

NOAA Technical Memorandum ERL GLERL-57

THE COUPLED LAKES MODEL FOR ESTIMATING THE LONG-TERM RESPONSE  
OF THE GREAT LAKES TO TIME-DEPENDENT LOADINGS  
OF PARTICLE-ASSOCIATED CONTAMINANTS

John A. Robbins

Great Lakes Environmental Research Laboratory  
Ann Arbor, Michigan  
April 1985



UNITED STATES  
DEPARTMENT OF COMMERCE

Malcolm **Baldrige**,  
**Secretary**

NATIONAL OCEANIC AND  
ATMOSPHERIC ADMINISTRATION

Environmental Research  
Laboratories

Vernon **E. Derr**,  
Director

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THE COUPLED LAKES MODEL FOR ESTIMATING  
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TIME-DEPENDENT LOADINGS OF PARTICLE-ASSOCIATED CONTAMINANTS<sup>1</sup>

J.A. Robbins

The Coupled Lakes Model is a mathematical formalism and associated computer program for estimating the response of each of the Great Lakes to time-dependent loadings of tracers and contaminants. The model characterizes inputs arising from atmospheric delivery directly to the lakes and indirectly as losses from the drainage basins. The model treats the lakes as though instantaneously mixed and assumes equilibrium partitioning of constituents between water and suspended solids. Included in the formalism are the effects of particle settling, resuspension, mixed layer integration, radioactive decay and other first-order biogeochemical losses. Cs-137 (cesium-137), and Pu-239/240 (plutonium-239/240), in combination with measured concentrations in water and in resuspended materials, provide an excellent preliminary calibration of the model.

## 1. INTRODUCTION

The Coupled Lakes Model (CLM) is a mathematical formalism and associated computer program for estimating the long-term response of the Great Lakes to time-dependent loadings of particle-associated tracers and contaminants. The model uses estimated monthly rates of atmospheric deposition to the surface and drainage basin of each lake to compute concentrations in the water column and in resuspended sediments. Major assumptions of the model are

(1) The primary delivery route is through wet and dry fallout to the lake surface.

(2) Contributions from the drainage basin are small and the result primarily of the accumulation of atmospheric deposition. The losses from the drainage basin are characterized by a single residence time.

(3) Each lake is rapidly and uniformly mixed. This assumption can only be valid for estimating the long-term (yearly) response of the system.

(4) The partitioning of tracers and contaminants between water and solids is characterized by a single time-invariant coefficient.

(5) Constituents are removed from the water column primarily on settling particles and returned to it via resuspension from a well-mixed pool of resuspendible sedimentary material. Diffusional exchange is unimportant.

(6) The exchange between the resuspendible pool and underlying sediments is characterized by a single residence time.

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<sup>1</sup> GLERL Contribution No. 454.

(7) The mean concentration of solids in the water is constant and reflects the balance between loadings and losses through sedimentation and outflow.

(8) All removal processes (e.g., photolysis, evaporation, chemical or biological degradation, radioactive decay) are first order in nature. More complex representations are generally not justified by the quality of the available data.

## 2. DERIVATION

The schematic diagram of the processes considered in this mode are shown in figure 1. Through mass balance, the total mass of solids in the lake,  $mV$ , is related to the mass loading,  $L_m$ , by

$$V \frac{dm}{dt} = L_m - A_L J_- + A_L J_+ - Qm. \quad (1)$$

(See appendix A for the definitions of all terms used here and in other equations.) Since the mean concentration of solids is assumed to be constant,  $dm/dt = 0$ , and the net sedimentation rate,  $R$ , is given by

$$R = (L_m - Qm)/A_L = J_- - J_+. \quad (2)$$

Thus, the downward settling flux is

$$J_- = (1 + \beta)R, \quad (3)$$

while the resuspension flux is  $J_+ = \beta R$ .

Mass balance for a constituent in the water is

$$\begin{aligned} V \frac{dc_t}{dt} = & F_L A_L + L_D + Q' C'_T + J_+ C_p A_L \\ & - J_- C_s A_L - Q C_T - (\lambda + \lambda_w^*) C_T V. \end{aligned} \quad (4)$$

The term on the left-hand side of this equation is the change in the total amount of constituent in the lake (amount per year). The first term on the right-hand side is the total atmospheric loading; the second is the loading from the drainage basin; the third is the loading from upstream lakes; the fourth is the loading via resuspension; the fifth is the loss via particle settling; the sixth is the loss via outflow; and the last is the loss through all first-order processes, including radioactive decay.

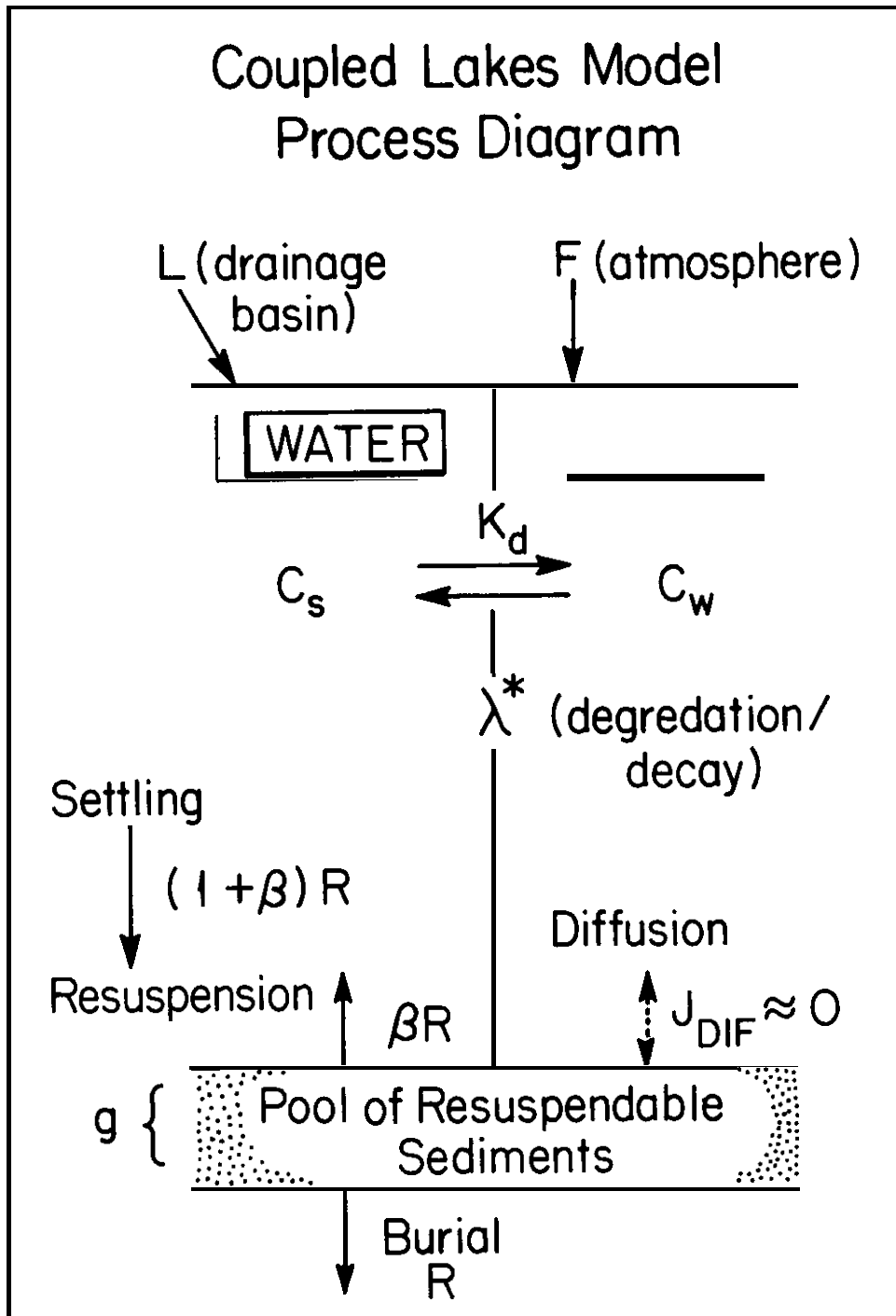


Figure 1.--Processes included in the formulation of the **Coupled Lakes Model** for **particle-associated tracers and contaminants**.



Since the total concentration  $C_T$  is related to the concentration on solids  $C_S$  by

$$C_T = C_S(m + 1/K_D), \quad (5)$$

eq. (4) reduces to

$$\frac{dC_T}{dt} = \frac{F_{L'}}{H} + \frac{L_{D'}}{V} + \frac{Q'}{V} C_T' - \frac{(1 + \beta)R}{(m + \frac{1}{K_D})H_L} C_T - (\lambda_h + \lambda_w^* + \lambda)C_T. \quad (6)$$

The corresponding mass balance equation for the resuspendible pool is

$$\frac{dc_p}{dt} = C_s J_- - J_+ C_p - R C_p - (\lambda_p^* + \lambda)C_p \text{ g.} \quad (7)$$

The term on the left-hand side is the change in the total amount in the resuspendible pool (amount per square centimeter per year). The first term on the right-hand side is the amount transferred to the pool by association with settling particles; the second is the amount lost via resuspension; the third is the amount lost through burial; and the fourth is the amount lost through degradation processes and radioactive decay. In terms of the reciprocal particle residence time characteristic of the pool,  $\lambda_p = R/g$ , the equation becomes

$$\frac{dc_p}{dt} = \frac{(1 + \beta)}{(m + \frac{1}{K_D})} \lambda_p C_T - [(1 + \beta)\lambda_p^* + \lambda]C_p. \quad (8)$$

Eq. (6) and (8) constitute a set of coupled equations for each lake of the form

$$\frac{dC_{Ti}}{dt} = \frac{F_{Li}}{H_i} + \frac{L_{Di}}{V_i} + \frac{Q_i C_{Ti}'}{V_i} + \alpha_{1i} C_{Pi} - \alpha_{2i} C_{Ti} - \alpha_{3i} C_{Ti} \quad (9)$$

$$\frac{dC_{Pi}}{dt} = \alpha_{4i} C_{Ti} - \alpha_{5i} C_{Pi}, \quad (10)$$

where

$$\alpha_{1i} = \beta_i R_i / H_i \quad (\text{grams per cubic centimeter per year})$$

$$\alpha_{2i} = (1 + \beta_i)R_i / (M_i + \frac{1}{K_{Di}})H_i \quad (\text{per year})$$

$$\alpha_{3i} = \left( \frac{Q_i}{V_i} + \lambda_{wi}^* + \lambda \right) \quad (\text{per year})$$

$$\alpha_{4i} = (1 + \beta_i) \lambda_{Pi} / \left( M_i + \frac{1}{K_{Di}} \right) \quad (\text{cubic centimeters per gram per year})$$

$$\alpha_{5i} = (1 + \beta_i) \lambda_{Pi} + \lambda_{Pi}^* + \lambda \quad (\text{per year}). \quad (11)$$

The representation used to characterize drainage basin transport is based on the study of  $^{90}\text{Sr}$  (strontium-90) in U.S. tributaries by Menzel (1974). Concentrations of this fallout radionuclide in streams are related to the time-dependent atmospheric deposition rates through "direct" and "indirect" transfer terms. Menzel found that a small percentage of the stream concentration could be accounted for in terms of the amount deposited on the drainage basin in the previous 2 months, while the remainder was related to the total amount accumulated on the drainage basin. The present model thus assumes that the loading from the drainage basin has the form

$$L_D = L_D (\text{direct}) + L_D (\text{indirect}), \quad (12)$$

where the direct term is given by

$$L_D (\text{direct}) = f_D F_D (t) A_D. \quad (13)$$

For  $^{90}\text{Sr}$ , the fraction falling on the watershed that is directly transferred ranged from 0.6% to 2.2%. In the model, the direct transfer fraction is taken to be 2.2% for all constituents.

Mass balance for the amount stored on the drainage basin is

$$\frac{dt_D}{dt} = (1 - F_D) F_D A_D - (\lambda_D + \lambda_D^* + \lambda) T_D. \quad (14)$$

The amount transferred to the tributary is then  $\lambda_D T_D$  (amount per year) so that the loading to the lake is

$$L_D = f_D F_D A_D + \lambda_D T_D \quad (15)$$

and the mean concentration in runoff is

$$C_R = L_D / Q_R. \quad (16)$$

Since tributary contributions to the lakes are small, some inaccuracy in this representation is of minor consequence even for relatively mobile constituents such as <sup>90</sup>Sr.

The coupling of the lakes occurs through the flows shown schematically in figure 2 and represented by the term  $Q' C'_T$  in eq. (6). This term has a form that depends on the lake.

Lakes Superior and Michigan ( $i = 1, 2$ ),  $Q' C'_T = 0$ ,

Lake Huron ( $i = 3$ ),  $Q' C'_T = Q_1 C_{T1} + Q_2 C_{T2}$ ,

Lakes Erie and Ontario ( $i = 4, 5$ ),  $Q' C'_T = Q_{i-1} C_{T i-1}$ .

A special situation is encountered for Lakes St. Clair and Erie. Since the hydraulic residence time of Lake St. Clair is very short (less than 10 days), it is likely that atmospherically loaded constituents are not efficiently retained, but pass directly into Lake Erie. In the model, loadings to the lake surface and to the drainage basin of Lake St. Clair are added directly to the loadings of Lake Erie.

