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Sediment Trap Study in the Green Bay Mass Balance Program: Mass and Organic Carbon Fluxes, Resuspension, and Particle Settling Velocities

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SEDIMENT RESUSPENSION AND PARTICLE SETTLING VELOCITIES IN GREEN BAY

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ABSTRACT. This research is a part of a large, multidisciplinary program designed to measure and model the mass balance of congener-specific polychlorinated biphenyls (PCB) and dieldrin in Green Bay, western Lake Michigan. In this report, we document the results of our sediment trap study designed to collect representative samples of settling particulate material from five sites within the southern portion of the bay. Measuring the mass collected allowed us to calculate the gross downward flux of particulate matter and particle settling velocities. The mass balance models being applied to Green Bay explicitly require these particle settling velocities and vertical fluxes of mass and particulate organic carbon. Mass and carbon fluxes from sediment traps located 2 m above bottom and distributed throughout southern Green Bay showed that seasonal flux patterns were generally high prior to stratification, declined to minimum values during summer, and then generally reached much higher fluxes during fall overturn. In the epilimnion, seasonal patterns are similar to the near bottom samples although mass flux is approximately 10% of the near bottom flux, and carbon flux is approximately 20%. Settling velocities for epilimnetic samples are approximately 0.5 m/day, similar to open-lake values. Significantly higher settling velocities (4-6 m/day) during the stratified period were calculated for the 2 m above bottom region. These rates imply that a large recharging of the particle pool by either horizontal transport or local sediment resuspension occurs throughout the year. During the unstratified period, settling velocities throughout the water column are approximately 12-18 m/day, more than an order of magnitude higher than during stratification. At this rate, the particle residence time in the water column is only a few days, again implying frequent recharging. Sediment resuspension estimated by a steady state model required to support trap observations is about 10 g/m2/day with scale thicknesses of 5-7 m, and there is little seasonal variation until late September.

1. INTRODUCTION

In 1978 and again in 1987, the Great Lakes Water Quality Agreement between the United States and Canada was revised to address specific concerns relating to high levels of potentially toxic contaminants reported within the ecosystem. While contaminants are of concern, the modeling tools needed to manage them within the Great Lakes ecosystem are untested, and resource managers and regulators are understandably wary of their results.

Major advances in our comprehension of the transport and fate of contaminants have been achieved through a mass balance modeling approach. These models are a means to synthesize information on contaminant sources, sinks, and processes that regulate concentrations and residence times. The models are built using process rates and fluxes reported from laboratory and field studies and applied to individual ecosystems, and small amounts of available system data are used to "fine tune" parameter values. Although they are in wide use and are believed to be of significant value as synthesis and diagnostic tools, these models have never been rigorously verified on independently collected data sets. The testing of contaminant mass balance models is the primary objective of the Green Bay Mass Balance Study

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(GBMBS), of which the research results reported herein are a part. The GBMBS was organized and supported by the U.S. Environmental Protection Agency with cooperation from several U.S. federal agencies, including NOAA's Great Lakes Environmental Research Laboratory (GLERL) and from the states of Wisconsin and Michigan.

The objectives of the overall GBMBS are (1) to carry out a detailed mass balance of Great Lakes toxic substances, notably individual PCB congeners in Green Bay, and (2) based on the results, apply predictive tools that will aid resource managers in evaluating the impact of management decisions (EPA, 1989). The objectives of the portion of the mass balance study reported here are (1) to quantify the seasonal flux of resuspended sediments within the bay, and (2) to estimate net ensemble particle settling velocities.

Green Bay is a long (193 km), narrow (22 km) embayment connected to northwestern Lake Michigan via channels through the Door Peninsula (Figure 1). During the stratified period for Lake Michigan (June-November), warm bay water is exported through these channels via the epilimnion and is replaced by cold Lake Michigan water via the hypolimnion resulting in an estimated water residence time of about 0.6 years for the bay (Miller and Saylor, 1985). The waters of the northern basin of Green Bay have characteristics similar to Lake Michigan. Although the water moving past Chambers Island in the center of the bay is substantial during the ice-free period (Table 1), it is clear from ongoing work at the University of Wisconsin (D.N. Edgington, personal communication) that most of the contaminant rich particulate matter settles in the deeper portions of the southern basin. The Fox River, located at the southern end of the bay, is the major tributary and the major source of most of the contaminants. Exchange with the open lake through the Sturgeon Bay channel is small.

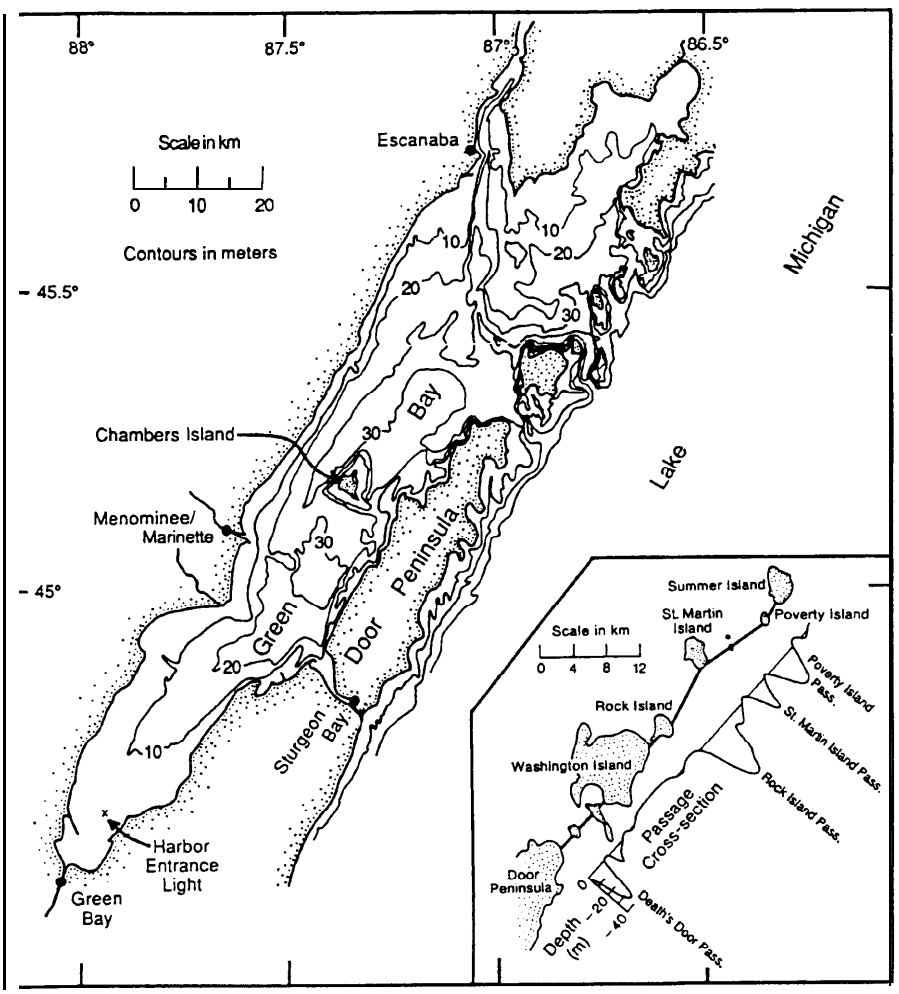


Figure 1 .--Bathymetric map of Green Bay showing locations of the major urban areas. The inset box shows an enlarged map of the mouth region and a bathymetric cross section along the indicated transect. (From Gottlieb et. al. 1990.)

Table 1 .--Net water mass transport (m^3/s): Green Bay 1977
(Calculated from Miller and Saylor, 1985; Miller, pers. corn.)

Month	Sturgeon Channel	Chambers Is. East	Chambers Is. West	Door Chnls Epilimnion	Door Chnls Hypolimnion	Sum[d]
Jan	-10"	+150[b]	+120[b]	-300[a,c]		-310
Feb	- 5	+100	+100	-200"		-205
Mar	+ 5	+120	+80	-200"		-195
Apr	- 5	+350	-300	-300"		-305
May	- 5	+1100	-1000	-1850	+1550	-305
June	- 5	+2700	-2550	-3600	+3300	-295
July	0	+3600	-3450	-5400	+5100	-300
Aug	0	+2600	-2500	-2100	+2000	-100
Sept	- 5	+1000	-900	-1350	+1200	-155
Oct	- 5	+400	-350	-750	+500	-255
Nov	- 5	+140	+140	-300"		-345
Dec	-10	+150	+150	-350"		-360
Avg	- 4	+1034	-871	-254		-258

a. Negative = out of bay
b. Positive = northward
c. Unstratified
d. Exchange with Lake Michigan = Door Channels + Sturgeon Channel
Data does not include river input or precipitation, thus not balanced.

Green Bay is relatively shallow, so particle residence times in the water column, based on work in open Lake Michigan, will be on the order of days to weeks. Since persistent, hydrophobic contaminants have a strong affinity for particles, the process of sorption and settling into the sediments is generally a major removal mechanism; contaminants with a high degree of affinity for settling particles can thus be very efficiently scavenged from the system. However, studies of the long-term behavior of certain fallout radionuclides and stable contaminants (Sly, 1982; DOE, 1980) have shown that higher levels persist in the lakes than expected if scavenging were the sole transport mechanism. This is thought to be due primarily to a combination of bioturbation and resuspension (Eadie et al., 1984), which brings contaminants initially transferred to sediments back up into the water column. At the surface of the sediment, freshly deposited matter is typically mixed with older material by the movement and feeding activities of organisms inhabiting the upper layers of sediment (1- 10 cm thick). Thus, materials that have been buried are reintroduced into the resuspendible pool (Eadie and Bobbins, 1987). In this shallow system, coupling between the water column and the sediment resuspendible pool is a major internal recycling process mediating contaminant concentrations and residence times.

The processes that characterize the behavior of hydrophobic contaminants are shown in their simplest form in Figure 2. These processes of particle-contaminant transfer, settling and resuspension, bioturbation, and burial are intimately interconnected and together control the phase distribution, bioavailability, and long-term behavior of most trace contaminants in aquatic systems. Contaminant-particle affinities are related to both the chemical's properties and the composition of the substrate. The composition of the pool of particles in Green Bay will vary considerably because of combinations of physical, chemical, and

biological processes. Very little is known about particle characteristics and fluxes during the winter when the bay is covered by ice. In early spring, the lake is isothermal, and storm events resuspend vast quantities of fine sedimentary matter that have undergone considerable alteration and are relatively low in organic carbon and high in clay mineral content. During this period, the composition of the particulate material in the water column is virtually the same from top to bottom. As spring progresses, the bay warms and stratifies. Primary production increases (Richman et al., 1984), especially within the epilimnion, and phytoplankton and zooplankton dominate the particle pool. Particle sinking and zooplankton grazing cause large quantities of nonliving organic particles to descend through the epilimnion. During the stratified period, the epilimnion is largely decoupled from underlying colder hypolimnion waters so particle transport is only downward. Little of the particulate material residing near the bottom of the deeper regions of the bay can be resuspended into the epilimnion during the stratified period. In late fall, the bay cools, stratification breaks down, and fine sedimentary materials are again resuspended throughout the waters of the bay.

In this report, we document the results of our sediment trap study in which representative samples of settling particulate material were collected from five sites within southern Green Bay. Measuring the mass collected allows us to calculate the gross downward flux of particulate matter and particle settling velocities. The difference between this measurement of gross downward flux and the net sediment accumulation rate, which is being measured by others in this program, is a good long term approximation of the flux due to sediment resuspension. Under stable, stratified conditions, shorter term resuspension fluxes can be estimated from trap flux profiles at a single station. The mass balance models being applied to Green Bay explicitly require the particle settling velocities and vertical fluxes of mass and particulate organic carbon (POC) that we present in this report.

2. SAMPLING DESIGN AND RATIONALE

Sediment traps have been used with success to collect samples of settling particulate material in the Great Lakes and elsewhere. The GLERL sediment trap design and sample-handling procedures are described by Eadie et al. (1984). The cylindrical traps have an internal diameter of 10 cm and an aspect ratio of 5:1 above the funnel (Figure 3). A powder funnel near the bottom of the cylinder empties directly into a 500 ml polyethlylene bottle. Prior to deployment, 25 ml of $CHCl_3$ was added to the sample bottles. The bottles were continuously saturated with the poison; a pool of $CHCl_3$ remained in the bottles upon retrieval. Chloroform inhibits bacterial activity in sediment traps by more than 99% when present at

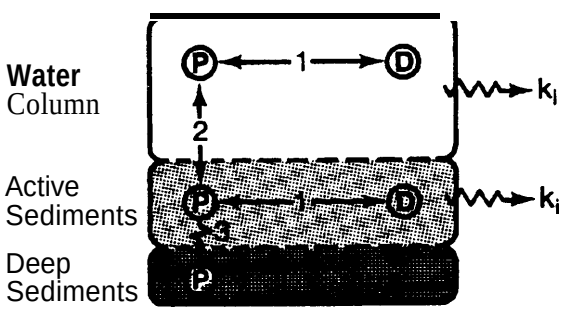


Figure Il.--Schematic diagram of the minimum fundamental processes required to account for the long-term behavior of particle-associated contaminants in Green Bay. Abbreviations are as follows: P represents particle-associated contaminant, and D is the dissolved fraction. The major processes are shown as (1) partitioning, (2) settling and resuspension, and (3) bioturbation and burial. The rate constants (k_i, i= 1 . ..n) represent losses from the system from processes such as outflow, radioactive decay, evaporation, and chemical or biological degradation.

concentrations of at least half-saturation (Lee et al., 1989), but it is not an effective poison when it is present at low concentrations (e.g., 1 ml per 3927 ml; Gundersen and Wassman, 1990).

In the usual mode of deployment, two traps were attached to a frame that was fastened to the anchored mooring line held taught by a submersible float. During open water conditions, a surface spar buoy was attached to the array, while over-winter deployments used only subsurface floats and an acoustic release. At Station 40, the traps were directly attached to the bottom mounted tripod deployed by Dr. Barry Lesht of Argonne National Laboratory. Traps were deployed in vertical arrays at Stations 43 (main sediment depositional area), at Stations 44 and 46 (on the east and west sides of Chambers Island), and at shallower Stations 40 and 41 in the southern part of the basin (Figure 4). In every case, trap pairs were placed at 2 m above the bottom. Additional traps were selectively placed at intermediate depths. In most cases, exposure times were about 1 month. Deployment intervals are illustrated in Figure 5.

