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Application of the Great Lakes Toxic Chemical Decision Support System to priority toxic chemicals in Lake Ontario and Lake Erie

By:

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NWRI RESEARCH SUMMARY

Plain language title
Application of the Great Lakes Toxic Chemical Decision Support System to priority toxic chemicals in Lake Ontario and Lake Erie

What is the problem and what do sicentists already know about it?
There has been a long history of loadings of toxic chemicals to the Great Lakes that has resulted in their distribution through the lake ecosystems. The problem is to be able to predict the future fate and transport of these chemicals and to provide answers to management questions that have been the basis of the Lake Ontario and Lake Erie LaMPs, the Canada-United States Strategy for Virtual Elimination of Toxic Substances in the Great Lakes Basin, and the Canada Ontario Agreement. Scientists have examined a small subset of these priority toxic chemicals and have a general understanding of their behaviour and concentrations in the various media.

Why did NWRI do this study?
NWRI was asked to provide decision support system technology and water quality modelling expertise in the development of the Great Lakes Toxic Chemical Decision Support System, which incorporates databases required to support the operation of a suite of mass balance and air transport models as well as data required for their calibration and verification. The system was applied to Lake Ontario and Lake Erie for most of the priority toxic chemicals to predict their concentrations in various media over time. This is in support of the Great Lakes 2020 program as well as the Canada-Ontario Agreement.

What were the results?
A modified version of the Rate Constant Model (RateCon) (Mackay et al., 1994) has been run for anthracene, benzo(a) pyrene (B(a)P), dieldrin, fluoranthene, lead, DDE, DDT, hexachlorobenzene (HCB), mercury, mirex, polychlorinated biphenyls (PCBs), dioxins (TCDDs), pentachlorophenol, and furans (TCDFs) for Lake Ontario. A subset of these has been run for Lake Erie, due to more limited loadings data being available. The model results indicate that the lakes are still net sinks for metals such as mercury and lead. Assuming that the measured concentrations at the lake outlets are representative of whole lake values, then either the lakes are still responding to historically higher loadings or the estimated loadings are underestimated for PCBs, lead, and fluoranthene.

How will these results be used?
These results will be used to answer questions forming the basis of the toxic subtance virtual elimination programs being carried out both in Canada and the United States.

Who were our main partners in the study?
Environment Canada - Toxics Prevention Division - Ontario Region; Ontario Ministry of Environment

Sommaire des recherches de l'INRE

Titre en langage clair
Application du système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs aux produits chimiques d'intérêt prioritaire présents dans le lac Ontario et le lac Érié.

Quel est le problème et que savent les chercheurs à ce sujet?
Il y a longtemps que des charges de produits chimiques toxiques sont rejetées dans les Grands Lacs avec, comme résultat, leur distribution dans l'ensemble des écosystèmes lacustres. Le problème est de pouvoir prédire le devenir et le transport futurs de ces produits chimiques et de fournir des réponses aux questions de gestion qui ont été à la base des PAP des lacs Ontario et Érié, de la Stratégie Canada - États-Unis pour l'élimination virtuelle des substances toxiques rémanentes des Grands Lacs, et enfin de l'Accord Canada-Ontario. Les scientifiques ont examiné un petit ensemble de ces produits chimiques d'intérêt prioritaire et possèdent une connaissance générale de leur comportement et de leurs concentrations dans les divers milieux.

Pourquoi l'INRE a-t-il effectué cette étude?
On a demandé à l'INRE de fournir la technologie du système d'aide à la décision et l'expertise pour la modélisation de la qualité de l'eau aux fins de l'élaboration du système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs, qui incorpore les bases de données requises pour renforcer l'utilisation d'une série de modèles de bilan massique et de transport atmosphérique, ainsi que les données requises pour leur étalonnage et leur vérification. Le système a été appliqué aux lacs Ontario et Érié pour la plupart des produits chimiques toxiques d'intérêt prioritaire, de façon à pouvoir prédire leurs concentrations dans divers milieux en fonction du temps. Cela représente également un soutien pour le programme Grands Lacs 2020 ainsi que pour l'Accord Canada-Ontario.

Quels sont les résultats?
Une version modifiée du modèle RateCon (Rate Constant) (Mackay et al., 1994) a été utilisée pour les composés suivants dans le lac Ontario : anthracène, benzo(a)pyrène (B(a)P), diéldrine, fluoranthène, plomb, DDE, DDT, hexachlorobenzène (HCB), mercure, mirex, polychlorobiphényles (PCB), dioxines (TCDD), pentachlorophénol et furanes (TCDF). Vu le nombre limité de données concernant les charges, un sous-ensemble de ces composés a été traité pour le lac Érié. Les résultats obtenus avec le modèle montrent que les lacs demeurent des puits nets pour les métaux comme le mercure et le plomb. En supposant que les concentrations mesurées aux sorties du lac sont représentatives des valeurs globales pour le lac, on peut dire que celui-ci subit encore les effets de charges historiquement élevées, ou alors que les charges estimatives sont excessivement sous-estimées pour les PCB, le plomb et le fluoranthène.

Comment ces résultats seront-ils utilisés?

Ces résultats serviront à répondre aux questions qui sont à la base des programmes d'élimination virtuelle des substances toxiques, mis en œuvre tant au Canada qu'aux États-Unis.

Quels étaient nos principaux partenaires dans cette étude?

Environnement Canada - Division de la prévention des substances toxiques - Région de l'Ontario; ministère de l'Environnement de l'Ontario.

Application of the Great Lakes Toxic Chemical Decision Support System to priority toxic chemicals in Lake Ontario and Lake Erie

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Abstract

The Great Lakes Toxic Chemical Decision Support System (GLTCDSS) has been developed in order to integrate all of the available information on Tier I and II chemicals in support of designing, implementing and post-auditing the zero discharge and virtual elimination strategies. A modified version of the Rate Constant Model (RateCon) (Mackay et al., 1994) has been run for anthracene, benzo(a) pyrene (B(a)P), dieldrin, fluoranthene, lead, DDE, DDT, hexachlorobenzene (HCB), mercury, mirex, polychlorinated biphenyls (PCBs), dioxins (TCDDs), pentachlorophenol, and furans (TCDFs) for Lake Ontario. A subset of these has been run for Lake Erie, due to more limited loadings data being available. Historical loadings as well as projections of loadings (based upon current loadings reductions) to the year 2020 have been developed for PCBs. The steady-state model results indicate that the lakes are still net sinks for metals such as mercury and lead. Concentrations-to-loadings calculations indicate that for Lake Erie, either the lake is very far from steady-state and is responding to historically higher loadings or the estimated loadings are extremely underestimated for PCBs, lead, and fluoranthene, assuming that the measured concentrations at the outlet (Fort Erie) are representative of whole lake values.

Keywords: Mass balance model, decision support system, toxics, Great Lakes.

Application du système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs aux produits chimiques d'intérêt prioritaire présents dans le lac Ontario et le lac Érié

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Résumé

Le système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs (SADCPCTGL) a été élaboré afin d'intégrer toutes les données disponibles sur les produits chimiques de niveaux I et II et aider ainsi à la conception, à la mise en œuvre et à la vérification ultérieure des stratégies de rejets zéro et de quasi-élimination. Une version modifiée du modèle RateCon (Rate Constant) (Mackay et al., 1994) a été utilisée pour les composés suivants dans le lac Ontario : anthracène, benzo(a)pyrène (B(a)P), diéldrine, fluoranthène, plomb, DDE, DDT, hexachlorobenzène (HCB), mercure, mirex, polychlorobiphényles (PCB), dioxines (TCDD), pentachlorophénol et furanes (TCDF). Vu le nombre limité de données concernant les charges, un sous-ensemble de ces composés a été traité pour le lac Érié. Les charges historiques ainsi que les prévisions des charges jusqu'en 2020 (basées sur les réductions des charges actuelles) ont été déterminées pour les PCB. Les résultats du modèle à l'état d'équilibre montrent que les lacs demeurent des puits nets pour les métaux comme le mercure et le plomb. Dans le cas du lac Érié, les calculs des valeurs concentrations-sur-charges indiquent que le lac est très loin du niveau d'équilibre ou alors qu'il réagit à des charges historiquement élevées, ou encore que les charges estimatives sont excessivement sous-estimées pour les PCB, le plomb et le fluoranthène, en supposant que les concentrations mesurées à la sortie (Fort Érie) sont représentatives des valeurs pour l'ensemble du lac.

1. Introduction

The Canada-Ontario Agreement (COA) to reduce pollutants in the Great Lakes calls for the virtual elimination of thirteen Tier I and twenty-six Tier II chemicals, which are known to be toxic, persistent, and bioaccumulative. Information on the emissions and background levels of the Tier I and Tier II chemicals are stored in various databases in federal, state, and provincial agencies. The data are collected and measured with varying levels of error and uncertainty. Many of these chemicals require sophisticated analytical chemistry methods to make measurements and may only be accurate to the "order of magnitude" level. The challenge is how to make the best of the measured data and the existing body of scientific knowledge for qualifying, if not quantifying, the fate and pathways of these substances in the context of designing, implementing and post auditing the zero discharge and virtual elimination strategies.

