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USE OF SIMPLE BOX MODEL TO ESTIMATE PCB WATER COLUMN CONCENTRATIONS BEFORE AND AFTER CAPPING IN THE UPPER ESTUARY, DRAFT

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USE OF A SIMPLE BOX MODEL TO ESTIMATE PCB WATER COLUMN CONCENTRATIONS BEFORE AND AFTER CAPPING IN THE UPPER ESTUARY

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INTRODUCTION

The diffusive flux of PCBs from the sediments to the overlying water column is considered to be a primary mechanism by which PCBs enter upper New Bedford Harbor. One proposal for substantially reducing this flux is to cover all sediments in the upper estuary (north of Coggeshall Street) with PCB concentrations in excess of 50 ppm with a 45 cm thick sand cap (ASA, 1988). The upper estuary has the highest PCB sediment concentrations and is the primary source of PCBs to the harbor. The cap would eliminate PCB flux from the sediments to the overlying water due to both bioturbation and diffusive processes for an extended period of time (Thibodeaux, 1989).

One question which has not been adequately addressed is the relative benefit of the proposed cap to the water quality of New Bedford Harbor in terms of reduced PCB concentrations. This study was undertaken to estimate PCB concentrations in the water column in response to capping. The entire estuary north of the Hurricane Barrier was considered. A simple two-box PCB mass balance model which accounts for benthic flux, evaporation and exchange with adjacent boxes and offshore waters was used to provide a first-order estimate of water column concentrations before and after the capping operation. This estimate is based on several simplifying assumptions concerning flushing efficiencies and exchanges, evaporative loss and sediment flux. However, within its limitations the model is able to provide a valid first-order approximation of the improvement in water quality to be expected after capping.

This report represents a brief discussion of the model used, its application and results. The model is used to predict water column concentrations for three scenarios: present conditions, capping all sediments with PCB concentrations greater than 50 ppm in the upper estuary, and capping the entire upper estuary.

GOVERNING EQUATIONS OF THE BOX MODEL

A simple two-box model is used to represent the mass balance of PCBs in New Bedford Harbor. The upper box incorporates the area north of Coggeshall Street extending to Wood Street. The lower box includes the region from the Hurricane Barrier to Coggeshall Street (Figure 1).

The conservation of PCB mass for the two boxes is as follows:

Upper Box (north of Coggeshall Street)

$$W_U + Q_U C_L = C_U Q_U + C_U A_U K_e + Q_R C_U \qquad (1)$$

Lower Box (Hurricane Barrier to Coggeshall Street)

$$W_L + Q_L C_B + (Q_R + Q_U) C_U = C_L (Q_U + Q_L + Q_R) + C_L A_L K_e \qquad (2)$$

where

- C_U - PCB water column concentration in the upper box (g/cm^3)
- C_L - PCB water column concentration in the lower box (g/cm^3)
- C_B - PCB water column concentration south of the Hurricane Barrier (g/cm^3)
- Q_R - flow rate for the Acushnet River (cm^3/yr)
- Q_U - mean exchange rate between upper and lower estuary (cm^3/yr)
- Q_L - mean exchange rate between lower estuary and waters south of Hurricane barrier (cm^3/yr)
- A_U - water surface area of upper estuary (cm^2)
- A_L - water surface area of lower estuary (cm^2)
- K_e - PCB evaporation coefficient (cm/yr)
- W_U - PCB sediment bed release rate in the upper estuary (g/yr)
- W_L - PCB sediment bed release rate in the lower estuary (g/yr)

Order of magnitude analysis shows that the terms $Q_R C_U$ and $Q_R C_L$ in Equations 1 and 2 are small compared to the other terms in the equations. In physical terms this

