NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

MODELLING THE IMPACTS OF PCB DECOMMISSIONING IN THE LAKE SUPERIOR BASIN

Booty, W.G., C. McCrimmon and O. Rester

NWRI Contribution Number: 99-158

Modelling the Impacts of PCB Decommissioning in the Lake Superior Basin

Booty, W.G., C. McCrimmon and O. Rester

NWRI Contribution No. 99-158

Modélisation des impacts de l'élimination des PCB dans le bassin du lac Supérieur

Booty, W.G., C. McCrimmon et O. Rester

Contribution n° 99-158 de l'INRE

Key Words: Lake Superior, Mass Balance Modelling, PCB Decommissioning

Mots clés : lac Supérieur, modélisation du bilan massique, élimination des PCB

MANAGEMENT PERSPECTIVE

The Lake Superior Stage 2 LaMP, which focuses on load reductions and management options in support of Annex 2 of the Great Lakes Water Quality Agreement, includes a number of reduction targets for the 22 critical pollutants. These targets, which have been developed by the Lake Superior Binational Forum, need to be scientifically evaluated with regards to the reality of meeting virtual elimination of releases by 2020 and meeting the desired environmental goals specified within the Binational Program. At the request of the Lake Superior Binational Forum and with funding from OMOE, a mass balance model operating within the Great Lakes Toxic Chemical Decision Support System (GLTCDSS) was used to evaluate the impacts of various PCB decommissioning scenarios on lakewater, sediment, and biota for the period 1995 to 2020. This report gives an overview of the GLTCDSS, which was developed at NWRI in support of the Canada-Ontario Agreement (COA) to reduce pollutants in the Great Lakes. It also describes modifications to the RATECON mass balance model and how it was implemented within the GLTCDSS. Calibration of the model for PCBs in Lake Superior and calculations of the input loadings for the different decommissioning scenarios are provided. Finally, the outputs of the model for the various decommissioning scenarios are presented and the implications for the virtual elimination strategy are discussed.

SOMMAIRE À L'INTENTION DE LA DIRECTION

La deuxième étape du plan d'aménagement panlacustre du lac Supérieur, qui porte sur des réductions de charge et des options de gestion en application de l'annexe 2 de l'Accord sur la qualité de l'eau des Grands Lacs, prévoit un certain nombre d'objectifs pour la réduction de 22 polluants d'importance critique. On doit évaluer scientifiquement ces objectifs élaborés par le Forum binational du lac Supérieur par rapport aux objectifs d'élimination virtuelle prévus pour 2020 et aux objectifs environnementaux précisés dans le Programme binational. À la demande du Forum binational du lac Supérieur et avec le financement du ministère de l'Environnement de l'Ontario, on a utilisé un modèle de bilan massique utilisé dans le cadre du Système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs (SADCPCTGL) pour évaluer les impacts de divers scénarios d'élimination des PCB sur les eaux, les sédiments, et le biote du lac pour la période de 1995 à 2020. Ce rapport présente un aperçu du SADCPCTGL, élaboré par l'INRE en application de l'Accord Canada-Ontario (ACO) pour la réduction des polluants dans le bassin des Grands Lacs, et il décrit également des modifications apportées au modèle de bilan massique RATECON et sa mise en oeuvre dans le cadre du SADCPCTGL. On explique l'étalonnage du modèle utilisé pour les PCB pour le lac Supérieur et les calculs des apports pour différents scénarios d'élimination des PCB. Enfin, on présente les résultats du modèle pour les divers scénarios d'élimination des PCB, ainsi que les implications de la stratégie d'élimination virtuelle.

ABSTRACT

The impacts of various decommissioning schedules for PCB's currently stored within the Lake Superior Basin were evaluated through the application of the RATECON model operating within the Great Lakes Toxic Chemical Decision Support System. Model results indicate that compliance with the COA schedule versus the status quo condition over the period 1995-2000 results in slightly elevated lake water, sediment and biota concentrations. Compliance with the Forum schedule for decommissioning for the period 1995 to 2020 was found to result in concentrations in lake water, sediment and lake trout dropping from 0.09 ng/L, 32.5 ng/g, and .58 ug/g in 1995 to 0.01 ng/L, 5.15 ng/g, and 0.1 ug/g respectively in 2020.

RÉSUMÉ

On a évalué des impacts de divers plans d'élimination des PCB actuellement stockés dans le bassin du Lac Supérieur par l'application du modèle RATECON, utilisé dans le cadre du Système d'aide à la décision concernant les produits chimiques toxiques dans les Grands Lacs. Les résultats du modèle indiquent que l'application du calendrier de l'ACO, par rapport aux conditions de *statu quo* de la période de 1995 à 2000, entraîne des concentrations légèrement plus élevées dans les eaux, les sédiments et le biote du lac. On a constaté que, pour la période de 1995 à 2020, l'application du calendrier d'élimination des PCB du Forum entraînait des baisses de concentration de BPC dans les eaux, les sédiments et le touladi du lac de 0,09 ng/L, 32,5 ng/g et 0,58 µg/g (en 1995) à 0,01 ng/L, 5,15 ng/g, et 0,1 µg/g, respectivement.

MODELLING THE IMPACT OF PCB DECOMMISSIONING IN THE LAKE SUPERIOR BASIN

W.G. Booty, C. McCrimmon, and O. Resler
Aquatic Ecosystem Impacts Branch
National Water Research Institute
867 Lakeshore Rd., Burlington
Ontario L7R 4A6

Abstract: The impacts of various decommissioning schedules for PCB's currently stored within the Lake Superior Basin were evaluated through the application of the RATECON model operating within the Great Lakes Toxic Chemical Decision Support System. Model results indicate that compliance with the COA schedule versus the status quo condition over the period 1995-2000 results in slightly elevated lake water, sediment and biota concentrations. Compliance with the Forum schedule for decommissioning for the period 1995 to 2020 was found to result in concentrations in lake water, sediment and lake trout dropping from 0.09 ng/L, 32.5 ng/g, and .58 ug/g in 1995 to 0.01 ng/L, 5.15 ng/g, and 0.1 ug/g respectively in 2020.

Introduction

This study examines the effects of potential PCB decommissioning in the Lake Superior Basin, which has been suggested as one of the remediation actions to be carried out in support of the Canada-Ontario Agreement, the Binational Strategy for Virtual Elimination of Toxic Substances in the Great Lakes Basin and by the Work Group of the Lake Superior Binational Program, Lake Superior LaMP.
The production of PCBs has been banned since 1979, and efforts have focused on obtaining inventories of PCBs in the Lake Superior basin and to determining loads of PCBs from spills and other releases.

A load reductions schedule for PCB's had a goal of the destruction of accessible/in-control PCBs with a 5-10 year window to develop cost-effective solutions. Some of the guiding principles included:

1) emphasize destruction rather than storage (one-step rather than two-step process for destruction)
2) in-basin destruction is preferred where appropriate and practical
3) as out-of-control sources become accessible/in-control, management will follow the existing timeline for destruction
4) remove PCBs at the end of the useful lifespan of equipment

The recommendations for a timeline of destruction of accessible/in-control PCBs are:

Timeline (1995 baseline)

5 years (by the year 2000) -33%
10 years (by the year 2005) -60%
15 years (by the year 2010) -95%
25 years (by the year 2020) -100% or virtual elimination

In order to quantify the potential effects of decommissioning the stored PCBs within the Lake Superior watershed, a modified version of the RATECON model (Mackay et al., 1994) has been implemented within the Great Lake Toxic Chemical Decision Support System (GLTCDSS) (Booty et al., 1997) and has been run for the various loadings scenarios resulting from the recommended decommissioning procedures.