The first stage of the application of the decision support system is to collect all geo-referenced and non geo-referenced data on sources, releases and loadings and associated qualifying information and then to progressively synthesize them using remark codes, QA/QC ratings, confidence ranking, statistical analysis, and expert system techniques for proper use of data, treatment of below-detection data, and data gaps.

The next stage is the implementation of models for prediction of air transport and loadings of contaminants at continental, regional, and local scales. Also, mass balance models are required for predictions of concentrations and residence times of chemicals within the lakes and surrounding watersheds. Data required to operate the models such as system geometry, hydrometeorological forcing data, and basic physical and chemical properties of the system that govern transport and transformation processes must also be

entered into the system.

The RateCon model has previously been used to examine management questions regarding the virtual elimination of priority toxic chemicals for Lake Ontario (McKay et al, 1994; Thompson et al., 1999). This paper describes the application of the RateCon model to assess the state of 13 additional priority chemicals in Lakes Ontario and 10 priority toxic chemicals in Lake Erie. The results of the model application are examined with respect to their implications for the objectives specified in the COA agreement as well as the need for more rigorous modelling efforts, which would consider greater temporal and spatial detail as well as improved process representation.

2. GREAT LAKES TOXIC CHEMICAL DECISION SUPPORT SYSTEM

The RAISON for Windows Decision Support System shell that this system is based upon has evolved over the past decade at the National Water Research Institute of Environment Canada (Lam and Swayne, 1993, Lam et al., 1995). Its development has been client driven and its design is devoted to providing generic software tools for fast prototyping and practical implementation of environmental decision support systems. The architecture is open in design. All of the above system modules are directly linked within the RAISON system with functions and tools including modelling interfaces, neural network, uncertainty analysis, fuzzy logic, animation, visualization and optimization procedures (Booty et al., 2001)

In Figure 1 the conceptual design and component integration of the GLTCDSS (Booty et al., 1997, 1999) is shown. It consists of 3 different databases (Emissions, Loadings, and Background), which are linked to all of the system components. The air

emissions data are used as input to the air trajectory models, which are used to calculate the regional and long-range transport and loadings of the chemicals to each of the lake air sheds. These are used as loadings to the mass balance models, which are used to examine the fate of the toxic chemicals within the ecological system components.

Before the data can be used for decision support they need to be categorised, screened and analysed. The first step was to segregate the data into 3 main types: Emissions, Loadings, and Background. The background data include all of the physical and chemical data required as input to the models and for model calibration/confirmation. In order to be able to handle the wide array of data in an Access database efficiently, the data are further divided into data tables corresponding to the appropriate lake or channel.

Initial data screening and analysis is carried out through the statistics module. This includes the handling of below-detection data, which are typically a large fraction of the measured data for the toxic chemicals of concern in the Great Lakes. Outputs from the models are also sent to the statistics module for analysis and comparison with measured data during the calibration and verification steps. Once the data have been retrieved, it is saved to a database table. It can be saved into the format required for a particular model or for use in one of the other system modules, such as models or contouring.

3. RateCon Model

The RateCon model is a modified version of the model developed by Mackay et al., (1994). It consists of a whole lake model and a food chain model. All expressions for rates of chemical transport and transformation are written in "rate constant" form, which

allows for easy comparison of magnitudes of diverse processes. The reader is referred to the original paper for the full details of the model design. It may be considered a screening level model which has been shown to be a useful tool for examining the fate of PCBs in Lake Ontario, both in steady-state and unsteady-state mode of operation (Mackay 1989, Mackay et al. 1994, Thompson et al., 1999). It has been modified by converting it from Basic to Visual Basic, with improved input and output screens as well as input error checking. In addition, it was modified to allow the unsteady-state calculations to be run separately from the steady-state calculations and to allow for variable loadings over time. Capabilities were also added to allow the storing and recalling of unsteady-state results, which are displayed by linking with the RAISON plotting routines.

4. Steady-State Model Applications

The model may be operated in a number of steady-state modes. There are 4 options:

1) Forwards, loading to concentration:

   This is the most common mode and is used to calculate concentrations in all the compartments using loadings input by the user.

2) Backwards, concentrations in both water and sediments to loading:

   This mode allows the user to determine what the loadings need to be in order to arrive at the water and sediment concentrations observed in the lake.

3) Backwards, concentration in water only to loading:

In this mode loadings are calculated that are required to arrive at the observed water concentrations only.

4) Backwards, concentrations in sediment only to loading:

In this mode loadings are calculated that are required to arrive at the observed sediment concentrations only.

There is also the option to operate the model in pseudo steady-state mode, where there is a net long term inventory change of the chemical in the water and sediment, rather than being set to zero, as is the case for the steady-state condition.

4.1 Loadings-to-Concentrations in Lake Ontario

The physical properties used as input to the model are shown in Table 1. Chemical specific properties for Lake Ontario priority chemicals are shown in Table 2. The values shown in the table are those actually used in the model and which have been determined during the model calibration process. They are all within the range of values that have been used in earlier modelling efforts (Mackay et al., 1994, Rodgers et al, 1987, Mackay 1989) or from other process related publications (Hoff et al., 1996) and handbooks (Mackay et al., 1992, Howard et al. 1991), with the exception of DDE. Transformation rates for DDE in the literature were found to be too low. They need to be similar to those for DDT for the model to predict concentrations that are within the ranges found in the lake media.

The loadings have been derived from all available sources in Canada and the United States. Atmospheric concentrations were obtained from the Integrated Atmospheric

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Deposition Network database for 1990-1997 and calculated loadings reported in the literature include those from Hoff et al., (1996), and Eisenreich and Strachan, (1992). Terrestrial loadings have been obtained from a large number of sources, including ARET, 1995; Canviro Consultants, 1988; CCPA, 1994; Cohen et al., 1995; Data Interpretation Group, 1995; Fox et al., 1996; Kuntz et al., 1990; Lake Ontario LaMP, 1997; Litten, 1996; Leonardelli, 1996; Ministry of the Environment, 1990, 91 (a), 91 (b), 91(c), 92 (a), 92 (b), 92 (c), 92 (d); MOEE, 1993 (a), 93 (b), 94, 95; Williams et al., 2000; Niagara River Toxics Management Plan, 1999; Putnam, 1995; Schroeter and Assoc., 1992; Snodgrass and D'Andrea, 1992; Thompson, 1992; USEPA and NYSDEC, 1989, 93(a), 93(b), 94(a), 94(b), 95, 96; and Zenon (1989).

A review of the data available in the system indicated that 1995 would be the best year to use for the steady-state modelling and as a baseline for the time variable modelling due to the high number of coincident records within the databases for that year. The land-based and atmospheric values used as input to the model are presented in Table 3.

The ambient water, sediment and biota data, which have been incorporated into the GLTCDSS background database, have been obtained from the following sources:

- Water and suspended data from Anderson et al. (1999), Biberhofer (1994), Brownawell et al. (1996), ENVIRODAT, Halfon and Schito (1993), Kuntz (1990), L'Italien (1993), Merriman (1998), STAR Database, STORET, USGS;

- Sediment data from ENVIRODAT, Golden et al. (1994), Halfon and Schito (1993), Howdashell and Hites (1996), Long et al. (1995), L. Ontario RAP,

NYSDEC (1995, 1996), Painter et al. (2001), Pearson and Swackhamer (1995), Pearson et al. (1997, 1998), Richard et al. (1997), STAR, Wong et al. (1995);

- Biota data from Borgmann and Whittle (1988, 1991, 1992), DeVault et al. (1989, 1996), Halfon and Schito (1993), Huestis et al. (1996), Niimi and Oliver (1989), Skinner and Bauer (1989), Skinner and Jackling (1989), Skinner (1990a, 1990b, 1991), Scheider et al. (1998), Suns et al. (1991).

The results of the steady-state modelling are summarized in Table 4 for the lake and in Table 5 for the food chain. A comparison of model predicted and measured data are presented in Table 6 for selected model parameters. Looking first at concentrations in the water column, the model predicted values fall within the observed ranges plus or minus the confidence intervals for PCBs, HCB, B(a)P, mirex, DDE, lead, and anthracene. The model predicts lower concentrations than those observed for mercury, dieldrin, and fluoranthene. Assuming that the rate constants used within the model are reasonable, then it would appear that the lake is either still far from steady state or the loadings for these chemicals have been underestimated. For example, for dieldrin, the total loadings would have to be increased to 146 kg/year for the model to predict a water concentration of 0.16 ng/L. Values for DDT and TCDD are all below the detection limit. No data is available for pentachlorophenol or TCDF.