### 3. COMPUTER PROGRAM

A FORTRAN program written for the Digital Equipment Corporation VAX 11-780 computer solves the above set of differential equations. The program, listed in appendix B, is well documented through the use of comment lines and requires little additional explanation. The calculation proceeds in monthly time steps corresponding to the radionuclide data files SRDL and SRDB described in a previous report (Robbins, 1985). SRDL and SRDB contain monthly deposition rates of <sup>90</sup>Sr to the surface and drainage basins of the six Great Lakes. Rates of deposition of <sup>137</sup>Cs (cesium-137) and Pu (plutonium) isotopes are derived from these source files by appropriate transformation of the <sup>90</sup>Sr data. The program in appendix B is written for the case of Pu. The transformation of the <sup>90</sup>Sr values in units of microCuries per square kilogram per month to <sup>239/240</sup>Pu values in units of femtoCuries per square centimeter per month is shown on lines 183-203 of this program. It has been found to be most convenient to have separate versions of the generic program (CLM) for each of the three radionuclides used to calibrate the model. These programs are CLSR, CLCS, and CLPU for Sr, Cs, and Pu, respectively. These programs differ only in their treatment of the source data in SRDL and SRDB and in the value of the drainage basin residence time (line 75).

#### 3.1 Input

A sample input file is provided in appendix C. In the current versions of the CLM (CLSR, CLCS, and CLPU), the data file consists of a minimum of seven lines.

Line 1: AN, AMT  
AN = number of months in files SRDL and SRDB (372 maximum)  
AMT = units of amount  
format(F8.3,10A4)

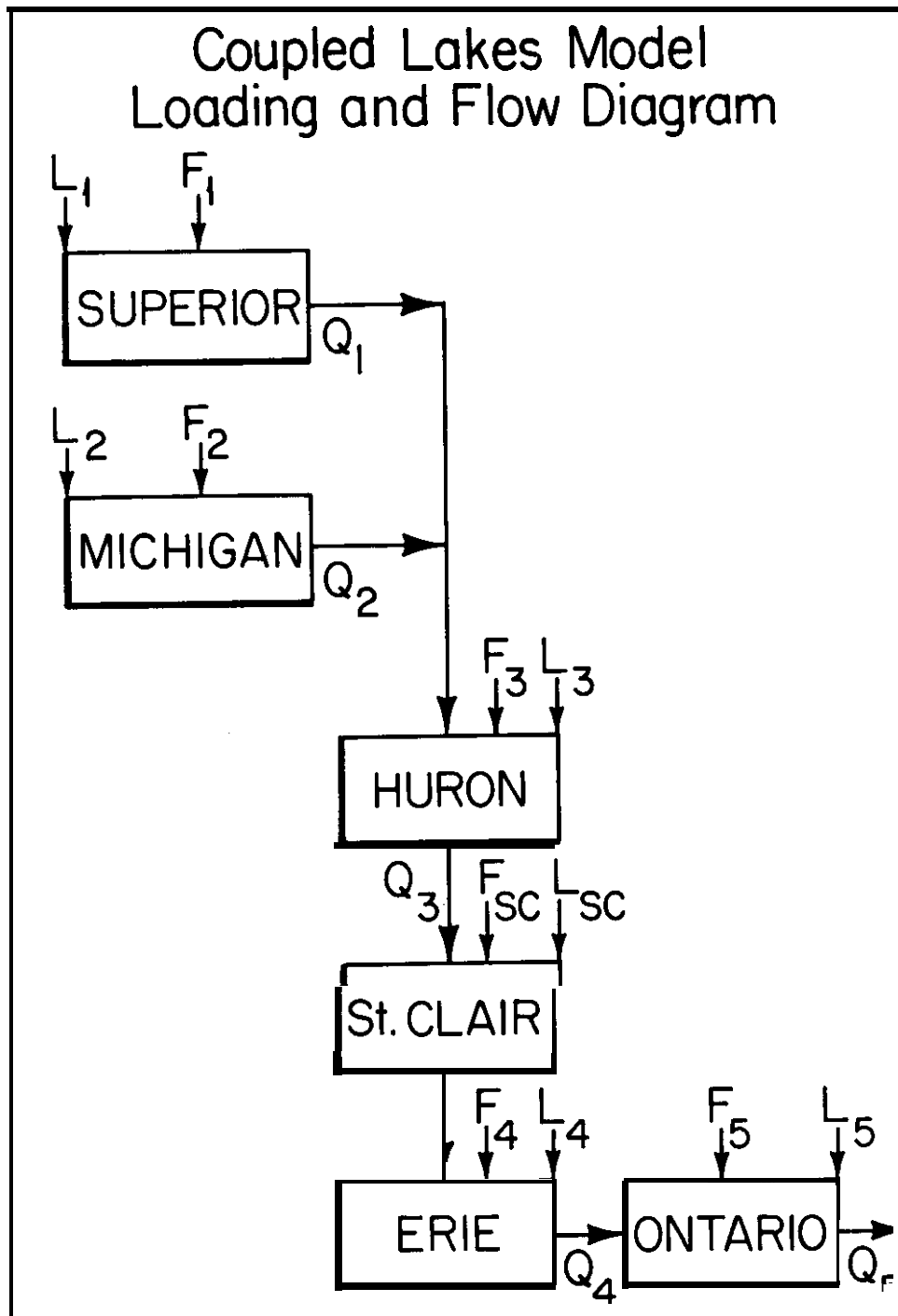


Figure 2.--Schematic diagram of the loading and flow of tracers and contaminants through the Great Lakes system. Loadings to Lake St. Clair are passed on directly to Lake Erie.

Line 2: Case Identification (alphanumeric). Format(20A4)

Line 3: THLF, TBG, TSPA  
 THLF = half-life (years)  
 TBG = beginning date (1950 for SRDL/SRDB)  
 TSPA = spacing of output data (months)  
 format(3F8.3)

Line 4: partition coefficient,  $K_D$  (units of  $10^5$  cubic centimeters per gram) (L = 1, 5)  
 format(5F8.3)

Line 5: resuspension factor,  $\beta$  (L = 1, 5)  
 format(5F8.3)

Line 6: pool residence time,  $T_{RP}$  (years) (L = 1, 5)  
 format(5F8.3)

Line 7: blank to stop; new case ID to continue (20A4)

### 3.2 Output

A sample output file is provided in appendix D. The output on unit 4 commences with a single page listing of all "fixed" parameters and derived quantities. The second page lists current "variable parameters" followed by a table with pairs of entries for each lake. The pairs are total concentration in units of amount per liter and concentration on resuspendible solids in amount per gram solids. The length of this table is adjusted by changing the value of TSPA. The output on unit 7 consists of another table of pairs of entries for each lake. These pairs are the mean (total) concentration in runoff from the drainage basin (CR) and the amount stored on the drainage basin (amount per square centimeter).

## 4. PRELIMINARY RADIONUCLIDE CALIBRATION

### 4.1 General Approach

The special properties of the fallout radionuclides and excellent quality of the records of their loadings to the Great Lakes make them attractive for calibration of long-term response models such as the CLM (cf. Wahlgren et al., 1980; Tracy and Prantl, 1983). Records of the monthly deposition of  $^{90}\text{Sr}$  at some sites in the Great Lakes Region are nearly continuous over a 30-year period. As indicated earlier, rates of deposition of the other fallout radionuclides of interest,  $^{137}\text{Cs}$  and  $^{239/240}\text{Pu}$ , may be reliably inferred from the  $^{90}\text{Sr}$  data. Collector-based measurements of fallout may be corrected for the small (30%) effects of collector efficiency by comparison with integrated fallout on soils within the drainage basin. Because  $^{90}\text{Sr}$  is only weakly particle associated and essentially conservative in each of the lakes, insignificant amounts of the isotope reside in sediments. Thus, fallout to the lake can be corrected for inaccuracies in estimating overlake deposition simply by comparison with measured amounts in water. Such corrections applied to  $^{90}\text{Sr}$

will also apply to co-deposited  $^{137}\text{Cs}$  and Pu. Therefore, application of the CLM to the  $^{90}\text{Sr}$  data fixes the magnitude of the loadings for all of the fallout radionuclides.

In contrast to  $^{90}\text{Sr}$ , the other nuclides of interest are strongly particle associated. At the present time only a small fraction of the activity in each lake is in the water. Efficient particle scavenging and settling have removed the lion's share of the load to the sediments. What little is left in the water appears to be largely the result of resuspension. Hence, the particle-associated radionuclides serve, in principle, to determine the magnitude of resuspension and the size of the pool of resuspendible sediments. These values can be determined with minimum ambiguity because, for the radionuclides, there are no degradation terms except for radioactive decay, which is precisely known.

#### 4.2 $^{90}\text{Sr}$

First, the magnitude of the drainage basin residence time is fixed by requiring that the mean concentration in tributaries be reproduced. This value is known for Lake Michigan from some recent work by D. Nelson (Argonne National Laboratory, done for GLERL under contract) to be  $0.30 \text{ pCi L}^{-1}$  as of 1982. The value of  $T_{\text{RD}}$  that generates this mean concentration is 900 years. This value corresponds to an annual loss rate of about 0.1% per year. The residence time obtained for  $^{90}\text{Sr}$  on the drainage basin of Lake Michigan is assumed to apply for the other drainage basins as well.

Second, the monthly deposition rate to the lake surface (but not the drainage basin) is multiplied by a factor that reproduces observed concentrations in each lake (line 84 in appendix B). The modified values range from +3% to -15% of the unnormalized value. Such small corrections, while included, are in fact completely within the "noise" of the data and representation. The resulting time-dependent concentrations and all known measured concentrations (in some cases, annual averages) are shown in figure 3. The dashed line in each figure is the concentration expected in the absence of tributary loading. Tributaries add very little  $^{90}\text{Sr}$  to the total inventory in the water. Some data agree poorly with the model, especially for Lake Huron. While it is beyond the scope of this report to discuss the results in any detail, it suffices to say that not all reported data are of comparable quality or accuracy. Some of the early  $^{90}\text{Sr}$  data were obtained from water subjected to treatment and filtration processes and thus under-estimate actual amounts present (Lerman, 1972).

#### 4.3 $^{137}\text{Cs}$

First, for  $^{90}\text{Sr}$  the drainage basin residence time is fixed so as to reproduce measured mean concentrations in Lake Michigan tributaries. For  $^{137}\text{Cs}$ , this value is  $1.5 \times 10^4$  years, corresponding to an annual loss rate of 0.007% per year. This residence time is applied to all drainage basins.

Second, values for the mean sedimentation rates and concentration of solids were taken from the work of Thomann and DiToro (1983), with the exception of values for Lake Ontario, where mean solids concentration (m) was taken

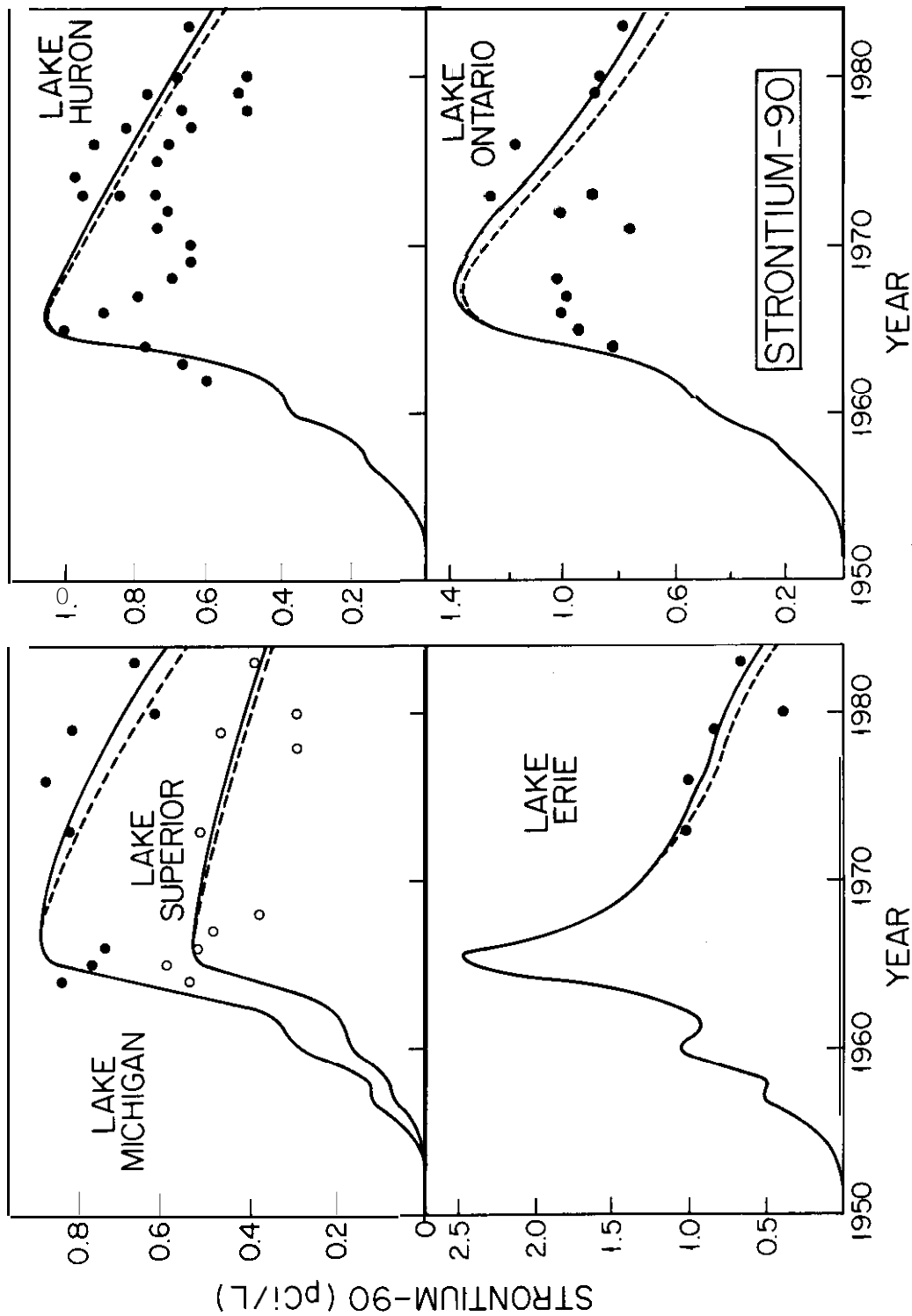


Figure 3.--Concentration of  $^{90}\text{Sr}$  in the five Great Lakes. Solid line: Coupled Lakes Model results with minor corrections for overlake deposition. Dashed line: Coupled Lakes Model results without drainage basin contributions. Points: All known measurements. Data are of equal quality.

