fig. 4: Mercury Kriging Results for Lake Ontario (Inset: Annual Circulation in Lake Ontario - Isobaths every 50 m - Source: modified after BELETSKY et al., 1999)

Due to the proximity of Lake Erie and Lake Ontario to industrial and agricultural areas, it is likely that point sources and runoff are significant sources of lead. Calculations from 1993 on lead emissions to the atmosphere in the Great Lakes indicate that the main source is non-ferrous metal production (34%), followed by steel manufacturing and waste disposal (27 and 25%, respectively), and coal combustion (10%) - (PIRRONE and KEELER, 1996). The lead prediction surface for Lake Erie (Fig. 5) had acceptable cross validation results. Areas of higher concentrations were found in the south-central part of the lake near Cleveland, Ohio. The prediction surface representing lead for Lake Ontario (Fig. 6) estimated the variability well with a SRMSPE value of 0.9331; however, it features an ASE value of 39.77. Therefore the results should be interpreted with some caution. A possible reason for these results is the location of two sediment sampling sites in Hamilton Harbour which may skew the results in the western part of the lake.

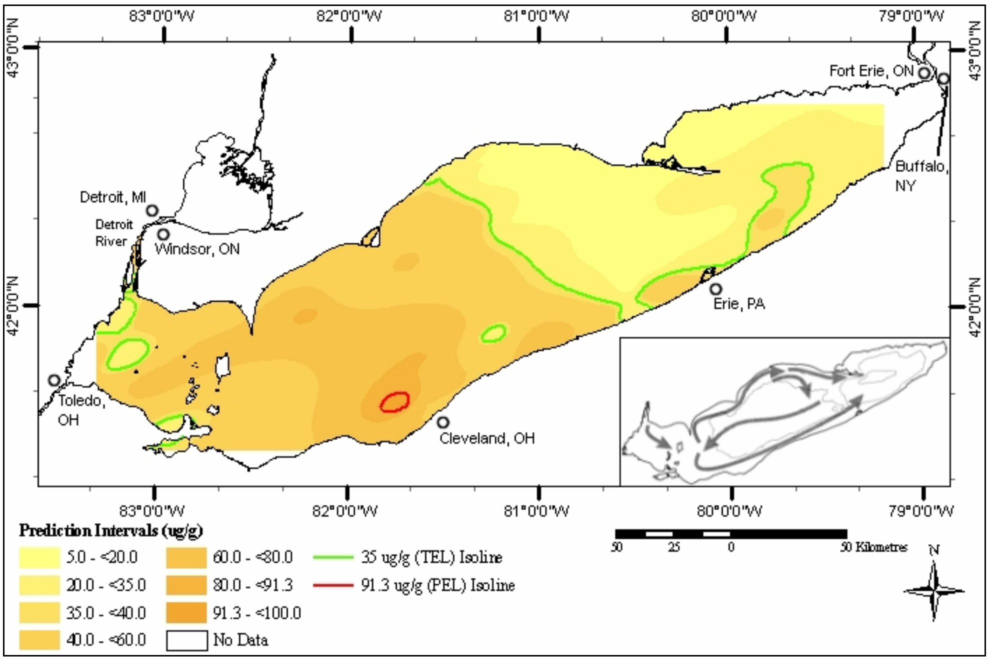

Fig. 5: Lead Kriging Results for Lake Erie (Inset: as per Fig. 3)