Concentrations in the sediments predicted by the model fall within the observed ranges, plus or minus the confidence intervals, for PCBs, HCB, mirex, mercury, and lead. The model predicted values fall below the observed values for mirex and B(a)P, and above for fluoranthene . No adjustment of the rate constants within a reasonable range can be made that would allow the model predicted sediment concentrations to fall within the observed

ranges. However, it should be noted that ranges vary widely around the lake due to point sources. For example, the distribution of B(a)P around Lake Ontario is shown in Figure 2.

No observed data was available for dieldrin, pentachlorophenol, DDT, DDE, TCDD, TCDF, and anthracene.

Observed lake trout concentrations are considered next for fish of age 4 years and greater. Concentrations predicted by the model fall within the observed ranges for PCBs, mirex, DDT, and DDE. The model over predicts the concentrations for HCB and TCDD and seriously under predicts for mercury. The food chain model within RateCon does not allow for the modelling of the different species of chemicals such as mercury. Models developed specifically for mercury cycling within lakes, such as the Regional Cycling Model (R-MCM) (Harris et al., 1996) and the fate and transport model of mercury in Lake Michigan (Rygwelski, 1998) have demonstrated that this is the approach that should be used. No observed data are available for B(a)P, dieldrin, pentachlorophenol, lead, TCDF, fluoranthene, and anthracene.

The presence of zebra mussels must also be considered as a confounding factor in the cycling of toxic chemicals in the lake. They have caused a reduction in water column concentrations of particulate matter (mostly in the near shore zone) by out-competing planktonic herbivores for autochthonously produced organic carbon and depositing it to the sediments. During the growing season the flux of hydrophobic toxic chemicals (K_{oc}'s in the range 5-6) to the sediment is increased, causing increased potential for bioaccumulation in the benthic food chain. Secondly, by decreasing the concentration of biotic and abiotic particulate matter in the water column, there is an increase in dissolved

or bioavailable phases of the toxic chemicals in the water column, creating a potential for increased bioaccumulation in the pelagic food chain (DePinto and Narayanan, 1997). Consequently, chemicals such as PCB's, HCB, B(a)P, DDT, and DDE may be at higher concentrations than would be predicted without the presence of zebra mussels. As an example, the results of running the model with suspended solids concentrations reflecting pre-zebra mussel conditions (4.0 mg/L) and with zebra mussels (1.2 mg/L) are compared in Table 7. It can be seen that the model predicts a decrease in water concentrations with mussels for PCBs, HCB and B(a)P. There is no significant impact predicted for DDT and DDE. Concentrations of all five chemicals are predicted to significantly increase in the sediments and in lake trout due to the presence of the zebra mussels.

All of the results have inherent uncertainties, which are difficult to quantify. Many of the rate constants or their distributions have never been directly measured. In this paper, for the steady-state calculations, the results are used to compare the overall behaviour of the chemicals in the system. The RateCon model is a screening level model and as such it is not designed to examine seasonal and spatial variations in a lake. The ambient data indicate that there are significant heterogeneities in the concentrations of the priority chemicals in Lake Ontario. A more advanced model is being developed for Lake Ontario (DePinto et al., 1998, 1999) that is able to characterize the lake in greater spatial and temporal detail. It also incorporates a mercury submodel similar to that of Rygwelski, (1998).

4.2 Loadings-to-Concentrations in Lake Erie

The physical-chemical input data for Lake Erie are shown in Table 8. Loadings data are shown in Table 9. The loadings used in these examples have been derived from all available sources in Canada and the United States. Atmospheric concentrations and loadings reported in the literature include those from Hoff et al., (1996); Eisenreich and Strachan, (1992); and Kelly et al. (1991). Terrestrial loadings data have been obtained from ARET, Leonardelli, 1996, Kelly et al. (1991) and STORET. The physical-chemical data used as input to the model for Lake Erie for PCBs, HCB, B(a)P, mercury, DDT, dieldrin, lead, TCDD, TCDF, anthracene and fluoranthene are the same as those shown in Table 2.

The results for the concentrations in fish are shown in Table 11. No information on trends in the concentrations of these contaminants in fish, which are included in the RateCon model for Canadian waters of Lake Erie, was available for comparing with model outputs. Spottail shiner (*Notropis hudsonius*) PCBs concentrations ranged from 80-150 ng/g in 1995, as compared to the model predicted concentrations of 574 ng/g for alewife (*Alosa pseudoharengus*).

The impact of zebra mussels on chemical concentrations in Lake Erie are examined by running the model with suspended solids concentrations reflecting pre-zebra mussel conditions (mg/L) and with zebra mussels (1.0 mg/L) are compared in Table 12. As was seen in Lake Ontario, their net effect is to increase concentrations in the water column, sediments, and in the biota.

4.3 Concentrations-to-Loadings for Lake Erie

The availability of 10 years of Lake Erie outflow chemistry data collected as part of the Niagara River Upstream/Downstream Program (Williams et al., 2000) provided the opportunity to calculate the loads required to generate the measured outflows from Lake Erie.

Assuming steady-state conditions and using 1995 output loads from Lake Erie, the annual terrestrial loads required as input to Lake Erie are shown in Table 13. It is assumed that the atmospheric inputs are fixed and are those used in the loadings-to-concentrations runs shown in Table 9.

Considering PCBs, it is clear that the measured outflows from Lake Erie (226 kg/yr, ± 48 kg/yr) are substantially greater than those predicted by the model (61 kg/yr ± 1.3 kg/yr)). In this case, to match the measured outflow, the terrestrial loading must be 7.9 times greater than the estimated value.

For Hg, the measured outflow (440 kg/yr ±10kg/yr) is 1.35 times the mean calculated value of 325 kg/yr (±17 kg/yr). The estimated loading of 2584 kg/yr must be increased to 3750 kg/yr to achieve the measured outflow. For B(a)P, the situation is reversed. The measured outflow (140 kg/yr ±33 kg/yr) is 120 kg/yr less than the mean steady-state calculated value (260 kg/yr). The terrestrial loadings would have to be 118 kg/year rather than the estimated value of 431 kg/year.

The measured outflow of lead from Lake Erie for 1995 of 73,000 kg/yr is 3.3 times greater than that predicted by the model using the estimated loadings. Again either the lake is far from steady-state and is responding to historically higher loadings of lead or the estimated loadings are underestimated, assuming that the measured values are correct and reflect the whole lake concentrations.

There are no estimated loadings for fluoranthene, but assuming steady-state conditions, the loading required to match the measured outflow of 475 kg/yr is 7300 kg/yr. For anthracene, the model predicted and measured values fall within the range of uncertainty. For HCB, the measured discharge load rate for HCB is 4 kg/yr. The model predicts a mean discharge load of 32 kg/yr. Even if the terrestrial loadings are reduced to zero, the measured discharge cannot be met, given the atmospheric loadings.

In the case of dieldrin, the measured outflow of 31 kg/yr (±2 kg/yr) is just slightly less than the model predicted value of 38.5 kg/yr (±1.0 kg/yr). For DDT, the RateCon model calculated mean load rate of 5.5 kg/yr (±0.4 kg/yr) falls within the range of the measured value of 3.5 kg/yr (±2.4 kg/yr).

There is no information on the estimated loading of DDE to Lake Erie. However, for Lake Ontario it has been estimated to be 45 kg/yr. To generate the measured discharge loading of 16 kg/yr from Lake Erie, the terrestrial loading would have to be 800 kg/yr.

5. Unsteady-State Model Applications

Historical loadings as well as projections of loadings (based upon current loadings reductions) to the year 2020 have been developed for Lake Ontario for PCBs. Historical loadings data have been obtained or calculated from Thomas et al. (1987), Rapaport and Eisenreich (1988), Halfon and Oliver (1990). The modelling results are shown in Figure 3. The earliest measured data are for sediments collected in 1968. Water column data are available from 1983. It can be seen that measured water column data collected during the 1980's vary from non detects to 330 ng/L. The model predicted water column

concentration for 1993 passes through the measured values for 1993 of ND to 4.7 ng/L. Model results indicate that in Lake Ontario, by the year 2020, lake water, sediment and lake trout concentrations will drop to 0.08ng/L; 10.4ng/g; and 0.27 ug/g from 0.11ng/L; 16.2 ng/g and 0.41 ug/g in 1995 respectively.

In Figure 4, historical loadings that are used to run the model as well as the model outputs are shown for HCB. It can be seen that the model predicted concentrations fall well within the range of measured data for all media.

In Figure 5, historical loadings of mirex used as input to the model, the model results and measured data are presented. The model tends to over predict water column and sediment concentrations. However, lake trout body burdens of mirex are higher than what would be predicted based upon the historical loads that have been determined. Measured data for smelt (*Osmerus mordax*) are too few in number to be able to make any definite conclusion. As pointed out in the study by Velleux et al. (1995), on the Oswego River, estimates of tributary discharges of mirex were probably significantly underestimated. Based upon 1990 field data, they suggest that there may be a continuing mirex source to the Oswego River and that export to Lake Ontario averaged 15 kg/year. The enhanced tributary study (Boyd and Biberhofer, 1999) indicates that there are also underestimated sources on the Canadian side of the lake.