taken to be  $1.0 \text{ mg L}^{-1}$  rather than  $0.5 \text{ mg L}^{-1}$ . Values for the partition coefficient ( $K_D$ ) were estimated from the work of Alberts and Wahlgren (1981) to be  $3.6 \times 10^5 \text{ cm}^3 \text{ g}^{-1}$ . The estimate was based on an assumed solids concentration of  $0.5 \text{ mg L}^{-1}$ . However, the work of Alberts and Wahlgren indicated that the fraction of  $^{137}\text{Cs}$  dissolved in each lake was essentially the same. Since the mean solids concentration in Lake Erie is generally an order of magnitude higher, this result suggests that the real invariant from lake to lake is the fraction dissolved rather than  $K_D$ . That is, the product of  $K_D$  and  $m$  is taken to be constant from lake to lake. [Note that  $f_{dis} = 1/(m K_D + 1)$ ]. This result is also in agreement with the now very general observation that  $K_D$  decreases with increasing  $m$  such that  $m K_D \sim \text{constant}$ . Hence final values of  $K_D$  were chosen to produce a value of  $f_{dis} = 0.847$  in each lake. A second invariant for each lake appears to be the particle settling velocity,  $v_s = J_m^{-1}$ . Application of the CLM to the  $^{137}\text{Cs}$  data showed that a nearly optimum value of  $v_s$  is  $1.2 \text{ m d}^{-1}$ , which corresponds well to non epilimnetic trap-based measurements of this quantity. Values of the resuspension factor were chosen to produce a value of  $v_s = 1.2$  for each lake. With this parameter fixed, the value of the pool residence time was adjusted to reproduce the observed concentrations measured in the 1970's.

The results of this approximate calibration procedure are shown in figure 4. Time-dependent concentrations of  $^{137}\text{Cs}$  predicted by the CLM are compared with measured concentrations. For lakes other than Lake Huron, the only data are from the 1970's, when there was relatively little change in concentrations. For this reason, inferred values of  $T_R$  are considerably uncertain. The Lake Huron data provide the best confirmation of the suitability of the CLM.

#### 44 $^{239/240}\text{Pu}$

The drainage basin residence time as for  $^{90}\text{Sr}$ , was fixed so as to reproduce measured mean concentrations in Lake Michigan tributaries. For  $^{239/240}\text{Pu}$ , this value is  $2.4 \times 10^4$  years, corresponding to an annual loss rate of 0.004% per year. This residence time is applied to all drainage basins.

Since the resuspension parameters and pool residence times are set, in principle, by the  $^{137}\text{Cs}$  data, the only remaining variable is the fraction of dissolved plutonium. Work done by Alberts and Wahlgren shows that  $f_{dis}$  for plutonium is essentially the same for each lake and smaller than  $f_{dis}$  for  $^{137}\text{Cs}$  by a factor of 1.06. To reproduce this value of  $f_{dis}$  (0.800), a value of  $K_D = 5.0 \cdot 10^5$  is required for  $m = 0.5 \text{ mg L}^{-1}$ . Values of  $K_D$  for other solids concentrations are chosen to obtain  $f_{dis} = 0.800$  in each lake.

The results for plutonium are shown in figure 5. Time-dependent concentrations are compared with measured values for each lake. The agreement is excellent. It should be kept in mind that the only changes made for the plutonium calculation were (1) a change in the drainage basin residence time, (2) a change in the half-life from 30.2 years to 25,000 years ( $\lambda = 0$ ), and (3) a slight adjustment in the value of  $K_D$ . Since the resuspension factor and pool residence time are set by the  $^{137}\text{Cs}$  data, the plutonium data provide a test of the idea that these latter parameters are system properties that remain fixed for future choices of contaminants and tracers.



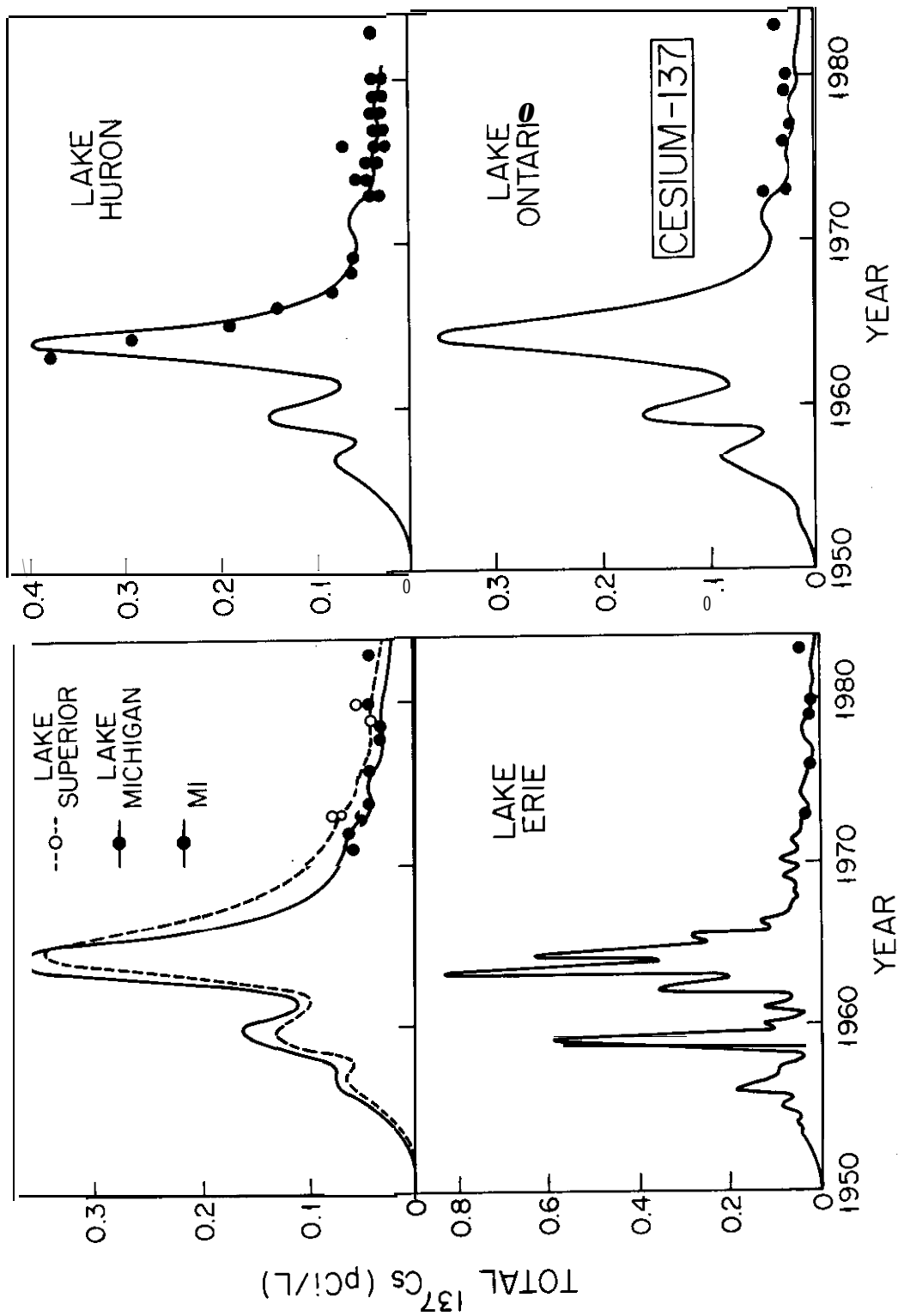


Figure 4.--Concentration of <sup>137</sup>Cs in the five Great Lakes. Unlike <sup>90</sup>Sr, very little <sup>137</sup>Cs remains in the water column because of the affinity of the latter isotope for settling particles. A preliminary calibration of the Coupled Lakes Model produces excellent agreement between theory and observation, especially for Lake Huron.

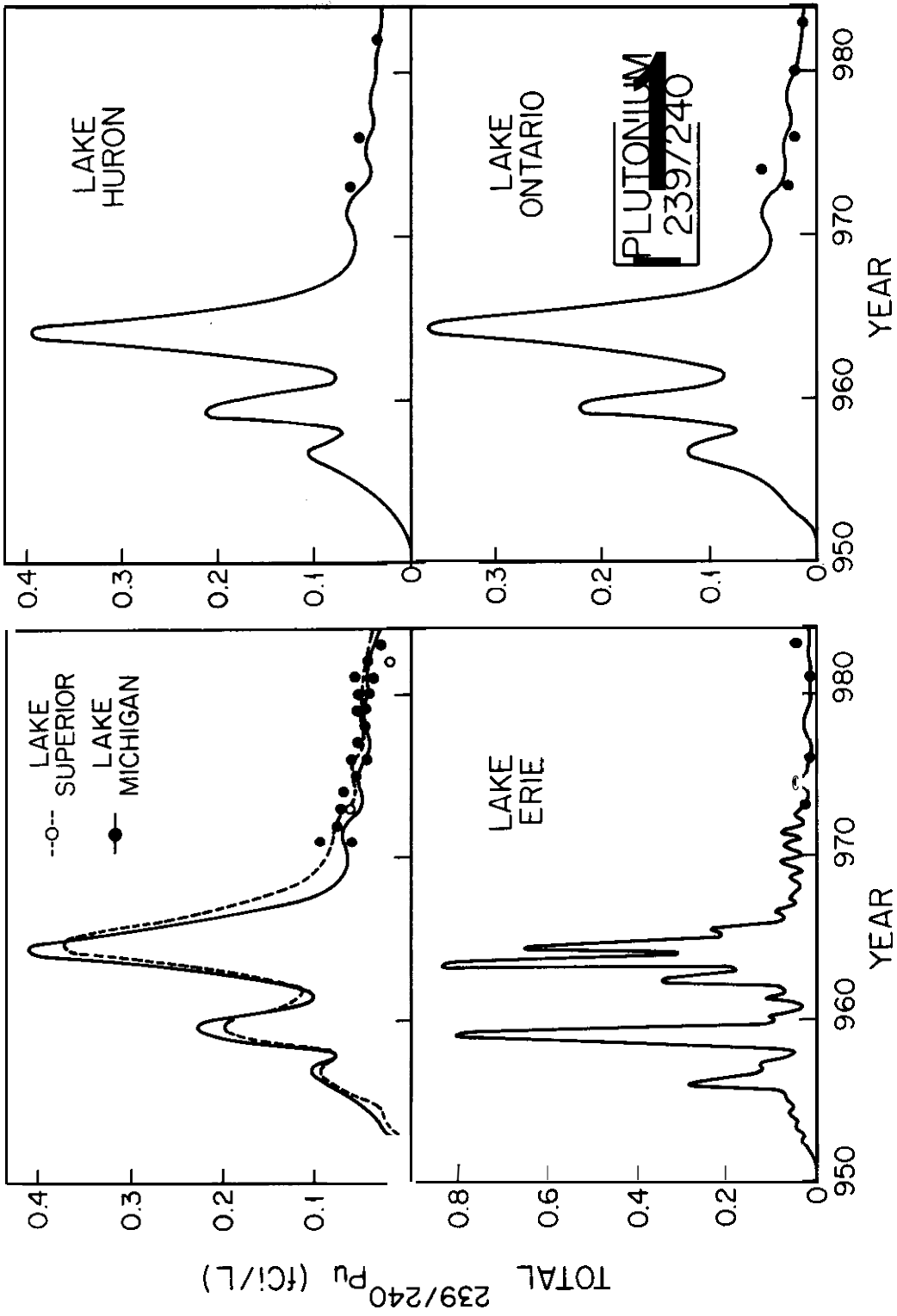


Figure 5.--Concentrations of  $^{239/240}\text{Pu}$  in the five Great Lakes. Like  $^{137}\text{Cs}$ , very little plutonium remains in the water column because of the affinity of the isotopes for settling particles. The theoretical profiles are based on the calibrated version of the Coupled Lakes Model for which there are no free parameters.