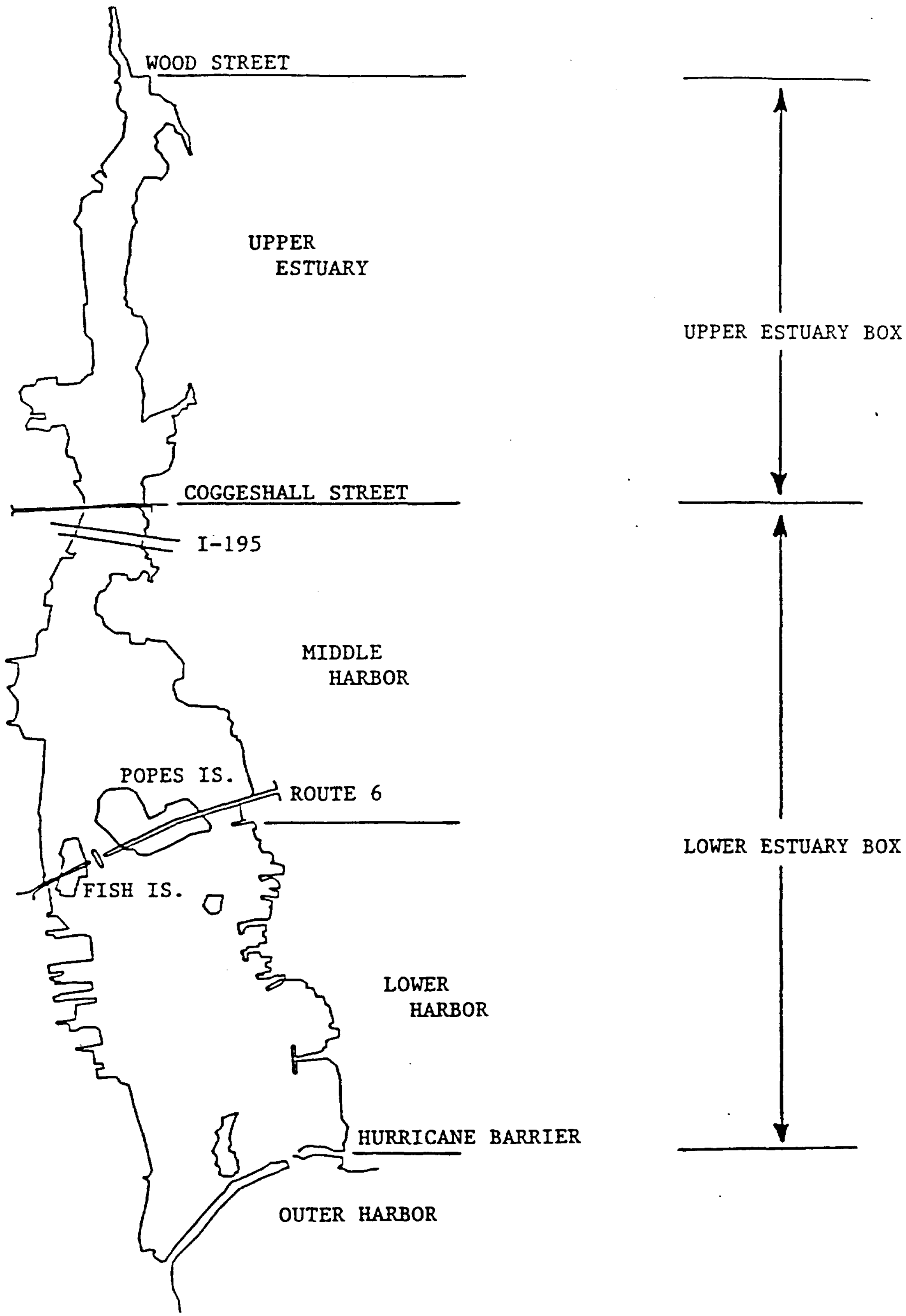

Figure 1 New Bedford Harbor study area showing division of estuary into boxes for box model.

indicates that the net advective transport of PCBs from the upper to lower estuary and from the lower estuary to outside the Hurricane Barrier due to the Acushnet River flow is small.

Using these assumptions and solving Equations 1 and 2 simultaneously, equations are obtained for the upper and lower estuary PCB water column concentrations.

$$C_U = \frac{W_U \ (Q_U + Q_L + A_L \ K_e) + Q_U \ (W_L + C_B \ Q_L)}{(Q_U + A_U K_e) \ (Q_U + Q_L + A_L \ K_e) - Q_U^2} \qquad (3)$$

$$C_L = \frac{W_U \ Q_U + (Q_U + A_U \ K_e) \ (W_L + C_B \ Q_L)}{(Q_U + A_U \ K_e)(Q_U + Q_L + A_L \ K_e) - Q_U^2} \qquad (4)$$

These equations are an expansion of the box model presented by Thibodeaux (1989) since they consider the complete PCB mass balance in both boxes. Inherent in these equations is the assumption that the Acushnet River flow transports little PCB.

SPECIFICATION OF BOX MODEL PARAMETERS

In this section, the value (or range of values) used for each parameter in the box model equations is briefly described, and the rationale for its selection is presented.

Surface Area

The surface area associated with each sediment concentration interval in the upper and lower estuary was determined by Balsam Environmental Consultants (Balsam, 1989a,b). These data are presented in Table 1. Figure 2 shows contours of total PCB concentrations in the upper 30.5 cm (12 in) of the upper estuary sediments. Figures 3 and 4 present total PCB contours in the upper 15 cm (6 in) of the sediments for the Middle Harbor and Lower Harbor, respectively. These two areas comprise the lower estuary.

Exchange Rate

Thibodeaux (1989) estimated Q_U as 1.84 x 10^6 m^3/day and Q_L as 5 Q_U. Q_U was estimated as the transport of two tidal prism volumes per day. We assume that Q_L was selected to be 5 Q_U since the area of the upper estuary is approximately 1/5 of the total surface area of the New Bedford estuary (see Table 1) and the tidal range is

Table 1 Area of sediment PCB concentration contour intervals in the upper and lower estuary. Areas determined by Balsam Environmental Consultants for the contour intervals shown in Figures 2-4.

Location	Concentration Interval (ppm)	Area (m^2)	Area (acres)	% of Total
Upper Estuary	0-10	84,986	21	11.0
	10-50	169,974	42	22.1
	50-100	80,940	20	10.5
	100-500	202,350	50	26.3
	500-1000	72,846	18	9.5
	1000-2000	40,470	10	5.3
	2000-5000	93,081	23	12.1
	5000-10000	12,141	3	1.6
	10000-15000	6,071	1.5	0.8
	15000-25000	5,666	1.4	0.7
	>25000	1,214	0.3	0.2
		769,739		
Lower Estuary				
Middle Harbor	0-5	290,696	71.83	53.4*
	5-10	119,225	29.46	18.2
	10-25	306,560	75.75	14.9
	25-50	221,209	54.66	7.4
	>50	183,734	45.40	6.0
		1,121,424		
Lower Harbor	0-5	1,346,842	332.8	
	5-10	439,059	108.49	
	10-25	150,953	37.30	
	>25	5,706	1.41	
		1,942,560		

* Middle Harbor and Lower Harbor areas combined to calculate % of total area for each concentration interval in the lower estuary.