6. Discussion

It is interesting to compare the 1995 steady-state results for Lake Ontario (Table 4) with those for Lake Erie (Table 10). Total mass of chemical in the system is predicted to be greater in Lake Ontario than in Lake Erie for PCBs, HCB, dieldrin, lead, lead, DDE,

fluoranthene, and anthracene The reverse is true for B(a)P, mercury, and DDT, reflecting the different magnitudes and sources of loadings for these chemicals in the two basins. Total mass in the system is predicted to be approximately the same in both lakes for TCDF and TCDD. Total water concentration is predicted to be greater for Lake Ontario than in Lake Erie for PCBs, HCB, mercury, lead, DDT, and TCDF. The total water concentration of B(a)P, dieldrin, TCDD, anthracene and fluoranthene is predicted to be greater in Lake Erie than in Lake Ontario. Sediment concentrations are predicted to be higher for PCBs, HCB, lead, and TCDD in Lake Ontario than in Lake Erie. The reverse is predicted for B(a)P, mercury, dieldrin, DDT, TCDF, anthracene and fluoranthene.

Model predicted steady-state results for concentrations in fish, as shown in Tables 5 and 11 for Lake Ontario and Lake Erie respectively, are compared next for the two lakes. The model predicts that concentrations of PCBs, HCB, B(a)P, dieldrin, DDT, TCDD, TCDF, anthracene and fluoranthene will be higher in Lake Erie than Lake Ontario fish. Only the metals, mercury and lead, are predicted to be at higher concentrations in Lake Ontario fish. Over the past 15-20 years, of all the sport fish consumption restrictions for the Great Lakes, Lake Erie had the fewest (19%) while Lake Ontario had the most (45%) For Lake Erie, the contaminants causing the advisories were PCBs (76%) and mercury (24%) (Scheider et al., 1998).

7. Conclusions

Currently there is still insufficient data to allow a simple screening level model such as RateCon to be applied for octachlorostyrene, chlordane, toxaphene, heptachlor, 1,4-dichlorobenzene, 3,3'-dichlorobenzidine, hexachlorocyclohexane, 1,6-dinitropyrene, 1,8-

dinitropyrene, and tributyl tin, and many of the PAH's. This includes loadings data, basic physical-chemical properties required as model coefficients, and ambient data required for model calibration and verification. This means that not all of the priority chemicals of concern of the COA can be evaluated with regards to meeting the CAO goals.

The RateCon model has been used to predict the historical trends in concentrations of PCBs, and HCB in Lake Ontario. It was observed that the model under predicts the historical concentrations of mirex in Lake Ontario lake trout. This appears to be due to underestimations of historical loadings of mirex to Lake Ontario.

Concentrations-to-loadings calculations indicate that for Lake Erie either the lake is very far from steady-state for PCBs, lead, and fluoranthene and is responding to historically higher loadings, that the estimated loadings are extremely underestimated, or the measured values at Fort Erie do not reflect whole lake concentrations. The impacts of exotic species such as zebra mussels on chemical dynamics within Lake Erie have been evaluated (Morrison et al. 2000, Dobson and Mackie, 1998, DePinto and Narayanan, 1997). The changes in suspended solids concentrations (POC and DOC) and their characteristics as a result of the zebra mussels have been taken into account in the model runs for the 1995 steady-state calculations.

The wide range of spatial values for measured data around the lakes has indicated the need for a spatially segmented model to address areas of concern. For Lake Ontario, the LOTOX2 model has been developed to address this concern and is the focus of future research.

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Tables

FIGURES

Figure 1. Great Lakes Toxic Chemical Decision Support System conceptual design.

Figure 2. Spatial distribution of B(a)P in sediment for Lake Ontario for samples collected between 1987-1993.

Figure 3. Loadings and model predicted versus measured PCB concentrations in Lake Ontario media.

Figure 4. Loadings and model predicted versus measured HCB concentrations in Lake Ontario media.

Figure 5. Loadings and model predicted versus measured Mirex concentrations in Lake Ontario media.

TABLE 1. Lake Ontario physical-chemical input data

Water surface area (m^2)	1.95×10^{10}
Sediment surface area (m^2)	1.17×10^{10}
Water volume (m^3)	1.67×10^{12}
Sediment active layer depth (m)	0.01
Suspended solids concentration (g/m^3)	1.2
Volume fraction solids in sediment	0.08
Sediment solids density (kg/m^3)	2000
Organic carbon content (g/g)	0.02
Deposition rate of solids (g/day m^2 water area)	0.73
Resuspension rate (g/day m^2 sediment area)	0.22
Burial rate (g/day m^2 sediment area)	0.95
Temperature ($^{\circ}$C)	8
Rain rate (m/y)	0.89

TABLE 2

Property	PCBs	HCB	B(a)P	Mirex	Hg	DDT	DDE	Pent	Dield	Lead	TCDD	TCDF	Fluor	Anth
Fraction on depositing particles in water	0.5	0.2	0.7	0.8	0.8	0.9	0.9999	0.99	0.4	0.8	0.995	0.999	0.6	0.95
Fraction dissolved in water column	0.5	0.8	0.3	0.2	0.2	0.1	0.0001	0.01	0.6	0.2	0.005	0.001	0.4	0.05
Fraction dissolved in sediment	0.0002	0.0024	0.3	1.5E-04	5.3E-04	0.01	0.01	0.1	0.5	5.3E-04	0.01	0.01	0.3	0.05
Fraction sorbed in atmosphere	0.05	0.001	0.7	0.5	0.05	0.09	0.09	0.9	0.4	1.0	0.7	0.7	0.5	0.6
Scavenging ratio of aerosols	1.0E05	1.0E06	1.5E05	2.0E06	1.8E05	1.75E05	1.75E05	1.5E05	1.0E05	1.8E05	1.5E05	1.5E-05	1.0E05	1.0E05
Dry Deposition Velocity (m/h)	7.2	7.2	5.2	7.2	7.2	5.0	5.0	5.0	7.2	7.2	5.0	5.0	7.2	5.0
Air-Water exchange MTC: air side (m/h)	15.5	21.2	15.9	15.9	1.0	15.2	15.2	15.0	14.9	1.0	15.2	15.2	15.9	15.0
Air Water exchange MTC: water side (m/h)	0.025	0.03	0.03	0.02	0.01	0.02	0.02	0.02	0.025	0.01	0.02	0.02	0.02	0.03
Air-Water Partition coefficient	0.005	0.0002	1.8E-08	0.008	2.9E-04	5.3E-05	0.0003	1.8E-06	0.0018	1.0E-05	2.0E-05	2.0E-05	2.7E-04	7.2E-04
Log octanol-water partition coefficient	6.6	5.5	6.04	6.89	1.0E-05	6.28	5.73	4.16	3.69	0.0	6.5	7.7	4.69	4.54
Sediment-water diffusion MTC (m/h)	0.0001	0.0001	0.001	0.0001	0.001	0.0001	0.001	1.0E-05	0.0001	0.0001	0.0001	0.001	0.0001	0.0001
Transformation half life in water (h)	5.0E05	1.0E06	9600	80000	1.0E06	300	2000	110	10000	7.0E-08	10000	15000	1000	5000
Transformation half life in sediment (h)	5.0E05	1.0E06	14,000	1.0E05	1.0E06	1.0E05	10000	4000	26000	7.0E-08	10000	15000	10000	10000

Table 3

Compound	Municipal	Industrial	Tributary	Non-Point	Wet Deposition	Dry Deposition
PCBs	19.0	4.0	648	2.8	58.0	5.7
HCB	1.7	0.32	33.0	0.0	5.2	0.16
Mercury	0.26	0.03	775	0.1	347	221
Mirex	0.5	0.40	16.8	0.0	4.5	0.5
B(a)P	0.01	0.58	300	0.13	26.0	5.1
Dieldrin	0.0	4.0	43	5.0	11.0	1.7
Pentachlor	0.0	0.0	7.0	0.0	50.1	0.43
DDT	3.0	3.0	20	16.0	3.4	3.8
DDE	0.01	0.01	20.8	0.01	0.35	6.8
Lead	82000	22000	374000	200	4.32E+4	4430
TCDD	0.01	0.01	0.02	0.0	5.2E-3	1.0E-5
TCDF	3.5	0.3	0.1	0.0	0.1	0.05
Fluoranthene	0.0	0.0	475	1.87	121	4.3
Anthracene	0.01	0.23	26	2.34	520.6	256.2