Deployment and retrieval began in spring 1989 in conjunction with Dr. Nathan Hawley's cruises to deploy transmissometers and current meters at these same sites. Additional collections of total suspended matter (TSM) at the trap depths and analysis of trapped material for organic carbon allow us to calculate approximate monthly ensemble net particle settling velocity (flux/TSM) for these locations. At the site with high sediment deposition (Station 43), the frequency of trap sampling was increased to nine retrievals with the collaboration of Dr J. val Klump, University of Wisconsin-Milwaukee (UWI). Dr. val Klump's Sea Grant project involved sampling at this station. His cruises were scheduled at times approximately intermediate to ours and he retrieved and redeployed our traps. He took one of each pair of trap samples for nondestructive analysis of Be-7 and Cs-137, which were subsequently returned to GLERL.

Traps were deployed over the winter (minimum trap depth = 10 m; acoustic releases); one station (# 44) was retrieved with samples intact. The acoustic release and samples from station 41 apparently washed ashore, but the samples are of no value. The remaining 2 Stations, 43 and 46, did not respond to acoustic signals, and although extensively searched for, have not yet been retrieved. After retrieval, trap bottles were taken to GLERL (or UWI) and stored at 4 °C for 2-3 days to allow the sediments to settle. Overlying water (-450 ml) was vacuum siphoned off and the trapped material was transferred to a clean beaker. These samples were then air dried at 60 °C to a constant weight. After weighing, they were ground to a fine powder in an agate mortar and pestle and transferred into clean scintillation vials for storage in a freezer.

Organic carbon measurements on (1N HCl acidified) trap and suspended matter were made on a Varian CHN analyzer, a high-temperature (925 °C) combustion procedure well documented in the manufacturer's literature. All carbon analyses and TSM measurements were measured in duplicate and triplicate respectively. All filters and trap samples

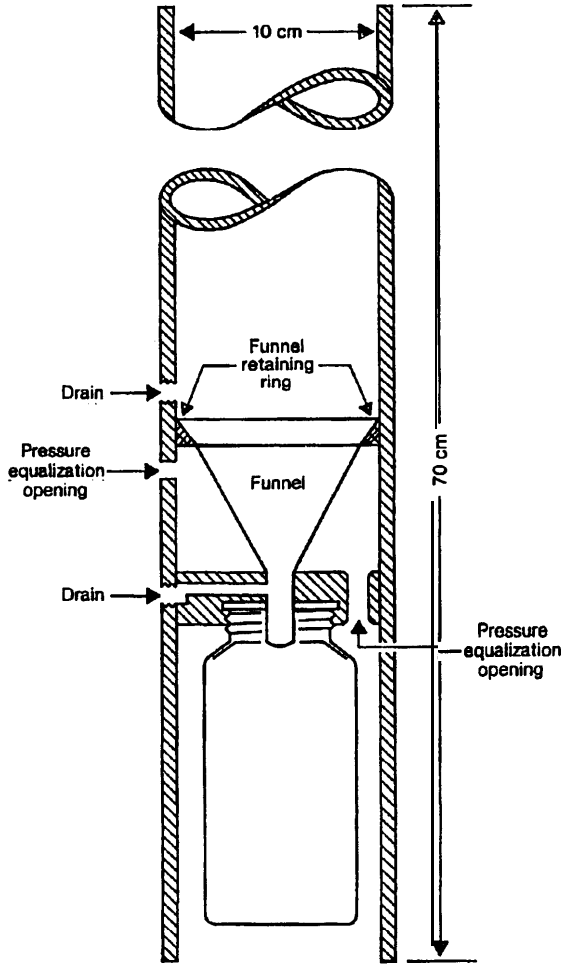


Figure 3.--Schematic of the sediment trap used in this study.

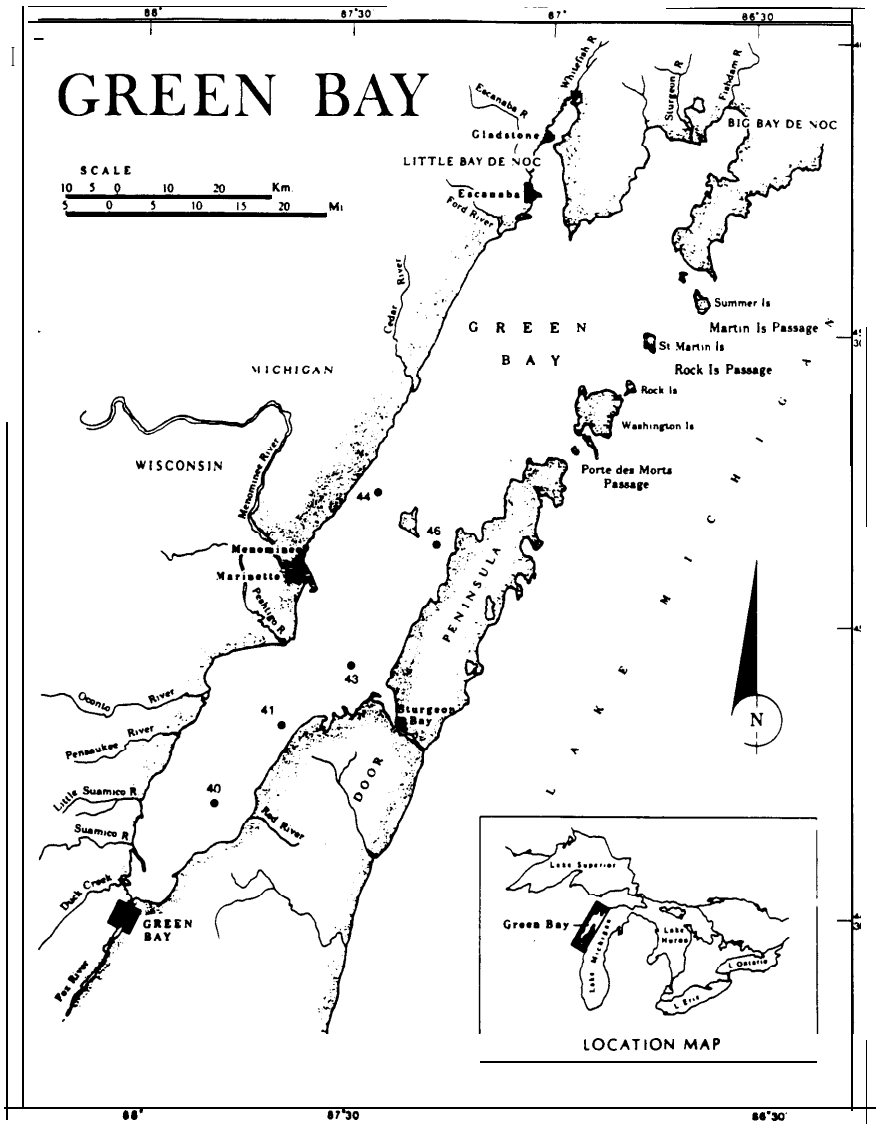


Figure 4.--Map of Green Bay showing the locations of our five sediment trap stations.

were weighed on a GLERL analytical balance, regularly maintained by a service contract, and calibrated with known standard weights. The Varian-supplied CHN standard is a protein of known composition; we also used other known carbon standards to assure highest data quality.

3. MEASUREMENT PRECISION

3.1 Sediment Trap Fluxes

During the spring-fall period, 60 pairs of traps were deployed; only one sample was lost, and one sample was fouled by the presence of a fish within the trap. Mass fluxes were calculated from the weighed mass of material collected in the trap divided by the trap area and length of deployment. The 58 pairs of samples are shown in Figure 6a; the larger mass flux of each pair is plotted on the y axis versus the smaller of each pair on the x axis. When all 58 pairs are included, the resulting regression is

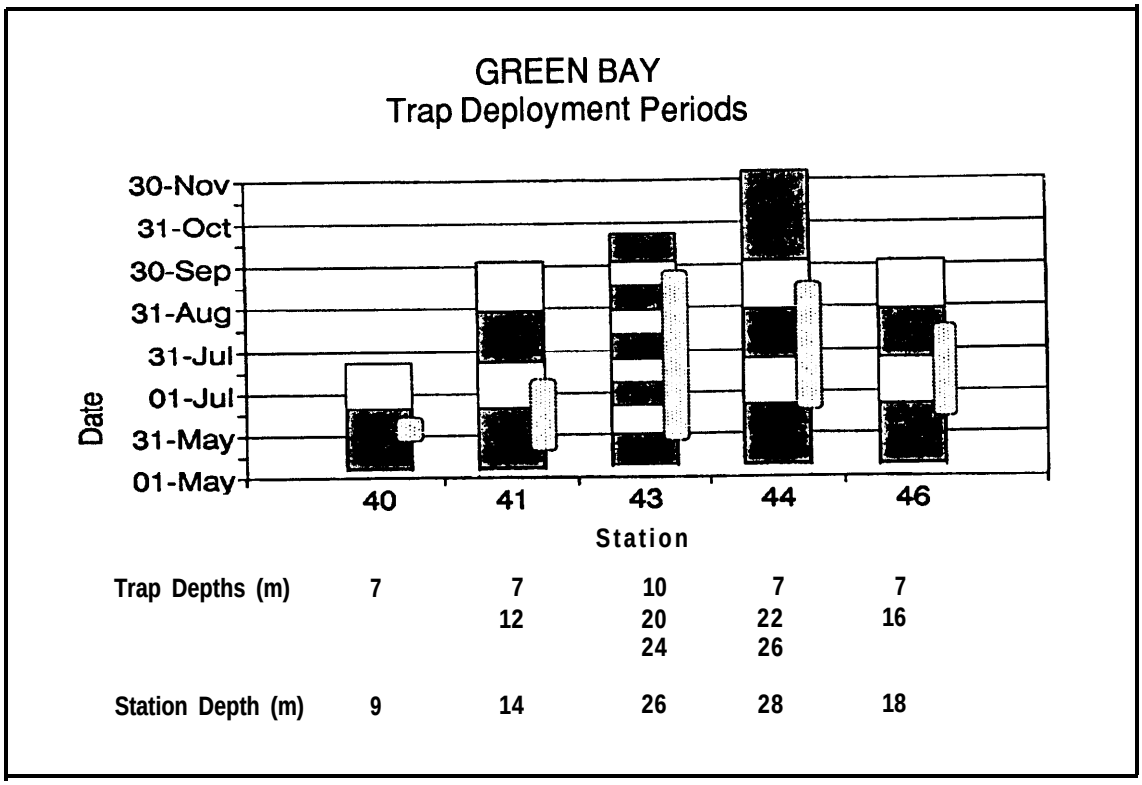


Figure 5.--Trap deployment periods for our five stations. The intervals represent individual collections, approximately monthly, for all stations except 43 where biweekly collections were possible. The period of thermal stratification at each station is indicated by the dotted rectangle on the right side of each station bar. Trap and station depths are listed below the figure.

Large Flux = 1.077 x Small Flux $r^2 = 0.98$

The average difference (in percent) between pairs is then 100(1.077 -1.0)/2 or 3.85%. Since the vast majority of the data are at low flux rates, and the few high flux values can heavily weight the regression; we also present the same paired mass flux comparison for all values below 12 $g/m^2/day$ in Figure 6b. In this comparison we have removed the nine largest flux values. The resultant 49 pairs yield the regression:

Large Flux = 1.13 x Small Flux $r^2 = 0.95$

At these lower fluxes, the average difference between pairs is 100(1.13-1.0)/2, or 6.5%.

3.2 Fluxes at Station 43

Almost one half of all the mass flux data comes from Station 43. There were nine collections of the GLERL traps at this site during 1989, four by GLERL and five by University of Wisconsin researchers. They dried one sample of each pair from these collections for nondestructive radiometric analysis. These were then returned to GLERL for analysis. Prior to this arrangement, UWI technicians were carefully trained in GLERL's sample handling procedures. A comparison of the mass fluxes calculated from traps handled by GLERL and UWI is presented in Figure 7a and b, which illustrate all 22 pairs and the low flux (19 pairs) data, respectively. For all the data, the relationship is

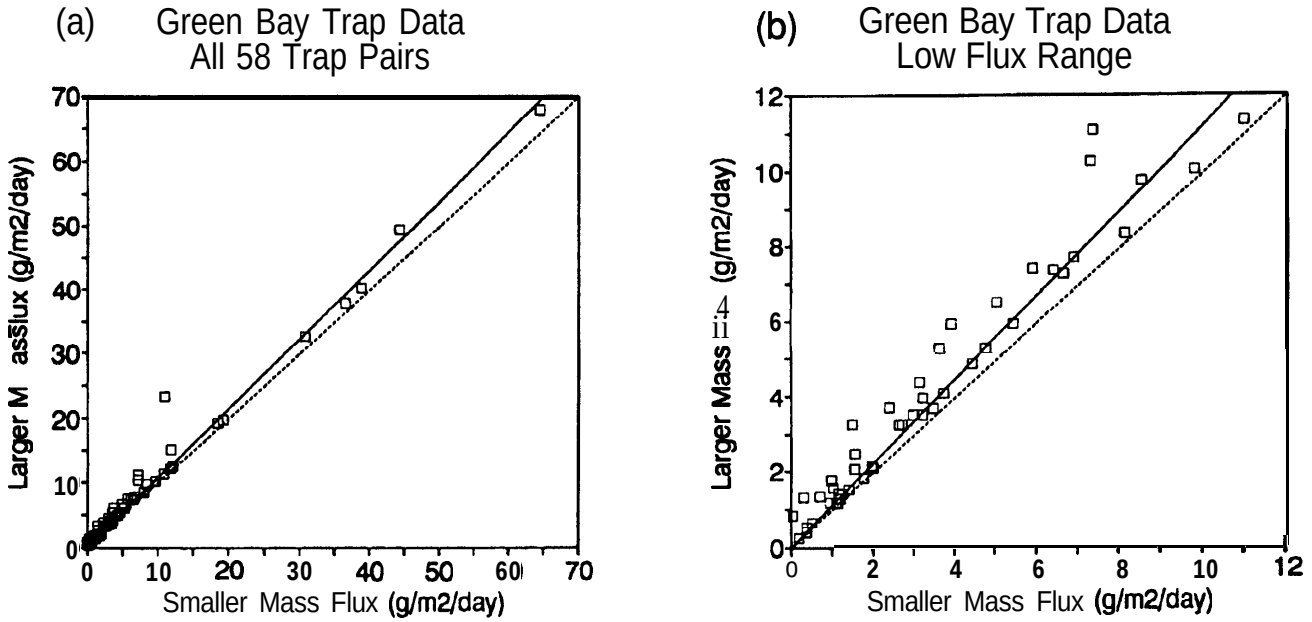


Figure 6.--Comparison of the mass of material collected in the pairs of traps at each station: (a) all trap data plotted as larger flux versus smaller (of the pair) flux, (b) expanded scale for samples where fluxes were less than 12/g/m2/day. The larger sample of each pair is plotted on the y-axis against the smaller of each pair on the x-axis.

