Using Geovisualization to Assess Sediment Contamination in the “Sixth” Great Lake

K. Wayne FORSYTHE and James P. WATT

Abstract

Although Lake St. Clair is not officially recognized as being a Great Lake, it is an important part of the Great Lakes system. Many communities depend on the lake for drinking water and recreational uses. In addition, the lake is an important transport route for natural resources and manufactured products. The St. Clair River, which flows into the lake from the northeast, is a major source of deposited contaminants. Sediment sampling surveys were conducted in 1970/1974 and 2001 by Environment Canada as part of a continuing monitoring program. Traditional dot maps were compared with GIS-based kriging results to assess contaminant patterns. Mercury and lead were analyzed as they are pollutants that have major environmental implications. The results show that Lake St. Clair generally has lower levels of sediment contamination away from the main flow and circulation patterns leading to its Detroit River outlet. Lake wide spatial distributions are much more apparent using the kriging technique. Mercury contaminant levels are well above the Probable Effect Level or PEL (which relates to the impact that contaminants can have on lake ecosystems) in some parts of the lake while lead contamination is not as severe. Lower mercury and markedly decreased lead contamination levels were observed in the more recent data.

1 Introduction

The Laurentian Great Lakes (Fig. 1) contain one-fifth of the world's fresh surface water with only the polar ice caps and Lake Baikal in Siberia containing more (GLIN 2004). The system consists of five major lakes (Superior, Michigan, Huron, Erie, and Ontario) plus their connecting waterways. Among these is Lake St. Clair which is located between Lake Huron and Lake Erie. The lake is not officially known as the “sixth” Great Lake; however there is a case that it should be considered due to its important location. There has been some movement into officially recognizing Lake St. Clair as a Great Lake (DETROIT NEWS 2002) but the comparatively small size of the lake has been a stumbling point. Lake St. Clair is currently considered to be part of the Lake Erie Basin (GREAT LAKES COMMISSION 2003). There is a precedent for a sixth lake as the term has been applied to Lake Champlain (located in upstate New York). This however was a matter of convenience as the purpose was only to open up Great Lakes research funding sources for Lake Champlain (DENCITIES 1998) rather than it being a part of the Great Lakes Basin. Georgian Bay (part of Lake Huron) is also sometimes referred to as Ontario’s “sixth” Great Lake especially for tourism.
marking (400ELEVEN 2005). In addition, Lake of the Woods which is located on the Canada-US border between northwest Ontario and the State of Minnesota is also considered by some to be a “sixth” Great Lake (DIGITAL WIZARDS 2002). It however drains into Lake Winnipeg and eventually Hudson Bay.

Industrial development and urbanization in the Great Lakes Basin have brought about a host of problems (FORSYTHE 2004). One of the most heavily industrialized areas is located along the St. Clair River (which drains into Lake St. Clair). It is sometimes referred to as “chemical valley” due to the numerous industrial and oil refining sites located there. Releases of pollutants into the river have led to polluted water and sediment within Lake St. Clair. The Canadian federal government specifies Threshold Effect Level (TEL) and Probable Effect Level (PEL) guidelines for sediment contamination. The TEL refers to the concentration below which adverse biological effects are expected to occur rarely, while the PEL defines the level above which adverse effects are expected to occur frequently (CCME 1999). These are outlined for mercury and lead in Tab. 1.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>TEL</th>
<th>PEL</th>
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<tbody>
<tr>
<td>Mercury</td>
<td>0.17 ug/g</td>
<td>0.486 ug/g</td>
</tr>
<tr>
<td>Lead</td>
<td>35 ug/g</td>
<td>91.3 ug/g</td>
</tr>
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2 Study Area and Data

Lake St. Clair drains part of the Canadian Province of Ontario and the American State of Michigan. It has a surface area of 1114 km² compared with Lake Superior (the largest Great Lake) at 82100 km² and Ontario (the smallest Great Lake) at 18690 km² (GLIN 2004). It is shallow, averaging 3 metres deep and the maximum depth is only 6.4 metres, compared to
Lake Superior’s maximum depth of 406 metres. The lake is constantly being dredged in order to allow for large ships to navigate through the water system. The Canadian side of the lake is characterized by wetland areas and agriculture however growth in urban and recreational developments has encroached on the wetlands in the United States and they are slowly disappearing (GLIN 2004). The north-eastern portion of Lake St. Clair is an extensive delta system; the largest within the Great Lakes Basin (GREAT LAKES COMMISSION 2003). The watershed is home to nearly five million people, all of whom rely in some way on this natural resource. It provides inhabitants with drinking water, recreational resources, aesthetic beauty, and numerous economic advantages. Because of the close association between the human population and the watershed, water quality is tied directly to the resident’s quality of life (GREAT LAKES COMMISSION 2003).