Table 4

Parameter	PCBs	HCB	B(a)P	Mirex	Hg	Dield	Penta	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Total mass in water (kg)	390	582	433	11.3	4868	177	3.3	2.44	10.6	3.4E+5	0.024	1.6	611	543
Total mass in sediment (kg)	4742	544	1.3	66.1	4069	4.0	0.009	4.5	2.7	2.2E+6	0.034	5.3	33.7	76.6
Total mass in system (kg)	5132	1126	435	77.4	8936	181	3.3	7.0	13.3	2.5E+6	0.058	6.9	644	619
Total mass dissolved in water (kg)	195	466	130	2.3	974	106	3.29	0.24	1.1E-3	6.9E+4	1.2E-4	1.6E-3	244	27.1
Total mass on settling particles (kg)	195	116	303	9.1	3894	71	0.03	2.19	10.6	2.7E+5	0.024	1.6	366	516
Total mass in sediment pore water (kg)	0.95	1.31	0.91	0.01	2.1	2.0	0.008	0.05	0.03	1151	3.4E-4	5.3E-3	10.1	3.8
Total mass on particles in sediment (kg)	4741	542	0.39	66.1	4067	2.0	8.9E-4	4.5	2.7	2.2E+6	0.03	5.3	88.3	72.7
Volatilization rate from water (kg/year)	377	177	0.004	4.0	28.1	26.4	0.09	0.02	3.8E-4	7.0E-4	3.7E-6	5.0E-5	88.3	4.0E-3
Outflow rate from the lake (kg/year)	60	89	67	1.7	749	27.3	0.51	0.37	1.6	5.3E+4	3.7E-3	0.25	94	83.5
Transformation rate in water (kg/year)	4.7	35	274	0.9	0.3	41.4	182	35.5	32.3	0.21	0.01	0.66	618	659
Water to sediment transport rate (kg/year)	507	292	794	22.5	2984	177	0.08	5.5	26.4	6.8E+5	0.06	4.03	913	401
Sediment to water transport rate (kg/year)	107	142	794	4.2	2083	176	0.08	4.2	24.1	2.1E+5	0.03	0.73	887	339
Transformation rate in sediment (kg/year)	57.6	35	0.6	4.0	0.25	0.94	0.01	0.28	1.7	13	0.02	2.15	20.5	46.5
Burial rate from sediment (kg/year)	342	118	0.08	14.3	881	0.43	1.9E-4	1.0	0.6	4.7E+5	7.3E-3	1.15	5.1	15.8
Total water concentration (ng/L)	0.23	0.35	0.26	0.006	2.91	0.11	2.0E-3	1.5E-3	6.4E-3	206	1.4E-5	9.7E-4	0.37	0.32
Dissolved water concentration (ng/L)	0.12	0.28	0.08	0.001	0.58	0.06	1.9E-3	1.5E-4	6.4E-7	41	7.2E-8	9.7E-7	0.15	0.02
Dissolved sediment concentration (ng/L)	2.7	11.2	7.7	0.08	18.3	17.1	0.07	0.39	0.23	9835	2.9E-3	0.05	0.77	32.7
Sediment concentration (ng/g)	84	29	0.03	3.5	217	0.11	4.8E-5	0.24	0.14	1.2E+5	1.8E-3	0.28	0.01	3.9

Dield = Dieldrin
Penta = Pentachlorophenol
Fluor = Fluoranthene
Anth = Anthracene

Booty

Table 5

Alewife

Parameter	PCBs	HCB	Hg	Mirex	B(a)P	Dieldrin	Penta	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.41	0.054	4.1E-8	0.03	0.22	7.3E-5	2.9E-6	0.02	2.3E-3	2.9E-6	3.1E-4	0.08	0.01	2.4E-3
Concentration lipid (ng/g)	5890	773	5.8E-4	362	3209	1.04	0.04	321	33.1	0.04	4.4	1143	179	33.9
Biomag factor wrt water	12.4	8.8	1.0	34.4	37.6	2.2	1.45	1153	9.7E+4	1.0	1.9E+4	2.3E+4	25.0	60.1
Biomag factor wrt sediment	0.56	0.22	0.03	0.55	0.38	0.008	0.04	0.43	0.26	0.004	0.48	0.503	0.04	0.03

Lake Trout

Parameter	PCBs	HCB	Hg	Mirex	B(a)P	Dieldrin	Penta	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	1.85	0.13	9.3E-8	0.12	0.79	8.2E-5	5.0E-6	0.09	6.7E-3	6.6E-6	1.4E-3	0.37	0.01	1.7E-3
Concentration lipid (ng/g)	11540	828	5.8E-4	771	4963	0.51	0.03	569	41.5	0.04	8.7	2303	75.4	10.7
Biomag factor wrt water	24.3	9.4	1.0	73.3	58	1.08	1.11	2048	1.2E+5	1.0	3.8E+4	4.7E+4	10.5	19.1
Biomag factor wrt sediment	1.1	0.23	0.03	1.17	0.58	0.004	0.03	0.77	0.33	0.004	0.94	1.01	0.018	0.009

Sculpin

Parameter	PCBs	HCB	Hg	Mirex	B(a)P	Dieldrin	Penta	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.72	0.08	4.7E-8	0.05	0.39	9.7E-5	3.6E-6	0.04	3.9E-3	3.4E-6	5.9E-4	0.16	0.02	3.6E-3
Concentration lipid (ng/g)	9024	1035	5.9E-4	600	4898	1.21	0.04	519	49.1	0.04	7.4	1987	237	44.9
Biomag factor wrt water	19.0	11.7	1.0	57.1	57.4	2.6	1.6	1867	1.4E+5	1.0	3.2E+4	4.1E+4	33.0	79.6
Biomag factor wrt sediment	0.86	0.29	0.03	0.91	0.58	0.009	0.04	0.70	0.39	0.004	0.80	0.87	0.056	0.04

Smelt

Parameter	PCBs	HCB	Hg	Mirex	B(a)P	Dieldrin	Penta	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.65	0.03	2.3E-8	0.05	0.23	2.9E-5	1.4E-6	0.03	1.7E-3	1.7E-6	4.8E-4	0.15	0.004	7.0E-4
Concentration lipid (ng/g)	1.6E+4	794	5.8E-4	1150	5818	0.73	0.035	736	42.4	0.04	12.0	3830	100	17.6
Biomag factor wrt water	34.2	9.0	1.0	109	68	1.55	1.24	2646	1.2E+5	1.0	5.3E+4	7.9E+4	14.0	31.1
Biomag factor wrt sediment	1.5	0.22	0.03	1.75	0.69	0.006	0.3	0.995	0.34	0.004	1.3	1.69	0.023	0.015

Table 6

Chemical	Dissolved Water Concentration (ng/L)			Sediment Concentration (ng/g)			Lake Trout Concentration (ug/g)		
	Observed range	Model Median	±90% CI	Observed range	Model Median	±90% CI	Observed range	Model Median	±90% CI
PCBs	ND - 2.0	0.12	0.01	ND-4226	82	8	0.1-5.0	1.85	0.13
HCB	0.003-0.30	0.27	0.13	0.04-31.2	31	1.2	0.001-0.08	0.14	0.002
B(a)P	0.0-1.48	0.08	0.002	30-119	0.03	0.01	NA	0.79	0.02
Mirex	ND - 0.11	0.001	0.0004	4.3-35.6	3.6	1.0	0.01-0.63	0.12	0.04
Mercury	2.6-25	0.26	0.02	20-800	323	17	0.02-0.4	4.2E-8	5.0E-9
Dieldrin	0.155-0.34	0.06	0.02	NA	0.11	0.04	NA	4.5E-5	1.0E-6
Pentachlor	NA	0.002	2.0E-4	NA	6.9E-6	3.0E-7	NA	4.8E-6	6.0E-7
DDT	ND	1.5E-4	1.1E-5	NA	0.24	0.02	0.005-0.11	0.09	0.008
DDE	ND-0.017	6.4E-7	2.0E-7	NA	0.275	0.03	0.05-6.8	0.013	0.001
Lead	ND-1250	41	5	2000-8.5E05	1.2E05	4000	NA	6.6E-6	2.6E-7
TCDD	ND	1.8E-7	1.6E-7	NA	6.5E-3	9.0E-4	ND-7.7E-05	4.9E-3	7.9E-4
TCDF	NA	9.7E-7	1.4E-8	NA	0.28	0.01	NA	0.38	0.02
Fluoranthene	0.2-7.8	0.15	0.01	0.03-0.2	1.26	0.03	NA	0.002	3.0E-4
Anthracene	0.0-0.238	0.02	0.005	NA	15.7	4.4	NA	6.7E-03	9.0E-4

NA = Not Available
ND = Non Detect
CI = Confidence Interval

Booty

Table 7

Chemical	Water Concentration (ng/L)		Sediment Concentration (ng/g)		Lake Trout Concentration (ug/g)	
	With mussels	Without mussels	With mussels	Without mussels	With mussels	Without mussels
PCBs	0.12	0.18	82	36.9	1.85	0.98
HCB	0.28	0.36	31	11.6	0.14	0.07
B(a)P	0.08	0.08	0.02	0.006	0.79	0.26
DDT	1.5E-4	1.5E-4	0.24	0.07	0.09	0.03
DDE	6.4E-7	6.7E-7	0.14	0.05	0.007	0.002