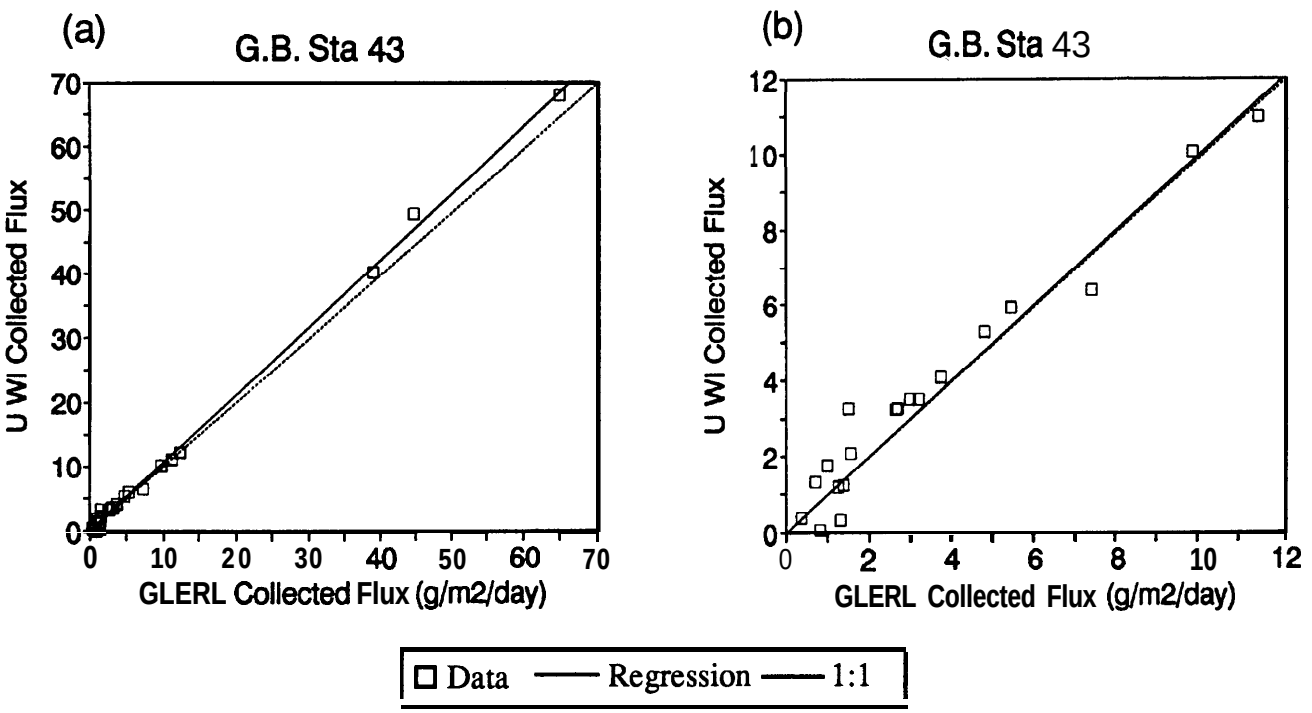


Figure 7.--Comparison of mass fluxes in pairs of traps at Station 43, where one of each pair was handled by GLERL and the other by Dr. J. val Klump, University of Wisconsin.

UWI Flux = 1.06 x GLERL Flux $r^2 = 0.99$

and for fluxes below 12 $g/m^2/day$

UWI Flux = 1.01 x GLERL Flux $r^2 = 0.96$

These are not different from the differences between pairs handled only by GLERL, therefore, the data are combined for subsequent calculations.

3.3 Organic Carbon Analysis

Duplicates from each trap sample were analyzed for organic carbon. Since all traps were paired, this resulted in quadruplicates for each site. In addition, six sets (duplicates of each pair) of blind replicates were included in the analysis; thus at these six sites, eight replicate carbon samples were measured. The data, presented in Table 2, show a mean coefficient of variation of 5.3 +/- 2.1%.

Carbon blanks were determined at the beginning and during each autosampling (60 sample) run. Blanks were always less than 10% of the value for the samples, and the samples were corrected for this. The accuracy of the carbon analysis was determined by running a known standard (acetanilide; C = 71.09%) as (approximately) every twentieth sample. The average carbon value for these analyses was 70.94% (Table 2). Based on this result, we did not alter the instrument reported values.

3.4 Total Suspended Matter

TSM samples were taken in triplicate at each station. Water was filtered through preweighed 47 mm glass fiber filters until the filtering rate was greatly reduced by clogging. The volume was recorded and the filter returned to its Petri dish. After returning to our laboratory, the filters were dried at 60 °C to a constant weight. Control (unused but preweighed) filters were used to correct for balance drift. For the triplicates, the standard deviation was less than 10% of the mean TSM at all stations.

Table 2.--Precision for trap organic carbon

Trap Pair	Mean O.C.(%)	Std Dev n = 8	C.V.(%)
1042/1043	3.55	0.18	5.07
959/960	3.63	0.11	3.03
1019/1020	4.12	0.15	3.66
991/992	4.67	0.21	4.50
9891990	7.21	0.54	7.49
967/968	9.96	0.82	8.23
Mean			5.33
Acetanilide Standard	70.94	1.65	2.1

C.V. = coefficient of variation = 100 x standard deviation / mean

4. RESULTS

All the data collected in this project and discussed in this report are presented in Tables 3 (containing the raw data) and 4 (edited averages). These data are also available from the principal author as spreadsheet or ASCII files.

4.1 Mass and Organic Carbon Fluxes

At four of our five stations, there was sufficient water depth to examine flux profiles by deploying traps in vertical arrays: three depths at Stations 43 and 44 and two depths at Stations 41 and 46.

4.1.1 Station 44

We use this station on the west side of Chambers Island (total depth = 28 m) as an example of the traditional presentation of mass flux profiles; our subsequent illustrations are intended to be more comprehensive but inevitably arc more difficult to understand. There were four collections at this station during 1989, and the only successful overwinter samples were also collected here. The mass flux data for the first three retrievals are presented in Figure 8. The shapes of these profiles are reminiscent of mass flux profiles collected in the open Great Lakes (Eadie et al., 1984; 1989); that is, they exhibit an exponential increase in mass flux near the bottom. The top of the near-bottom traps in all cases for Green Bay was 2 m above bottom. The first of the profiles presented was mostly collected prior to stratification (5/09 - 6/21/89). Our experience is that under these conditions, the fluxes are similar throughout the water column, even in waters deeper than 100 m. The strong vertical gradient indicates that the bottom traps are being supplied from a near-bottom layer rich in particulate matter and that mixing is insufficient to introduce much of these materials into the upper part of the water column. Some vertical transport or a pulse of river input is suggested by the fact that the trap nearest the surface has its highest flux (by about 2x) during this period. The other two profiles were collected during strongly stratified conditions. The upper

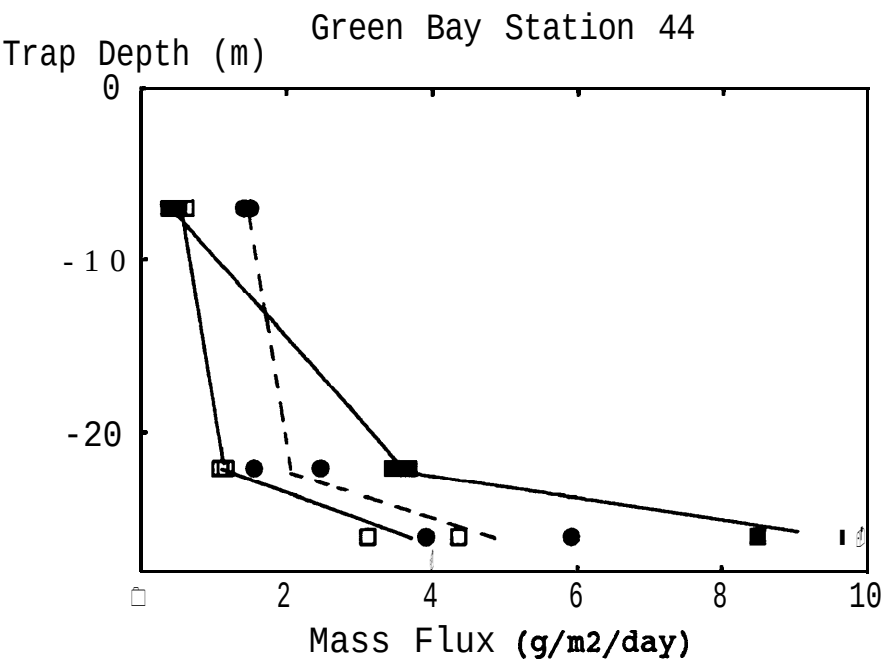


Figure 8.--Mass flux profiles for three collection periods at Station 44. Solid circles represent collection period 1, open boxes collection period 2, and solid boxes collection period3.

Table 3.--Green Bay Sediment Trap Data

#	STA	LAT	LON	Z (M	TRP (M)	DAT IN	OUT	DAYS	T	P #	AREA CM2	MASS (G)	FLUX G/M2/D	ORG mg/G	N mg/G	TSMin mg/L	TSMout mg/L	NOTES
989	GB	43 44.93	87.5	26	20	890726	890810	15	S	2	81.07	0.3965	3.2604	76.4	22.1	1.14		5
990	GB	43 44.93	87.5	26	20	890726	890810	15	S	2	81.07	0.3273	2.6914	67.8	16.8			
991	GB	43 44.93	87.5	26	24	890726	890810	15	S	2	81.07	1.4838	12.2013	46.5	12.1	1.92		5
992	GB	43 44.93	87.5	26	24	890726	890810	15	S	2	81.07	1.5044	12.3707	46.9	12.2			
997	GB	43 44.93	87.5	26	10	890810	890830	20	S	2	81.07	0.2041	1.2586	176.3	43.2		1.72	
998	GB	43 44.93	87.5	26	10	890810	890830	20	S	2	81.07	0.225	1.3878	151.8	40.4			
999	GB	43 44.93	87.5	26	20	890810	890830	20	S	2	81.07	0.5684	3.5055	92.8	23.5		2.05	5
1000	GB	43 44.93	87.5	26	20	890810	890830	20	S	2	81.07	0.4817	2.9708	76.8	21.4			
1001	GB	43 44.93	87.5	26	24	890810	890830	20	S	2	81.07	1.6295	10.0496	51	13.8		1.91	5
1002	GB	43 44.93	87.5	26	24	890810	890830	20	S	2	81.07	1.5809	9.7499	51.9	13.8			
1013	GB	43 44.93	87.5	26	10	890830	890913	14	S	2	81.07	0.1994	1.7568			1.72	2.9	5
1014	GB	43 44.93	87.5	26	10	890830	890913	14	S	2	81.07	0.1138	1.0026	125.4	32.9			
1015	GB	43 44.93	87.5	26	20	890830	890913	14	S	2	81.07	0.3977	3.5039	70.1	20	2.05	1.6	5
1016	GB	43 44.93	87.5	26	20	890830	890913	14	S	2	81.07	0.3626	3.1947	80.8	22.5			
1017	GB	43 44.93	87.5	26	24	890830	890913	14	S	2	81.07	1.7113	15.0772	47	13.1	1.91		5
1018	GB	43 44.93	87.5	26	24	890830	890913	14	S	2	81.07	1.3575	11.9601	42.2	11.2			
1023	GB	43 44.93	87.5	26	10	890913	891005	22	S	2	81.07	0.6624	3.7138	47.3	12.7	2.9	2.26	
1024	GB	43 44.93	87.5	26	10	890913	891005	22	S	2	81.07	0.7242	4.0603	83.5	21.6			5
1025	GB	43 44.93	87.5	26	20	890913	891005	22	S	2	81.07	0.9611	5.3885	83.5	21.5	1.6	2.9	
1026	GB	43 44.93	87.5	26	20	890913	891005	22	S	2	81.07	1.0565	5.9234	71.8	19.5			5
1027	GB	43 44.93	87.5	26	24	890913	891005	22	S	2	81.07	5.3595	30.0487	58.9	14.7		3.02	5
1038	GB	43 44.93	87.5	26	10	891005	891024	19	S	2	81.07	6.1967	40.2282	41.1	11.8	2.26	3.4	5
1039	GB	43 44.93	87.5	26	10	891005	891024	19	S	2	81.07	5.984	38.8474	41.9	11			
1040	GB	43 44.93	87.5	26	20	891005	891024	19	S	2	81.07	7.6116	49.4136	38.6	10.1	2.9	3.52	5
1041	GB	43 44.93	87.5	26	20	891005	891024	19	S	2	81.07	6.9015	44.4037	37.2	10.6			
1042	GB	43 44.93	87.5	26	24	891005	891024	19	S	2	81.07	10.458	67.892	35.3	10.2	3.02	3.88	5
1043	GB	43 44.93	87.5	26	24	891005	891024	19	S	2	81.07	9.951	64.6006	35.7	10.5			
941	GB	44 45.23	87.44	28	7	890509	890621	43	S	2	81.07	0.5259	1.5085	138.9	15.4		1.14	
942	GB	44 45.23	87.44	28	7	890509	890621	43	S	2	81.07	0.4935	1.4156	135	15.6			
943	GB	44 45.23	87.44	28	22	890509	890621	43	S	2	81.07	0.5457	1.5653	101.4	11.9		2.14	
944	GB	44 45.23	87.44	28	22	890509	890621	43	S	2	81.07	0.8598	2.4663	93.7	11.1			
945	GB	44 45.23	87.44	28	26	890509	890621	43	S	2	81.07	2.0618	5.9143	90.6	11.1			
946	GB	44 45.23	87.44	28	26	890509	890621	43	S	2	81.07	1.3634	3.9109	93.9	11.9			
977	GB	44 45.23	87.44	28	7	890621	890725	34	S	2	81.07	0.1739	0.6309	195	47.4	1.14	1.03	
978	GB	44 45.23	87.44	28	7	890621	890725	34	S	2	81.07	0.1436	0.521	153.5	35.4			
979	GB	44 45.23	87.44	28	22	890621	890725	34	S	2	81.07	0.324	1.1754	93.7	21.8	2.14	1.51	
980	GB	44 45.23	87.44	28	22	890621	890725	34	S	2	81.07	0.3046	1.105	92.2	18.4			
981	GB	44 45.23	87.44	28	26	890621	890725	34	S	2	81.07	0.8584	3.1141	56.5	12.8		1.85	
982	GB	44 45.23	87.44	28	26	890621	890725	34	S	2	81.07	1.2016	4.3592	46.1	11.4			
1003	GB	44 45.23	87.44	28	7	890725	890829	35	S	2	81.07	0.1097	0.3866	193.3	42.7	1.03	1.03	
1004	GB	44 45.23	87.44	28	7	890725	890829	35	S	2	81.07	0.1445	0.5092	85.4	15			
1005	GB	44 45.23	87.44	28	22	890725	890829	35	S	2	81.07	1.0415	3.6705	56.4	14	1.51	1.22	
1006	GB	44 45.23	87.44	28	22	890725	890829	35	S	2	81.07	0.9786	3.4487	49.8	13.8			
1007	GB	44 45.23	87.44	28	26	890725	890829	35	S	2	81.07	2.7659	9.7475	46.3	11.9	1.85	1.55	
1008	GB	44 45.23	87.44	28	26	890725	890829	35	S	2	81.07	2.405	8.4756	47.8	12.3			
1028	GB	44 45.23	87.44	28	7	890829	891004	36	S	2	81.07	0.278	0.9525	151.8	37.7	1.03	1.45	
1029	GB	44 45.23	87.44	28	7	890829	891004	36	S	2	81.07	0.3411	1.1687	122.8	29.7			