In this report we first give an overview of the GLTCDSS and it's features. Secondly the modifications to the RATECON model are described along with a description of how it was implemented into the GLTCDSS. Thirdly the calibration of the model for PCBs in Lake Superior for the period up to 1995 is described. Fourthly, the calculations of the input loadings for the different decommissioning scenarios are presented. Finally, the outputs of the model for the various decommissioning scenarios are presented and the implications for the virtual elimination strategy are discussed.

Methodology

Great Lakes Toxic Chemical Decision Support System

In support of the 1994 Canada-Ontario Agreement (CAO) to reduce pollutants in the Great Lakes, a decision support system has been developed and applied to answering management questions regarding the implementation and post-auditing of the zero-discharge and virtual elimination strategies for Tier I and Tier II chemicals. The RAISON for Windows Decision Support System shell that this system is based upon is the most recent version of RAISON (Regional Analysis by Intelligent Systems ON microcomputers) which has been developed over the last decade at the National Water Research Institute of Environment Canada (Lam and Swayne, 1993, Lam et al., 1995). The system consists of a number of modules such as a database, spreadsheet, GIS/Layer, statistics, expert system, contouring, spatial visualization, and graphs. The architecture is open in design and all of the modules are directly linked within the RAISON system with functions and tools including modelling interfaces, neural networks, uncertainty analysis, fuzzy logic, animation, visualization and optimization procedures.

In Figure 1 the conceptual design and component integration of the GLTCDSS is shown. Data within the system are divided into emissions, loadings and background data. The background data include all of the physical and chemical data that are required as input to the models and for model calibration/confirmation.

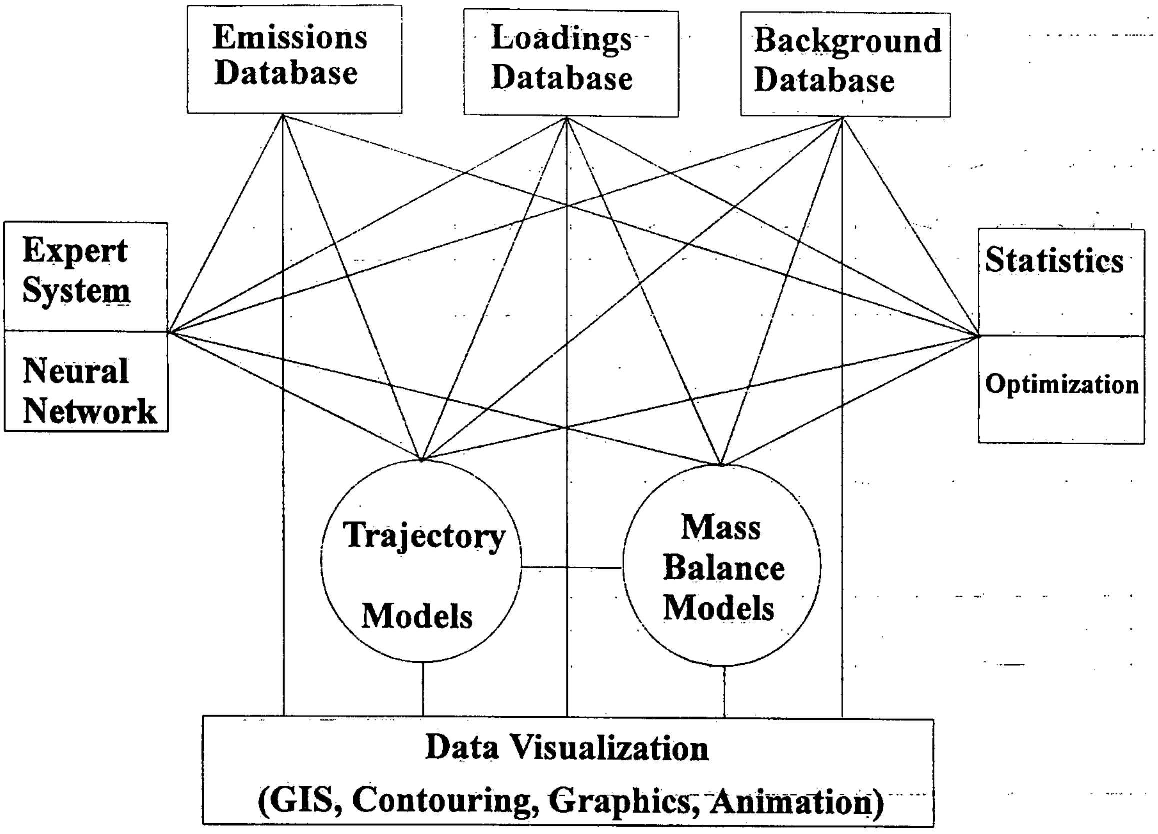

Figure 1 Great Lakes Toxic Chemical decision Support System schematic.

RATECON Model

The Rate Constant Model of Chemical Dynamics in a Lake Ecosystem (Mackay et al., 1994) consists of two components, a whole lake model and a food chain model. All process rates within the model are expressed as rate constants and operates in either steady-state or unsteady-state mode. It has been applied for PCBs in Lake Ontario (Mackay et al., 1994) and Lake Superior (Mackay et al., 1993).
In order to operate the model within the GLTCDSS most efficiently, the original Basic source code was converted to Visual Basic (VB) and a user-friendly VB interface was created for inputting data and running the model. Modifications were also made to the code to allow for variable loading for the unsteady-state numerical calculations. In addition, the program was modified to allow direct plotting of model outputs, storing and recalling unsteady-state results, and input data error checking. It was also modified to allow running the unsteady-state section of the model independently of the steady-state.

Scenario 1 Status Quo
No new in-basin or out-of basin actions which assumes that there will be 5%/yr decommissioning along with existing long-term spills and fires occurring at current rates. Based upon the quantity of PCBs being used and stored in the basin and upon current frequency of spills and cleanup efficiency, an estimated 53 kg/yr (31 kg/yr US side, 22 kg/yr on Canadian side) of PCBs enter the lake.

Scenario 2 Status Quo/ Binational Strategy
No additional in-basin actions but out-of basin controls are taken to meet Binational strategy for virtual elimination.

Scenario 3 Compliance with COA Schedule/Status Quo
In-basin compliance with COA schedule for removal of PCBs but status quo for out-of basin controls.

Scenario 4 Compliance with COA/Binational Strategy
In-basin compliance with COA schedule for removal of PCBs and out-of basin controls to meet Binational Strategy for virtual elimination.

Scenario 5 Compliance with Forum Schedule/Status Quo
In-basin compliance with Forum schedule and status quo for out-of basin actions. It is assumed that US loads remain the same.