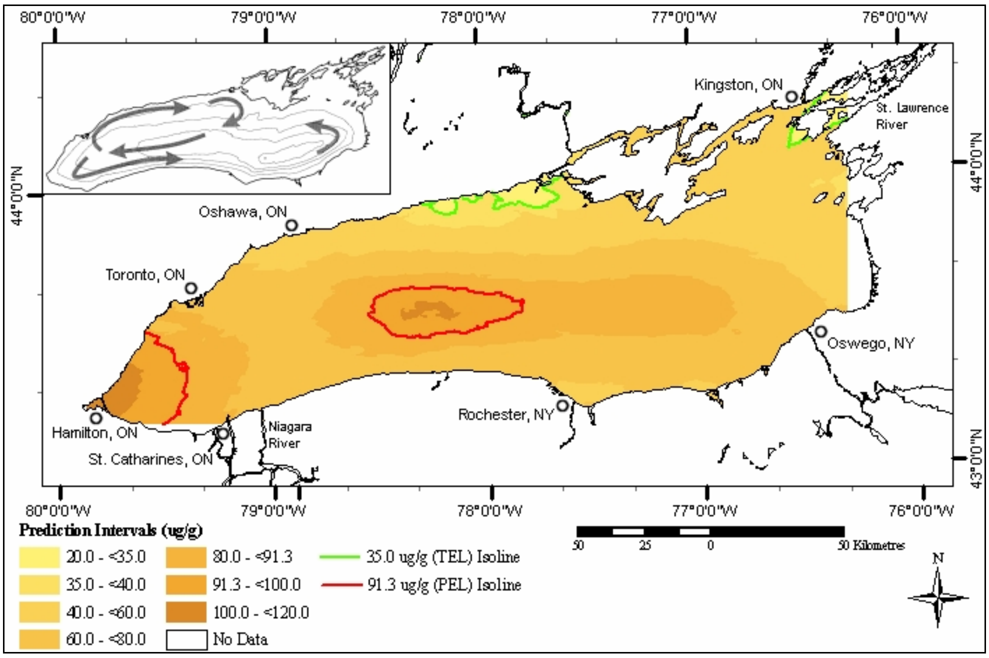

Fig. 6: Lead Kriging Results for Lake Ontario (Inset: as per Fig. 4)

3.2 Polychlorinated Biphenyls (PCBs) and Hexachlorobenzene (HCB)

The manufacturing of PCBs was banned in Canada and the U.S. in 1977 after scientific evidence revealed that they were the cause of environmental and human health problems (EPA, 1995). NETTESHEIM (2003) states that PCBs exhibit a "strong urban effect," with atmospheric PCB concentrations higher in urban areas. The highest concentrations of PCBs in the air over the Great Lakes were found by McCONNELL et al. (1998) at the eastern and western extremes of Lake Erie, near Detroit and Buffalo, respectively. This indicates that local point source emissions to the air from industrial and urban areas are a significant source of PCBs through atmospheric deposition. The results for Lake Erie (Fig. 7) have a higher than desired ASE result (42.30), however the SRMSPE result of 1.056 is very close to normal. PCBs were estimated to have high concentrations in the deep lake regions of Lake Ontario (Fig. 8). When the actual measured values are compared to the isobaths throughout the lake, the predictions seem reasonable, but high ASE results are the reason to suspect inconsistent outcomes from the kriging analysis. A possible explanation for these cross-validation results is a biased prediction supported by a MPE value of 2.572.

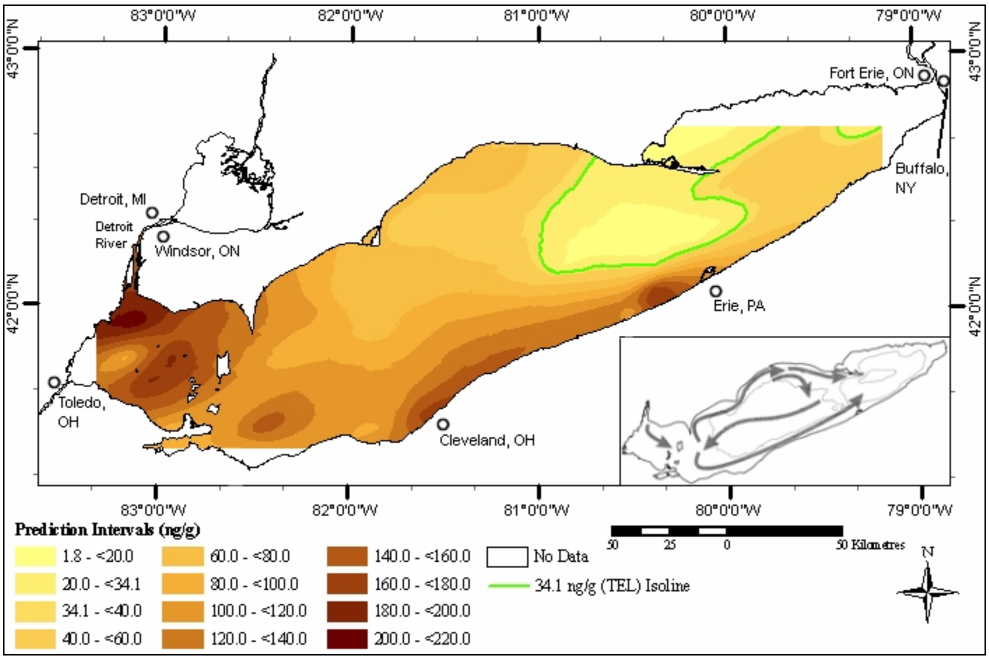

Fig. 7: PCB Kriging Results for Lake Erie (Inset: as per Fig. 3)