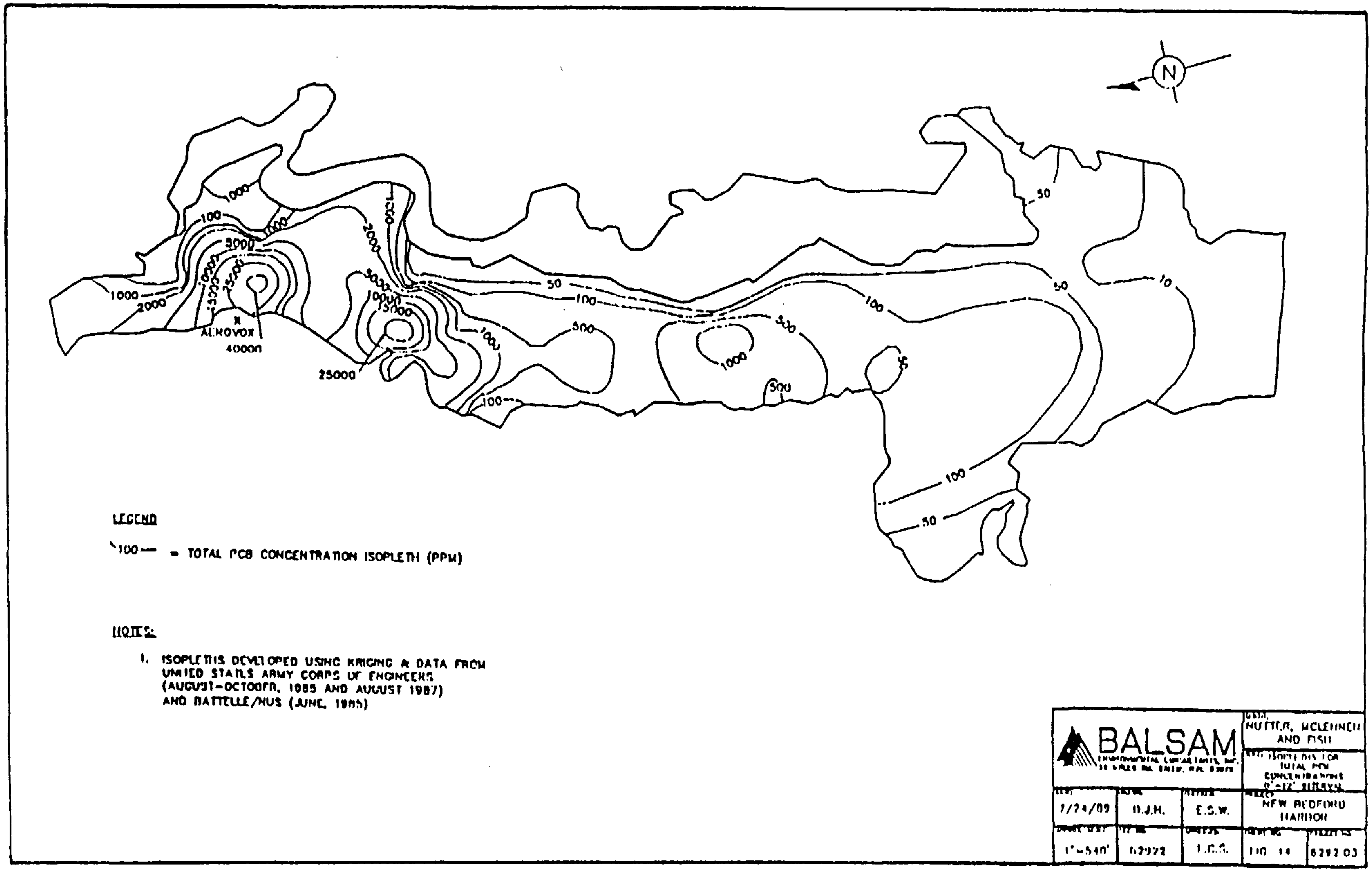

Figure 2 Total PCB concentrations in the sediments of the upper estuary (0-12") (from Balsam, 1989a).