Scenario 6 Compliance with Forum Schedule/Binational Strategy
In-basin compliance with Forum schedule and out-of basin controls to meet Binational Strategy.

COA Schedule for PCBs
Seek to decommission 90% of high-level PCBs , destroy 50% of the high-level PCB waste now in storage, and accelerate the destruction of stored low-level PCB waste, by the year 2000.

FORUM Schedule for PCBs

Timeline (1995 baseline) to Destroy Accessible/In-Control PCBs
- 5 years (by the year 2000) - 33 percent reduction
- 10 years (by the year 2005) - 60 percent reduction
- 15 years (by the year 2010) - 95 percent reduction
- 25 years (by the year 2020) - 100 percent or virtual elimination

Binational Strategy Affect on LRT of PCBs to Lake Superior Airshed
There has been no air modelling research carried out to evaluate the affect of reductions of PCBs outside of the Lake Superior Watershed on air concentrations within the airshed. Hoff et al, 1996 reviewed the IADN data from 1988 to 1994 and the estimated wet and dry deposition showed a large decrease between 1988 and 1992 (550 kg/yr - 160 kg/yr). Between 1992 and 1994, the loading estimates changed from 160 kg/yr to 85 kg/yr. If it is assumed that the PCB wet and dry deposition continues to follow the same trend in to the future, by the year 2000 the deposition rate will drop to 62 kg/yr (42.3 wet, 19.7 dry, 0.56 ng/m^3 air [ ]). By the year 2005 it would be 44 kg/yr (30 wet, 14 dry, 0.047 ng/m^3 air [ ]) by the year 2010 33 kg/yr (22.5 wet, 10.5 dry, 0.035 ng/m^3 air [ ]) and by the year 2020 25kg/yr (17.06 wet, 7.94 dry, 0.026 ng/m^3 air [ ]).

PCB Emissions due to Spills and Accidental Releases in the Canadian Basin
It is assumed that 0.4 percent of the PCBs in use are spilled annually with a 99.7 percent efficiency of cleanup when spilled to land. It is assumed that 1.7 percent of spills take place to media (ex. water) where recovery is only 50 percent. It is further assumed that 7.2 mg/kg of PCBs spilled are lost to the atmosphere by evaporation. The following scenario loadings assume the worst case scenario where all of the PCB released to the atmosphere eventually reaches the lake.

<u>Scenario 1 Loadings</u>

<u>Decommissioning</u>
1995-2000
5% decommissioning /yr
5% of PCBs = 23,611 kg
1% = 236 kg
Land Load = 0.708 kg/yr
Air Load = 0.0017 kg/yr
Water Load = 2.0 kg/yr

<u>Decommissioning plus Spills</u>
1995-2000
Land = 5.6 +8.0 + 0.708 = 14.308 kg/yr
Air = 0.013 + 0.02 + 0.0017 = 0.0347 kg/yr
Water = 16.0 + 22.6 + 2.0 = 40.6 kg/yr

2001-2005
Land = 0.75x5.6 + 8.0 + .708 = 12.908
Air = 0.75x0.013 + 0.02 + .0017 = 0.0314
Water = 0.75x16.0 + 22.6 +2.0 = 36.6

2006-2010
Land = 0.5 x5.6 + 8.0 + .708 = 11.508
Air = 0.5x.013 + 0.02 + .0017 = 0.0282
Water = 0.5x 16.0 + 22.6 + 2.0 = 32.6

2011-2015
Land = 0.25x5.6 + 8.0 +.708 = 10.108
Air = 0.25x0.013 + .02 + .0017 = 0.02495
Water = 0.25x16.0 + 22.6 + 2.0 = 28.6
<u>Scenario 3 Loadings</u>
1995-2000

<u>Decommissioning</u>

90 % decommissioning/5 yrs = 18%/yr

18% of PCBs = 85,000 kg
1% = 850 kg

Land Load = 2.55 kg/yr
Air Load = 0.0061 kg/yr
Water Load = 7.225 kg/yr

Decommissioning plus Spills

1995

Land Load = 5.6 + 8.0 + 2.55 = 16.15 kg/yr
Air Load = 0.013 + 0.02 + 0.0061 = 0.0391 kg/yr
Water Load = 16.0 +22.6 + 7.225 = 45.825 kg/yr

1996

Land Load = 0.82x5.6 + 8.0 +2.55 = 15.142 kg/yr
Air Load = 0.82x0.013 + 0.02 + .0061 = 0.0368 kg/y
Water Load = 0.82x16.0 + 22.6 + 7.225 = 42.945 kg/yr

1997

Land Load = 0.64x5.6 + 8.0 +2.55 = 14.134 kg/yr
Air Load = 0.64x0.013 + 0.02 + 0.0061 = 0.0344 kg/yr
Water Load = 0.64x16.0 + 22.6 + 7.225 = 40.065 kg/yr

1998

Land Load = 0.46x5.6 + 8.0 + 2.55 = 13.126 kg/yr
Air Load = 0.46x0.013 + 0.02 + .0061 = 0.032 kg/yr
Water Load = 0.46x16.0 + 22.6 + 7.225 = 37.185 kg/yr

1999

Land Load = 0.28x5.6 + 8.0 +2.55 = 12.118 kg/yr
Air Load = 0.28x0.013 + 0.02 + 0.0061 = 0.0297 kg/yr
Water Load = 0.28x16.0 + 22.6 + 7.225 = 34.305 kg/yr

2000

Land Load = 0.1x5.6 + 8.0 + 2.55 = 11.11 kg/yr
Air Load = 0.1x0.013 + 0.02 + 0.0061 = 0.0274 kg/yr
Water Load = 0.1x16.0 + 22.6 + 7.225 = 31.425 kg/yr

Scenario 5 Loadings Calculations

Decommissioning

1995-2000

33% of total PCBs = 157,392 kg
1% = 1574 kg
Land load = 4.72kg/5 yrs = 0.94 kg/yr

Air Load = 0.011 kg/5yrs = 0.00226 kg/yr
Water Load = 13.38 kg/5 yrs = 2.68 kg/yr

2001-2005
27% of PCB's = 127,500 kg
1% = 1275 kg
Land Load = 3.82kg/5 yrs = 0.765 kg/yr
Air Load = 0.0092kg/5yrs = 0.0018 kg/yr
Water Load = 10.84 kg/5 yrs = 2.17 kg/yr

2006-2010
35% of PCBs = 165,279 kg
1% = 1653 kg
Land Load = 4.96/5 yrs = 0.992 kg/yr
Air Load = 0.0119kg/5yrs = 0.0024 kg/yr
Water Load = 14.05/5yrs = 2.81 kg/yr

2011-2020
5% of PCBs = 23,611 kg
1% = 236 kg
Land Load = 0.708 kg/10yrs = 0.0708 kg/yr
Air Load = 0.0017kg/10yrs = 0.00017 kg/yr
Water Load = 2.0kg/10yrs = 0.2 kg/yr

Decommissioning and Spills

1995-2000
Land = 5.6 + 8.0+ 0.94 = 14.54 kg/yr
Air = 0.013 +0.02 + 0.00226 = 0.03526 kg/yr
Water = 16.0 + 22.6 + 2.68 = 41.28 kg/yr