Table 8

Water surface area (m^2)	2.57×10^{10}
Sediment surface area (m^2)	1.41×10^{10}
Water volume (m^3)	4.84×10^{11}
Sediment active layer depth (m)	0.01
Suspended solids concentration (g/m^3)	1.0
Volume fraction solids in sediment	0.08
Sediment solids density (kg/m^3)	2000
Organic carbon content (g/g)	0.02
Deposition rate of solids (g/day m^2 water area)	0.74
Resuspension rate (g/day m^2 sediment area)	0.35
Burial rate (g/day m^2 sediment area)	1.0
Temperature ($^\circ$ C)	10
Rain rate (m/y)	0.9

Booty

Table 9

Compound	Municipal	Industrial	Tributary	Non-Point	Wet Deposition	Dry Deposition	Absorption
PCBs	9.0	0.7	740	0.0	21	16	57.6
HCB	100	129	512	0.0	219	27	31.2
B(a)P	5.0	1.0	425	0.0	180	63	14.0
Mercury	0.25	0.02	2584	0.0	437	291	0.21
Dieldrin	10	5.4	61	0.0	28	5.6	54.5
DDT	15	15.9	62	0.0	34	4.3	4.3
DDE	0.0	0.0	20.0	0.0	0.34	6.9	0.005
Lead	53400	2500	350000	0.0	47000	18000	0.0
TCDD	0.0	0.0	0.14	0.0	0.005	1.0E-05	0.02
TCDF	3.5	0.3	0.1	0.0	0.1	0.05	0.15
Fluoranthene	0.0	0.0	0.0	0.0	20	25	1768
Anthracene	0.01	0.23	26.0	2.34	520	256	124

Table 10

Parameter	PCBs	HCB	B(a)P	Hg	Dield	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Total mass in water (kg)	89	83	675	844	100	9.29	6.48	5.7E+4	0.024	0.64	246	117
Total mass in sediment (kg)	2041	443	3.4	1.3E+4	13	96.6	8.85	2.0E+6	0.213	5.86	78.4	157
Total mass in system (kg)	2131	526	678	1.4E+4	113	105.8	15.32	2.0E+6	0.237	6.5	325	274
Total mass dissolved in water (kg)	44.7	66.6	540	169	60	0.93	6.5E-4	1.1E+4	1.2E-4	6.0E-3	99	11.7
Total mass on settling particles (kg)	44.7	16.7	135	675	40	8.4	6.5	4.6E+4	0.024	0.64	148	106
Total mass in sediment pore water (kg)	0.41	0.89	2.4	6.9	6.5	0.97	0.09	1044	0.002	0.059	23.5	15.7
Total mass on particles in sediment (kg)	2041	442	1.01	1.3E+4	6.5	95.6	8.8	2.0E+6	0.211	5.8	54.9	141
Volatilization rate from water (kg/year)	393	853	0.07	22.7	67.6	0.34	1.2E-3	5.3E-3	1.6E-5	8.9E-5	162	43
Outflow rate from the lake (kg/year)	34	32	260	325	38.5	3.57	2.5	2.2E+4	0.009	0.25	94.8	45
Transformation rate in water (kg/year)	1.1	5	427	0.5	60.7	188	17.9	3.5	0.01	0.26	1496	713
Water to sediment transport rate (kg/year)	643	241	2074	9725	575	120	92.9	6.5E+5	0.34	9.16	2123	1515
Sediment to water transport rate (kg/year)	152	113	2072	6760	571	92.2	86.0	2.0E+5	0.20	5.47	2063	1388
Transformation rate in sediment (kg/year)	24.8	27	1.5	7.9	3.0	5.9	4.9	119	0.09	2.37	47.6	95
Burial rate from sediment (kg/year)	466	101	0.23	2957	1.5	21.8	2.0	4.5E+5	0.04	1.32	12.5	32
Total water concentration (ng/L)	0.18	0.17	1.4	1.7	0.20	0.02	0.013	117	4.9E-5	1.0E-3	0.51	0.24
Dissolved water concentration (ng/L)	0.09	0.14	1.1	0.35	0.12	1.9E-3	1.3E-6	23.5	2.5E-7	1.3E-6	0.20	0.02
Dissolved sediment concentration (ng/L)	2.9	6.3	16.7	48.6	46	6.8	0.63	7385	0.015	0.41	166.4	111
Sediment concentration (ng/g)	90	20	0.04	573	0.2	4.2	0.39	8.7E+4	0.009	0.26	2.4	6.3

Dield = Dieldrin
Fluor = Fluoranthene
Anth = Anthracene

Booty

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Table 11
Alewife

Parameter	PCBs	HCB	B(a)P	Hg	Dieldrin	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.45	0.03	0.61	2.8E-8	1.2E-4	0.41	6.6E-3	7.8E-6	1.7E-3	0.08	0.026	0.009
Concentration lipid (ng/g)	6423	461	8689	3.5E-4	1.7	5887	95	0.11	23.7	1143	380	127
Biomag factor wrt water	17.5	10.6	7.1	1.0	2.8	1611	1.3E+5	1.0	3.1E+4	2.3E+4	38	151
Biomag factor wrt sediment	0.56	0.23	0.47	0.007	0.008	0.45	0.28	0.01	0.50	0.503	0.05	0.03

Lake Trout

Parameter	PCBs	HCB	B(a)P	Hg	Dieldrin	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	2.1	0.08	2.2	5.6E-8	1.1E-4	1.7	0.02	1.8E-5	7.7E-3	0.37	0.027	0.007
Concentration lipid (ng/g)	1.3E+4	517	1.4E+4	3.5E-4	0.69	1.1E+4	125	0.11	48	2303	170	43
Biomag factor wrt water	35.7	11.9	11	1.0	1.13	2983	1.7E+5	1.0	6.2E+4	4.7E+4	17.0	51
Biomag factor wrt sediment	1.1	0.26	0.75	0.007	0.003	0.84	0.37	0.01	1.0	1.01	0.02	0.01

Sculpin

Parameter	PCBs	HCB	B(a)P	Hg	Dieldrin	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.82	0.05	0.96	2.8E-8	1.7E-4	0.77	0.011	8.9E-6	3.2E-3	0.16	0.04	0.013
Concentration lipid (ng/g)	1.0E+4	627	8689	3.6E-4	2.1	9603	142	0.11	39.8	1987	506	170
Biomag factor wrt water	27.6	14.4	7.1	1.0	3.4	2627	2.0E+5	1.0	5.1E+4	4.1E+4	50.7	202
Biomag factor wrt sediment	0.88	0.32	0.47	0.007	0.009	0.74	0.42	0.01	0.83	0.87	0.062	0.04

Smelt

Parameter	PCBs	HCB	B(a)P	Hg	Dieldrin	DDT	DDE	Lead	TCDD	TCDF	Fluor	Anth
Concentration (ug/g)	0.74	0.02	0.65	1.4E-8	4.5E-5	0.57	5.2E-3	4.5E-7	2.7E-3	0.15	0.008	2.7E-3
Concentration lipid (ng/g)	1.9E+4	496	1.6E+4	3.5E-4	1.1	1.4E+4	129	0.11	67	3830	214	67
Biomag factor wrt water	50.5	11.4	13	1.0	1.8	3891	2.0E+5	1.0	8.6E+4	7.9E+4	21.4	79
Biomag factor wrt sediment	1.6	0.25	0.9	0.007	0.005	1.09	0.39	0.01	1.4	1.69	0.026	0.017

Booty

Table 12

Chemical	Water Concentration (ng/L)		Sediment Concentration (ng/g)		Lake Trout Concentration (ug/g)	
	With mussels	Without mussels	With mussels	Without mussels	With mussels	Without mussels
PCBs	0.09	0.16	90	33	1.85	0.94
HCB	0.14	0.15	20	4.7	0.13	0.03
B(a)P	1.1	1.1	0.04	0.01	2.2	0.85
DDT	1.9E-3	2.1E-3	4.2	1.0	1.74	0.41
DDE	3.2E-7	4.1E-7	0.10	0.03	5.2E-3	1.4E-3

Booty

Table 13

| Chemical	Mean Measured Load	±90% CI	RateCon Terrestrial Loadings	Estimated Terrestrial Loadings	RateCon Mean Loadings	Model ±90% CI
PCBs	226	48	5900	750	61	1.3
Hg	440	10	3750	2584	325	17
B(a)P	140	33	118	431	260	16
Lead	73000	35000	1.4E06	4.2E05	22000	170
Fluoranthene	475	110	7300	NA	94.8	6
Anthracene	36	31	<0.0	28.5	45	4.8
HCB	4	0.1	<0.0	122	32	2.2
Dieldrin	31	2	45	76.4	38.5	1.0
DDT	3.5	2.4	44	129	5.5	0.4
DDE	16	2.2	800	NA	0.6	0.06