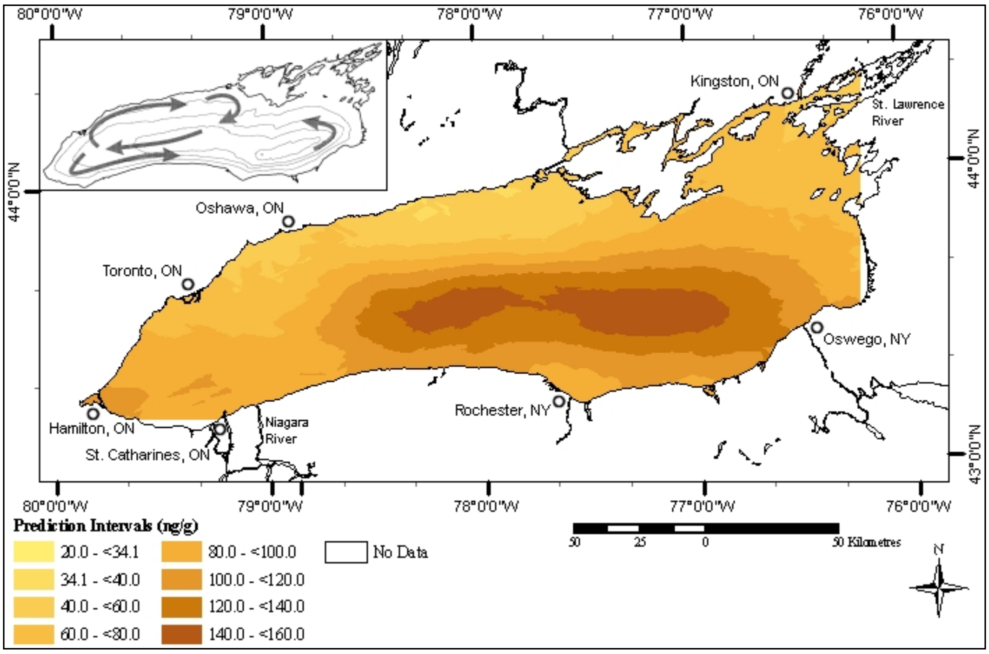

Fig. 8: PCB Kriging Results for Lake Ontario (Inset: as per Fig. 4)

Hexachlorobenzene (HCB) occurs as a byproduct of several chlorination processes, in particular chlor-alkali plants, during the manufacturing of solvents, and in the production of pesticides. It can also be produced in the combustion of chlorinated organic chemicals, chlorine manufacturing, metal manufacturing, and the incineration of municipal waste. HCB is resistant to degradation, and adsorbs strongly in soil and sediment (ATSDR, 2002). The cross validation results for Lake Erie were very good and the predicted surface (Fig. 9) indicates that concentrations of HCB are low throughout the lake. The predicted surface for Lake Ontario HCB (Fig. 10) contrasts sharply with that of Lake Erie. Higher concentrations are again found in the deep lake basins. The prediction surface near perfectly estimated the variability and featured a SRMSPE value of 0.9748.