2001-2005
Land = 0.67x5.6 + 8.0+ 0.765 = 12.517 kg/yr
Air = 0.67x0.013 +0.020 + 0.0018 = 0.0305 kg/yr
Water = 0.67x16.0 + 22.6+ 2.17 = 35.49 kg/yr

2006-2010
Land = 0.4x5.6 + 8.0 + 0.992 = 11.512 kg/yr
Air = 0.4x0.013 + 0.02 + 0.0024 = 0.0276 kg/yr
Water = 0.4x16.0 + 22.6 + 2.81 = 31.81 kg/yr

2011-2020
Land = .05x5.6 + 8.0 + 0.07 = 8.35 kg/yr
Air = .05x.013 + 0.02 + 1.7E-04 = 0.02082 kg/yr
Water = .05x16.0 + 22.6+0.2 =23.6 kg/yr

Results

Model Calibration

The rate constants used for the steady-state calibration of the model are shown in Table 1. Data from 1980 to 1992 showed that the total PCB water concentrations decreased by a first order rate of 0.2 yr^{-1}. Total PCB lakewater concentration in 1980 was 2.4 ng/L and dropped to 0.18 ng/L by 1992. In 1995 the concentration was 0.09 ng/L

Table 1 Mass Balance Calculation of the Fate of PCB in Lake Superior
Rate Constants (yrs-1), PCB

Evaporation from water (y-1)	0.75177
Outflow from lake (y-1)	0.005236
Transformation in water (y-1)	0.012141
Water to sediment transport (y-1)	0.346563
Water to sediment deposition (y-1)	0.343034
Water to sediment diffusion (y-1)	0.003528
Sediment to water transport (y-1)	0.143588
Sediment to water resuspension (y-1)	0.116782
Sediment to water diffusion (y-1)	0.026806
Transformation is sediment (y-1)	0.012141
Burial from sediment (y-1)	0.036494
Total rate Constant from Water (y-1)	1.115709
Total rate Constant from Sediment (y-1)	0.192224
Rate of water concentration change (y-1)	-0.2
Rate of sediment concentration change (y-1)	-0.02

The values used for the key parameters in the model are shown in Table 2.

Table 2 Mass Balance Calculation of the Fate of PCB in Lake Superior
key parameters

Water surface area (m2)	82100000000
Sediment surface area as fraction of water area	0.75
Sediment Area (m2)	61580000000
Water volume (m3)	1.223E+13
Sediment Volume (m3)	307900000
Mean Water Depth (m)	148.9647
Sediment active layer depth (m)	0.005
Water residence time based on outflow (y)	191
Concentration of particles in water column (mg/L)	0.5
Suspended solids mass (kg)	6115000000
Volume fraction particles in surface sediment	0.1
Solids Concentration in bottom sediment (mg/L)	200000
Density of sediment particles (Kg/m3)	2000
Sediment solids mass (kg)	61580000000

Organic carbon content of sediment	0.02
Fraction chemical on depositing particles	0.2
Fraction dissolved in Water	0.8
Fraction Chemical on particles in sediment	0.999847
Fraction chemical dissolved in sediment	0.000153
Fraction Chemical sorbed in atmosphere	0.05
Fraction gaseous chemical in atmosphere	0.95
Scavenging ratio	100000
Dry Deposition Velocity (m/h)	7.2
Rain rate (m/y)	0.76
Temperature (C)	8
Air-Water exchange MTC: air side (m/h)	15.9
Air Water exchange MTC: water side (m/h)	0.02
Overall water side MTC (m/h)	0.01598
Air-Water Partition coefficient	0.005
Log octanol-water partition coefficient	6.6
Octanol-water partition coefficient	3981000
Sediment-water diffusion MTC (m/h)	0.0001
Transformation half life in water (h)	500000
Transformation half life in sediment (h)	500000
Transformation rate constant in water (h-1)	0.000001386
Transformation rate constant is sediment (h-1)	0.000001386
Deposition rate of solids water area per day (g/m2/d)	0.35
Deposition Rate sediment area (g/m2/d)	0.466667
Resuspension rate of solids sediment area per day (g/m2/d)	0.32
Burial rate of solids sediment area per day (g/m2/d)	0.1
Ratio deposition per year to particles in water	1.715172
Ratio deposition per year to sediment solids	0.170333
Mass particles depositied per year (kg)	10490000000
Ratio resuspension per year to sediment solids	0.1168
Mass sediment buried per year (kg)	7192000000
Ratio sediment buried per year to sediment solids	0.0365
Mass sediment buried per year (kg)	2247000000

The steady state mass balance diagram is shown in Figure 2. These results are in close agreement with those of Jeremiason et al. They assumed that tributary loadings of PCB was 110 kg/y, based upon a mean PCB concentration of 2 ng/L in all tributaries and a total inflow rate of 5.4 x 10^{13} L/year. The 2 ng/L is based upon remote PCB rain concentrations in Eisenreich et al. However, in Hoff et al, the rain concentration of PCB's is given as 1.2 ng/L, which gives a loading of 65 kg/yr, which is closer to the 73 kg/yr determined by Dolan, 1992, which was based upon measurements from 20 tributaries. Hoff et al calculated wet atmospheric loadings of 58 kg/yr (+/- 22%), dry atmospheric loadings of 27 kg/yr (+/- 100%), and absorption of 320 kg/yr (+/- 110%). The RATECON model was run with the wet and dry values of Hoff et al.