<sup>137</sup>Cs and for <sup>239/240</sup>Pu, the optimum values differ, presumably because of the insensitivity of concentrations to the choice of  $T_{RP}$ . Values based on <sup>137</sup>Cs and <sup>239/240</sup>Pu are given in table 1. The preliminary calibration uses the average of these values for the value of  $T_{RP}$ . The estimate of the pool residence time may be improved by requiring computed concentrations of <sup>137</sup>Cs and <sup>239/240</sup>Pu in the pool of resuspendible sediments to match measured concentrations of near-bottom trap materials for each of the lakes. For Lake Michigan, such data are available and computed values of  $C_p$  agree well with observation.

## 5. USE OF THE CLM FOR OTHER CONSTITUENTS

It should be kept in mind that the present calibration of the model is tentative. Future calibrations involve (1) optimization of selected parameter values by least-squares methods, (2) systematic study of the errors in parameter estimates, (3) refinements in the choice of parameters, such as mean sedimentation rates and solids concentrations, that are presently inadequately characterized, (4) use of near-bottom trap data to further fix values of the inadequately determined pool residence times, and (5) application of the model to other tracers whose time-dependence is known well enough to provide additional tests of the formalism.

Solutions to the set of equations can be obtained for <sup>137</sup>Cs and <sup>239/240</sup>Pu without inquiry into the physical meaning of the parameters. In considering the application of the CLM to other constituents, it is useful to treat solutions initially apart from their physical significance for Pu. An example of this is treatment of the alpha coefficients for Pu in table 2. The values given in table 2 may be considered to be the partially optimized coefficients that provide an adequate representation of the Pu concentration in each of the lakes.

Table 1.--Values of *the resuspendible pool residence time,  $T_{RP}$  (years)*, based on <sup>137</sup>Cs data and on <sup>239/240</sup>Pu data

Lake	$T_{RP}$ ( <sup>137</sup> Cs)	$T_{RP}$ (Pu)	Average
Superior	40	80	60
Michigan	120	110	120
Huron	60	30	50
Erie	140	140	140
Ontario	80	240	160

Table 2.--Values of *the alpha coefficients for plutonium obtained through preliminary model calibration with three fallout radionuclides*

Lake	Alpha values				
	$a_1(10^{-6} \text{ g cm}^{-3} \text{ yr}^{-1})$	$a_2(\text{yr}^{-1})$	$a_3(10^{-2} \text{ yr}^{-1})$	$a_4(10^{-4} \text{ cm}^3 \text{ g}^{-1} \text{ yr}^{-1})$	$a_5(10^{-2} \text{ yr}^{-1})$
Superior	0.73	0.559	0.588	1.40	3.50
Michigan	1.62	0.973	0.996	1.00	2.50
Huron	1.70	1.42	4.55	1.54	3.84
Erie	37.4	4.49	36.4	0.043	1.07
Ontario	2.30	0.978	12.90	0.236	1.18

The physical meaning of these terms, however, becomes important when a solution is desired for a different constituent. Since a new constituent will be characterized by a different set of  $K_D$  and degradation terms, the new alpha coefficients may be obtained using the relations given by eq. (11)

$$\alpha_1' = \frac{\beta R}{H} = \alpha_1$$

$$\alpha_2' = \frac{(1 + \beta)R}{(M + \frac{1}{K_D})H} = \frac{J-}{M} \cdot \frac{M K_D'}{M K_D' + 1} \cdot \frac{1}{H} = \frac{V_S(1 - f_{dis}')}{H}$$

Hence

$$\alpha_2' = \alpha_2(1 - f_{dis}')/(1 - f_{dis})$$

$$\alpha_3' = \alpha_3 + \lambda_w'^*$$

$$\alpha_4' = \frac{\frac{R}{(M + \frac{1}{K_D})g}}{\frac{1}{K_D'}}$$

$$= \frac{J-}{M} \cdot \frac{M K_D'}{M K_D' + 1} \cdot \frac{1}{g}$$

$$= V_S(1 - f_{dis}') \cdot \frac{1}{g}$$

Hence

$$\alpha_4' = \alpha_4(1 - f_{dis}')/(1 - f_{dis})$$

$$\alpha_5' = \alpha_5 + \lambda_w'^*$$

where the primed quantities refer to the values associated with the new tracer or contaminant and the unprimed quantities refer to Pu and the alpha values in table 2.

## 6. AVAILABILITY

This program is available from the Great Lakes Environmental Research Laboratory. For further information, contact Dr. John A. Robbins, U.S. Department of Commerce, NOAA, Great Lakes Environmental Research Laboratory, 2300 Washtenaw Avenue, Ann Arbor, MI 48104, (313) 668-2283.

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## Appendix A: Definitions

The formalism, as well as the computer program, has been developed in units of centimeters, grams, and years.

### Drainage Basin:

- $F_D$  = atmospheric loading to the drainage basin (amount per square centimeter per year)
- $A_D$  = area of the drainage basin (square centimeters)
- $T_D$  = amount stored on the basin (amount)
- $f_D$  = fraction of the loading transferred directly to tributaries
- $T_{RD}$  = basin retention (years)
- $\lambda_D = 1/T_{RD}$  (per year)
- $L_D$  = contaminant loading from tributaries (amount per year)
- $L_m$  = tributary mass loading (grams per year)
- $Q_R$  = runoff from the basins (cubic centimeters per year)
- $C_R$  = mean total concentration in runoff (amount per cubic centimeter)

### Water Column:

- $F_L$  = atmospheric loading to the lake surface (amount per square centimeter per year)
- $A_L$  = surface area of the lake (square centimeters)
- $V$  = volume of the lake (cubic centimeters)
- $Q$  = outflow of the lake (cubic centimeters per year)
- $m$  = mean solids concentration (grams per cubic centimeter)
- $C_w$  = concentration in the dissolved phase (amount per cubic centimeter)
- $C_s$  = concentration on solids (amount per gram solids)
- $C_T$  = total contaminant concentration (amount per cubic centimeter)
- $= mC_s + C_w$
- $K_D$  = partition coefficient (cubic centimeters per gram) =  $C_s/C_w$
- $J_-$  = downward mass flux (grams per square centimeter per year)

$J_+$  = resuspension mass flux (grams per centimeter per year)  
 $R$  = net sedimentation rate (grams per square centimeter per year)  
 $\beta$  = resuspension factor =  $J_+/R$   
 $H$  = mean lake depth =  $V/A_L$  (centimeters)  
 $T_h$  = hydraulic retention time (years) =  $V/Q$   
 $\lambda_h$  =  $1.0/T_h$  (per year)  
 $\lambda_w^*$  = over-all first-order loss rate constant excluding radioactive decay (per year)  
 $\lambda$  = radioactive decay constant (per year) =  $0.6932/t_{1/2}$   
 $v_s$  = particle settling velocity (centimeters per year) =  $J_-/m$   
 $f_s$  = fraction on solids =  $C_s/C_T = mK_D/(1 + mK_D)$   
 $f_w$  = fraction dissolved =  $1 - f_s = 1/(1 + mK_D)$

Resuspendible pool:

$T_{RP}$  = particle residence time in the resuspendible pool (years)  
 $\lambda_p$  =  $1.0/T_{RP} = R/g$  (per year)  
 $C_p$  = concentration on solids in the pool (amount per gram solids)  
 $\lambda_p$  = over-all first-order loss rate constant excluding radioactive decay



Appendix B: FORTRAN Program to Run the CLM

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1          PROGRAM CLRN
2          C COUPLED LAKES MODEL FOR ESTIMATING THE RESPONSE
3          C OF THE GREAT LAKES TO NON-POINT SOURCE LOADINGS
4          C OF TRACERS AND CONTAMINANTS.
5          C
6          C
7          C
8          C VERSION FOR RADIONUCLIDE CALIBRATIONS.
9          C
10         C
11         C
12         C THIS VERSION OF THE PROGRAM FORMATTING AND
13         C ORDERING OF FIXED AND VARIABLE PARAMETERS
14         C IS DESIGNED FOR CALIBRATION OF THE MODEL
15         C USING FALLOUT RADIONUCLIDE DEPOSITION DATA
16         C DEVELOPED PREVIOUSLY AND BASED ON THE PW
17         C MODEL. CALIBRATION RADIONUCLIDES ARE SR-90,
18         C CS-137 AND PU-239/240. PARAMETERS SET, IN
19         C PRINCIPLE, BY THE RADIONUCLIDES ARE THE
20         C RESUSPENSION FACTOR, THE PARTICLE RESIDENCE
21         C TIME IN THE RESUSPENDABLE POOL AND A COM-
22         C BINATION OF VARIABLES WHICH INCLUDE THE
23         C MASS SEDIMENTATION RATE, CONCENTRATION OF
24         C SUSPENDED SOLIDS AND THE PARTITION COE-
25         C FFICIENT.
26         C
27         C
28         C PROGRAM WRITTEN BY J. A. ROBBINS, GREAT LAKES
29         C ENVIRONMENTAL RESEARCH LABORATORY, 2300 WASHTENAW
30         C AVENUE, ANN ARBOR, MICHIGAN, 48104.
31         C VERSION OF 7/20/1984.
32         C
33         C
34         C UNIT 1: MAIN CONTROL/DATA CARDS
35         C UNIT 2: FLUX TO LAKE SURFACE
36         C UNIT 3: FLUX TO THE DRAINAGE BASIN
37         C UNIT 4: CONCENTRATION IN WATER AND POOL
38         C UNIT 5: TERMINAL INPUT
39         C UNIT 6: SYSTEM/TERMINAL OUTPUT
40         C UNIT 7: MEAN TRIBUTARY CONCS/DRAINAGE BASIN STORAGE
41         C UNIT 8: COMPARTMENT STORAGE AND MASS BALANCE CHECK
42         DIMENSION TLA(5,3000), SSD(5,3000), SOU(5,3000), LAKE(5,2)
43         DIMENSION TLB(5,3000), SFL(5,3000), FL(5,3000), FD(5,3000)
44         DIMENSION AL(5), AD(5), VL(5), Q(5)
45         DIMENSION CSM(5), RM(5), QR(5), ELSV(5,3000)
46         DIMENSION BETA(5), TRSP(5), FRD(5), TRDB(5)
47         DIMENSION ELSP(5), ELDB(5), G(5)
48         DIMENSION TDEGW(5), TDEGP(5), TDEGD(5)
49         DIMENSION ELW(5), ELP(5), ELD(5)
50         DIMENSION AKD(5), LBL(20), FW(5)

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51         DIMENSION HM(5),HRT(5),VEL(5),TDSC(3000)
52         DIMENSION CT(5,3000),CP(5,3000),TD(5,3000)
53         DIMENSION CTRIB(5),STOR(5),FML(5)
54         DIMENSION AMT(10),ENU(5)
55         DIMENSION ALP1(5),ALP2(5),ALP3(5),ALP4(5),ALP5(5)
56         DIMENSION IYR(3000),IMO(3000)
57         DATA LB/' '/
58         DATA LAKE/'SUPE','MICH','HURO','ERIE','ONTA',
59         1 'RIOR','IGAN','N ',' ',' ','RIO '/
60 C LAKE AREAS AND VOLUMES PLUS DRAINAGE BASIN AREAS ARE TAKEN
61 C FROM THE "COORDINATED GREAT LAKES PHYSICAL DATA" REPORT
62 C MAY, 1977. AVAILABLE FROM THE GREAT LAKES ENVIRONMENTAL
63 C RESEARCH LABORATORY, 2300 WASHTENAW AVE., ANN ARBOR, MICH.
64         DATA AL/8.21,5.78,5.96,2.57,1.90/
65 C LAKE SURFACE AREAS (10**4 KM**2).
66         DATA AD/12.77,11.80,13.13,5.88,6.06/
67 C DRAINAGE BASIN AREAS (10**4 KM**2)
68         DATA VL/12.10,4.92,3.54,0.484,1.640/
69 C LAKE VOLUMES (10**3 KM**3)
70         DATA Q/71.1, 49., 161.,176.,211./
71 C MEAN OUTFLOWS ( KM**3/YR )
72         DATA QR/49.5,35.2,48.3,20.2,27.7/
73 C MEAN TRIBUTARY RUNOFF (KM**3/YR)
74 C DATA FROM "GREAT LAKES MONTHLY HYDROLOGIC DATA. NOAA DATA
75 C REPORT ERL GLERL-26. F.H. QUINN AND R. N. KELLEY.
76         DATA CSM/.5 ,.5 ,.5 , 5., 1./
77 C MEAN CONCENTRATION OF SUSPENDED SOLIDS ( MG/L ).
78         DATA RM/98.,69.,110.,1410.,224./
79 C MEAN SEDIMENT ACCUMULATION RATES (G/M**2/YR).
80 C DATA FROM THOMANN AND DITORO. J. GREAT LAKES
81 C RESEARCH 9:474-496:1983.
82         DATA FRD/.022,.022,.022,.022,.022/
83 C DIRECT TRANSFER FRACTION.
84         DATA ENU/.072,.072,.072,.072,.072/
85 C DRAINAGE BASIN RATE CONSTANT FACTOR (1/YR).
86         DATA TDEGW/0.0,0.0,0.0,0.0,0.0/
87 C WATER COLUMN DEGREDAION LIFETIME (YEARS).
88 C NOTE ZERO VALUES CORRESPOND TO AN INFINITE LIFETIME.
89         DATA TDEGP/0.0,0.0,0.0,0.0,0.0/
90 C RESUSPENDABLE POOL DEGREDAION LIFETIME.
91         DATA TDEGD/0.0,0.0,0.0,0.0,0.0/
92 C DRAINAGE BASIN DEGREDAION LIFETIME.
93         DATA FML/1., 1., 1., 1., 1./
94 C FACTOR APPLIED TO FL TO NORMALIZE SR-90 DEPOSITION TO OBTAIN
95 C OBSERVED CONCENTRATIONS IN EACH LAKE.
96         WRITE(4,101)
97         101 FORMAT('1', 'COUPLED LAKES MODEL: FIXED PARAMETER LIST'/)
98         WRITE(4,121)
99         121 FORMAT(41X,'S',9X,'M',9X,'H',8X,'E',9X,'O')
100        WRITE (4,102) (AL(L), L=1,5)