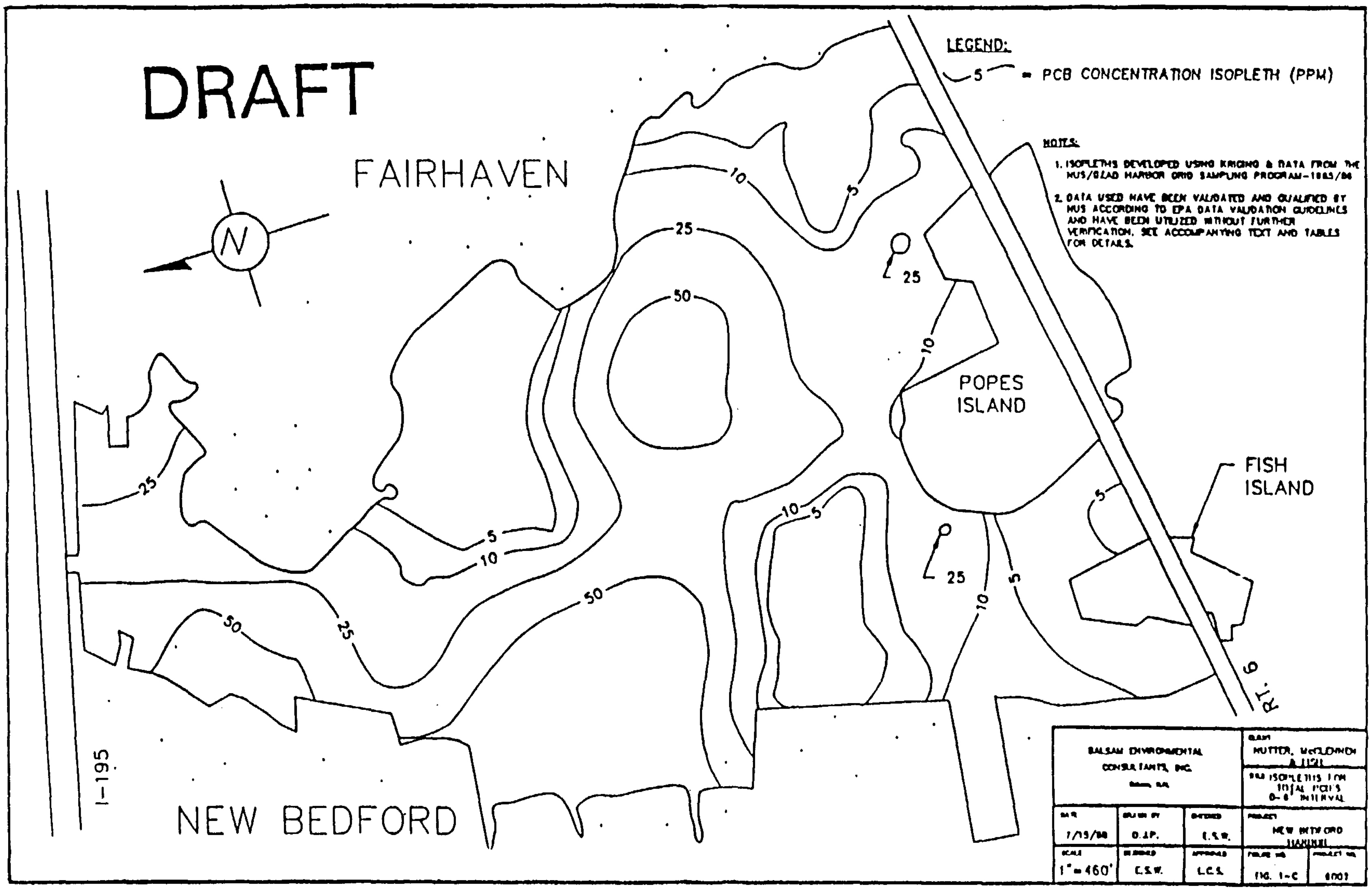

Figure 3 Total PCB concentrations in the sediments of the Middle Harbor (0-6") (from Balsam, 1989b).

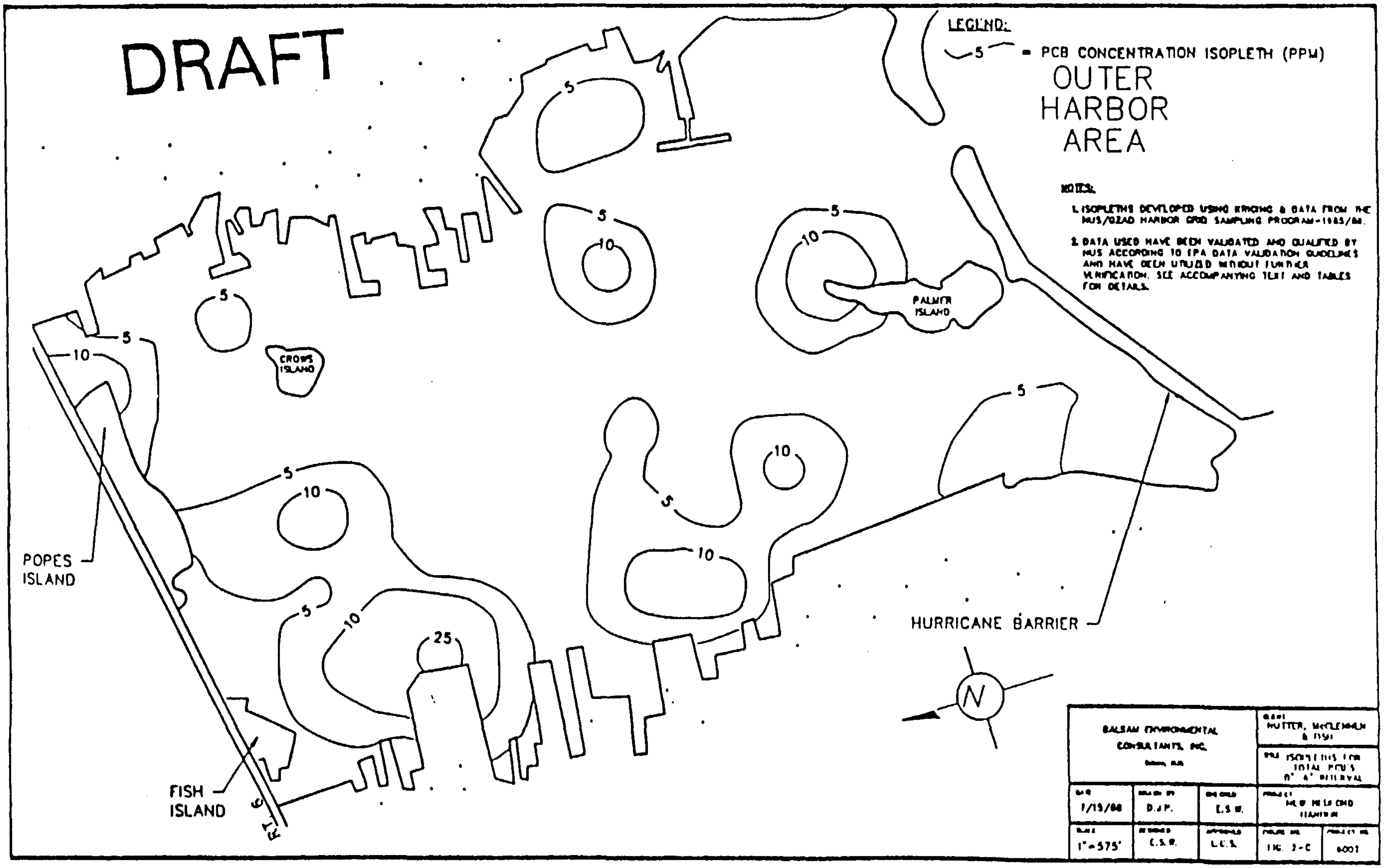

Figure 4 Total PCB concentrations in the sediments of the Lower Harbor (0-6") (from Balsam, 1989b).

approximately uniform throughout the system. These values for Q_U and Q_L are reasonable estimates of the tidal prism volumes exchanged per day. Calculating Q_U and Q_L using this approach assumes the tide is 100% efficient in flushing each of two boxes representing the estuary.