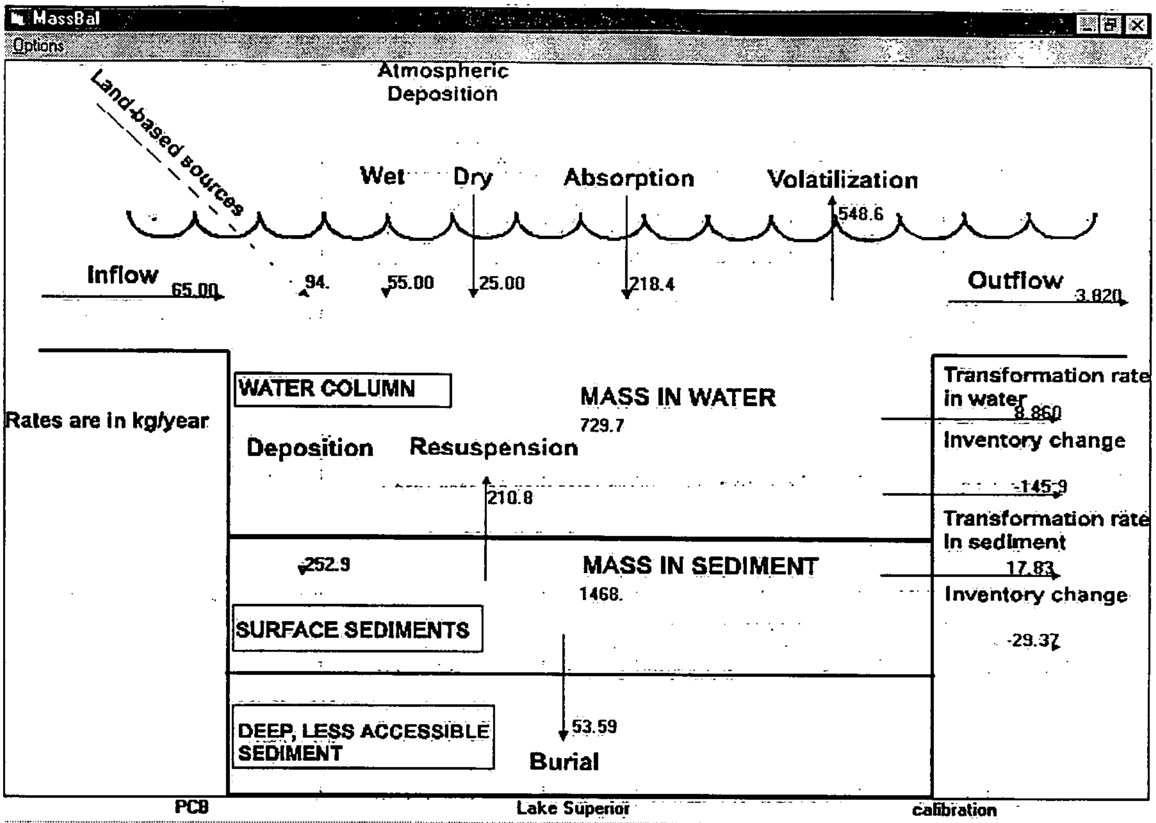

Figure 2 Calibration mass balance diagram for steady state PCB in Lake Superior for 1995.

Table 3 Mass Balance Calculation of the Fate of PCB in Lake Superior
Mass balance summary and concentrations, PCB

Total mass in water (kg)	729.7109
Total mass in sediment (kg)	1468
Total mass in system (kg)	2198
Total mass dissolved in water (kg)	583.7687
Total mass on settling particles in water (kg)	145.9422
Total mass dissolved in sediment pore water (kg)	0.224663
Total mass on particles in sediment (kg)	1468
Inputs of chemical to the Lake (kg/year)	
Total inputs to the lake (kg/y)	457.3609
Municipal point sources (kg/y)	21
Industrial point sources (kg/y)	20
Tributary loadings (kg/y)	65
Other and non-point loadings (kg/y)	53
Total inputs to the water except atmospheric (kg/y)	159
Rain dissolution (kg/y)	1.18552
Wet deposition of particles (kg/y)	31.198
Total wet deposition (kg/y)	55
Dry deposition (kg/y)	25
Absorption (kg/y)	218.3609

Total atmospheric inputs (kg/y)	298.3609
Input concentrations	
Concentration in rain (ng/L)	0.881467
Concentration in air (ng/m3)	0.1
Concentration in air in gaseous form (ng/m3)	0.095
Concentration in air in aerosol form (ng/m3)	0.005
Process rates (kg/year)	
k1 evaporation rate from water (kg/y)	548.5746
k2 outflow rate from the lake (kg/y)	3.820476
k3 transformation rate in water (kg/y)	8.859683
k4 water to sediment transport rate (kg/y)	252.8906
k5 sediment to water transport rate (kg/y)	210.8422
k6 transformation rate in sediment (kg/y)	17.8282
k7 burial rate from sediment (kg/y)	53.58789
Total rate of removal from water (kg/y)	814.1453
Total rate of removal from sediment (kg/y)	282.2583
Water to sediment deposition rate (kg/y)	250.3159
Water to sediment diffusion rate (kg/y)	2.574678
Sediment to water resuspension rate (kg/y)	171.4812
Sediment to water diffusion rate (kg/y)	39.36097
Water inventory change (kg/y)	-145.9422
Sediment inventory change (kg/y)	-29.36772
Concentrations	
Total water concentration (ng/L)	0.059666
Dissolved water concentration (ng/L)	0.047733
Total sediment concentration (ng/L)	4769
Dissolved sediment concentration (ng/L)	0.729722
Sorbed sediment concentration (ng/L)	4769
Total water concentration (kg/m3)	5.967E-11
Total sediment concentration (kg/m3)	4.769E-06
Sediment concentration on solids (ng/g)	23.84346
Sediment concentration in organic carbon (ng/g)	1192

In Table 4 the steady state concentrations for the food chain are shown.

Table 4 Mass Balance Calculation of the Fate of PCB in Lake Superior
Food chain parameters and concentrations, PCB

Organism	Zooplankton	Sculpin	Smelt	Lake Trout
Concentration (ng/kg)	9501	201800	185200	529100
Concentration (ug/g)	0.009501	0.201786	0.185155	0.529092
Concentration lipid (ng/g)	190.0266	2522	4629	3307
Biomag factor wrt water	1	13.27356	24.35914	17.40191
Biomag factor wrt sed	0.065412	0.868249	1.593379	1.138293

Scenario 1Status Quo

In figures 3-5 the scenario1 model results are presented for concentrations in water, sediment and lake trout for the period 1995-2020.

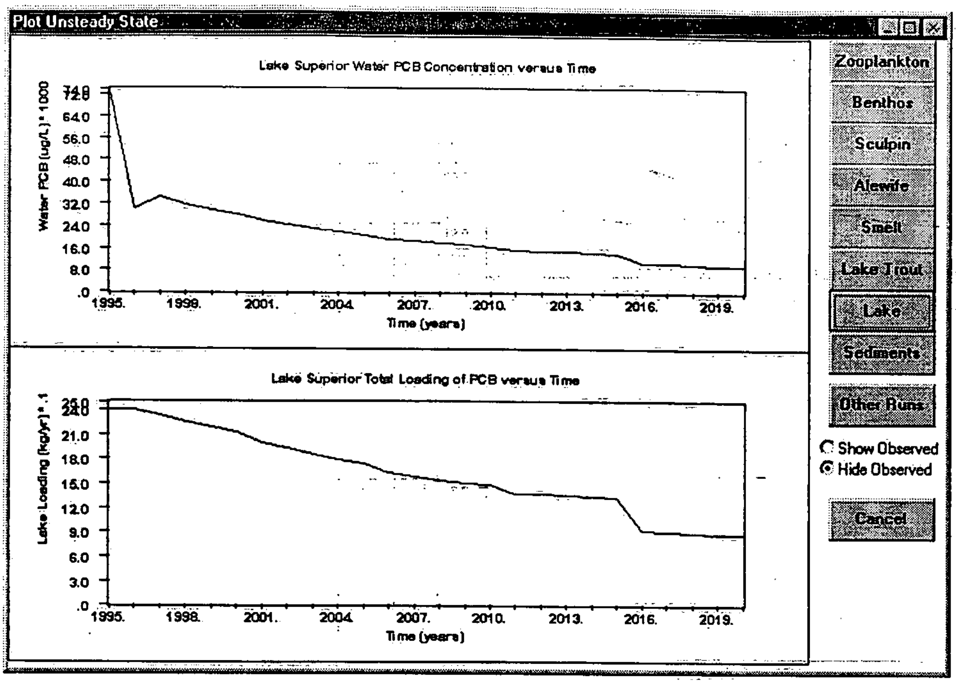

Figure 3 Status quo scenario 1 prediction of total water concentration of PCB.