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101      102 FORMAT(/,1X,'LAKE AREAS (10**4 KM**2):',7X,6F10.1)
102      WRITE(4,103) (AD(L), L=1,5)
103      103 FORMAT(1X,'DRAIN. BASIN AREAS (10**4 KM**2)',6F10.1)
104      WRITE(4,104) (VL(L), L=1,5)
105      104 FORMAT(1X,'LAKE VOLUMES (10**3 KM**3)',6X,6F10.1)
106      WRITE(4,105) (Q(L), L=1,5)
107      105 FORMAT(1X,'MEAN OUTFLOWS (KM**3/YR):',7X,6F10.1)
108      WRITE(4,195) (QR(L), L=1,5)
109      195 FORMAT(1X,'MEAN RUNOFF (KM**3/YR):',9X,6F10.1)
110      WRITE(4,106) (CSM(L), L=1,5)
111      106 FORMAT(1X,'MEAN SOLIDS CONC. (MG/L):'7X,6F10.1)
112      WRITE(4,107) (RM(L), L=1,5)
113      107 FORMAT(1X,'MEAN SED. RATES (G/M**2/YR):',4X,6F10.1)
114      WRITE(4,108) (FRD(L), L=1,5)
115      108 FORMAT(1X,'DIRECT TRANSFER FRACTION:',9X,6F10.3)
116      WRITE(4,110) (TDEGW(L), L=1,5)
117      110 FORMAT(1X,'DEG. LIFE-TIME WATER (YR):',6X,6F10.1)
118      WRITE(4,111) (TDEGP(L), L=1,5)
119      111 FORMAT(1X,'DEG. LIFE-TIME POOL (YR):',7X,6F10.1)
120      WRITE(4,112) (TDEGD(L), L=1,5)
121      112 FORMAT(1X,'DEG. LIFE-TIME DR. BASIN (YR):',2X,6F10.1)
122      WRITE(4,412) (FML(L),L=1,5)
123      412 FORMAT(1X,'R-N FLUX MULTIPLIER:',13X,6F10.2)
124      C AREA OF LAKE ST CLAIR (10**4 KM**2)
125          ALSC=0.1114
126      C AREA OF ST CLAIR DRAINAGE BASIN (10**4 KM**2)
127          ADSC=1.243
128      C CONVERT TO CM**2
129          ALSC=ALSC*1.0E+14
130          ADSC=ADSC*1.0E+14
131      C THESE VALUES ARE USED TO COMPUTE ADDITIONAL INPUT TO L ERIE.
132      C DO ALL CONVERSIONS TO CGS UNITS
133          DO 10 L=1,5
134          ENU(L)=ENU(L)/12.0
135          AL(L)=AL(L)*1.0E+14
136          AD(L)=AD(L)*1.0E+14
137          VL(L)=VL(L)*1.0E+18
138          Q(L)=(Q(L)*1.0E+15)/12.0
139          QR(L)=(QR(L)*1.0E+15)/12.0
140      C FLOW IN CM**3/MONTH
141          CSM(L)=CSM(L)*1.0E-06
142          RM(L)=(RM(L)*1.0E-04)/12.0
143      C SEDIMENTATION RATE IN G/CM**2/MONTH
144          HM(L)=VL(L)/AL(L)
145      C MEAN LAKE DEPTH IN CM.
146      C CONVERT THIS TO M FOR PRINTOUT.
147          HM(L)=HM(L)/100.
148          HRT(L)=VL(L)/Q(L)
149      C HYDRAULIC RESIDENCE TIME (MONTHS)
150      C CONVERT TO YEARS FOR PRINTOUT

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151         HRT(L)=HRT(L)/12.0
152     10 CONTINUE
153         WRITE(4,113) (HM(L), L=1,5)
154     113 FORMAT(1X,'MEAN LAKE DEPTH (M):',12X,6F10.1)
155         WRITE(4,114) (HRT(L), L=1,5)
156     114 FORMAT(1X,'HYDRAULIC RESIDENCE TIME (YR):',2X,6F10.1)
157     C
158     C
159     C
160     C NOTE READ IN FLUX DATA.
161     C FORMAT IS CURRENTLY SET FOR RADIONUCLIDE
162     C FLUX DATA IN MCI/KM**2/MO AND CONVERSION
163     C EITHER TO PCI/CM**2/MO OR FCI/CM**2/MO.
164     C THE FACTOR 1.26 IS DERIVED FROM THE RELATION OF THE
165     C RESULTS OF THE ATMOSPHERIC FALLOUT MODEL (PWW)
166     C TO ACTUAL GROUND ACCUMULATION DATA.
167     C
168     C CURRENTLY THE LAKE AND DRAINAGE BASIN SR-90
169     C FLUXES ARE OBTAINED FROM SRDL AND SRDB RESPECTIVELY.
170     C CS-137 FLUXES FROM CSDL AND CSDB RESPECTIVELY.
171     C PU-239/240 FLUXES FROM PUDL AND PUBD RESPECTIVELY.
172     C ALL INPUT FILE VALUES IN MCI/KM**2/MO.
173     C
174     C
175     C
176         READ(1,555) AN, FMPY,(AMT(L), L=1,10)
177     555 FORMAT(2F8.3,10A4)
178     C FMPY IS A MULTIPLIER OF ALL FLUX DATA TO CONVERT AMT TO UNITS
179     C INDICATED BY AMT.
180     C AN=THE NUMBER OF MONTHLY INCREMENTS IN INPUT
181     C AMT= THE UNITS OF AMT. FOR EXAMPLE IF THE UNITS
182     C OF THE FLUX FL AND FD ARE MICROGRAMS/CM**2/MONTH
183     C THEN AMT=MICROGRAMS.
184     C AMT IS USED ONLY AS A LABEL.
185         N=AN
186         DO 7 J=1, N
187             READ(2,345) (FL(L,J), L=1,5)
188             READ(3,345) (FD(L,J), L=1,5)
189     345 FORMAT(10X,3F10.3,10X,2F10.3)
190     C THE FILES SRDL AND SRDB HAVE ENTRIES FOR LAKE
191     C ST. CLAIR. FORMAT 345 SKIPS THIS ENTRY.
192         DO 22 L=1,5
193             FL(L,J)=0.1*FL(L,J)
194     C CONVERTS FROM MCI/KM**2/MO TO PCI/CM**2/MO
195             FL(L,J)=FMPY*FL(L,J)
196     C FMPY=1 KEEPS PCI/...; FMPY=1000 CONVERTS TO FCI/...
197             FL(L,J)=1.26*FL(L,J)
198     C RENORMALIZES TO MEASURED SOIL DEPOSITION VALUES.
199             FL(L,J)=FML(L)*FL(L,J)
200     C RENORMALIZATION TO LAKE-CONCENTRATIONS OF SR-90 (ANL DATA).

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201         FD(L,J)=0.1*FD(L,J)
202         FD(L,J)=FMPY*FD(L,J)
203         FD(L,J)=1.26*FD(L,J)
204     C NOTE THAT DRAINAGE BASIN VALUES ARE NOT RENORMALIZED.
205         22 CONTINUE
206         7 CONTINUE
207     C
208     C
209     C
210         1 READ(1,200) (LBL(J), J=1, 20)
211     200 FORMAT(20A4)
212         IF(LBL(1)-LB)5,5,6
213         5 STOP
214         6 WRITE(4,201) (LBL(J), J=1, 20)
215     201 FORMAT('1','CASE: ',20A4,/)
216         WRITE(4,202)
217     202 FORMAT(1X,'COUPLED LAKES MODEL: VARIABLE PARAMETER LIST')
218         READ(1,100) THLF, TBG, TSPA
219         IBG=TBG
220         ISPA=TSPA
221     100 FORMAT(10F8.3)
222     C COMPUTE ARRAY OF YEARS AND MONTHS FOR OUTPUT.
223         IM=0
224         DO 30 J=1, N
225             IY=(J-1)/12
226             IYR(J)=IY+IBG
227             IM=IM+1
228             IF(IM-12)31,31,32
229         31 IMO(J)=IM
230         GO TO 30
231         32 IM=1
232         IMO(J)=1
233         30 CONTINUE
234         WRITE(4,203) THLF
235     203 FORMAT(1X,'HALF-LIFE (YR):',F8.2)
236         WRITE(4,213) AN
237     213 FORMAT(1X,'NUMBER OF MONTHS:',F8.0)
238         WRITE(4,223) TBG
239     223 FORMAT(1X,'BEGINNING DATE (YR):',F8.0)
240         WRITE(4,224) TSPA
241     224 FORMAT(1X,'OUTPUT VALUE SPACING (MONTHS):',F4.0)
242         DO 9 J=1, N
243             TDSC(J)=0.0
244         DO 9 L=1,5
245             TD(L,J)=0.0
246             CT(L,J)=0.0
247             CP(L,J)=0.0
248             TLA(L,J)=0.0
249             TLB(L,J)=0.0
250             SFL(L,J)=0.0

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251         SSD(L,J)=0.0
252         SOU(L,J)=0.0
253         9 CONTINUE
254     C THLF=RADIOACTIVE HALF-LIFE (YEARS)
255     C AN=THE NUMBER OF MONTHLY INCREMENTS IN INPUT
256     C TBG=THE BEGINNING TIME IN YEARS.
257     C START THE CALCULATION ON JAN 1 OF DESIRED YEAR.
258         IF(THLF)2,2,3
259         2 ELAM=0.0
260         GO TO 4
261         3 ELAM=0.69315/(12.0*THLF)
262         4 CONTINUE
263     C ELAM IN UNITS OF MONTH**-1
264     C NOW COMPUTE REMAINING RATE CONSTANTS FROM THE
265     C CORRESPONDING LIFETIMES.
266     C THE METHOD OF DEFINING THE LIFETIMES ALLOWS
267     C A ZERO ENTRY TO CORRESPOND TO ELAM=0 IN EACH CASE.
268     C LIFETIMES OR RESIDENCE TIMES ARE ENTERED IN UNITS
269     C OF YEARS.
270     C RATE CONSTANTS OR RECIPROCAL LIFETIMES ARE COMPUTED
271     C IN UNITS OF MONTHS**-1.
272         DO 90 L=1,5
273         IF(TRSP(L))91,91,92
274     C TRSP=PARTICLE RESIDENCE TIME IN THE POOL.
275         91 ELSP(L)=0.0
276         GO TO 93
277         92 ELSP(L)=1.0/(12.0*TRSP(L))
278         93 IF(TDEGW(L))97,97,98
279     C TDEGW=DEGREATION LIFETIME IN THE WATER.
280         97 ELW(L)=0.0
281         GO TO 99
282         98 ELW(L)=1.0/(12.0*TDEGW(L))
283         99 IF(TDEGP(L))80,80,81
284     C TDEGP=DEGREATION LIFETIME IN THE POOL.
285         80 ELP(L)=0.0
286         GO TO 82
287         81 ELP(L)=1.0/(12.0*TDEGP(L))
288         82 IF(TDEGD(L))83,83,84
289     C TDEGD=DEGREATION LIFETIME ON THE DRAINAGE BASIN.
290         83 ELD(L)=0.0
291         GO TO 90
292         84 ELD(L)=1.0/(12.0*TDEGD(L))
293         90 CONTINUE
294     C READ IN ADDITIONAL VARIABLES
295         READ(1,100) (TRDB(L), L=1,5)
296     C DRAINAGE BASIN RESIDENCE TIME (YR) AS OF 1982.
297         WRITE(4,109) (TRDB(L), L=1,5)
298         109 FORMAT(1X,'DRAINAGE BASIN RES. TIME (YR):',2X,6F10.1)
299         DO 78 L=1, 5
300         IF(TRDB(L))94,94,95