Table 3.--Green Bay Sediment Trap Data

#	STA	LAT	LON	Z (M	TRP (M)	DAT IN	OUT	DAYS	T	P #	AREA CM2	MASS (G)	FLUX G/M2/D	ORG mg/G	N mg/G	TSMin mg/L	TSMout mg/L	NOTES
923	GB 40	44.7	87.82	9	7	890508	890620	43	S	2	81.07	12.76	36.6021	61.7	6.4		5.14	
924	GB 40	44.7	87.82	9	7	890508	890620	43	S	2	81.07	13.154	37.7323	62.8	7.1			
959	GB 40	44.7	87.82	9	7	890620	890724	34	S	2	81.07	5.316	19.2855	35.7	9.4	5.14	6.67	
960	GB 40	44.7	87.82	9	7	890620	890724	34	S	2	81.07	5.4257	19.6834	37.4	9.7			
925	GB 41	44.83	87.66	14	7	890508	890620	43	S	2	81.07	1.3783	3.9537	146.1	17.5		2.93	
926	GB 41	44.83	87.66	14	7	890508	890620	43	S	2	81.07	1.1187	3.209	141.9	17.4			
927	GB 41	44.83	87.66	14	12	890508	890620	43	S	2	81.07	4.228	12.128	78.8	9.4			
928	GB 41	44.83	87.66	14	12	890508	890620	43	S	2	81.07	4.115	11.8039	86.6	10.1			
961	GB 41	44.83	87.66	14	7	890620	890724	34	S	2	81.07	0.3155	1.1446	138.4	33.3	2.93	1.58	
962	GB 41	44.83	87.66	14	7	890620	890724	34	S	2	81.07	0.3172	1.1507	149.8	37.3			
963	GB 41	44.83	87.66	14	12	890620	890724	34	S	2	81.07	2.1202	7.6917	51	12.9		1.18	
964	GB 41	44.83	87.66	14	12	890620	890724	34	S	2	81.07	1.89	6.8566	47.3	13.2			
993	GB 41	44.83	87.66	14	7	890724	890830	37	S	2	81.07	0.5325	1.7752	90	24.6	1.58	4.37	
994	GB 41	44.83	87.66	14	7	890724	890830	37	S	2	81.07	0.549	1.8302	96.5	26.8			
995	GB 41	44.83	87.66	14	12	890724	890830	37	S	2	81.07	2.4234	8.0788	45.1	12.9	1.18	4.92	
996	GB 41	44.83	87.66	14	12	890724	890830	37	S	2	81.07	2.4974	8.325701	47.2	13			
1019	GB 41	44.83	87.66	14	7	890830	891005	36	S	2	81.07	5.425	18.5875	40.7	11.4	4.37	4.57	
1020	GB 41	44.83	87.66	14	7	890830	891005	36	S	2	81.07	5.641	19.3276	41.6	12.1			
1021	GB 41	44.83	87.66	14	12	890830	891005	36	S	2	81.07	9.526	32.6386	42.8	13.1	4.92	4.93	
1022	GB 41	44.83	87.66	14	12	890830	891005	36	S	2	81.07	8.9987	30.832	34.5	10.7			
929	GB 43	44.93	87.5	26	10	890510	890525	15	S	2	81.07	0.1911	1.5714	196.6	23.1		1.48	4
930	GB 43	44.93	87.5	26	10	890510	890525	15	S	2	81.07	0.1254	1.0312	209.3	25.1			
931	GB 43	44.93	87.5	26	20	890510	890525	15	S	2	81.07	0.2514	2.0673	119.4	14.8		1.29	4
932	GB 43	44.93	87.5	26	20	890510	890525	15	S	2	81.07	0.19	1.5624	121.6	14			
933	GB 43	44.93	87.5	26	24	890510	890525	15	S	2	81.07	1.7015	13.9915	79.6	9.4			4
934	GB 43	44.93	87.5	26	24	890510	890525	15	S	2	81.07	1.0356	8.5158					3
935	GB 43	44.93	87.5	26	10	890525	890622	28	S	2	81.07	0.0748	0.3295	169.5	43	1.48		4
936	GB 43	44.93	87.5	26	10	890525	890622	28	S	2	81.07	0.3006	1.3242	218				
937	GB 43	44.93	87.5	26	20	890525	890622	28	S	2	81.07	0.7314	3.222	61.6	16.8	1.29		4
938	GB 43	44.93	87.5	26	20	890525	890622	28	S	2	81.07	0.5975	2.6321	105.9	12.6			
939	GB 43	44.93	87.5	26	24	890525	890622	28	S	2	81.07	2.5689	11.3165	80.5	10			
940	GB 43	44.93	87.5	26	24	890525	890622	28	S	2	81.07	2.4911	10.9738	54.4	13.6			4
965	GB 43	44.93	87.5	26	10	890622	890705	13	S	2	81.07	0.0086	0.0645	284	52.5		2.12	4
966	GB 43	44.93	87.5	26	10	890622	890705	13	S	2	81.07	0.0879	0.834	197	46.2			
967	GB 43	44.93	87.5	26	20	890622	890705	13	S	2	81.07	0.3443	3.2668	101.5	14.9		4.12	4
968	GB 43	44.93	87.5	26	20	890622	890705	13	S	2	81.07	0.1592	1.5105	97.6	24			
969	GB 43	44.93	87.5	26	24	890622	890705	13	S	2	81.07	0.557	5.2849	53.2	13.4			4
970	GB 43	44.93	87.5	26	24	890622	890705	13	S	2	81.07	0.5012	4.7554	59.3	16.5			
971	GB 43	44.93	87.5	26	10	890705	890726	21	S	2	81.07	0.066	0.3877	214.5	44.5	2.12	2.45	5
972	GB 43	44.93	87.5	26	10	890705	890726	21	S	2	81.07	0.0641	0.3762	253				
973	GB 43	44.93	87.5	26	20	890705	890726	21	S	2	81.07	0.2174	1.2769	122	33.7			1
974	GB 43	44.93	87.5	26	20	890705	890726	21	S	2	81.07	0.2058	1.2088	151	41.1			1
975	GB 43	44.93	87.5	26	24	890705	890726	21	S	2	81.07	1.2497	7.3402	56	15.4		1.92	5
976	GB 43	44.93	87.5	26	24	890705	890726	21	S	2	81.07	1.0836	6.3646	52	14.5	4.12	1.14	5
987	GB 43	44.93	87.5	26	10	890726	890810	15	S	2	81.07	0.1632	1.342	121.4	31.3	2.45		5
988	GB 43	44.93	87.5	26	10	890726	890810	15	S	2	81.07	0.0864	0.7105	145.6	40.5			

Table 3.--Green Bay Sediment Trap Data

#	STA	LAT	LON	Z (M)	TRP (M)	DAT IN	OUT	DAYS	T	P #	AREA CM2	MASS (G)	FLUX G/M2/D	ORG mg/G	N mg/G	TSMin mg/L	TSMout mg/L	NOTES
1030	GB	44 45.23	87.44	28	22	890829	891004	36	S	2	81.07	1.4553	4.9862	52.6	13.5	1.22	1.92	
1031	GB	44 45.23	87.44	28	22	890829	891004	36	S	2	81.07	1.8892	6.4729	42.5	12.7			
1032	GB	44 45.23	87.44	28	26	890829	891004	36	S	2	81.07	3.2281	11.0603	39.1	11	1.55	3.29	
1033	GB	44 45.23	87.44	28	26	890829	891004	36	S	2	81.07	6.7984	23.2931	36.5	10.4			
1067	GB	44 45.23	87.44	28	12	891004	900515	223	U	2	81.07	13.3668	7.3934					
1068	GB	44 45.23	87.44	28	12	891004	900515	223	U	2	81.07	10.5763	5.85					
1069	GB	44 45.23	87.44	28	22	891004	900515	223	U	2	81.07	18.567	10.2698					
1070	GB	44 45.23	87.44	28	22	891004	900515	223	U	2	81.07	13.1242	7.2592					
1071	GB	44 45.23	87.44	28	26	891004	900515	223	U	2	81.07	7.9419	4.3928					
1072	GB	44 45.23	87.44	28	26	891004	900515	223	U	2	81.07	8.7671	4.8493					
947	GB	46 45.14	87.29	18	7	890509	890622	44	S	2	81.07	0.5054	1.4168	159.9	19.6			
948	GB	46 45.14	87.29	18	7	890509	890622	44	S	2	81.07	0.4187	1.1737	165	20.6			
949	GB	46 45.14	87.29	18	16	890509	890622	44	S	2	81.07	0.8539	2.3937	47.7	5.9			
950	GB	46 45.14	87.29	18	16	890509	890622	44	S	2	81.07	1.3233	3.7096	45.1	5.5			
983	GB	46 45.14	87.29	18	7	890622	890725	33	S	2	81.07	0.0511	0.191	160	37.4		0.88	
984	GB	46 45.14	87.29	18	7	890622	890725	33	S	2	81.07	0.0626	0.234	195	50.1			
985	GB	46 45.14	87.29	18	16	890622	890725	33	S	2	81.07	0.5744	2.1469	40	8.1		1.87	
986	GB	46 45.14	87.29	18	16	890622	890725	33	S	2	81.07	0.524	1.9586	37.9	9.9			
1009	GB	46 45.14	87.29	18	7	890725	890829	35	S	2	81.07	0.5937	2.0922	50.9	15.7	0.88	1.68	
1010	GB	46 45.14	87.29	18	7	890725	890829	35	S	2	81.07	0.5689	2.0048	58	16.5			
1011	GB	46 45.14	87.29	18	16	890725	890829	35	S	2	81.07	1.029	3.6265	40.3	12.5	1.87	1.74	
1012	GB	46 45.14	87.29	18	16	890725	890829	35	S	2	81.07	1.49	5.251	39	11.8			
1034	GB	46 45.14	87.29	18	7	890829	891004	36	S	2	81.07	2.1123	7.2373	37.8	11.6	1.68	1.94	
1035	GB	46 45.14	87.29	18	7	890829	891004	36	S	2	81.07	1.9256	6.5976	42.9	12.1			
1036	GB	46 45.14	87.29	18	16	890829	891004	36	S	2	81.07	3.2368	11.0901	42.1	11.9	1.74	1.96	
1037	GB	46 45.14	87.29	18	16	890829	891004	36	S	2	81.07	2.1328	7.3075	43.2	12.6			

FLAGS (F): 1- QUESTIONABLE DATA, DEFICIENT SAMPLE DUE TO FLUSHING, SPILLED, FUNNEL OUT OF POSITION, ETC.
2- DEPTH AND/OR TOTAL VOLUME MAY BE IN ERROR.
3- CONTAMINATED, FISH IN TRAP, ETC.
4- SAMPLE DRIED AND COUNTED IN COLLECTION BOTTLE BY UNIV. OF WISCONSIN.
WEIGHT BY GLERL OF MATERIALS SCRAPED FROM COLLECTION BOTTLE.
5- SAMPLE DRIED AND COUNTED I N COLLECTION BOTTLE BY UNIV. OF WISCONSIN.
WEIGHT DETERMINED BY GLERL BY SUBTRACTING THE WEIGHT OF THE CLEANED BOTTLE AFTER REMOVAL OF THE SEDIMENT, FROM THE WEIGHT OF THE BOTTLE CONTAINING THE DRIED SEDIMENT.
6- SAMPLES MAY BE CONTAMINATED WITH CORROSION MATERIALS ON ALUMINUM FRAMES AND BRACKETS DUE TO GALVANICACTIONBETWEENTHE ALUMINUM ANDTHE STAINLESS STEEL MOORING CABLE.
7- ALUMINUM OXIDE CONTAMINATION FROM DEPOSITS ON ALUMINUM FRAMES.
PRESERVATIVE (P): 1 = HGCL2, 2 = CHCL3, 3 = SODIUM AZIDE (NAN3), 0 = NONE
DEPLOYMENT PERIOD (T): S = STRATIFIED, U = UNSTRATIFIED, Y = YEAR