A review of Teeter (1988), EPA (1983), and ASA (1989) shows that of the PCB mass leaving the upper estuary with the ebb tide, a good portion returns on the following flood tide. The amount returning on the flood is approximately 25 to 50% of that leaving on the ebb (Table 2). This lower efficiency in flushing is caused by the lack of complete mixing (assumed in the box model) between water leaving the upper estuary on the ebb and water in the lower estuary.

A simplified box model (Swanson and Jayko, 1988) was applied to the estuary to estimate the inter-box exchange rates. Four boxes were employed based on the system's geometry and the distribution of salinity measurements: the upper estuary, between Coggeshall Street and I-195, between I-195 and Route 6, and between Route 6 and the Hurricane Barrier. Using salinity observations and freshwater as input, the percent of Q_U that actually transported material between the upper and lower estuary was assessed. The ASA (1987) salinity data set was used and gave a flushing rate of 45.6% Q_U. Based on this analysis and the PCB flux studies, the exchange rate efficiency is roughly 25 to 50% of Q_U.

The values of Q_U and Q_L used in this study for 25, 50 and 100% efficiency are tabulated below.

Exchange Efficiency	Q_U (m^3/day)	Q_L(m^3/day)
100%	$1.84 * 10^6$	$9.20 * 10^6$
50%	$9.20 * 10^5$	$4.60 * 10^6$
25%	$4.60 * 10^5$	$2.30 * 10^6$

Evaporation Coefficient

Thibodeaux (1989) used a value of K_e = 1.68 m/day and calculated that evaporation accounts for 41% of the PCBs released from the sediments of the upper estuary. The remaining PCBs (59%) are transported seaward through the Coggeshall Street Bridge transect.

Table 2 Summary of measured PCB concentrations in the water column of the upper estuary.

Source	Total PCB Water Column Concentrations (ng/l) Mean	Maximum	Minimum	Location
EPA (1983)	1570	2940	760	North of bridge*
ASA (1989)**	1365/305	3800/960	210/100	North of bridge*
Battelle (1985)	3603	5889	826	Upper estuary

* Coggeshall Street Bridge
**Aroclor 1242/Aroclor 1254

Source	Total PCB Water Column Concentrations (ng/l)* Ebb	Flood
Teeter (1988)	1300-5800	500-3000
EPA (1983)	1311-1757	674-1130
ASA (1989)**	330-1500	110-450

* intensive tidal cycle survey data taken at Coggeshall Street Bridge
**data presented for Aroclor 1242 only

An independent assessment of evaporative losses from Lyman et al. (1982, Table 15-4) gives K_e = 2.37 m/day, 41% higher than Thibodeaux's estimate. This value, however, is uncorrected for solubility effects in seawater. Using this value for K_e, evaporative loss is responsible for 50% of the PCBs released. Both values are used in this analysis to determine their impact on final water column concentrations.

Sediment PCB Flux

The sediment bed PCB release rate in the upper estuary has recently been investigated by Thibodeaux (1989). This study used a mass balance approach to correlate PCB water column concentrations and sediment flux. The relationship derived by Thibodeaux (1989) is presented in Figure 5. Numerous surveys have measured total PCB concentrations in the waters of the upper estuary (Battelle, 1985; EPA, 1983; Teeter, 1988; ASA, 1989). A summary of upper estuary PCB concentrations is presented in Table 2. Assuming a mean tidally averaged concentration of 2000 ng/l from these studies and using Figure 5, a flux rate (W_U) of 1700 kg/yr can be estimated from the upper estuary sediments, under present conditions assuming evaporation and an outer harbor concentration of 100 ng/l (see Figure 5).

Unfortunately, a similar relationship has not been derived for the lower estuary. Therefore an estimate of W_L was made using the following procedure. From Thibodeaux (1979) we know

$$W_U = \sum_n F_n A_n = \sum_n K\,(C_{pw} - C_w)_n A_n \qquad (5)$$

where

F_n = flux per unit area for a given PCB concentration interval, n

A_n = surface area for a given PCB concentration interval, n

K = flux constant

C_{pw} = sediment pore water PCB concentration

C_w = water column PCB concentration

The value of K can be calculated for the upper estuary using Equation 5 and knowing the value for W_U and C_w. For this study the simplifying assumption is made that K is constant for the entire estuary. K may be slightly different in contaminated and uncontaminated areas; however, determination of a variable K was beyond the scope of this investigation. The sediment PCB flux in the lower estuary (W_L) can then be