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301 C TRDB=PARTICLE RESIDENCE TIME ON THE DRAINAGE BASIN.
302   94 ELDB(L)=0.0
303     GO TO 96
304   95 ELDB(L)=1.0/(12.0*TRDB(L))
305   78 CONTINUE
306   96 READ(1,100) (AKD(L), L=1,5)
307 C PARTITION COEFFICIENT (10**5 CM**3/G).
308   WRITE(4,204) (AKD(L), L=1,5)
309   204 FORMAT(1X,'PART. COEFF. (10**5 CM**3/G):',5X,6F10.3)
310   READ(1,100) (BETA(L), L=1,5)
311 C RESUSPENSION FACTOR (DIMENSIONLESS).
312   WRITE(4,205) (BETA(L), L=1,5)
313   205 FORMAT(1X,'RESUSPENSION FACTOR:',13X,6F10.2)
314   READ(1,100) (TRSP(L), L=1,5)
315 C RESIDENCE TIME IN THE RESUSPENDABLE POOL.
316   WRITE(4,206) (TRSP(L), L=1,5)
317   206 FORMAT(1X,'POOL RESIDENCE TIME (YR):'7X,6F10.1)
318 C DO LAST CONVERSIONS
319   DO 11 L=1,5
320     AKD(L)=AKD(L)*1.0E+05
321     IF(TRSP(L))12,12,13
322   12 ELSP(L)=0.0
323     GO TO 919
324   13 ELSP(L)=1.0/(12.0*TRSP(L))
325   919 FW(L)=1.0/(AKD(L)*CSM(L)+1.0)
326 C FW=THE FRACTION DISSOLVED.
327 C MEAN SETTLING VELOCITY
328   VEL(L)=(1.0+BETA(L))*RM(L)/CSM(L)
329 C CONVERT TO M/DAY
330   VEL(L)=VEL(L)/(100.*30.4)
331 C SIZE OF THE RESUSPENDABLE POOL
332   G(L)=12.0*RM(L)*TRSP(L)
333   11 CONTINUE
334   WRITE(4,415) (G(L), L=1,5)
335   415 FORMAT(1X,'POOL SIZE (G/CM**2):',14X,6F10.3)
336   WRITE(4,115) (VEL(L), L=1,5)
337   115 FORMAT(1X,'MEAN SETTLING RATE (M/DAY):',5X,6F10.1)
338   WRITE(4,207) (FW(L), L=1,5)
339   207 FORMAT(1X,'FRACTION DISSOLVED:',15X,6F10.3)
340   WRITE(4,208)
341   208 FORMAT('0','OUTPUT UNIT(4):: [WATER:(AMT/L), RES POOL:(AM'
342     1,'T/G SOLIDS)]',/)
343   WRITE(4,216) (AMT(K), K=1,10)
344   216 FORMAT(1X,'UNITS OF AMT:',10A4,/)
345 C DEFINE ALPHA VARIABLES
346   DO.21 L=1,5
347     ALP1(L)=BETA(L)*RM(L)*AL(L)/VL(L)
348     BOT=CSM(L)+(1.0/AKD(L))
349     ALP2(L)=(1.0+BETA(L))*RM(L)*AL(L)/(BOT*VL(L))
350     ALP3(L)=((Q(L)/VL(L))+ELW(L)+ELAM)

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351         ALP4(L)=(1.0+BETA(L))*ELSP(L)/BOT
352         ALP5(L)=ELAM+(1.0+BETA(L))*ELSP(L)+ELP(L)
353     21 CONTINUE
354     C NOW FOR THE HEART OF THE CALCULATION AT LAST.
355     C COMPUTE LOADING FROM THE DRAINAGE BASINS.
356         DO 8 J=2, N
357         DO 198 L=1,5
358         IF(J-144)75,75,76
359         75 ELE=4.48*ELDB(L)
360         GO TO 77
361         76 ARG=384-J
362         ELE=ELDB(L)*EXP(ARG*ENU(L))
363         77 CONTINUE
364         ELSV(L,J)=ELE
365     C THIS SIMULATES THE MEASURED CHANGE IN THE D-B LOSS
366     C RATE CONSTANT BETWEEN 1962 AND 1982.
367     C USES THE MEASUREMENTS OF MENZEL AND NELSON FOR
368     C STRONTIUM-90 AND ASSUMES THAT THE SAME DEPENDENCE
369     C APPLIES TO THE OTHER FALLOUT RADIONUCLIDES.
370     C THIS TREATMENT CAN BE APPLIED WITH CAREFUL THOUGHT
371     C TO OTHER CONSTITUENTS.
372         TD(L,J)=TD(L,J-1)+(1.0-FRD(L))*AD(L)*FD(L,J)
373         TD(L,J)=TD(L,J)-(ELAM+ELE+ELD(L))*TD(L,J-1)
374         IF(L-4)40,41,40
375         41 TDSC(J)=TDSC(J-1)+(1.0-FRD(L))*ADSC*FD(L,J)
376         TDSC(J)=TDSC(J)-(ELAM+ELE+ELD(L))*TDSC(J-1)
377         40 CONTINUE
378         TDBL=FRD(L)*FD(L,J)*AD(L)+ELE*TD(L,J)
379         IF(L-4)42,43,42
380         43 TDBL=TDBL+FRD(L)*FD(L,J)*ADSC+ELE*TDSC(J)
381         42 CONTINUE
382         TLB(L,J)=(1.0-ELAM)*TLB(L,J-1)+(TDBL/AL(L))
383     C TDBL=THE TOTAL LOADING FROM THE DRAINAGE BASIN.
384     C NOW COMPUTE THE TOTAL LAKE LOADING BY ADDING ON THE
385     C TRANSFER DIRECTLY TO EACH LAKE
386         TOTL=FL(L,J)*AL(L)+TDBL
387         FLUXA=FL(L,J)
388         IF(L-4)44,45,44
389         45 TOTL=TOTL+FL(L,J)*ALSC
390         FLUXA=FLUXA+FL(L,J)*ALSC/AL(L)
391         44 CONTINUE
392         TLA(L,J)=(1.0-ELAM)*TLA(L,J-1)+FLUXA
393     C TL=DECAY-CORRECTED AMOUNT ENTERING EACH LAKE.
394     C UNITS OF TOTL ARE AMT/MONTH.
395     C UNITS OF TL ARE AMT/CM**2.
396     C NEXT COMPUTE TOTAL CONCENTRATIONS IN THE WATER COLUMN.
397         CT(L,J)=CT(L,J-1)+(TOTL/VL(L))+ALP1(L)*CP(L,J-1)
398         CT(L,J)=CT(L,J)-ALP2(L)*CT(L,J-1)-ALP3(L)*CT(L,J-1)
399     C NEXT ADD ON INFLOW CONTRIBUTIONS.
400         GO TO (18,18,19,20,20), L

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401      19 T1=Q(1)*CT(1,J-1)
402          T2=Q(2)*CT(2,J-1)
403          SFL(L,J)=(1.0-ELAM)*SFL(L,J-1)+(T1+T2)/AL(L)
404          CT(L,J)=CT(L,J)+(T1+T2)/VL(L)
405          GO TO 18
406      20 TRM=Q(L-1)*CT(L-1,J-1)
407          SFL(L,J)=(1.0-ELAM)*SFL(L,J-1)+TRM/AL(L)
408          CT(L,J)=CT(L,J)+TRM/VL(L)
409      C COMPUTE CONCENTRATIONS IN THE RESUSPENDABLE POOL.
410          18 CP(L,J)=CP(L,J-1)+ALP4(L)*CT(L,J-1)-ALP5(L)*CP(L,J-1)
411          SOU(L,J)=(1.0-ELAM)*SOU(L,J-1)+(CT(L,J-1)*Q(L)/AL(L))
412      C DECAY-CORRECTED LOSS VIA OUTFLOW IN AMT/CM**2
413          SSD(L,J)=(1.0-ELAM)*SSD(L,J-1)+CP(L,J-1)*RM(L)
414      C DECAY-CORRECTED STORAGE IN PERMANENT SEDIMENTS (AMT/CM**2).
415          198 CONTINUE
416          8 CONTINUE
417      C WRITE TOTAL CONC IN WATER AND R-S POOL ON UNIT 4.
418          WRITE(4,233)
419          233 FORMAT(///,10X, 'COUPLED LAKE MODEL: TOTAL CONCENTRATION'
420          1, ' IN WATER AND IN THE RESUSPENDABLE POOL',/)
421          WRITE(4,212)
422          212 FORMAT(1X, 'YEAR', 2X, 'MO', 8X, 'SUPERIOR', 11X, 'MICHIGAN',
423          112X, 'HURON', 15X, 'ERIE', 14X, 'ONTARIO')
424          WRITE(4,211)
425          211 FORMAT(1X, '_____', 5(5X, '_____' ))
426          DO 14 J=1, N, ISPA
427      C CONVERT CT(L,J) TO AMT/LITER.
428          DO 15 L=1, 5
429          15 CT(L,J)=1000.0*CT(L,J)
430          WRITE(4,210) IYR(J), IMO(J), ((CT(L,J),CP(L,J)),L=1,5)
431          210 FORMAT(1X, I4, 2X, I2, 5(2X, F8.3, 1X, F8.3))
432          14 CONTINUE
433          WRITE(4,217)
434          217 FORMAT(1X, 104('-'))
435          WRITE(7,209)
436          209 FORMAT('1', 'OUTPUT UNIT(7):: [TRIB CONC:(AMT/L), BASIN'
437          1, ' STORAGE:(AMT/CM**2)]',/)
438          WRITE(7,216) (AMT(K), K=1,10)
439          WRITE(7,214)
440          214 FORMAT(///,10X, 'COUPLED LAKES MODEL: MEAN TRIBUTARY CON'
441          1, 'CENTRATION AND DRAINAGE BASIN STORAGE',/)
442          WRITE(7,212)
443          WRITE(7,211)
444      C WRITE APPROX MEAN TRIB CONCS AND D B STORAGE ON UNIT 7.
445          DO 16 J=1, N, ISPA
446          DO 17 L=1, 5
447          CTRIB(L)=ELSV(L,J)*TD(L,J)/QR(L)
448      C CONVERT TRIB CONCENTRATIONS TO AMT/L.
449          CTRIB(L)=1000.*CTTRIB(L)
450      C CONVERT BASIN STORAGE TO AMT/CM**2