Table 4.--Green Bay Trap Averaged Data

#	STA	LAT	LON	Z (M	TRP (M)	DAT IN	OUT	Mid Day	DAYS	TRAP FLUX G/M2/D	ORG C mg/G	O.C.FLUX mgC/m2/d	N mg/G	C/N atomic	Vel S m/d	TSM avg	TSMin mg/L	TSM out
923	GB 40	44.7	87.82	9	7	890508	890620	149.5	43	37.17	62.3	2314	6.8	10.78	7.23	5.14		5.14
959	GB 40	44.7	87.82	9	7	890620	890724	188	34	19.48	36.6	712	9.6	4.46	3.30	5.90	5.14	6.67
925	GB 41	44.83	87.66	14	7	890508	890620	149.5	43	3.58	144.0	516	17.5	9.63	1.22	2.93		2.93
927	GB 41	44.83	87.66	14	12	890508	890620	149.5	43	11.97	82.7	989	9.8	9.89				
961	GB 41	44.83	87.66	14	7	890620	890724	188	34	1.15	144.1	165	35.3	4.77	0.51	2.26	2.93	1.58
963	GB 41	44.83	87.66	14	12	890620	890724	188	34	7.27	49.2	358	13.1	4.40	6.16	1.18		1.18
993	GB 41	44.83	87.66	14	7	890724	890830	223.5	37	1.80	93.3	168	25.7	4.23	0.61	2.97	1.58	4.37
995	GB 41	44.83	87.66	14	12	890724	890830	223.5	37	8.20	46.2	379	13.0	4.16	2.69	3.05	1.18	4.92
1019	GB 41	44.83	87.66	14	7	890830	891005	260	36	18.96	41.2	780	11.8	4.09	4.24	4.47	4.37	4.57
1021	GB 41	44.83	87.66	14	12	890830	891005	260	36	31.74	38.7	1230	11.9	3.79	6.44	4.93	4.92	4.93
929	GB 43	44.93	87.5	26	10	890510	890525	137.5	15	1.30	183.5	247	22.0	9.70	0.88	1.48		1.48
931	GB 43	44.93	87.5	26	20	890510	890525	137.5	15	1.81	120.5	218	14.4	9.77	1.41	1.29		1.29
933	GB 43	44.93	87.5	26	24	890510	890525	137.5	15	13.99	79.6	1114	9.4	9.88				
935	GB 43	44.93	87.5	26	10	890525	890622	159	28	0.83	193.8	172	43.0	4.60	0.56	1.48	1.48	
937	GB 43	44.93	87.5	26	20	890525	890622	159	28	2.93	83.8	239	14.7	7.04	2.27	1.29	1.29	
939	GB 43	44.93	87.5	26	24	890525	890622	159	28	11.15	67.5	754	11.8	7.03				
965	GB 43	44.93	87.5	26	10	890622	890705	179.5	13	0.45	240.5	91	49.4	5.64	0.21	2.12		2.12
967	GB 43	44.93	87.5	26	20	890622	890705	179.5	13	2.39	99.6	240	19.5	6.35	0.58	4.12		4.12
969	GB 43	44.93	87.5	26	24	890622	890705	179.5	13	5.02	56.3	282	15.0	4.41				
971	GB 43	44.93	87.5	26	10	890705	890726	196.5	21	0.38	233.8	89	44.5	5.62	0.17	2.29	2.12	2.45
973	GB 43	44.93	87.5	26	20	890705	890726	196.5	21	1.24	136.5	169	37.4	4.26	0.47	2.63	4.12	1.14
975	GB 43	44.93	87.5	26	24	890705	890726	196.5	21	6.85	54.0	370	15.0	4.20	3.57	1.92		1.92
987	GB 43	44.93	87.5	26	10	890726	890810	214.5	15	1.03	133.5	133	35.9	4.36	0.42	2.45	2.45	
989	GB 43	44.93	87.5	26	20	890726	890810	214.5	15	2.98	72.1	216	19.5	4.37	2.61	1.14	1.14	
991	GB 43	44.93	87.5	26	24	890726	890810	214.5	15	12.29	46.7	574	12.2	4.48	6.40	1.92	1.92	
997	GB 43	44.93	87.5	26	10	890810	890830	232	20	1.32	164.1	216	41.8	4.57	0.77	1.72		1.72
999	GB 43	44.93	87.5	26	20	890810	890830	232	20	3.24	84.8	277	22.5	4.40	1.58	2.05		2.05
1001	GB 43	44.93	87.5	26	24	890810	890830	232	20	9.90	51.5	509	13.8	4.35	5.18	1.91		1.91
1013	GB 43	44.93	87.5	26	10	890830	890913	249	14	1.38	125.4	126	32.9	4.45	0.60	2.31	1.72	2.9
1015	GB 43	44.93	87.5	26	20	890830	890913	249	14	3.35	75.5	252	21.3	4.14	1.84	1.83	2.05	1.6
1017	GB 43	44.93	87.5	26	24	890830	890913	249	14	13.52	44.6	607	12.2	4.29	7.08	1.91	1.91	
1023	GB 43	44.93	87.5	26	10	890913	891005	267	22	3.89	65.4	257	17.2	4.43	1.51	2.58	2.9	2.26
1025	GB 43	44.93	87.5	26	20	890913	891005	267	22	5.66	77.7	438	20.5	4.41	2.51	2.25	1.6	2.9
1027	GB 43	44.93	87.5	26	24	890913	891005	267	22	35.14	50.0	1712	13.3	4.37	11.64	3.02		3.02
1038	GB 43	44.93	87.5	26	10	891005	891024	287.5	19	39.54	41.5	1641	11.4	4.25	13.97	2.83	2.26	3.4
1040	GB 43	44.93	87.5	26	20	891005	891024	287.5	19	46.91	37.9	1780	10.4	4.28	14.61	3.21	2.9	3.52
1042	GB 43	44.93	87.5	26	24	891005	891024	287.5	19	66.25	35.5	2351	10.4	4.00	19.20	3.45	3.02	3.88
941	GB 44	45.23	87.44	28	7	890509	890621	150.5	43	1.46	137.0	200	15.5	10.31	1.28	1.14		1.14
943	GB 44	45.23	87.44	28	22	890509	890621	150.5	43	2.02	97.6	195	11.5	9.89	0.94	2.14		2.14
945	GB 44	45.23	87.44	28	26	890509	890621	150.5	43	4.91	92.3	452	11.5	9.36				
977	GB 44	45.23	87.44	28	7	890621	890725	189	34	0.58	174.3	101	41.4	4.93	0.53	1.09	1.14	1.03
979	GB 44	45.23	87.44	28	22	890621	890725	189	34	1.14	93.0	106	20.1	5.43	0.62	1.82	2.14	1.51

Table 4.--Green Bay Trap Averaged Data

#	STA	LAT	LON	Z (M	TRP (M)	DAT IN	OUT	Mid Day	DAYS	TRAP FLUX G/M2/D	TRAP ORG C mg/G	TRAP O.C.FLUX mgC/m2/d	TRAP N mg/G	TRAP C/N atomic	Vel S m/d	TSM avg	TSMin mg/L	TSM out
981	GB	44 45.23	87.44	28	26	890621	890725	189	34	3.74	51.3	188	12.1	4.93	2.02	1.85		1.85
1003	GB	44 45.23	87.44	28	7	890725	890829	223.5	35	0.45	139.4	59	28.9	5.96	0.43	1.03	1.03	1.03
1005	GB	44 45.23	87.44	28	22	890725	890829	223.5	35	3.56	53.1	189	13.9	4.46	2.61	1.37	1.51	1.22
1007	GB	44 45.23	87.44	28	26	890725	890829	223.5	35	9.11	47.1	428	12.1	4.54	5.36	1.70	1.85	1.55
1028	GB	44 45.23	87.44	28	7	890829	891004	259	36	1.06	137.3	144	33.7	4.76	0.86	1.24	1.03	1.45
1030	GB	44 45.23	87.44	28	22	890829	891004	259	36	5.73	47.6	269	13.1	4.22	3.65	1.57	1.22	1.92
1032	GB	44 45.23	87.44	28	26	890829	891004	259	36	17.18	37.8	641	10.7	4.12	7.10	2.42	1.55	3.29
1067	GB	44 45.23	87.44	28	12	891004	900515	388.5	223	6.62							1.45	
1069	GB	44 45.23	87.44	28	22	891004	900515	388.5	223	8.76							1.92	
1071	GB	44 45.23	87.44	28	26	891004	900515	388.5	223	4.62							3.29	
947	GB	46 45.14	87.29	18	7	890509	890622	151	44	1.30	162.5	210	20.1	9.43				
949	GB	46 45.14	87.29	18	16	890509	890622	151	44	3.05	46.4	141	5.7	9.50				
983	GB	46 45.14	87.29	18	7	890622	890725	189.5	33	0.21	177.5	38	43.8	4.77	0.24	0.88		0.88
985	GB	46 45.14	87.29	18	16	890622	890725	189.5	33	2.05	39.0	80	9.0	5.11	1.10	1.87		1.87
1009	GB	46 45.14	87.29	18	7	890725	890829	223.5	35	2.05	54.5	111	16.1	3.94	1.60	1.28	0.88	1.68
1011	GB	46 45.14	87.29	18	16	890725	890829	223.5	35	4.44	39.7	175	12.2	3.81	2.46	1.80	1.87	1.74
1034	GB	46 45.14	87.29	18	7	890829	891004	259	36	6.92	40.4	278	11.9	3.97	3.82	1.81	1.68	1.94
1036	GB	46 45.14	87.29	18	16	890829	891004	259	36	9.20	42.7	391	12.3	4.06	4.97	1.85	1.74	1.96

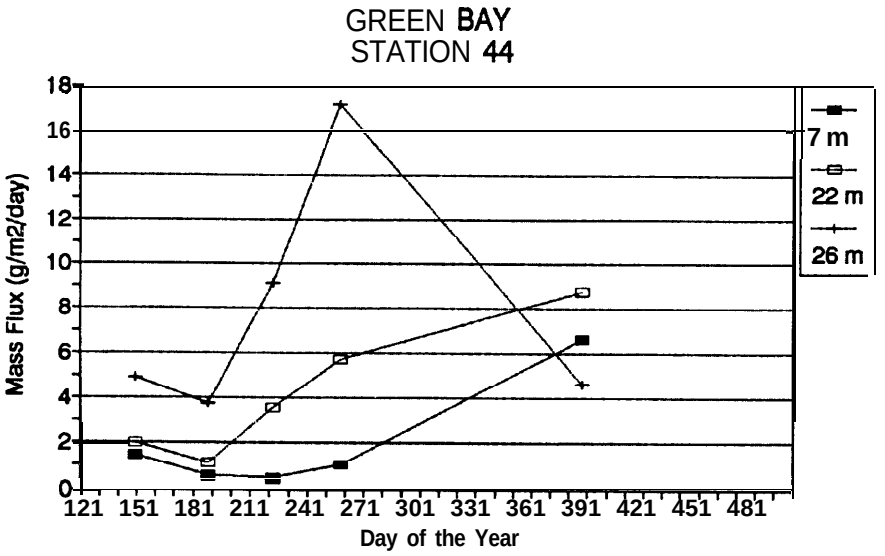


Figure 9.--Mass fluxes for all five collections at Station 44. The symbols are placed at the mid-point in each deployment. For details see Tables 3 and 4. The fluxes from traps at each depth are connected, the symbols are shown in the insert.

trap, at 7 m below the surface, was consistently in the epilimnion during these collections. The low fluxes are characteristic of periods when the epilimniom is isolated from the resuspended sediments.

The results from all five deployments at this station are presented in Figure 9, the basic format for presenting the rest of our trap data for this project. The mass fluxes from the fourth deployment (8/29 - 10/04/89) were again during the stratified period, but the values at all depths are higher. This may be due to a major storm on September 23 resulting in recorded waves of up to 18 feet in open Lake Michigan. Gottlieb et al. (1990) and personal communications with Saylor and Miller confirm that there were strong currents in this west passage around Chambers Island and distinct two layer flow for most of the stratified period. Near-bottom currents were higher during September than for any other month at this location; thus, local resuspension may explain the much larger mass fluxes observed. The last collection (10/04 - 5/15/90) was the only overwinter data that we successfully collected; the other three deployments were lost (Station 40 was not deployed). Unfortunately, the samples collected are a combination of the very high fluxes in late fall, as illustrated by the prior samples, and probable low fluxes during the period of ice cover. A clear picture of these over-winter fluxes can only be obtained with automated sequencing sediment traps. In addition, for a shallow system like Green Bay, internal recycling of hydrophobic constituents will probably be dominated by episodic sediment resuspension; therefore, traps that collect sufficient mass over relatively short time scales (< week) are desirable. Automated sequencing traps have been built and successfully used in marine applications; as part of this study, we constructed and tested a prototype autosequencing sediment trap.

4.1.2 Station 43

Station 43 is located within the sediment depositional zone near Sturgeon Bay in 26 m of water and represents our most detailed data set. The nine mass flux profile measurements are presented in Figure 10. Most of the first and all of the last deployments were collected prior to stratification. Again we see a very large difference between the near-bottom and upper traps, when we would have expected a more well-mixed system. Only the last collection (10/05 - 10/24/89) showed high fluxes throughout the water column. For the third through seventh collections, the 10 m deep trap was primarily in the epilimnion, and the 20 m-deep trap was below the thermocline (Gottlieb et al., 1990). Significantly more mass was collected in the 20 m traps throughout this period. As we show later, the material making up the differences in these fluxes was similar in its carbon character to the near-bottom trap material and probably is locally resuspended sediment. A more comprehensive chemical and physical analysis of these trap materials may confirm this. The mass flux at 2 m above bottom is generally higher at this site than at

Station 44 (Figure 9), especially in the spring. A distinct minimum in near-bottom flux occurs in early summer, soon after stratification. Unfortunately, the current meter at the nearest station failed during this period, and thus, the cause of this reduction in flux is not clear at this time.

The organic carbon measured in the nine sediment trap collections from Station 43 is presented in Figure 10. Epilimnion trap carbon concentrations are higher than deeper trap values, even for the first collection when there was no significant thermal stratification. There must be an early spring bloom in this region of the bay; the water column data collected by EPA (when available) will help to interpret these data. Organic carbon in near surface traps peaks in June and July and then declines to values equal to the lower traps by fall. The sediment organic carbon at this site is approximately 35 mg C/g (S. Fitzgerald personal communication), slightly lower than the values in all three depths of the last trap collection. The trap at 2 m above bottom exhibits carbon values significantly higher than this sediment value in early spring, implying that spring bloom materials are being captured by this trap. The transport of organic-rich particles to the bottom was examined in nearshore Lake Michigan by Gardner et al. (1989), who concluded that zooplankton grazing lagged behind the spring bloom, allowing a large flux of energy-rich organic matter to reach the bottom and fuel the benthos. A significant flux of polycyclic aromatic hydrocarbons (PAH), especially phenanthrene, appeared to accompany this spring pulse (Eadie