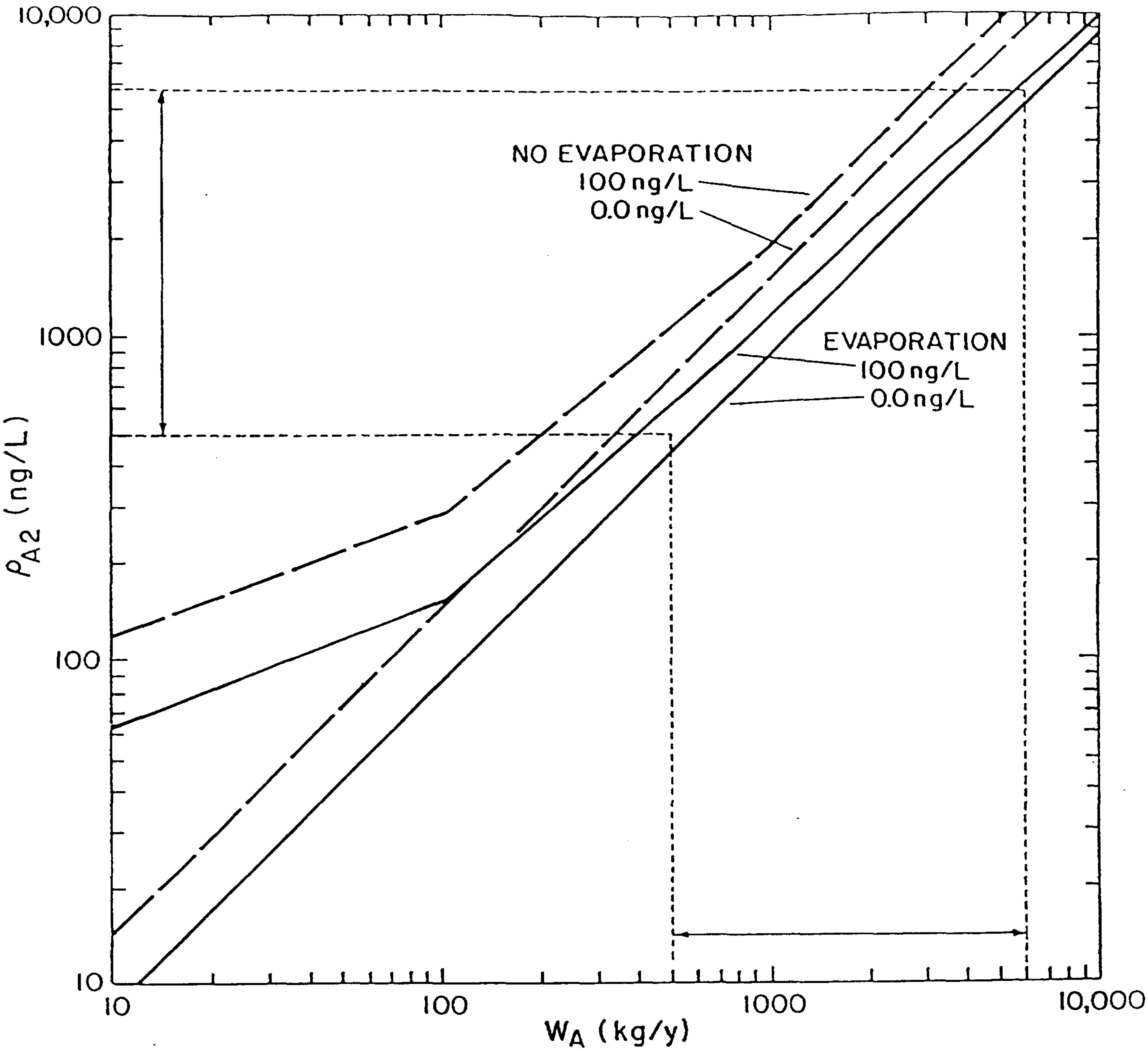

Figure 5 Mass balance model predicted relationship between PCB release rate (kg/yr) and water column PCB concentration (ng/l) in the upper estuary (from Thibodeaux, 1989).

calculated. Using the data in Table 1 and a water column concentration of 500 ng/l in the lower estuary based on measurements south of the Coggeshall Street Bridge and in the lower estuary (Table 3), a value of 12.0 kg/yr was calculated for W_L.

The values of W_U and W_L calculated above are first-cut estimates of the sediment flux for use by the box model. Since both fluxes depend on the water column PCB concentrations, they will vary to remain in balance with the water concentrations. Therefore these values should be regarded as initial conditions rather than as constants.

PCB Boundary Condition

The water column PCB concentrations south of the Hurricane Barrier (C_B) have been measured at several stations by Battelle (1985). Measured concentrations range from 25 to 120 ng/l. For this analysis a range of values from 0 to 120 ng/l are considered to simulate conditions from entirely clean outer harbor waters to the maximum observed concentration. The boundary concentration is held constant for each box model simulation, i.e., the concentration does not change in response to the different fluxes and water column concentrations in New Bedford Harbor.

BOX MODEL RESULTS

The box model described above was applied to New Bedford Harbor. Since PCB concentrations in the water column influence the flux of PCBs from the sediments which in turn influences the water concentration, an iterative procedure was employed in the box model to adjust upper and lower estuary water concentrations and sediment fluxes until a balance is achieved. Equation 5 with the value of K determined above was used to re-calculate sediment fluxes based on computed water concentrations. The model assumes that sediment, and therefore pore water, PCB concentrations remain unchanged from their initial condition regardless of the flux of PCBs out of (or into) the sediments.

Both present conditions and post-capping conditions were investigated. For each scenario the effects of various assumptions, such as exchange (flushing) efficiency, outer harbor water concentrations and the evaporation coefficient, were examined.

Pre-capping Conditions

The results for the present condition are summarized in Table 4. The sediment fluxes presented in Table 4 are net fluxes, i.e., if the sediment PCB concentration is so

Table 3 Summary of measured PCB concentrations in the water column of the lower estuary.

Source	Total PCB Water Column Concentrations (ng/l) Mean	Maximum	Minimum	Location
EPA (1983)	1330	2450	530	South of bridge*
ASA (1989)**	630/200	2300/440	70/100	South of bridge*
Battelle (1985)	370	1359	85	Lower estuary

* Coggeshall Street Bridge
** Aroclor 1242/Aroclor 1254

Table 4 Box model results for present conditions.

Exchange Efficiency	Water Concentration (ng/l) C_U	C_L	C_B	Sediment PCB Flux (kg/yr) W_U	W_L	K_e (m/day)
100%	1570	179	0	1676	2.2	1.68
	1578	193	25	1675	3.6	
	1585	207	50	1675	-9.4	
	1601	235	100	1672	-21	
	1607	247	120	1672	-26	
50%	2084	180	0	1623	1.8	1.68
	2087	190	25	1623	-2.4	
	2091	200	50	1622	-6.5	
	2098	220	100	1622	-15	
	2102	228	120	1621	-18	
50%	1702	128	0	1662	23	2.37
	1707	144	50	1662	16	
	1714	168	120	1661	6.7	
25%	2507	151	0	1579	14	1.68
	2509	157	25	1579	11	
	2510	164	50	1579	8.5	
	2513	176	100	1579	3.2	
	2514	182	120	1579	1.1	

low that the flux is from the water column to the sediment in that contour interval, the flux (negative) is subtracted from the cumulative flux for the box. Because the model adjusts the PCB flux from the sediments and the overlying water column concentrations to achieve steady state, the fluxes in the table do not agree with the initial conditions (W_U = 1700 kg/yr, W_L = 12.0 kg/yr) obtained as described previously. However, the adjusted net upper estuary flux differs by at most 7% from the initial value. In the lower estuary the adjusted fluxes range from positive to negative values of approximately the same order of magnitude as the initial estimate.