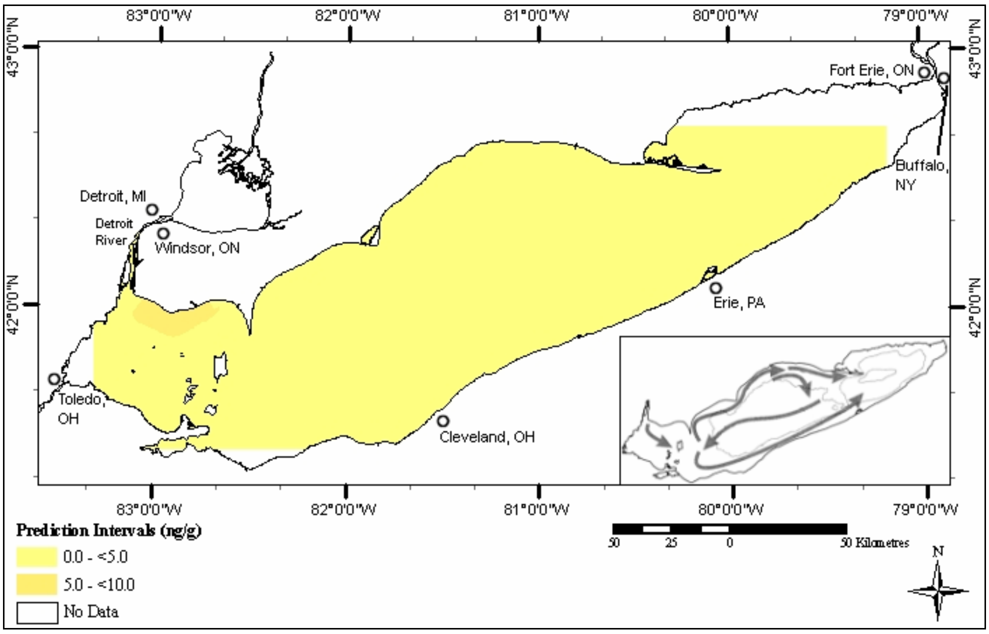

Fig. 9: HCB Kriging Results for Lake Erie (Inset: as per Fig. 3)

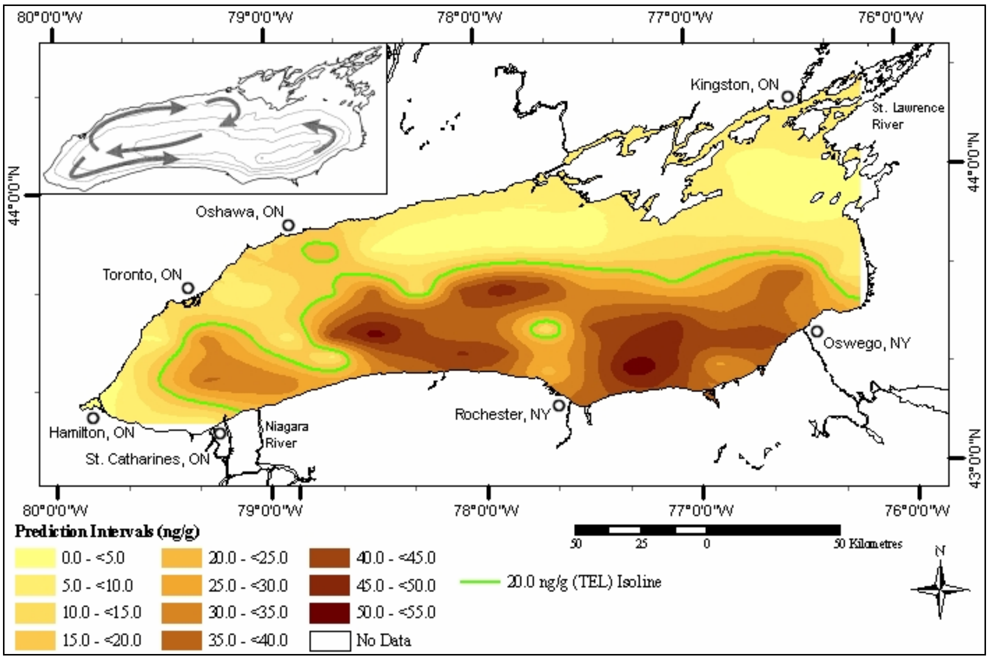

Fig. 10: HCB Kriging Results for Lake Ontario (Inset: as per Fig. 4)

4 Conclusion

The estimated patterns of sediment contamination that were developed in this research can be related to lake currents, lake bathymetry, and the location of urban areas. An examination of the distribution patterns reveals that major sources to the lakes (such as the Detroit River for Lake Erie and the Niagara River for Lake Ontario) have high contamination levels and pollution “plumes” in the prevailing current direction. The migration of contaminants into deep lake basins is occurring through natural distribution and redistribution processes. Contamination levels are also high near large urban industrial centres such as Detroit, Windsor, Cleveland, Hamilton, and Rochester. The overall level of contamination is lower in Lake Erie than Lake Ontario. This can in part be related to the shallow average depth of Lake Erie which results in the redistribution, resuspension (especially during storm events), and outflow of sediments. Continued remediation efforts as outlined in the Lakewide Management Plans should lead to improved sediment quality in the future.

5 References

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