NA – not available
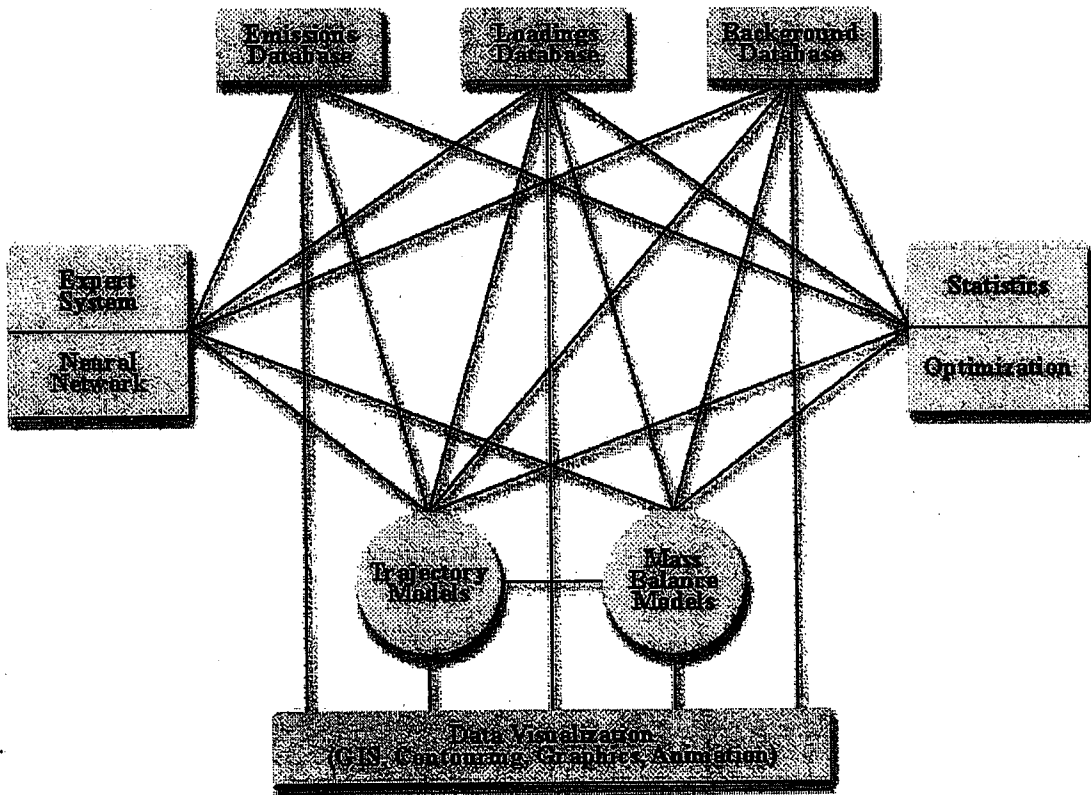
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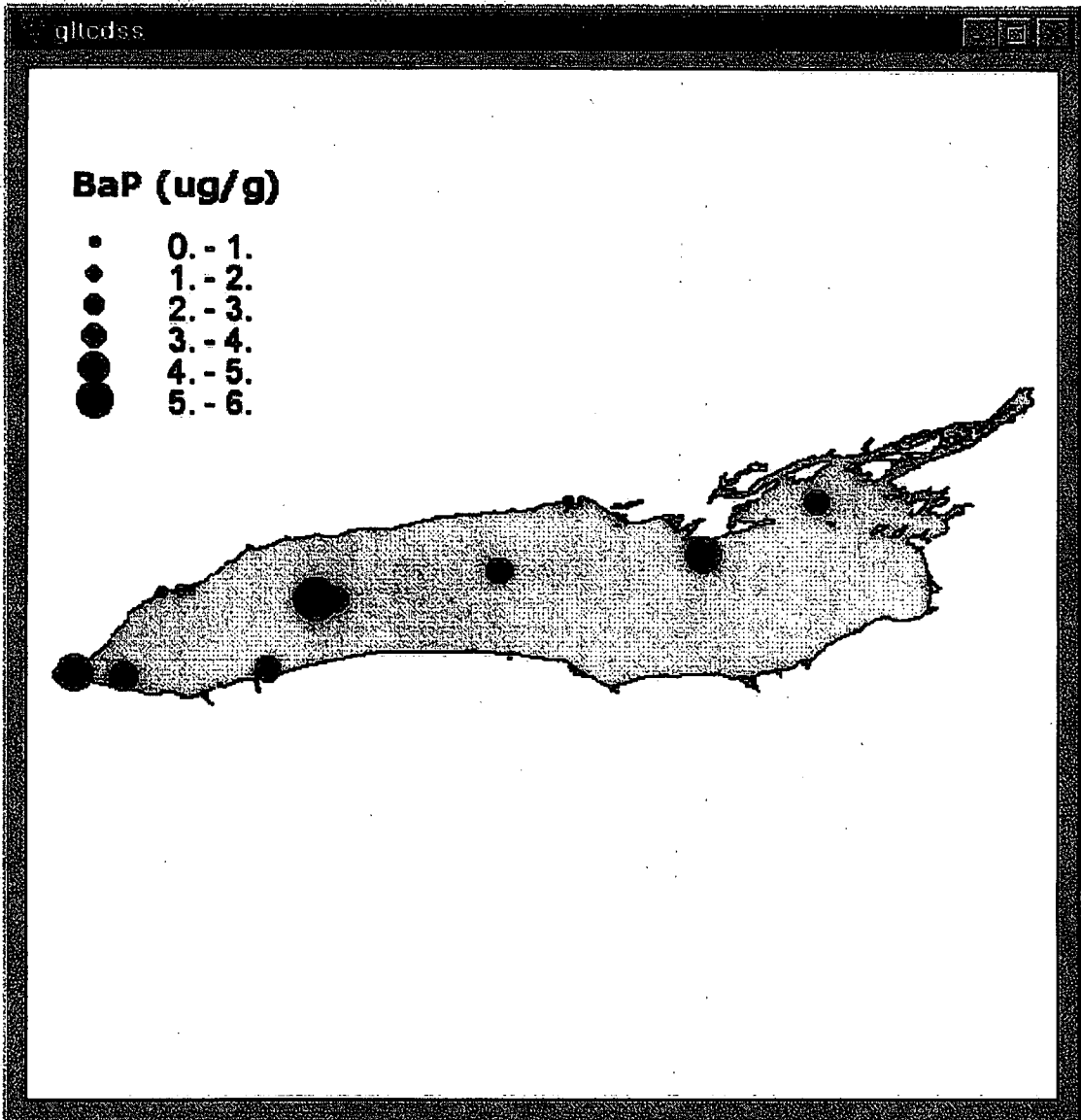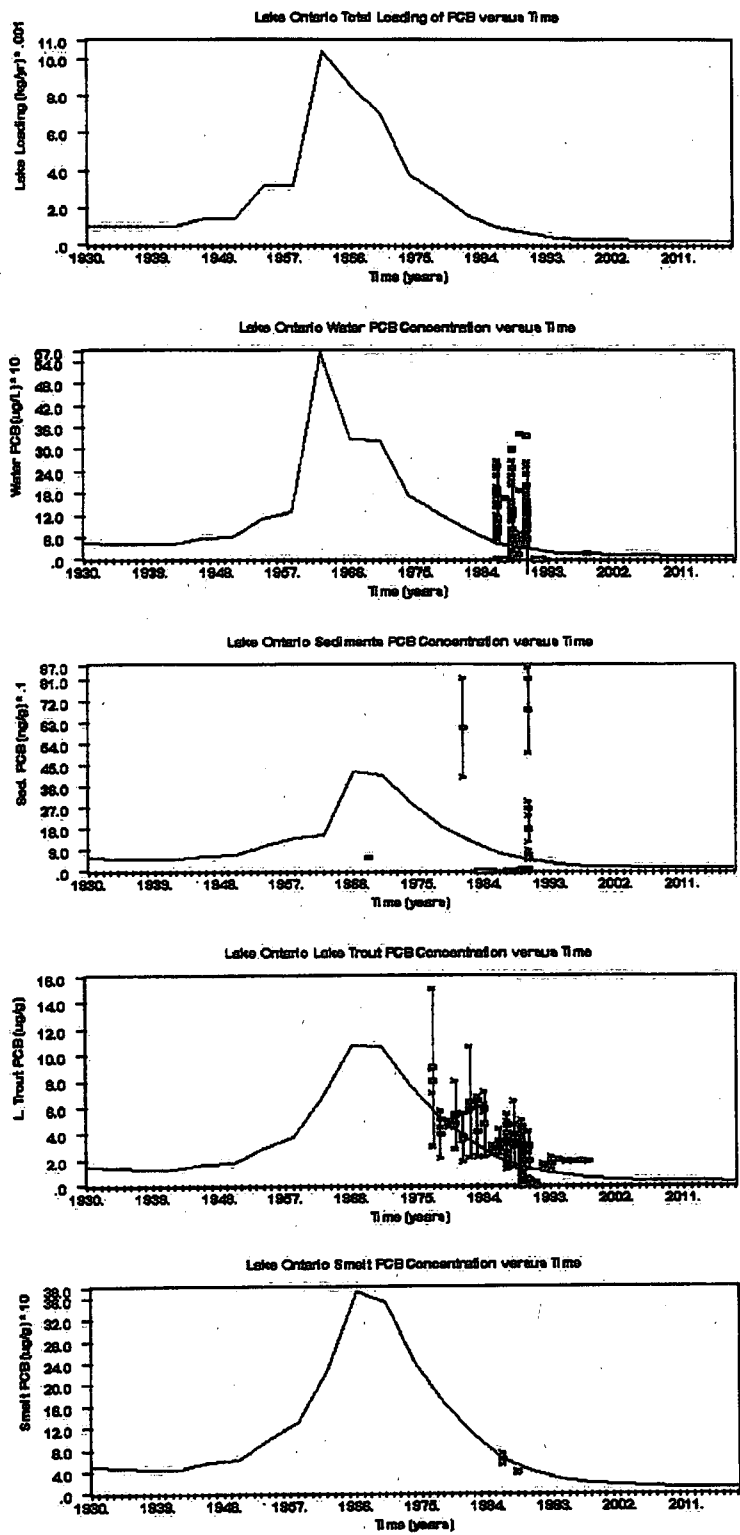