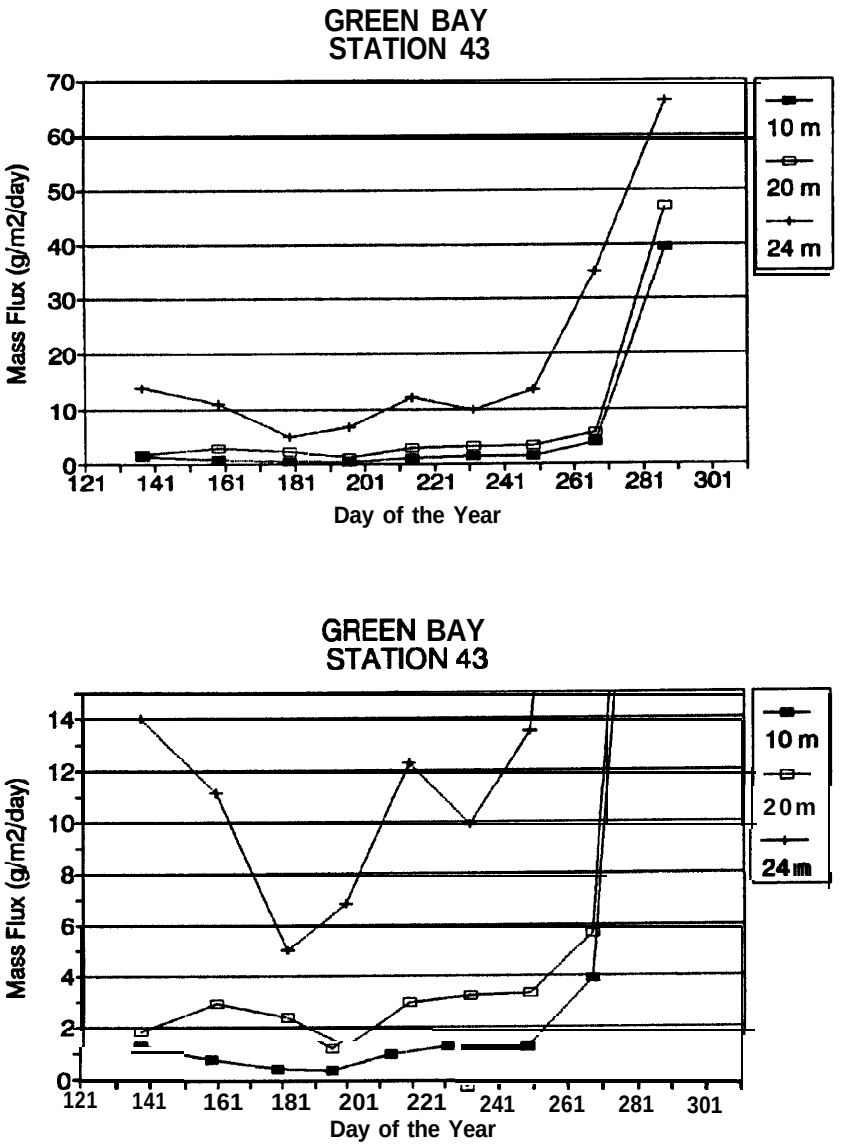
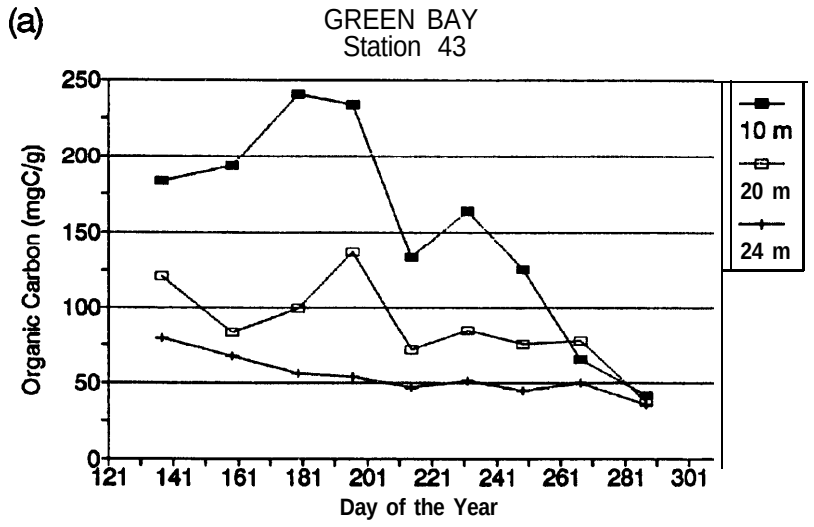


Figure lO.--Mass fluxes for all nine collections at Station 43. The lower panel is the same data on an expaned scale in order to see diferences in the upper two traps.



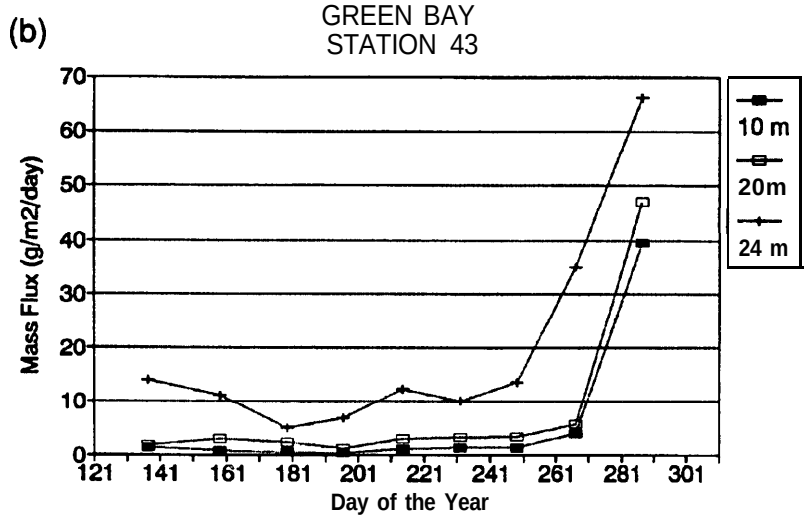


Figure 11 .--(a) The organic carbon content of material trapped at Station 43. Sediment organic carbon at this site is approximately 3.5%. (b) Organic carbon fluxes at Station 43.

et al., 1985), leading to maximum concentrations of PAH in the benthos at this time. Based on the organic flux in the spring, a similar pulsed loading of hydrophobic organic contaminants (HOC) may be occurring in Green Bay.

The fluxes of organic carbon for the nine collections at Station 43 are also presented in Figure 11. Throughout the year, there was very little difference between the carbon flux at the 10 m and 20 m traps. The organic carbon concentration was much greater in the 10 m traps. If we assume that the organic matter collected in the 20 m trap is a combination of the material collected in the 10 m trap plus materials from another source, then we can calculate the carbon composition of the other source; the minimum carbon composition of the excess trapped material can be estimated by

Excess Organic Carbon @ 20 m = O.C. Flux(20m -10m)/Mass Flux (20m -10m)

The results of calculations for both the 20 m and 24 m traps are shown in Figure 12. This calculation makes the simple assumption that the material from the trap above falls into the next deeper trap without alteration. Since we know from other Great Lakes trapping efforts that significant decomposition of organic matter occurs in the upper water column, this calculation provides a minimum carbon concentration for source of the excess material. The carbon content of the excess material (over the 10 m trap) captured by the 20 m trap is equivalent to that of the local sediment for the second, fifth, sixth, and ninth

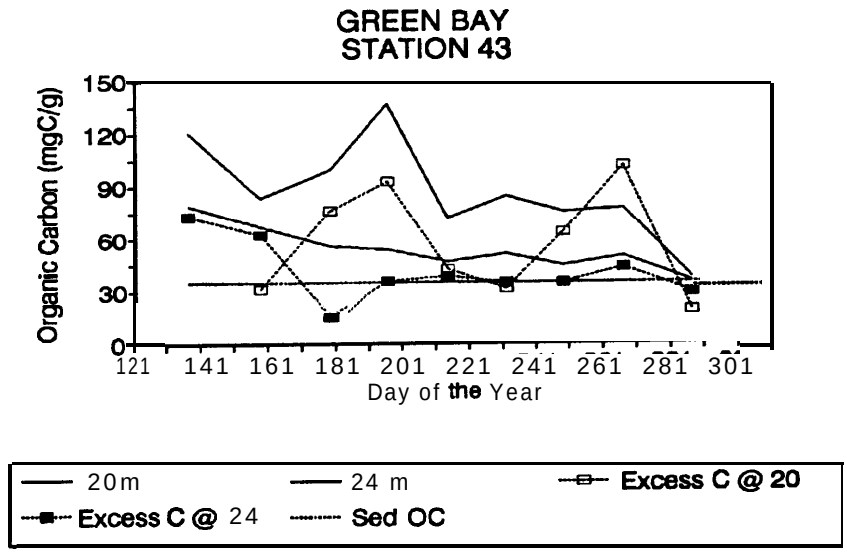


Figure 12.-- The calculated carbon content of "excess" material in the two bottom traps at Station 43. See text for details of calculation. The sediment organic carbon is shown as the straight, dotted line at 35 mgC/g. The carbon concentration in 20 m (upper line) and 24 m (lower line) traps are illustrated as solid lines. The lines with symbols represent the calculated carbon content of the trapped material from sources other than the trap immediately above.

collection periods. This implies that the extra mass captured during these periods was primarily composed of local resuspended sediment. During the other four collection periods, the carbon content of the excess trapped material was much higher than the sediments implying that relatively organic rich sources other than the sediments were important The extra material in the 2 m above bottom traps is close in carbon content to the local sediment except for the first few collections. The organic rich materials required in the first two collections could be the residue of the spring bloom discussed above.

4.1.3 Station 41

At 14 m, Station 41 is the shallowest station for which we have any vertical resolution. The mass and carbon flux data are presented in Figure 13. This far south in the bay, thermal stratification is established earlier and then breaks down in mid-summer. Thus, the first two collections are primarily during stratified conditions, and the second two collections are unstratified (see Figure 5). Mass flux and organic carbon content are clearly higher and lower respectively in the 12 m deep traps for the first three collections. Carbon concentration in the final trap collection was the same in both traps. Sediment carbon concentration is not available at this site, thus, we cannot speculate on the contribution of local sediments to the traps.

4.1.4 Station 46

This 18 m-deep station was located in the east channel between Chambers Island and the Door Peninsula. The passage on this side of Chambers Island is smaller in cross section than the west side passage by about a factor of 10. Generally, high current speeds were recorded here (Gottlieb et al., 1990). Of the four trap collections, the second was completely during stratified conditions and the last was completely during unstratified conditions; the other two were mixed (see Figure 5). Clearly higher mass fluxes were collected in the trap 2 m above bottom than in the mid-depth trap, Figure 14. During the first two collections, much higher organic carbon (4x) was collected in the upper trap, and equal carbon concentrations were observed in the last two collections.

Figure 13.--(a) Mass flux, (b) organic carbon concentration and (c) the flux of organic carbon for the four collections at Station 41.

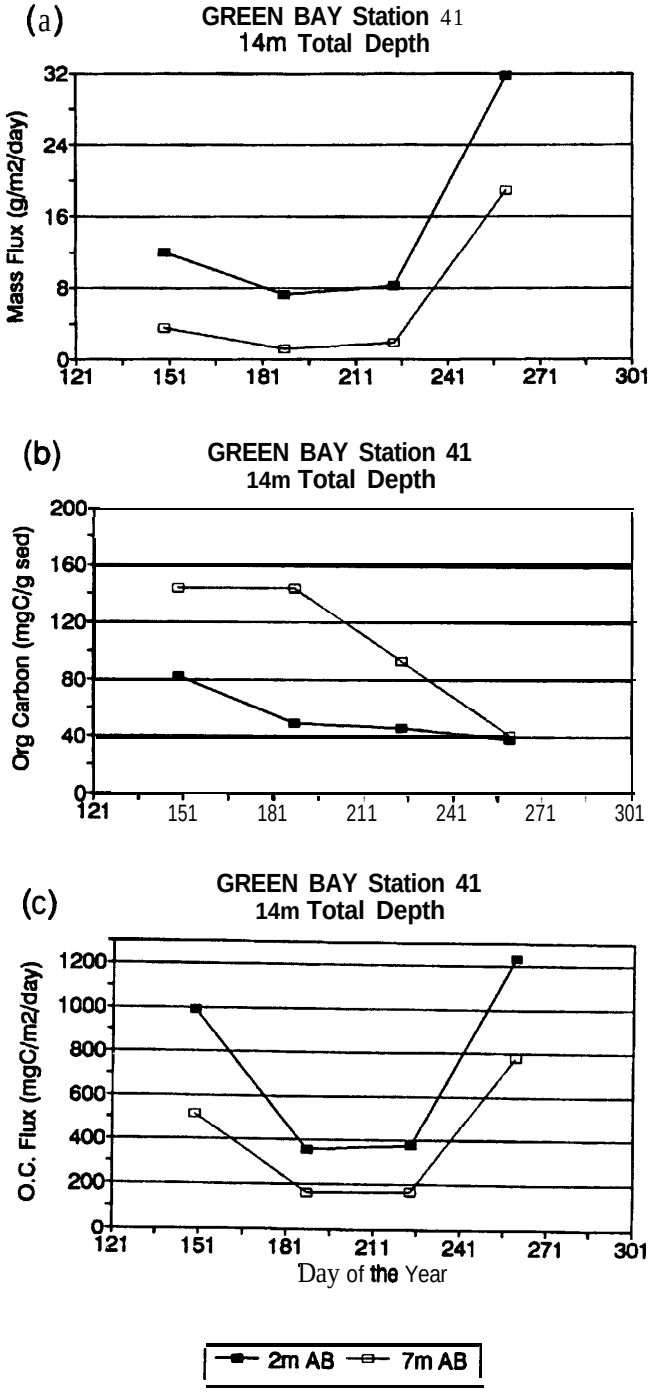


Figure 14.--(a) Mass flux , (b) organic carbon concentration, and (c) the flux of organic carbon for the four collections at Station 46.