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451         STOR(L)=TD(L,J)/AD(L)
452     17 CONTINUE
453         WRITE(7,210) IYR(J),IMO(J), ((CTRIB(L), STOR(L)), L=1,5)
454     16 CONTINUE
455         WRITE(7,217)
456 C WRITE COMPARTMENT STORAGE AND MASS BALANCE CHECK ON UNIT 8.
457     DO 772 L=1, 5
458         WRITE(8,201) (LBL(J), J=1, 20)
459         WRITE(8,881) (LAKE(L,K),K=1,2)
460     881 FORMAT(1X,'OUTPUT UNIT(8):: [DECAY-CORRECTED INVENTORY',
461     1 '(AMT/CM**2) FOR LAKE ',2A4,']',/)
462         WRITE(8,882)
463     882 FORMAT(1X,'YEAR',2X,'MO',5X,' AIR',
464     1 6X,'BASIN',5X,'INFLO',5X,'WATER',
465     2 6X,'OUT ',5X,'POOL',7X,'SED',14X,'CHECK')
466         WRITE(8,884)
467     884 FORMAT(1X,' _____ ',7(4X,' _____ '),12X,' _____ ')
468         DO 771 J=1, N, ISPA
469             SWC=0.001*CT(L,J)*VL(L)/AL(L)
470 C SWC=AMOUNT IN THE WATER COLUMN (AMT/CM**2).
471         SRP=CP(L,J)*G(L)
472 C SRP=AMOUNT IN THE RESUSPENDABLE POOL (AMT/CM**2)
473         CHK=TLA(L,J)+TLB(L,J)
474         CHK=CHK+SFL(L,J)-SWC-SOU(L,J)-SRP-SSD(L,J)
475 C CHK IS THE DIFFERENCE BETWEEN THE TOTAL AMT. IN THE SYSTEM
476 C AND THE SUM OF AMOUNTS ACTUALLY STORED IN EACH COMPARTMENT.
477 C CHK SHOULD BE ZERO IF THE DEGRADATION TERMS ARE ZERO.
478         WRITE(8,883) IYR(J), IMO(J), TLA(L,J), TLB(L,J), SFL(L,J),
479     1 SWC, SOU(L,J), SRP, SSD(L,J), CHK
480     883 FORMAT(1X,I4,2X,I2,7F10.2,10X,F10.6)
481     771 CONTINUE
482         WRITE(8,817)
483     817 FORMAT(1X,98(' '))
484     772 CONTINUE
485         GO TO 1
486     END

```

## Appendix C: Sample Input File

396. 1000. FEMTOCURIAS  
PU-239/240 CALIBRATIONS WITH NEW D-B MODEL IN PLACE.  
0.0 1950. 12.  
24000. 24000. 24000. 24000. 24000.  
5.0 5.0 5.0 .50 2.5  
1.1 2.0 .92 .5 .885  
60. 120. 50. 140. 160.

Appendix D: Sample Output File

COUPLED LAKES MODEL: FIXED PARAMETER LIST

	S	M	H		C
LAKE AREAS (10**4 KM**2):	6.2	5.8	6.0	2.6	1.9
DRAIN. BASIN AREAS (10**4 KM**2)	12.8	11.8	13.1	5.9	6.1
LAKE VOLUMES (10**3 KM**3)	12.1	4.9	3.5	0.5	1.6
MEAN OUTFLOWS (KM**3/YR):	71.1	49.0	151.0	176.0	211.0
MEAN RUNOFF (KM**3/YR):	49.5	35.2	48.3	20.2	27.7
MEAN SOLIDS CONC. (MG/L):	0.5	0.5	0.5	5.0	1.0
MEAN SED. RATES (G/M**2/YR):	98.0	69.0	110.0	1410.0	224.0
DIRECT TRANSFER FRACTION:	0.022	0.022	0.022	0.022	0.022
DEG. LIFE-TIME WATER (YR):	0.0	0.0	0.0	0.0	0.0
DEG. LIFE-TIME POOL (YR):	0.0	0.0	0.0	0.0	0.0
DEG. LIFE-TIME CR. BASIN (YR):	0.0	0.0	0.0	0.0	0.0
R-N FLUX MULTIPLIER:	1.00	1.00	1.00	1.00	1.00
MEAN LAKE DEPTH (CM):	141.4	65.1	59.4	18.8	06.3
HYDRAULIC RESIDENCE TIME (YR):	170.2	100.4	22.0	2.8	7.8

CASE: PU-239/240 CALIBRATIONS WITH NEW D-B MODEL IN PLACE.

COUPLED LAKES MODEL: VARIABLE PARAMETER LIST

HALF-LIFE (YR):	0.00				
NUMBER OF MONTHS:	396.				
BEGINNING DATE (YR):	1950.				
OUTPUT VALUE SPACING (MONTHS):	12.				
DRAINAGE BASIN RES. TIME (YR):	24000.0	24000.0	24030.0	24000.0	24000.0
PART. COEFF. (10**5 CM**3/G):	5.000	5.000	5.000	0.500	2.500
RESUSPENSION FACTOR:	1.10	2.00	0.92	0.50	0.88
POOL RESIDENCE TIME (YR):	60.0	120.0	50.0	140.0	160.0
POOL SIZE (G/CM**2):	0.588	0.828	0.550	19.740	3.534
MEAN SETTLING RATE (M/DAY):	1.1	1.1	1.2	1.2	1.2
FRACTION DISSOLVED:	0.800	0.800	0.800	0.800	0.800

OUTPUT UNIT(4):: [WATER:(AMT/L), RES POOL:(AMT/G SOLIDS)]

UNITS OF AMT: FEMTOCURIES

COUPLED LAKE MODEL: TOTAL CONCENTRATION IN WATER AND IN THE RESUSPENDABLE POOL

YEAR	MC	SUPERIOR		MICHIGAN		HURON		ERIE		ONTARIO	
1950	1	<b>0.000</b>	0.000	0.000	0.000	0.000	0.000	0.000	0.000	<b>0.000</b>	0.000
1951	1	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.000	<b>0.000</b>
<b>1952</b>	<b>1</b>	<b>0.016</b>	0.000	0.029	0.000	0.049	0.000	0.210	0.000	0.031	0.000
1953	1	0.136	1.135	0.200	1.338	<i>0.276</i>	3.063	0.276	0.137	<b>0.282</b>	0.431
1954	1	0.273	3.958	0.333	4.172	0.423	a.320	0.258	0.321	0.370	1.201
1955	1	0.360	3.448	0.496	8.321	0.590	16.397	0.561	0.600	0.393	2.373
1956	1	0.800	15.446	<i>0.761</i>	<i>14.777</i>	1.031	26.942	2.792	0.973	1.152	4.119
1951	1	0.960	27.335	1.014	24.521	1.289	45.933	1.123	1.896	1.346	7.381
1958	<b>1</b>	0.784	38.589	0.754	33.083	0.789	60.192	0.469	2.293	0.824	9.901
1959	1	1.723	32.918	1.358	44.414	2.376	77.034	3.301	3.298	2.331	13.022
1960	1	1.868	78.673	2.200	69.240	<i>2.212</i>	121.134	1.114	4.857	2.196	19.437
1961	1	1.370	98.861	1.256	85.339	1.019	141.920	0.396	5.188	1.113	23.258
1962	1	1.174	112.673	1.100	<i>94.461</i>	1.070	151.676	1.041	5.537	1.102	25.530
1963	1	1.724	130.932	1.897	109.980	2.214	176.351	1.715	6.575	2.129	29.650
1964	1	3.280	164.441	3.909	141.339	4.535	232.994	3.060	8.600	3.916	37.487
1965	1	3.371	209.370	3.482	178.429	3.357	288.452	2.053	10.334	<b>3.248</b>	46.372
1966	1	2.733	<i>247.231</i>	2.333	204.071	1.899	318.836	0.777	11.014	1.901	52.059
1967	1	1.897	271.009	1.396	217.884	<b>1.085</b>	329.457	0.453	11.279	1.017	34.927
1968	1	1.333	284.039	0.911	224.029	0.772	331.164	0.398	11.368	0.601	56.169
1969	1	1.076	291.173	0.758	<i>227.019</i>	0.704	330.571	0.334	11.460	0.487	56.349
<i>1970</i>	1	0.883	294.706	0.709	228.924	0.683	329.028	0.317	11.334	0.449	37.344
1971	1	0.837	296.595	0.736	230.691	0.768	329.221	0.349	11.666	0.527	37.889
1972	1	0.834	298.283	<i>0.734</i>	232.705	0.758	328.555	0.304	11.776	0.523	58.569
1973	1	<b>0.702</b>	298.707	<i>0.607</i>	233.699	0.382	326.450	0.223	11.803	0.381	<b>53.393</b>
1974	1	<b>0.606</b>	297.436	0.331	233.368	0.312	322.357	0.231	11.782	0.294	59.083
1975	1	0.618	295.762	0.599	<i>233.116</i>	0.387	319.076	0.300	11.832	0.335	59.236
1976	1	0.559	293.800	0.532	233.716	0.496	315.498	0.184	11.826	0.204	33.342
1977	1	0.496	290.977	0.463	232.907	0.433	310.629	0.149	11.779	0.219	53.246
1978	1	0.327	288.001	0.525	232.053	0.526	306.112	0.338	11.784	0.312	59.142
1979	<b>1</b>	0.337	285.560	0.332	231.881	0.508	302.684	<b>0.208</b>	11.804	0.291	<b>59.204</b>
1980	1	0.493	282.882	0.478	231.294	0.430	298.425	0.153	11.765	0.223	39.132
1981	1	0.431	279.643	0.438	230.111	0.396	293.411	0.141	11.710	0.189	58.921
1982	1	0.426	<i>216.032</i>	0.422	228.693	0.383	288.261	0.133	11.654	0.177	53.671



OUTPUT UNIT(7):: [TRIB CONC:(AMT/L), BASIN STORAGE:(AMT/CM\*\*2)]

UNITS OF AMT: FEMTOCURIES

COUPLED LAKES MODEL: MEAN TRIBUTARY CONCENTRATION AND DRAINAGE BASIN STORAGE

YEAR	HO	SUPERIOR		MICHIGAN		HURON		ERIE		ONTARIO	
1950	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1951	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1952	1	0.001	0.192	0.001	0.220	0.001	0.234	0.002	0.362	0.001	0.264
1953	1	0.013	2.700	0.016	2.580	0.015	2.968	0.018	3.339	0.015	3.728
1954	1	0.030	6.266	0.037	5.985	0.034	6.684	0.034	6.259	0.030	7.332
1955	1	0.050	10.351	0.066	10.562	0.059	11.645	0.064	11.841	0.054	13.181
1956	1	0.098	20.299	0.113	19.074	0.099	19.480	0.120	22.113	0.098	24.052
1957	1	0.143	29.741	0.179	28.627	0.156	30.645	0.194	35.693	0.150	36.827
1958	1	0.166	34.512	0.210	33.629	0.182	35.792	0.226	41.606	0.171	41.993
1959	1	0.268	55.747	0.325	51.977	0.270	53.128	0.351	64.617	0.262	64.057
1960	1	0.355	73.651	0.467	74.694	0.379	74.769	0.493	90.755	0.348	85.164
1961	1	0.379	78.734	0.499	79.668	0.407	80.214	0.517	95.155	0.370	90.649
1962	1	0.383	84.844	0.505	36.112	0.413	86.907	0.524	102.922	0.377	98.669
1963	1	0.446	106.321	0.584	107.037	0.476	107.664	0.586	123.720	0.432	121.358
1964	1	0.597	152.868	0.757	149.198	0.624	151.612	0.727	165.101	0.550	166.208
1965	1	0.681	187.286	0.836	177.132	0.679	177.256	0.803	195.886	0.595	193.059
1966	1	0.672	198.771	0.831	189.131	0.670	188.023	0.790	207.153	0.583	203.298
1967	1	0.640	203.393	0.792	193.832	0.639	192.627	0.753	212.196	0.555	207.887
1968	1	0.602	205.498	0.746	196.175	0.602	195.136	0.710	214.895	0.523	210.459
1969	1	0.569	208.708	0.704	198.957	0.568	197.869	0.670	217.809	0.493	213.293
1970	1	0.535	210.957	0.663	201.389	0.535	200.432	0.631	220.640	0.464	215.980
1971	1	0.506	214.481	0.627	204.650	0.507	204.015	0.597	224.158	0.439	219.649
1972	1	0.479	218.262	0.593	207.851	0.479	207.234	0.564	227.538	0.416	223.223
1973	1	0.448	219.425	0.555	209.127	0.449	208.559	0.528	229.094	0.390	224.983
1974	1	0.418	220.163	0.519	209.946	0.419	209.381	0.493	230.022	0.364	225.935
1975	1	0.393	222.270	0.487	212.101	0.394	211.448	0.463	232.230	0.342	228.299
1976	1	0.367	223.083	0.456	213.095	0.368	212.421	0.433	233.287	0.320	229.400
1977	1	0.342	223.362	0.425	213.426	0.343	212.780	0.404	233.658	0.299	229.853
1978	1	0.320	224.068	0.398	214.793	0.322	214.148	0.375	235.308	0.280	231.540
1979	1	0.300	226.349	0.373	216.401	0.301	215.522	0.354	236.831	0.262	232.936
1980	1	0.280	226.887	0.348	216.898	0.281	216.039	0.331	237.370	0.244	233.415
1981	1	0.261	227.119	0.324	217.169	0.262	216.319	0.308	237.676	0.228	233.707
1982	1	0.243	227.351	0.302	217.440	0.244	216.600	0.287	237.982	0.212	233.999

CASE: PU-239/240 CALIBRATIONS WITH NEW D-3 MODEL IN PLACE.

OUTPUT UNIT(8)::[DECAY-CORRECTED INVENTORY(AMT/CM\*\*2) FOR LAKE SUPERIOR]

YEAR	MO	AIR	BASIN	INFLC	WATER	OUT	POOL	SED	CHECK
1950	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1951	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1952	1	0.22	0.01	0.00	0.23	0.00	0.00	0.00	0.000000
1953	1	2.58	0.09	0.00	2.30	0.01	0.67	0.00	0.000000
1954	1	6.18	0.22	0.00	4.02	0.03	2.33	0.03	-0.000001
1955	1	10.04	0.37	0.00	5.30	0.05	4.97	0.08	0.000000
1956	1	20.45	0.72	0.00	11.79	0.10	9.08	0.19	0.000002
1957	1	29.73	1.06	0.00	14.14	0.18	16.07	0.40	0.000001
1958	1	34.04	1.23	0.00	11.55	0.26	22.75	0.72	0.000007
1959	1	56.05	1.99	0.00	25.43	0.35	31.12	1.15	0.000001
1960	1	73.4s	2.64	0.00	27.53	0.53	46.26	1.78	0.000019
1961	1	78.80	2.34	0.00	20.19	0.67	58.13	2.65	0.000022
1962	1	84.94	3.08	0.00	17.31	0.78	66.25	3.68	0.000025
1963	1	104.31	3.85	0.00	25.40	0.92	76.99	4.86	0.000032