Historical field research was conducted in 1970 and again in 1974 to acquire sediment core samples. More recently (in 2001) the lake was resampled, in part to assess whether sediment quality had improved. The samples were collected as part of the Environment Canada Great Lakes Sediment Assessment Program. A total of 45 samples were obtained in 1970/1974, with 34 samples collected in 2001. The top 3 cm of the sediment were sub-sampled from the core for analyses that included organic contaminants and metals (MARVIN et al. 2002 as found in JAKUBEK & FORSYTHE 2004).

3 Kriging

Kriging interpolation methods were initially developed for mining applications (JAKUBEK & FORSYTHE 2004). They utilize statistical models that incorporate autocorrelation among a group of measured points to create prediction surfaces. Specifically, weights are assigned to measurement points on the basis of distance; in which spatial autocorrelation is quantified in order to weight the spatial arrangement of measured sampling locations (JOHNSTON ET AL. 2001). By accounting for statistical distance with a variogram model, as opposed to Euclidean distance utilized in deterministic interpolation, customization of the estimation method to a specific analysis is possible (JAKUBEK & FORSYTHE 2004). 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. Furthermore, kriging accounts for both the clustering of nearby samples and for their distance to the point to be estimated (ISAAKS & SRIVASTAVA 1989). Given the statistical properties of this method, measures of certainty or accuracy of the predictions can be produced using a cross-validation process. It is arguable that kriging is the optimal interpolation method on the basis of its functionality and its ability to assess error statistically, when forming predicted surfaces.

For a kriging spatial interpolation model to provide accurate predictions, the Mean Prediction Error (MPE) should be close to 0, the Average Standard Error (ASE) should be as small as possible (below 20), and the Standardized Root-Mean-Squared Prediction Error (SRMSPE) should be close to 1 (FORSYTHE et al. 2004). If the SRMSPE is greater than 1, there is an underestimation of the variability of the predictions and if the SRMSPE is less than 1, overestimation of the variability is the result (JOHNSTON et al. 2001).
4 Analysis and Results

The use of mapping to assess sediment contamination helps in the identification of contamination patterns and provides a basis for decisions concerning the remediation measures that may be implemented. According to the Sediment Priority Action Committee, areas that have the highest sediment contamination levels (and problems associated with the contamination) tend to be in urban-industrial harbours, embayments, and river mouths. The issue is that these areas are normally: the spawning/nursery sites for most fish, the nesting and feeding areas for most aquatic avian fauna, the areas of highest biological activity, and have the most human contact (ZARULL et al. 1999).

4.1 Dot Maps for Mercury and Lead

The St. Clair River and the Detroit River are two areas of concern with respect to the seriousness of their condition due to sediment contamination. The main pollutants in Lake St. Clair include Polychlorinated Biphenyls (PCBs), mercury and Polycyclic Aromatic Hydrocarbons (PAHs) - (ENVIRONMENT CANADA 2004). Mercury levels throughout the lake have been studied by MARVIN et al. (2004) who showed that much of the lake contains levels at or above the PEL. The chemical and petroleum industries located on the Canadian side of the lake are responsible for the majority of these loadings. Historically, the disposal of these chemicals was not as stringently controlled and regulated and although dumping has subsided, the damage had already been done and the lake continues to retain the contaminants (WARREN & MACKAY 2004).

ArcGIS software was used to analyze and present the results in this research. The dot map for the 1970/1974 mercury data is displayed in Fig. 2. Three intervals are utilized indicating whether the values are below the TEL, between the TEL and PEL, or above the PEL. While patterns can certainly be implied, it is not completely clear as to where the highest and lowest contaminant concentrations can be found. The results for the 1970/1974 lead data are displayed in Fig. 3. Again some patterns are evident especially when they are compared with lake bathymetry. The dredging channels for larger ships are associated with higher contaminant values in the deeper portions of the lake. Overall, the concentrations for lead when compared to mercury are much lower.