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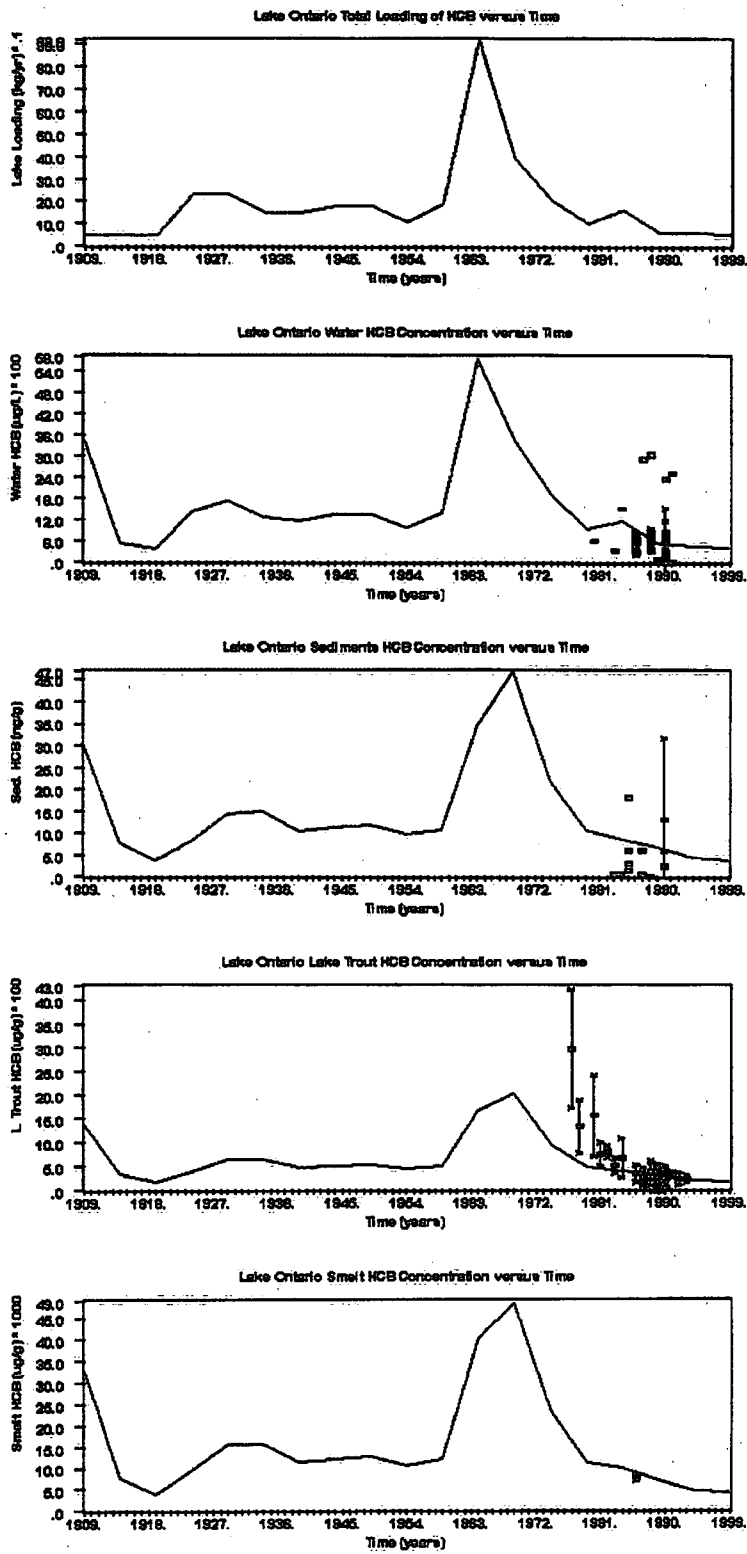
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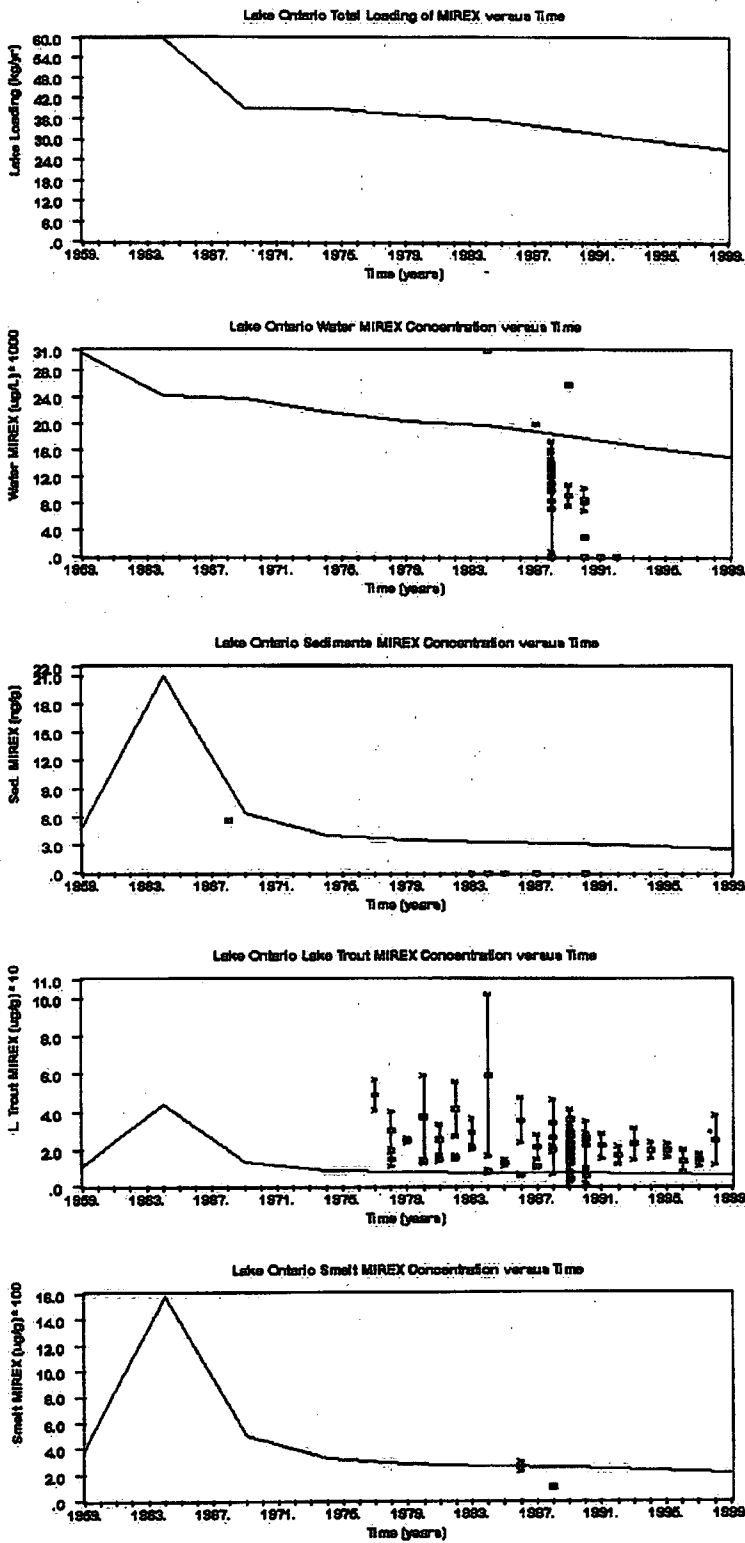
Figure 5

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