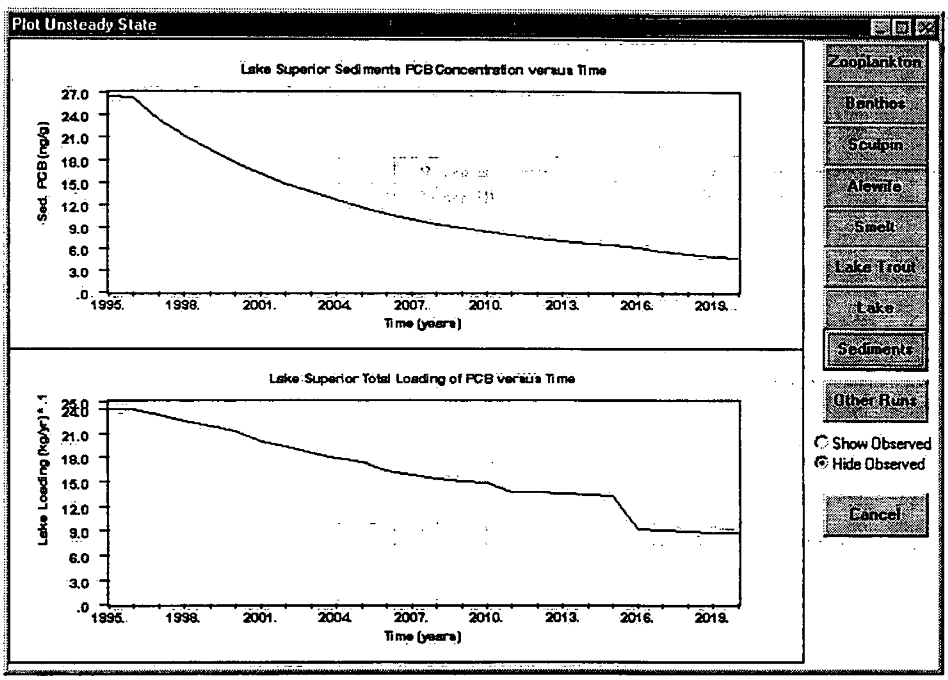

Figure 4 Status quo scenario1 model prediction of sediment concentration of PCB.

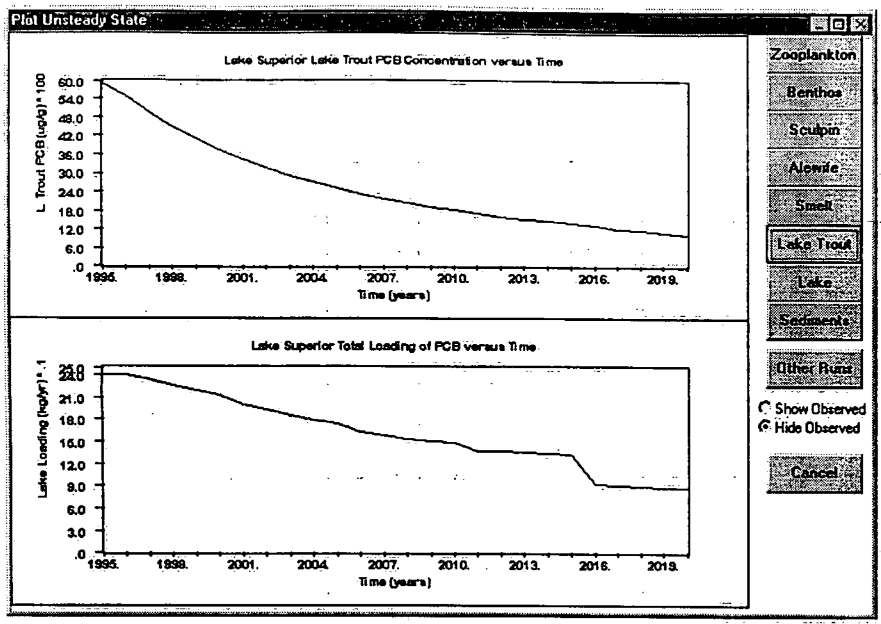

Figure 5 Status quo scenario1 model prediction of lake trout PCB concentrations.

Scenario 3

In Figures 6-8 the COA schedule for compliance schedule PCB concentrations for water, sediment and lake trout are presented.