4.2 Kriging Maps for Mercury and Lead

Ordinary kriging techniques were utilized based on the results of FORSYTHE et al. (2004) and JAKUBEK & FORSYTHE (2004). The kriging technique includes cross validation procedures which provide measures of accuracy for the predictions that are made. The MPE, ASE, and SRMSPE values for all of the kriging analyses are found in Tab. 2.

The mercury kriging results for Lake St. Clair from 1970/1974 are presented in Fig. 4. The MPE, ASE, and SRMSPE values are very close to the optimum. Areas of high contamination exist and these are mostly found in the deeper parts of the lake and where currents flow outward from the St. Clair River towards the Detroit River.
Fig. 2: Mercury Dot Map Results for Lake St. Clair 1970/1974

Fig. 3: Lead Dot Map Results for Lake St. Clair 1970/1974
**Tab. 2:** Kriging Cross Validation Results for Lake St. Clair

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MPE</th>
<th>ASE</th>
<th>SRMSPE</th>
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<tbody>
<tr>
<td>Mercury 1970/1974</td>
<td>0.07619</td>
<td>1.588</td>
<td>0.9155</td>
</tr>
<tr>
<td>Lead 1970/1974</td>
<td>0.8471</td>
<td>12.43</td>
<td>0.9065</td>
</tr>
<tr>
<td>Mercury 2001</td>
<td>8.396</td>
<td>232.2</td>
<td>0.9029</td>
</tr>
<tr>
<td>Lead 2001</td>
<td>0.2286</td>
<td>6.174</td>
<td>0.9600</td>
</tr>
</tbody>
</table>

When the kriging results are compared to the dot map (Fig. 2), it is evident that geovisualization provides an improved representation. Patterns are clearly defined and it is possible to identify which parts of the lake are associated with the TEL and PEL guidelines.

Fig. 4 estimates the locations for the highest lead concentrations from the 1970/1974 data in the central deep lake regions of Lake St. Clair. The predicted surface produced very reliable cross validation results, which were relatively unbiased and rendered an acceptable ASE value of 12.43. The SRMSPE value of 0.9065 indicates that the prediction may be a slight overestimation. No areas of the lake were found to be above the PEL; however there were areas between the TEL and PEL.
The 2001 mercury estimates are presented in Fig. 6. Caution must be used in interpreting the results as the cross validation values are far from ideal. The ASE of 232.2 is much too high and the MPE of 8.396 is well above zero. The data have a non-normal distribution (not ideal for use with the kriging technique) with an extreme value of 1.194 µg/g which is more than double the next closest value and six times the average value of 0.1957 µg/g. The lake has lower contaminant concentrations with a much smaller area above the PEL when compared to the 1970/1974 estimates (although areas of high toxicity are found in the same general locations).

The results for the 2001 lead data analysis (Fig. 7) are excellent with the SRMSPE value of 0.96 indicative of a very representative estimate. All parts of the lake had lead levels of approximately 10 µg/g that were well below the TEL of 35 µg/g. The higher concentration areas from the 1970/1974 data have disappeared and all areas of the lake have concentrations below the lowest value from the 1970/74 data (Fig. 5). This is an interesting finding and can in part be explained through the removal of lead from gasoline in the 1980’s (Li 2003) which was a major source of pollution. The lower contamination levels may also be related to resuspension and transport of lead through the Detroit River into western Lake Erie.
Fig. 6: Mercury Kriging Results for Lake St. Clair 2001

Fig. 7: Lead Kriging Results for Lake St. Clair 2001
5 Conclusion

The use of geovisualization software which integrates the kriging spatial analysis technique allowed for the patterns of sediment contamination in Lake St. Clair to be readily identified. Dot maps provide limited information concerning the areal extent of pollution. Deeper parts of the lake in the main flow path from the St. Clair River to the Detroit River were more contaminated than other parts of the lake. The kriging results were all statistically valid with the exception of the 2001 mercury data which must be interpreted with caution. A log-normal data transformation (FORSYTHE & MARVIN 2005; OUYANG et al. 2003) would be useful in further analyses of these data in order to obtain statistically valid results.

The levels of contamination reveal two trends. Mercury contamination levels have improved from 1970/1974 to 2001 although some areas of the lake are still above the PEL. Lead contaminant concentrations have markedly improved with no areas or the lake above the TEL for the most recent data set. This may be indicative of historically high amounts of mercury contamination that are still contained within lake sediments or continuing input from sources such as “chemical valley”. Continued research and remediation programs concerning Lake St. Clair would benefit if it became the “sixth” Great Lake.

6 References