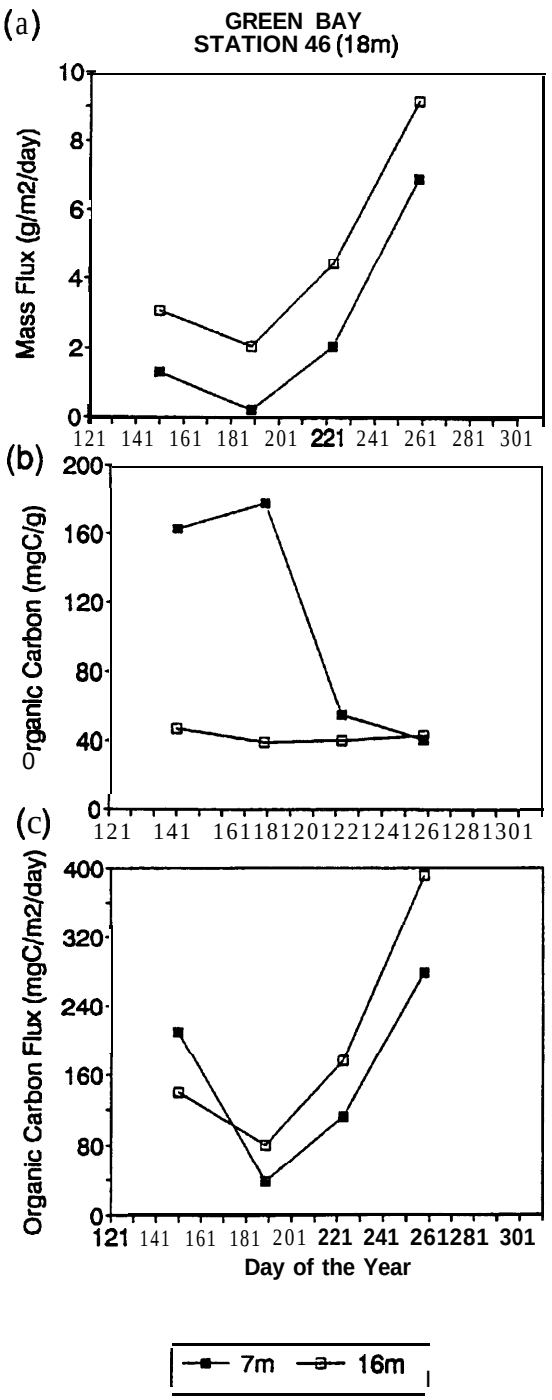
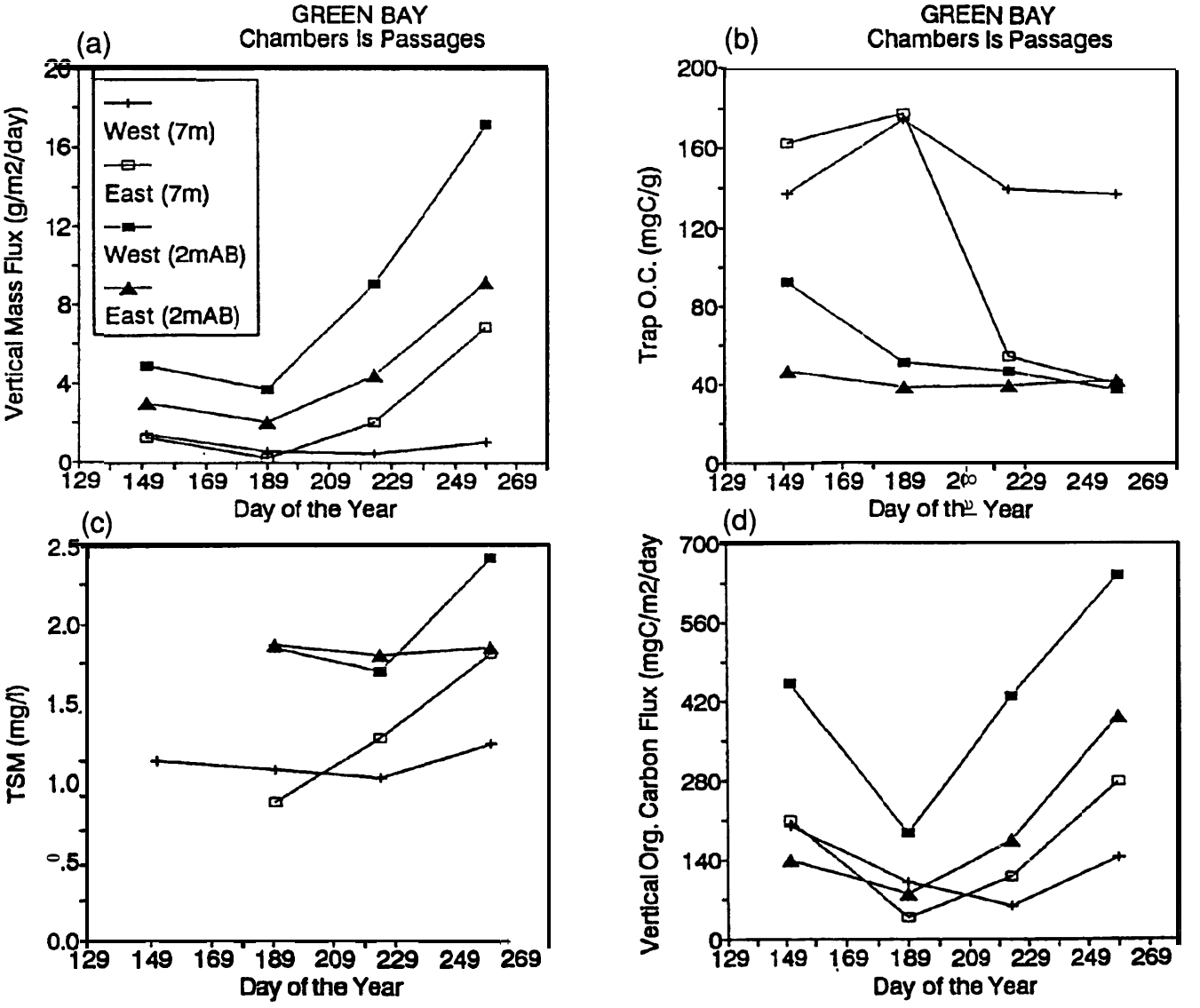


Figure 15.--A comparison of the (a) mass flux, (b) organic carbon concentration, (c) TSM, and (d) the vertical flux of organic carbon in the east and west passes around Chambers Island.



4.2 Comparison of Trap Data at the Chambers Island Passages

Sediment trap profiles were collected from both the east (Station 46, 18 m total depth) and west (Station 44, 28 m total depth) passages around Chambers Island in order to collect samples of materials moving between the northern and southern portions of Green Bay. A comparison of the collected materials is presented in Figure 15 for traps at 7 m below the surface and at 2 m above the bottom. For the first two collections, the mass fluxes were equal in the near surface traps and similar in the near bottom trap. The organic carbon content is also similar during this time. This implies that the materials moving between the northern and southern portions of the bay are comparable. During the third and fourth collections, the deeper, west channel remains strongly stratified, while on the shallow east side, strong currents create an isothermal environment. A distinct difference develops in the carbon content of the mobile particulate matter being collected by the traps. This pattern is also shown in the TSM data. Based on the flows calculated in Table 1 and current meter records at these sites (Gottlieb et al., 1990) during these last two collections (7/25 - 10/04/89) there is a net transfer of organic rich material in the western channel epilimnion from the northern to the southern basin. Horizontal fluxes of particulate matter and carbon will be calculated from Nathan Hawley's data when available.

Figure 16.--A comparison of (a) organic carbon flux and (b) mass flux at the 2 m above bottom depths for all five stations.

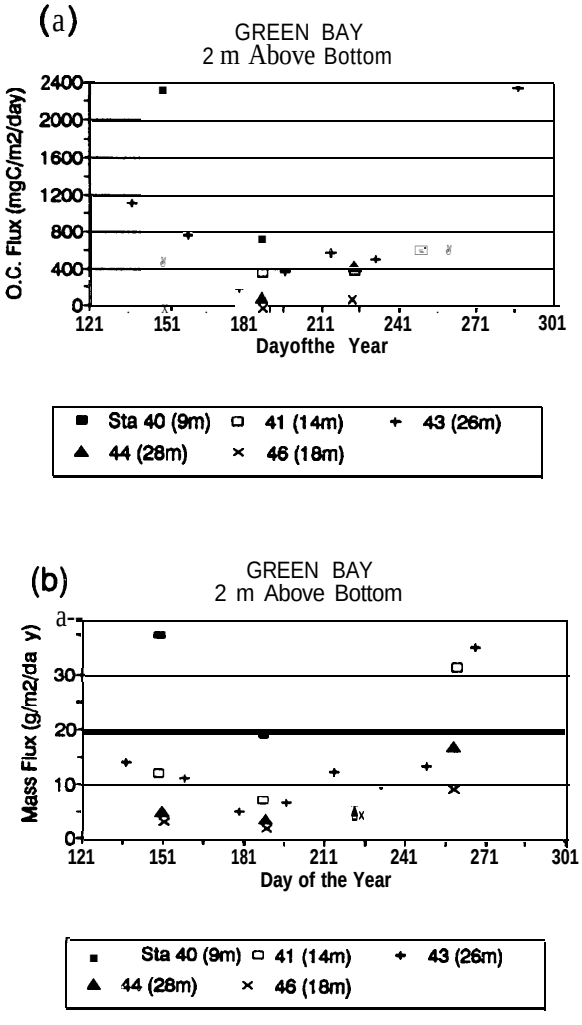
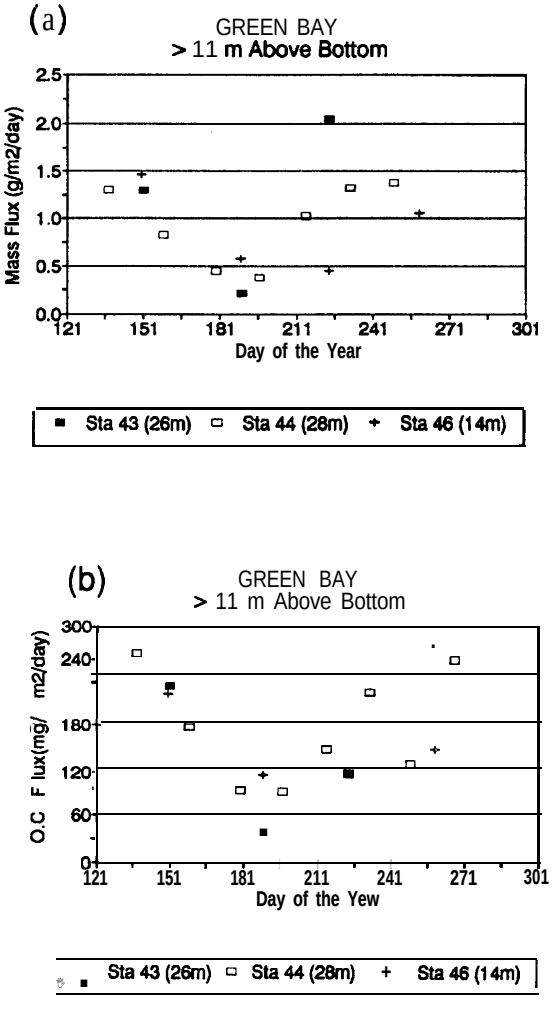


Figure 17.--A comparison of (a) mass flux, and (b) organic flux in the traps greater than 11 m above bottom for our three deepest stations.



4.3 Comparison of all Trap Data

Our sediment traps were distributed throughout southern Green Bay (see Figure 4). At each station, collections were made at 2 m above bottom. The mass fluxes from all stations is presented in Figure 16. Seasonal flux patterns in this bottom layer were similar for all stations. Generally high fluxes were observed prior to stratification, declining to minimum values during summer and then generally much higher fluxes during fall overturn. Similar patterns were observed in the flux of organic carbon. For the three stations where traps were placed at greater than 11 m above bottom, the seasonal patterns are similar (Figure 17), although mass flux is approximately 10% of the near bottom flux and carbon flux approximately 20%. There do not appear to be great differences among the trap flux measurements throughout the southern bay.

4.4 Particle Settling Velocities

There is an important distinction between the particulate matter in the bay collected as the total suspended matter associated with a water sample and that collected as settling matter in a sediment trap. The former represents an instantaneous estimate of the population of particles in the water (if the sample is large enough to capture the rare, large particles), while the latter is a time integrated sample of settling particles that, because of their size and/or density, have sufficiently high settling velocities to be captured.

Although imperfect, because of the different sampling time scales, a mean settling velocity for the ensemble of particles can be estimated by dividing trap-measured mass flux by the average concentration of TSM collected at the trap location at the tunes of deployment and retrieval. Settling velocities have been calculated for the nine collection periods at Station 43 (Figure 18). During the stratified period (collections 2-7), the settling velocities near the upper trap (10 m) are similar to those reported (Eadie et al., 1990) in open Lakes Michigan, Huron, and Superior (mean = 0.52 +/- 0.16 m/d), not significantly different from the value of 0.76 m/d reported by Rosa (1985) for epliminetic settling of particulate matter in offshore Lake Ontario, nor the 0.55 m/d calculated for two offshore stations (7 and 10) in Lake Erie (Charlton and Lean, 1987). Using the same approach, similar values (epilimnion = 0.66 m/d) were reported for the Swiss lake Zug (Bloesch and Sturm, 1986) and can be estimated (epilimnion = 0.75 m/d) for Greifensee (Lee et al., 1987). These calculated epilimnetic ensemble particle settling velocities fall within the range measured with in-situ settling chambers (-0.32 to 1.68 m/d) during stratified conditions in Lake Erie (Burns and Pashley, 1974).

Figure 18.--Calculated settling velocities for all collections at Station 43. The right panel is the same data for the upper two trap depths plotted on an expanded scale.

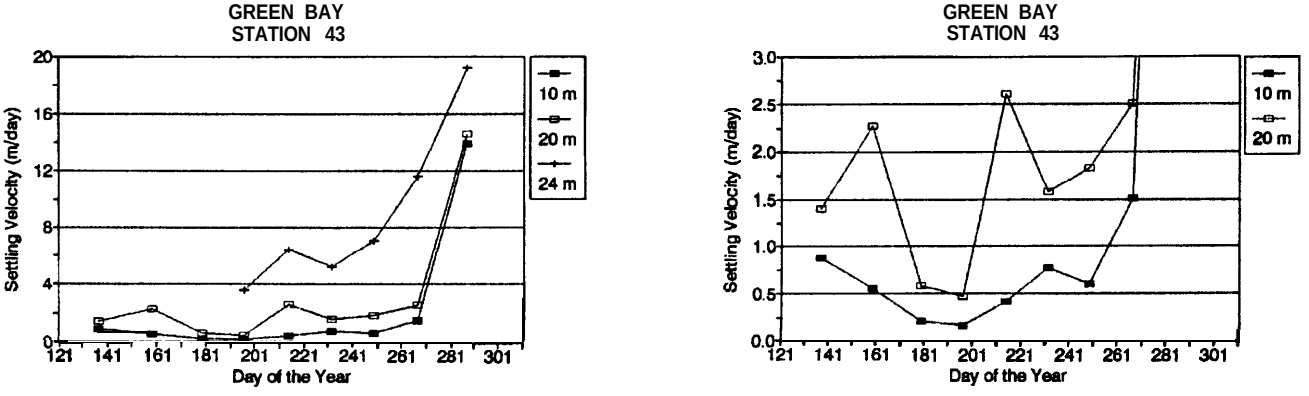
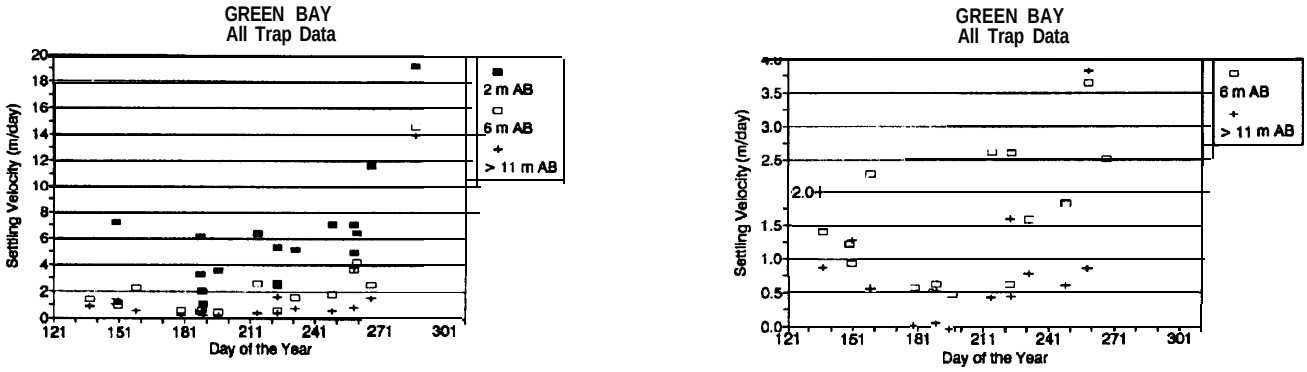


Figure lg.--Calculated settling velocities for all collections at Station 43. The right panel is the same data for the upper two trap depths plotted on an expanded scale.