The water column PCB concentrations shown in Table 4 are within the range of observed values in New Bedford Harbor. Battelle (1985) data show concentrations of 800-6000 ng/l in the upper estuary, 80-1300 ng/l in the lower estuary with most observations in the range of 100-500 ng/l, and 25-125 ng/l in the outer harbor. Values in the tables fall between 1570-2500 ng/l in the upper estuary and 130-250 ng/l in the lower estuary.

Examination of the values in Table 4 shows that the outer harbor water concentration (C_B) has very little impact on water concentrations in New Bedford Harbor. In the upper estuary there is less than a 3% difference in calculated concentrations due to change in the boundary condition. Concentrations in the lower estuary are more responsive to the outer harbor concentrations with at most a 30% difference in C_L for the range of C_B from 0 to 120 ng/l.

Calculated concentrations, particularly in the upper estuary, are more sensitive to the exchange efficiency of the system. Assuming complete exchange (100% efficiency) upper estuary concentrations are approximately 1590 ng/l. For a 25% efficiency the concentration increases to 2510 ng/l, almost a 60% increase. The lower estuary concentrations follow a similar pattern but the difference in values is not as large with only 25-30% change. A brief analysis varying the exchange efficiencies used for the upper and lower estuary (such that upper estuary efficiency was not equal to the lower estuary efficiency) showed little effect on the calculated concentrations. Concentrations were still within the range of values shown in Table 4.

The effects of evaporation were investigated using two evaporation coefficients which varied by 41%. The effect of this variation is a difference of 20-30% in the estimated water column concentrations. Increasing the evaporation coefficient has the expected result of decreasing the concentration and increasing the PCB sediment flux rate.

In summary, the selection of exchange efficiency has the greatest impact on predicted concentrations. The evaporation coefficient also has a strong influence on the concentrations; the outer harbor boundary condition has a relatively minor impact. Nevertheless, the water column concentrations predicted by all combinations of these parameters fall within the range of observed values in New Bedford Harbor. For a reasonable selection of parameters, 50% exchange efficiency and an evaporation coefficient of 1.68 m/day, concentrations are approximately 2100 ng/l and 220 ng/l in the upper and lower estuary, respectively (Table 4).

Capping Upper Estuary Sediments >50 ppm

Table 5 presents estimates of water column concentrations after all sediments with PCB concentrations greater than 50 ppm in the upper estuary have been capped. This entails capping approximately 67% of the upper estuary sediments (refer to Figure 2, Table 1) and assumes that the cap is 100% effective in prohibiting the flux of PCBs from the covered sediments. Water column concentrations predicted after capping range from 17-25 ng/l in the upper estuary and from 14-31 ng/l in the lower estuary. These values are reductions of approximately a factor of 100 for the upper estuary and 10 for the lower estuary from present conditions (shown in Table 4). Under some scenarios shown in Table 5, concentrations in the lower estuary are slightly higher than corresponding upper estuary concentrations.

It is interesting to note the difference in sediment flux rates in the upper and lower estuary between the before and after capping conditions. Comparing Tables 4 and 5 shows that the flux from the upper estuary has decreased from approximately 1620 kg/yr before capping to 10 kg/yr after capping. There is still a small flux of PCBs from the sediments that were not capped (concentrations less than 50 ppm), since the lower water column concentrations are sufficient to create a positive (out of) rather than negative (into) gradient between pore water and water column PCB concentrations. Meanwhile, the lower estuary shows increased fluxes after capping with values of approximately 67 kg/yr compared with pre-cap net fluxes of less than 20 kg/yr, and in fact negative under some scenarios investigated. The increase in flux from the sediments of the lower estuary after capping occurs because the lower water concentrations change the sign of the gradient between water column and pore water concentrations. Thus, instead of a negative flux with PCBs going from water to sediments, the reverse occurs.

Table 5 Box model results after capping all sediments with PCB concentrations in excess of 50 ppm in the upper estuary.

Exchange Efficiency	Water Concentration (ng/l) C_U	C_L	C_B	Sediment PCB Flux (kg/yr) W_U	W_L	K_e (m/day)
100%	17	14	0	11	70	1.68
	19	17	5	10	69	
	20	19	10	10	68	
	23	25	20	10	66	
	25	28	25	10	64	
50%	21	19	0	10	68	1.68
	21	21	5	10	67	
	22	23	10	10	67	
	24	27	20	10	65	
	24	29	25	10	64	
50%	16	16	0	11	69	2.37
	17	19	10	11	68	
	18	23	20	11	66	
25%	22	24	0	10	66	1.68
	23	25	5	10	66	
	23	27	10	10	65	
	23	29	20	10	64	
	24	31	25	10	63	

The sensitivity of water concentrations under capped conditions to various parameters used by the box model is seen by examining Table 5. The exchange efficiency has the greatest effect at low boundary condition (C$_B$ = 0-5 ng/l). Concentrations vary by generally 25% between the range of tested exchange efficiencies. As seen in the present conditions case, the effect of using different exchange efficiencies for the upper and lower estuary was negligible on the calculated concentrations.