1964	1	146.94	5.52	0.00	48.34	1.16	96.69	6.27	0.000034
1965	1	178.82	6.76	0.00	52.63	1.48	123.40	a.07	0.000013
1966	1	190.55	7.20	0.00	40.32	1.76	145.38	10.31	0.000013
1967	1	194.72	7.41	0.00	27.96	1.96	159.3s	12.85	0.000054
1968	1	196.82	7.52	0.00	19.64	2.10	167.03	15.57	0.000036
1969	1	200.00	7.67	0.00	15.86	2.21	171.21	1a.39	0.000094
1970	1	202.10	7.78	0.00	13.04	2.29	173.29	21.26	0.000071
1971	1	205.33	7.93	0.00	12.34	2.37	174.40	24.16	0.000097
1972	1	209.09	a.10	0.00	12.29	2.44	175.39	27.07	0.000154
1973	1	210.32	8.17	0.00	10.34	2.51	175.64	30.00	0.000166
1974	1	211.11	a.22	0.00	8.93	2.57	174.90	32.92	0.000095
1975	1	213.14	8.32	0.00	9.10	2.62	173.91	35.83.	0.000076
1976	1	214.01	8.37	0.00	a.24	2.67	172.7s	38.72	0.000069
1977	1	214.31	a.40	0.00	7.31	2.72	171.09	41.58	0.000061
1978	1	215.82	8.47	0.00	7.77	2.76	169.34	44.42	0.000095
1979	1	217.32	8.54	0.00	7.91	2.81	167.91	47.23	0.000065
1980	1	217.90	3.58	0.00	7.27	2.85	166.33	50.02	0.000065
1981	1	218.15	8.61	0.00	6.65	2.90	164.43	52.78	0.000046
1982	1	218.40	8.63	0.00	6.27	2.93	162.32	55.50	0.000046

CASE: PU-239/240 CALIBRATIONS WITH NEW D-B MODEL I N PLACE.

OUTPUT UNIT(B):: (DECAY-CORRECTED INVENTORY (AMT/CM\*\*2) FOR LAKE MICHIGAN 3

YEAR	MO	AIR	BASIN	INFLO	WATER	OUT	POOL	SED	CHECK
1950	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000c
1951	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1952	1	0.23	0.01	0.00	0.24	0.00	0.00	0.00	0.000000
1953	1	2.70	0.12	0.00	1.70	0.01	1.11	0.00	-0.000001
1954	1	6.07	0.28	0.00	2.33	0.04	3.45	0.02	-0.000002
1955	1	10.93	0.49	0.00	4.23	0.07	7.06	0.06	-0.000002
1956	1	18.14	0.84	0.00	6.48	0.13	12.24	0.14	-0.000001
1957	1	29.08	1.34	0.00	8.63	0.22	20.30	0.27	-0.000002
1958	1	32.99	1.58	0.00	6.42	0.29	27.39	0.47	-0.000003
1959	1	51.28	2.44	0.00	15.32	0.40	36.77	0.72	-0.000005
1960	1	74.27	3.51	0.00	18.72	0.62	57.33	1.10	0.300004
1961	1	80.00	3.77	0.00	10.69	0.77	70.66	1.64	0.000012
1962	1	86.62	4.09	0.00	9.36	0.87	<b>78.22</b>	2.26	-0.000002
1963	1	106.10	5.09	0.00	16.15	1.02	91.06	2.95	-0.000005
1964	1	148.34	7.07	0.00	33.27	1.31	117.03	3.79	0.000031
1965	1	175.52	a.40	0.00	29.64	1.66	147.74	<b>4.88</b>	0.000015
1966	1	187.94	9.01	0.00	19.85	1.92	168.97	6.20	0.000034
1967	1	192.76	9.27	0.00	<b>11.88</b>	2.08	180.41	7.66	0.000011
<b>1968</b>	1	195.19	9.43	0.00	7.75	2.18	<b>185.50</b>	9.18	0.000004
1969	1	197.82	9.60	0.00	6.46	2.25	187.97	10.74	0.000010
1970	1	200.46	9.76	0.00	6.03	2.32	189.55	12.31	0.000037
1971	1	203.62	9.95	0.00	6.27	2.38	191.01	13.90	0.000022
1972	1	206.74	10.13	0.00	6.25	2.45	192.68	15.50	0.000059
1973	1	208.06	10.22	0.00	5.17	2.51	193.50	17.10	0.000074
1974	1	<b>208.89</b>	10.30	0.00	4.52	2.55	193.39	1a.72	0.000050
1975	1	211.13	10.43	0.00	5.10	2.61	193.52	20.33	0.000046
1976	1	212.14	10.50	0.00	4.53	2.66	193.52	21.94	0.000023
1977	1	212.49	10.54	0.00	3.94	2.70	192.85	23.55	0.000034
1978	1	213.87	10.63	0.00	4.47	2.74	192.14	25.16	0.000034
1979	1	<b>215.51</b>	10.73	0.00	4.70	2.79	192.00	26.76	0.000061
<b>1980</b>	1	215.99	10.77	0.00	4.07	2.83	191.51	23.35	0.000076
1981	1	216.27	10.81	0.00	3.73	2.87	190.53	29.95	0.000061
1982	1	216.55	10.84	0.00	3.59	2.91	189.36	31.53	0.000061

CASE: PU-239/240 CALIBRATIONS WITH NEWD-SMDELIN PLACE.

OUTPUT UNIT(3):: (DECAY-CORRECTED INVENTORY(CMT/CM##2) FOR L A K E HURON 1

Y E A R M O	AIR	BASIN	INFLO	WATER	CUT	POGL	SED	CHECK
1950	1	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1951	1	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1952	1	0.28	0.01	0.00	0.29	0.00	0.00	0.000000
1953	1	3.22	3.15	0.02	1.64	0.05	1.68	-0.000001
1954	1	7.02	0.33	0.07	2.51	<b>9.15</b>	4.69	-0.000002
1955	<b>1</b>	12.29	0.58	<b>0.15</b>	3.51	0.30	9.02	-0.000002
1956	1	20.33	0.93	0.26	<b>6.42</b>	0.50	14.82	-0.000004
1957	1	32.61	1.54	0.45	7.66	0.36	25.27	-0.000009
<b>1958</b>	1	37.39	1.31	0.64	4.69	1.14	33.11	-0.000006
<b>1959</b>	1	56.53	2.69	0.37	14.11	1.49	42.37	-0.000011
1960	1	<b>80.17</b>	3.79	1.33	13.74	2.33	66.62	-0.000010
1961	1	86.13	4.09	1.67	6.41	2.78	78.06	-0.000020
1962	1	92.72	4.46	1.92	6.36	3.05	33.42	-0.000037
1963	<b>1</b>	113.99	5.53	2.26	13.15	3.59	96.99	-0.000074
1964	1	159.40	7.75	2.87	26.94	4.72	123.15	-0.000138
<b>1965</b>	1	164.30	9.03	3.65	19.94	<b>5.88</b>	153.65	-0.000161
1966	1	195.71	9.67	<b>4.28</b>	11.28	6.61	175.36	-0.000168
1967	1	199.98	9.95	4.72	6.44	7.02	<b>181.20</b>	-0.000187
1968	1	202.43	10.13	5.01	4.58	7.27	182.14	<b>-0.000183</b>
1969	1	205.21	10.31	<b>5.23</b>	4.18	7.49	<b>181.81</b>	-0.000153
1970	1	207.70	10.48	5.41	4.06	7.68	180.97	-0.000158
1971	1	211.20	10.70	<b>5.57</b>	4.56	7.89	180.52	-0.000164
1972	1	214.79	10.90	5.74	4.50	a.12	130.71	-0.000225
1973	1	216.13	11.01	5.89	3.46	8.30	179.55	-0.000206
1974	1	<b>216.97</b>	11.03	6.01	3.04	8.45	177.30	-0.000217
197s	1	219.04	11.22	6.14	3.49	3.61	175.49	-0.000244
1976	1	219.98	11.30	6.26	2.94	8.76	173.52	-0.000275
1977	1	220.35	11.35	6.36	2.57	<b>8.89</b>	170.85	<b>-0.000286</b>
1978	1	221.74	11.44	6.46	3.12	9.01	163.36	-0.000259
1979	1	223.04	<b>11.54</b>	6.57	3.02	9.16	166.48	-0.000225
1980	1	223.52	11.59	6.68	2.55	9.29	164.13	-0.000290
1981	1	223.79	11.62	6.77	2.35	9.40	161.38	-0.000232
1982	1	224.07	11.66	6.36	2.23	9.51	153.54	-0.000313

CASE: PU-239/240 CALIBRATIONS WITH N E WD-8 MODEL IN PLACE.

OUTPUT UNIT(8):: [DECAY-CORRECT'D INVENTORY (AMT/CM\*\*2) FOR LAKE ERIE 1

YEAR	MO	AIR	BASIN	INFLO	WATER	OUT	POOL	SED	CHECK
1950	1	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.000000
<b>1951</b>	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.300000
1952	1	0.37	0.02	0.00	0.39	0.00	0.00	0.00	0.000000
1953	1	3.54	0.21	0.13	0.52	<b>0.25</b>	3.10	0.01	0.000000
<b>1954</b>	1	6.64	0.39	0.36	0.49	<b>0.52</b>	6.34	0.04	0.000000
1955	1	12.54	<b>0.75</b>	0.70	1.06	0.97	11.85	0.10	-0.000004
1956	1	23.71	1.40	1.16	5.26	1.53	13.21	0.21	-0.000003
1957	1	38.80	2.26	1.99	2.11	3.03	37.44	0.42	-0.000014
1958	1	45.34	2.65	2.65	0.33	3.75	45.29	0.71	-0.000002
1959	<b>1</b>	70.62	4.11	3.44	6.59	5.40	65.10	1.08	-0.000001
1960	1	96.42	<b>5.79</b>	<b>5.40</b>	2.10	7.96	95.37	1.67	-0.000003
1961	1	101.55	6.11	6.45	0.75	<b>8.58</b>	102.41	2.38	0.000011
1962	1	109.89	6.65	7.08	1.96	9.23	109.29	3.13	-0.000031
1963	1	131.65	a.00	8.34	3.23	10.99	129.79	3.97	-0.000023
1964	1	173.30	10.64	10.96	5.76	14.35	169.77	5.02	-0.000032
1965	1	205.24	12.64	13.62	<b>3.87</b>	17.29	204.00	6.36	-0.000065
1966	1	216.53	13.42	15.34	1.46	18.55	217.42	7.86	-0.000051
1967	1	222.00	13.31	16.28	0.85	19.17	222.64	9.43	<b>-0.000018</b>
1968	1	224.78	14.05	<b>16.87</b>	0.75	19.51	224.41	11.03	-0.000025
1969	1	227.66	14.30	17.36	0.63	<b>19.85</b>	226.21	12.64	-0.000054
1970	1	230.78	14.54	17.82	0.60	20.19	223.09	14.26	-0.000120
1971	1	234.29	14.82	<b>18.30</b>	0.66	20.57	230.23	15.90	<b>-0.000098</b>
1972	1	237.63	15.08	<b>18.83</b>	0.57	20.95	232.47	17.55	-0.000x43
1973	1	239.33	15.23	19.25	0.42	21.19	232.99	19.21	-0.000158
1974	1	240.31	15.34	19.60	0.43	21.36	232.58	20.87	-0.000166
197s	<b>1</b>	242.82	15.53	19.96	0.57	21.64	233.56	22.54	-0.000034
1976	1	243.39	15.64	20.31	0.35	21.34	233.45	24.21	-0.000113
1977	1	244.32	15.70	20.61	0.23	21.96	232.51	25.87	-0.000095
<b>1978</b>	<b>1</b>	246.22	is.84	20.91	0.64	22.17	232.62	27.53	0.000008
1979	<b>1</b>	247.78	15.97	21.24	0.39	22.41	233.00	29.19	-0.000065
1930	1	248.36	16.04	21.54	0.29	22.55	232.25	30.36	-0.000067
1931	1	243.71	16.09	21.90	0.27	22.66	231.16	<b>32.51</b>	-0.000076
<b>1982</b>	1	249.06	16.14	22.05	0.26	22.77	230.05	34.16	-0.000114

CASE: PU-239/240 CALIBRATIONS WITH N E WD-SMCDLIN PLACE.

OUTPUT UNIT(8):: IDECAY-CORRECTED INVENTORY (AMT/CM\*\*2) FIR LAKE ONTARIO 1

YEAR	MC	AIR	BASIN	INFLO	WATER	OUT	POOL	SED	CHECK
1950	1	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1451	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000000
1952	1	0.25	0.02	0.00	0.27	0.00	0.00	0.00	0.000000
1953	1	3.58	0.27	0.34	2.43	0.20	1.54	0.00	0.000000
1954	1	6.85	0.53	0.70	3.19	0.57	4.30	0.02	-0.000001
1955	1	12.54	<b>0.96</b>	1.31	5.12	1.13	8.51	0.06	-0.000001
1356	1	22.92	1.75	2.14	9.94	1.97	14.76	0.13	0.000002
1957	<b>1</b>	35.02	2.60	4.17	11.62	3.54	<b>26.45</b>	0.23	-0.000002
1958	1	39.67	3.08	3.08	7.12	4.70	35.49	0.45	-0.000001
1959	1	61.79	4.69	7.31	20.12	5.31	46.67	0.69	0.000013
<b>1960</b>	1	<b>82.14</b>	6.26	10.17	18.96	9.43	69.73	1.05	-0.000004
1961	1	07.53	6.70	11.60	9.61	11.34	03.36	1.53	-0.000008
1962	1	95.81	7.34	12.48	9.51	12.55	91.50	2.07	-0.000019
1963	1	118.08	9.03	14.86	18.38	14.64	106.27	<b>2.68</b>	-0.000020
1964	1	158.35	12.32	13.41	33.80	18.51	134.35	3.42	-0.000059
1965	1	183.80	14.33	23.38	28.04	22.93	166.20	4.35	-0.000041
<b>1966</b>	1	194.07	15.16	23.10	16.41	25.89	186.58	3.45	-0.000043
1967	1	198.32	15.57	25.93	<b>8.78</b>	27.54	<b>196.06</b>	6.63	<b>-0.000063</b>
1968	1	200.60	15.84	26.38	3.18	28.43	201.31	7.90	-0.000055
1969	1	203.22	16.11	<b>26.84</b>	4.20	29.06	203.73	9.16	-0.000050
1970	1	205.76	16.38	<b>21.32</b>	3.88	23.61	205.52	10.44	-0.000063
1971	1	209.41	16.71	27.03	4.55	30.19	207.47	11.73	-0.000079
1972	1	212.94	17.03	28.34	4.53	30.83	209.91	13.03	<b>-0.000076</b>
1973	1	214.55	17.21	28.67	3.29	31.36	211.43	14.33	-0.000102
1974	1	215.48	17.34	28.89	2.33	31.73	211.78	13.67	-0.000088
1975	1	217.66	<b>17.56</b>	29.28	3.06	32.13	212.30	17.00	-0.000122
1976	1	218.74	17.69	29.54	2.43	32.51	212.68	18.32	-0.000107
1977	1	219.20	17.77	29.71	1.89	32.80	212.34	19.65	-0.000113
1978	1	220.78	17.93	29.99	2.69	33.07	211.96	20.98	-0.000114
1979	1	222.11	19.07	30.31	2.57	33.43	212.19	22.30	-0.000143
1980	1	222.59	18.14	30.50	1.95	33.73	211.93	<b>23.63</b>	-0.000074
1981	1	<b>222.89</b>	18.20	30.63	1.63	33.96	211.20	24.93	-0.000042
1982	1	223.18	18.25	30.80	1.53	34.16	210.28	26.27	-0.000048