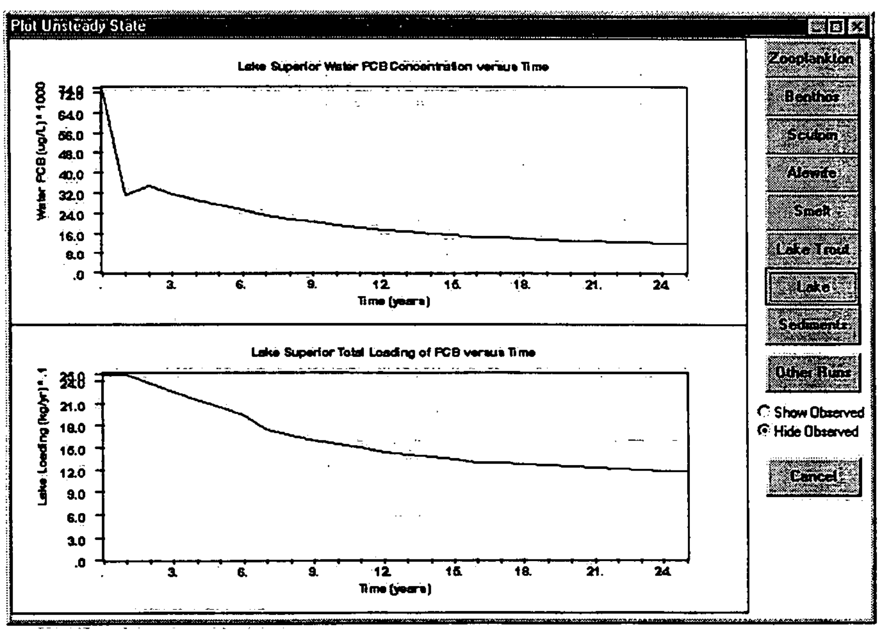

Figure 6 Scenario 3 Total water concentrations of PCB

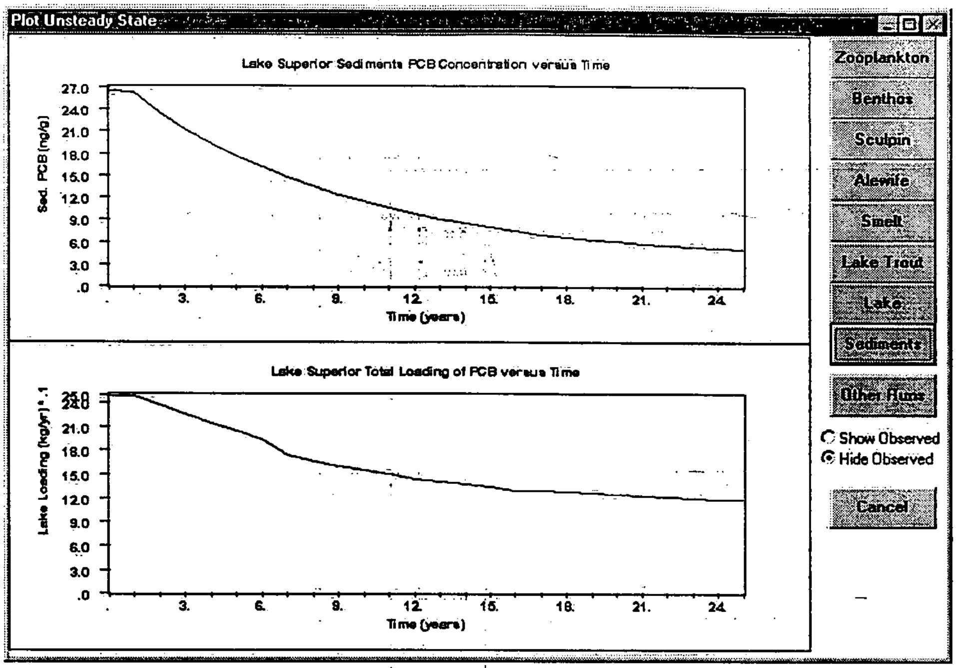

Figure 7 Scenario 3 Sediment concentrations of PCB

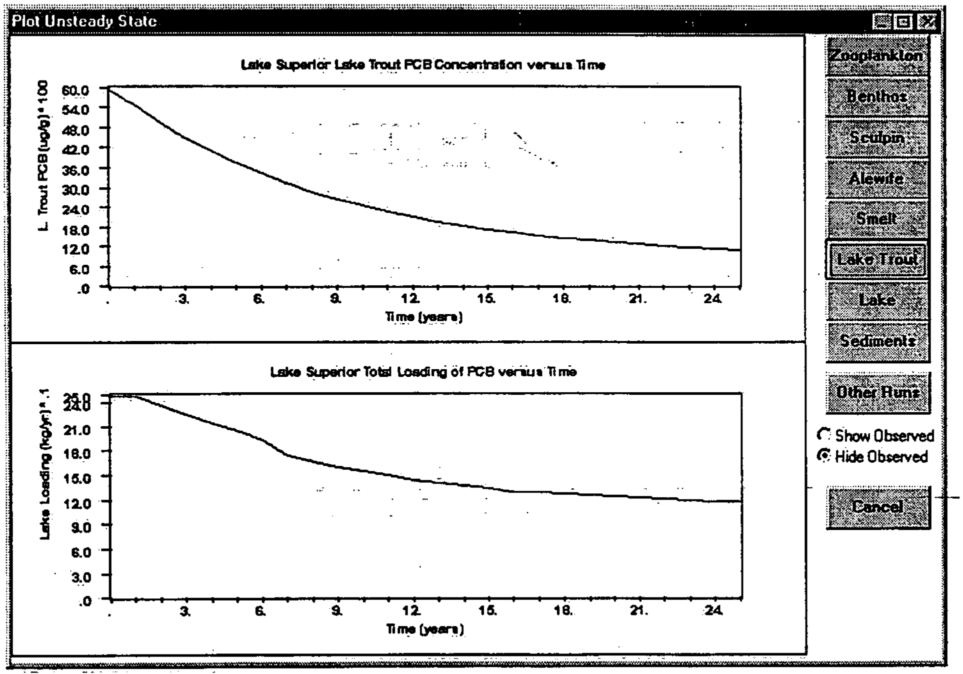

Figure 8 Scenario 3 lake trout PCB concentrations

Scenario 5 Forum Schedule
The results of the Forum reductions from the period 1995 to 2020 are shown in Figures 9-11