The outer harbor boundary condition is only varied between 0 and 25 ng/l because at concentrations of 25 ng/l and above, concentrations inside the harbor are lower than the boundary concentration. This is a physically unrealistic situation since in equilibrium the inner harbor should have the same concentration as the outer harbor. Furthermore, if the outer harbor PCB concentrations result from flushing of New Bedford Harbor and this source is greatly reduced through capping, the outer harbor would no longer be expected to show the elevated PCB levels which have been observed. A simple scaling between PCB loads in the estuary and outer harbor concentrations for the before and after capping conditions indicates outer harbor concentrations should be in the range 0-5 ng/l after capping. The variation of outer harbor water concentrations from 0 to 25 ng/l causes at most a 30% difference in lower estuary concentrations. This variability is most pronounced at high exchange efficiencies.

Variation of the evaporation coefficient has a similar effect to that seen previously. Again concentrations vary by approximately 25% with the change in evaporation coefficient.

Assuming 50% efficiency in the exchange rate, an evaporation coefficient of 1.68 m/day and an outer harbor water concentration of 5 ng/l, water concentrations in the upper and lower estuary would be approximately 21 ng/l after capping. With the higher evaporation coefficient, the concentrations would reduce to 17-18 ng/l. These values represent reductions by factors of 100 and 10 in the upper and lower estuary, respectively, over present conditions.

Capping Entire Upper Estuary

The box model was also used for a brief investigation of the resulting water column concentrations if the entire upper estuary were capped. The results of this analysis are summarized in Table 6. As can be seen from the table, with the entire upper estuary capped, the net flux is into the sediments and PCB concentrations are

Table 6 Box model results after capping entire upper estuary.

Exchange Efficiency	Water Concentration (ng/l) C_U	C_L	C_B	Sediment PCB Flux (kg/yr) W_U	W_L	K_e (m/day)
100%	7	13	0	-0.7	71	1.68
	8	16	5	-0.9	69	
	10	18	10	-1.0	68	
	13	24	20	-1.3	66	
50%	7	18	0	-0.7	68	1.68
	7	20	5	-0.7	68	
	8	22	10	-0.8	67	
	10	26	20	-1.0	65	
50%	5	15	0	-0.5	70	2.37
	5	17	5	-0.5	69	
	6	19	10	-0.6	68	
	7	22	20	-0.7	67	
25%	5	23	0	-0.5	66	1.68
	6	25	5	-0.5	66	
	6	26	10	-0.6	65	
	6	28	20	-0.6	64	

quite low in the upper estuary. In fact, concentrations are less than half what they are when only sediments with PCB concentrations greater than 50 ppm are capped. However, in the lower estuary, the flux and water column concentrations remain approximately the same as when only sediments greater than 50 ppm are capped. For the parameters cited above (50% exchange efficiency, 5 ng/l outer harbor concentrations, evaporation coefficient of 1.68 m/day) upper and lower estuary PCB concentrations are 7 and 20 ng/l, respectively. The lack of sensitivity of water concentrations in the lower estuary to the degree of capping in the upper estuary indicates that beyond a certain level of capping, the sediment PCB flux in the lower estuary will dominate the water concentrations.

As has been noted previously, calculated water concentrations in the lower estuary are strongly dependent on the outer harbor concentrations, particularly at high exchange efficiencies. The exchange efficiency has a relatively small impact on upper estuary water concentrations, and a relatively large impact on lower estuary concentrations, for the low (0-5 ng/l) outer harbor PCB concentrations which are expected to exist after capping.

CONCLUSIONS

A simple two-box mass balance model was applied to New Bedford Harbor to provide a first-order estimate of water concentrations under present conditions and after the proposed capping of all sediments in the upper estuary with PCB concentrations greater than 50 ppm. The model accounts for evaporative losses and transport of PCBs out of the estuary. The flux of PCBs from the sediments is calculated as a function of the water column concentration. For this calculation a flux constant is calculated from a previously derived relationship between water concentrations and sediment flux in the upper estuary (Thibodeaux, 1989). This flux constant is assumed to be valid for the entire estuary for all scenarios investigated.

The model does not account for any change in sediment pore water PCB concentrations due to the flux of PCBs into or out of the sediments. This level of detail is beyond the scope of this simple analysis. Because the model treats the estuary as two boxes, spatial resolution is lost. The model therefore assumes a uniform water concentration in each box and cannot address spatial gradients in the water column concentration. Within these limitations, however, the model is adequate to provide a first-order estimate of the improvement in water quality to be achieved by capping.

The analysis showed that capping the upper estuary sediments will markedly improve water quality. After capping all sediments with PCB concentrations greater than 50 ppm in the upper estuary, wate concentrations would be reduced by a factor of 100 to approximately 21 ng/l. Lower estuary water concentrations would improve by a factor of approximately 10, also to 21 ng/l. These results are assuming an exchange efficiency of 50%, evaporation of approximately 40% (K_e = 1.68 m/day) and a low outer harbor PCB concentration (0-5 ng/l). However, the estimated concentrations can vary by 15-55% depending on the parameter values specified in the model.

The improvement in water quality which could be expected if the entire upper estuary were capped was also examined using the box model. The additional capping further reduced water concentrations in the upper estuary by a factor of 2-4 (to approximately 5-10 ng/l) but had little impact on the lower estuary concentrations. This indicates that beyond a certain level of capping in the upper estuary, the sediment PCB flux in the lower estuary will dominate water concentrations.

The reduced PCB water column concentrations are less than the current EPA chronic criteria for aquatic life, 30 ng/l (EPA, 1986). This first-order analysis shows that capping the upper estuary sediments with PCB concentrations greater than 50 ppm will reduce water column concentrations in both the upper and lower estuary to levels below the chronic criteria of 30 ng/l. This result holds true for all the variations of exchange efficiency, evaporation coefficient and outer harbor water concentration investigated (Table 5).

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