The settling velocities calculated for the trap at 20 m (6 m above bottom) are approximately three times the values calculated for the epilimnion. However, the values for collections 3 and 4 (6/22 - 7/26/89) are much lower than for the rest of the year and are similar to the epilimnion values. Organic carbon was high in these two trap collections implying that the trapped material was primarily fresh, and that resuspended sediments were less important during this strongly stratified period.

Significantly higher settling velocities (4-6 m/d) during the stratified period were calculated for the 2 m above bottom region. These values are similar to those reported for the open Great Lakes (Eadie et al., 1990) and result in particle residence times of less than 1 day in the benthic nepheloid layer. These rates imply that a large recharging of the particle pool either via horizontal transport or local sediment resuspension occurs throughout the year. Contributions from these two sources have not yet been discriminated.

Thermal stratification breaks down at this site at the end of September. The last collection was during the unstratified period. Settling velocities throughout the water column are approximately 12-18 m/d, more than an order of magnitude higher than during stratification. At this rate, the particle residence time in the water column is only a few days, again implying frequent recharging.

If we include the settling velocities from all of the other stations, we see very similar results (Figure 19). All stations were sampled at 2 m above bottom, and the settling velocities calculated for this region during the stratified period were 2-7 m/d, with higher values both before and after stratification. The other data are presented as those at 6 m above bottom (three stations) and greater than 11 m above bottom (three stations). The latter are generally epilimnion samples and, as at Station 43, values during stratification are approximately 0.5 m/d. The values at 6 m above bottom are sometimes similar to the epilimnion values and sometimes significantly larger, reflecting the complicated thermal structure in the bay (Gottlieb et al., 1990).

4.5 Flux Profiles and Estimates of Sediment Resuspension

As illustrated in Figure 8, the observed mass flux profiles increase in apparent exponential fashion as the bottom is approached. This is consistent with all of our earlier observations (Eadie et al., 1984; 1990), and we have derived information from these profiles by fitting the mass flux data to

$$J = J_0 e^{bZ}$$

where J is the flux recorded by the traps, J_0 is the flux at the sediment-water interface, b is the inverse scale length, and **Z** is the height above bottom. Although this model assumes that all trapped material is

resuspended, it gives insignificantly different results if a small flux from the top, estimated from mid-summer epilimnion fluxes (ca. 0.4 g/m²/day), is subtracted. A more comprehensive model including sources at both top and bottom is developed in Robbins and Eadie (1991) but would represent over-interpretation in this application with only a three depth trap profile in shallow water. Application of the model to mass flux data is illustrated in Figure 20. The flux has an exponential form that has been least squares fit by the solid line. The resultant fit for this profile is

J_0 = 6.75 g/m²/day b^{-1} = 5.29 m r^2 = 0.88

The corresponding values for the remainder of the collections at Station 43 are presented in Figure 21. The results show that the sediment resuspension required by this model to support trap observations is about 10 g/m²/day with scale thicknesses of 5-7 m, and that there is little seasonal variation until late September.

When the model is applied to the flux profiles of organic carbon, the results (Figure 21) are also relatively constant throughout the year until fall. The scale thickness for organic matter is generally larger than for mass; this implies that organic-rich materials are transported farther than the total mass. This is consistent with observations that line-grained matter generally has more organic matter than the larger grain size fraction of sediments. It also implies that organic-rich materials and, presumably, associated HOC are being mobilized at the sediment-water interface and transported vertically over a considerable distance. Recalling the calculated settling velocities of approximately 1 m/day and average horizontal currents on the order of several centimeters/second (Gottlieb et al., 1990), the resuspended materials can be moved many kilometers before resettling into the sediments.

Finally, we can estimate the organic carbon content of the material being resuspended at the sediment-water interface. The ratio of J_0 for mass flux to J_0 for organic carbon flux is presented in Figure 22 for the nine collection periods at Station 43. The inverse of this ratio, also shown in Figure 22, is the calculated organic carbon content of the resuspended sediment at the interface. Except for the first collection, which we believe has organic-rich spring bloom material, and the last collection, which looks just like the local sediment, the organic carbon content is constant at approximately 5% carbon. Thus, the materials moving in the resuspendible pool are enriched in organic matter over local sediments. This is consistent with carbon enrichment in finer grained sediments and may be important in the mobilization of sedimentary HOC.

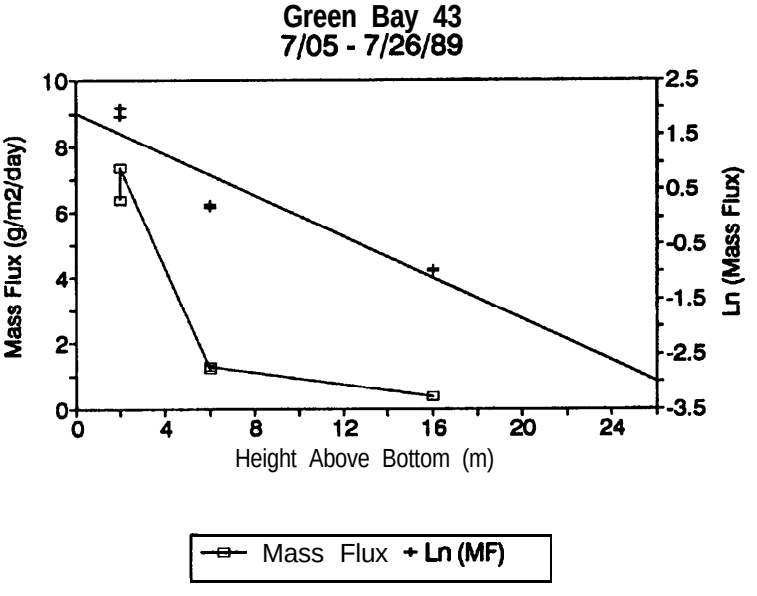


Figure 20.--A mass flux profile from Station 43. The data are also shown in natural log transform with a least squares regression fit used in our resuspension calculation.

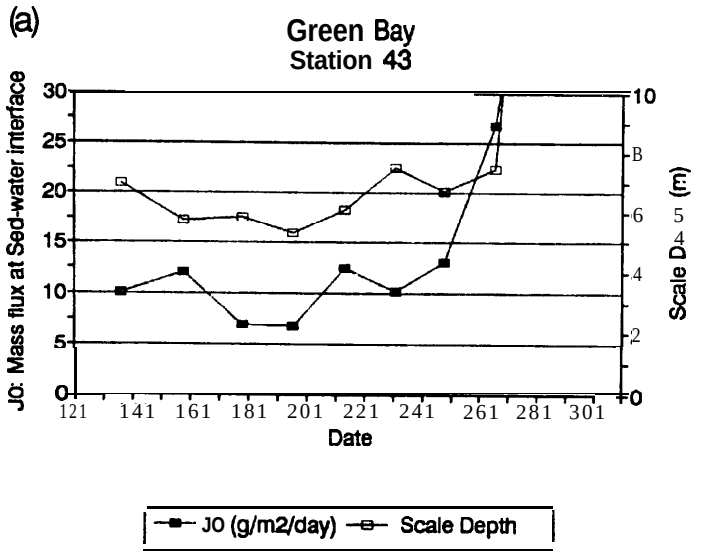


Figure 21 .--(a) The calculated mass flux at the sediment-water interface and associated scale depth and (b) a comparison of the scale depths of mass and organic carbon flux.

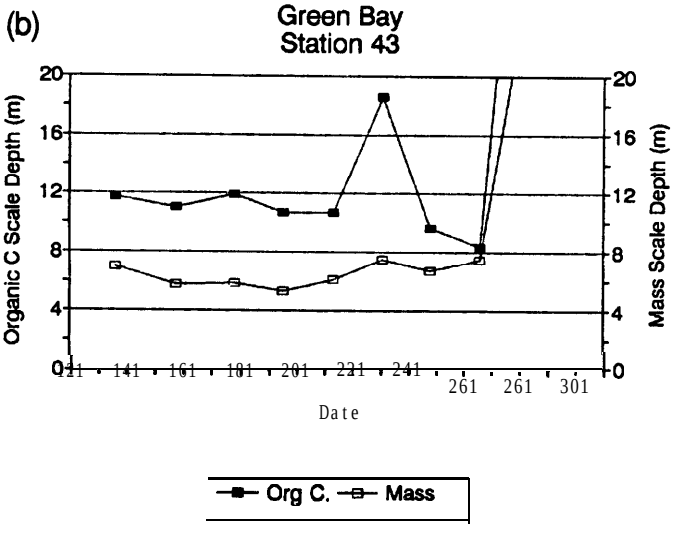
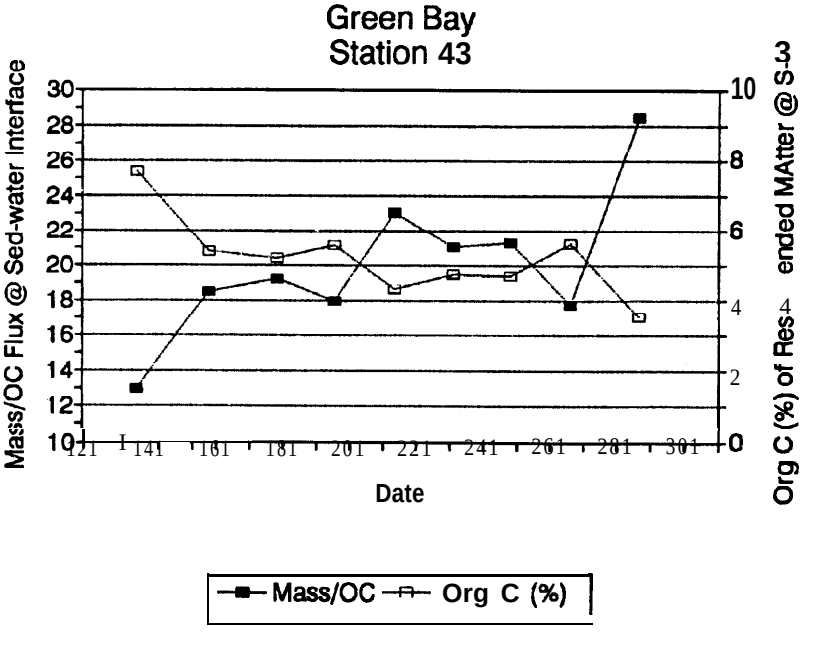


Figure 22.--The mass flux/ organic carbon flux calculated at the sediment-water interface. The inverse of this ratio (times 100) is the % organic carbon of the resuspending material.



The degree of partitioning of a contaminant between dissolved and particulate phases (K_d) is a complex function of the compound's intrinsic properties and the composition of the substrate. The affinity of a contaminant for particles is defined in terms of the partition coefficient K_d as

$$K_d = \frac{\text{concentration in particulate phase (ppm)}}{\text{concentration in dissolved phase (ppm)}}$$

For HOC, the use of K_{oc} (K_d/fraction organic carbon of the substrate), correlating the equilibrium distribution of contaminant to the organic carbon fraction of the particulate matter, has been shown to reduce the variability over a wide range of substrates.

If the HOC are partitioned onto the particulate matter as described by equilibrium K_{oc}, then the HOC concentration on resuspended sediment materials that are being transported will have concentrations that are elevated above the local sediment HOC concentration by the ratio of the organic content of resuspended matter (Figure 22) to sediment organic carbon (3.5%). This is generally around 1.5 at Station 43.

5. SUMMARY AND CONCLUSIONS

The mass fluxes from sediment traps located 2 m above bottom and distributed throughout southern Green Bay showed that seasonal flux patterns were similar for all stations. Generally high fluxes were observed prior to stratification, declining to minimum values during summer, and then generally much higher fluxes during fall overturn. Similar patterns were observed in the flux of organic carbon. For the three stations where traps were placed at greater than 11 m above bottom, the seasonal patterns are similar to the near bottom samples, although mass flux is approximately 10% of the near bottom flux, and carbon flux is approximately 20%. There were no great differences among the trap flux measurements throughout the southern bay.

A comparison of materials moving between the northern and southern portions of Green Bay showed that for the first two collection periods (spring) the mass fluxes were equal in the near-surface traps and similar in the near bottom trap. The organic carbon content is also similar during this time. This implies that the materials moving between the northern and southern portions of the bay are comparable. During the third and fourth collections (summer, stratified), a distinct difference develops in the carbon content of the mobile particulate matter being collected by the traps. During these last two collections (7/25 - 10/04/89), there is a net transfer of organic-rich material in the western channel epilimnion from the northern to the southern basin.

Settling velocities for epilimnetic samples are approximately 0.5 m/day, similar to open lake values. Significantly higher settling velocities (4-6 m/day) during the stratified period were calculated for the 2 m above bottom region. These values are also similar to those reported for the open Great Lakes and result in particle residence times of less than 1 day in the benthic nepheloid layer. These rates imply that a large recharging of the particle pool either via horizontal transport or local sediment resuspension occurs throughout the year. Contributions from these two sources have not yet been discriminated. During the unstratified period, settling velocities throughout the water column are approximately 12- 18 m/day, more than an order of magnitude higher than during stratification. At this rate, the particle residence time in the water column is only a few days, again implying frequent recharging.

Sediment resuspension estimated by a steady-state model required to support trap observations is about 10 $g/m^2/day$ with scale thicknesses of 5-7 m, and there is little seasonal variation until late September. Similar results are determined for the flux profiles of organic carbon. The scale thickness for organic matter is generally larger than for mass; this implies that organic rich materials arc transported farther than the total mass. It also implies that organic-rich materials and, presumably, associated HOC are being mobilized at the sediment-water interface and transported vertically over a considerable distance. Using the calculated settling velocities of approximately 0.5 m/day and average horizontal currents on the order of of several cm/sec, the resuspended materials can be moved many kilometers before resettling into the sediments. If the HOC are partitioned onto the particulate matter as described by equilibrium K_{oc}, then the HOC concentration on resuspended sediment materials will be approximately 50% higher than the local sediment HOC concentration.

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