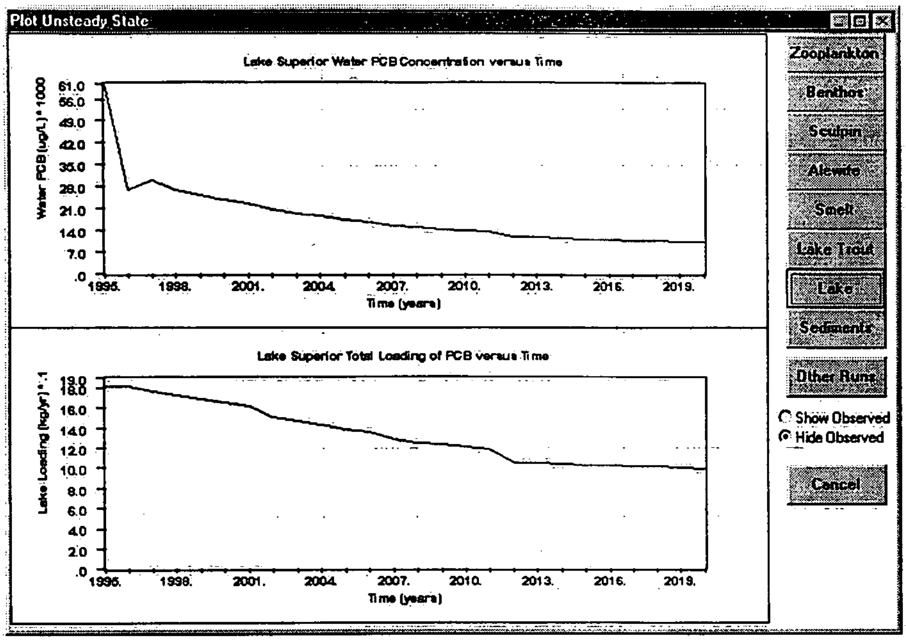

Figure 9 Scenario 5 Whole lake water concentrations for PCB

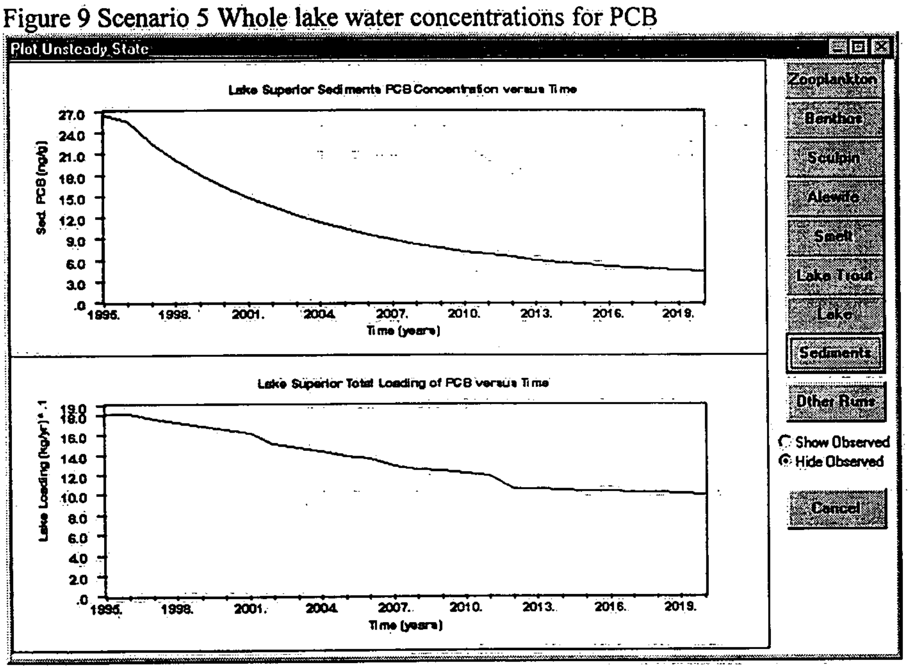

Figure 10 Scenario 5 Whole lake sediment PCB concentrations

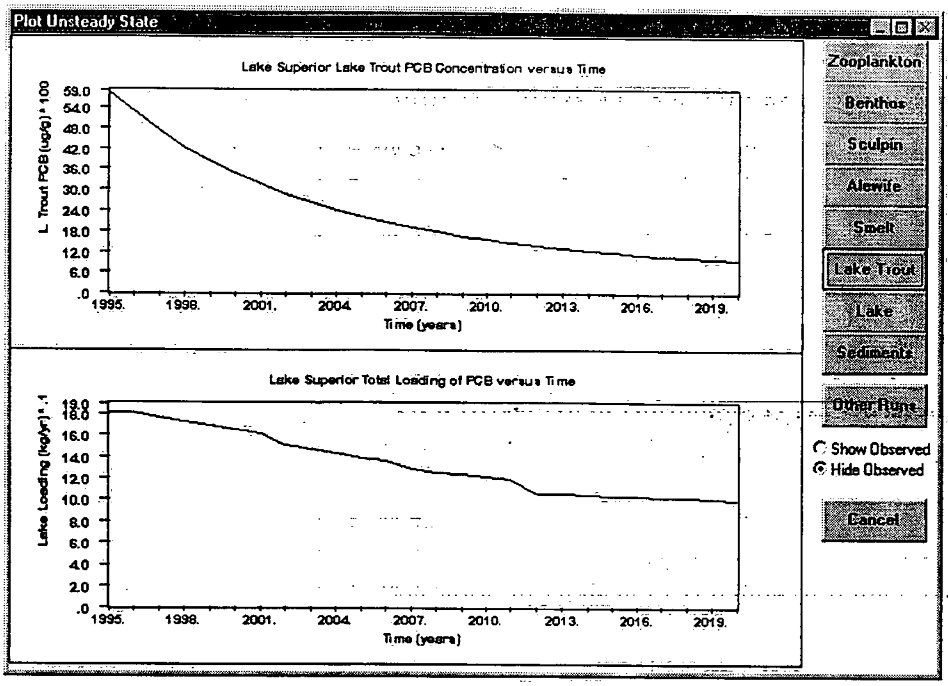

Figure 11 Scenario 5 Lake trout PCB concentrations

Conclusions

The steady state model results for the decommissioning of PCB's for the period 1995-2000, as represented by scenario 3 in compliance with the COA schedule, results in a slightly higher total mass in the lake water (744.1 kg) as compared to scenario 1 (732.8 kg), as expected from the increased loadings. Total sediment concentration for scenario 3 is expected to be 4863 ng/L as compared to the scenario 1 concentration of 4790 ng/L. The model predicts that this increased loading will result in a slight increase in lake trout concentration from 0.531 ug/g for scenario 1 to 0.539 ug/g for scenario 3.

The scenario 5 unsteady state model results indicate that water concentrations of PCB are expected to decrease from 0.04 ng/L in 1995 to 0.01 ng/L in 2020. Lake sediment PCB concentrations are predicted to decrease from 32.5 ng/g in 1995 to 4.45 ng/g in 2020. Lake trout PCB concentrations are expected to drop from 0.58 ug/g in 1995 to 0.1 ug/g in 2020.

It appears that the decommissioning of the PCB's in the watershed will result in marginal short term increases in levels within the lake water, sediment, and biota, but these will quickly be lowered due to the greater overall rates of losses from the system and the decreasing trend in atmospheric loadings currently observed.

References

Booty, W.G., Lam, D.C.L., Tseng, T., Smith, I. and Siconolfi, P. 1997. Great Lakes Toxic Chemical Decision Support System. In: Environmental Software Systems, Volume 2, IFIP TC5 WG5.11, April 28-May 2, 1997, British Columbia, Canada, Chapman & Hall, pp. 95-101.

De Vault, D.S., Hesselberg, R., Rodgers, P.W., and Feist, T.J. 1996. Contaminant Trends in Lake Trout and Walleye From the Laurentian Great Lakes. J. Great Lakes Res. 22(4):884-895.

Hoff, R.M., Strachan, W.M. J., Sweet, C.W., Chan, C.H., Shackelton, M., Bidleman, T.F., Brice, K.A., Burniston, D.A., Cussion, S., Gatz, D.F., Harlin, K. and Schroeder, W.H. 1996. Atmospheric Deposition of Toxic Chemicals to the Great Lakes: A Review of Data Through 1994. Atmospheric Environment Vol. 30, No. 20, pp. 3505-3527.

Hornbuckle, K.C., Jeremiason, J.D., Sweet, C.W., and Eisenreich, S.J. 1994. Seasonal variation in air-water exchange of polychlorinated biphenyls in Lake Superior. Environ. Sci. Technol. 28:1491-1501.

Jeremiason, J.D., Hornbuckle, K.C. and Eisenreich, S.J. 1994. PCBs In Lake Superior, 1978-1992: Decreases in Water Concentrations Reflect Loss by Volatilization. Environ. Sci. Technol. 28, 903-914.

Lake Superior Work Group, Lake Superior Binational Program, *Lake Superior Lakewide Management Plan (LaMP): Load Reduction Targets for Critical Pollutants*, LaMP Volume II - Critical Pollutants, Stage 2 - Load Reductions/Managment Options, September, 1996.

Mackay, D., Sang, S., Vhahos, P, Diamond, M., Gobas, F., and Dolan, D. 1994. A Rate Constant Model of Chemical Dynamics in a Lake Ecosystem: PCB's in Lake Ontario. J. Great Lakes Res. 20(4):625-642.

Mackay, D., Diamond, M., Gobas, F. and Dolan, D. 1992. Virtual Elimination of Toxic and Persistent Chemicals from the Great Lakes: The Rôle of Mass Balance Models. A report prepared for the International Joint Commission, January, 1992.

Pearson, R.F., Swackhamer, D.L., Eisenreich, S.J., and Long, D.T. 1998. Atmospheric Inputs of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans to the Great Lakes: Compositional Comparison of PCDD and PCDF in Sediments. J. Great Lakes Res., 24(1):65-82.

Rappaport, R.A. and Eisenreich, S.J. 1988. Historical Atmospheric Inputs of High Molecular Weight Chlorinated Hydrocarbons to eastern North America. Environ. Sci. Technol. 22, 931-941.

Virtual Elimination Task Force (VETF) 1993. *A Strategy for the Virtual Elimination of Persistent Toxic Substances*. International Joint Commission, Vol. I (72p) and II (112p).

NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
Canada L7R 4A6

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington; (Ontario)
Canada L7R 4A6

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
Canada S7N 3H5

Centre national de recherche en hydrologie
11, boulevard Innovation
Saskatoon; (Saskatchewan)
Canada S7N 3H5