

PROBING PARTICLE PROCESSES IN LAKE MICHIGAN USING SEDIMENT TRAPS

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Abstract. Sediment trap sampling at an offshore site in southern Lake Michigan has continued for an 18 year period with a sampling frequency ranging from weekly to semi-annually. During the 6 month unstratified period sediment trap mass and tracer profiles are nearly constant and they have been used to describe the extent of sediment resuspension. After stratification, mass flux rapidly declines and particle tracers are removed from the epilimnion at the rate of 0.5-1 m.d⁻¹. Exponential profiles of mass flux clearly show the persistence of a benthic nepheloid layer. High frequency sampling with near-bottom sequencing traps show order of magnitude ranges in mass flux over a few day period.

1. INTRODUCTION

Lake Michigan, with a surface area of 57,800 km² and volume of 4,920 km³, is the third largest of the North American Laurentian Great Lakes and the sixth-largest lake in the world. A population of approximately 14 million residing within the basin (EPA, 1987) coupled with a hydraulic residence time of 62 years (Quinn, 1992) has resulted in critical issues relating to anthropogenic contaminants. Rapid and efficient processes of sorption and settling through the average depth of 86m promotes internal removal of particle-reactive contaminants through sedimentation with the result that the large contaminant inventories presently reside in sediments. However, studies in the Great Lakes have shown that higher levels than expected, of these constituents, persist in the lakes if settling and burial were the sole transport process. Radiotracer studies with ²³⁹Pu ($t_{1/2} = 25,000$ years) and ¹³⁷Cs ($t_{1/2} = 30.2$ years) indicated removal from the water and >95% transferred to sediments in a few years (Robbins and Edgington, 1975; Wahlgren et al, 1980; Eadie and Robbins, 1987). Although initial removal of particle-reactive tracers from the water is rapid, a small residual concentration in the water, either on particles, in biota or in solution, has diminished exponentially on time scales of decades. Studies of Lehman (1979), Eadie, et al. (1984), Robbins and Eadie (1991), have shown that the small amount remaining in the system is primarily the result of an annual cycle of sediment resuspension and redeposition releasing constituents from sediments back into the water. The long-term decline of ²³⁹Pu and (decay-connected) ¹³⁷Cs in the lake has about a 20 year time constant (Wahlgren et al.,1980), which probably characterizes the net rate of incorporation of these tracers into permanent sediments (Robbins, 1982), a relatively long and inefficient process.

During the decades that these materials are part of the resuspendable pool, they constitute the major non-point source of nutrients and contaminants to the pelagic system. This material also serves as a food source for surface deposit feeders, suspension feeders, the microbial food web, and is probably the source for some of the material that makes up the benthic nepheloid layer (Chambers and Eadie, 1981; Eadie and Robbins, 1987) which plays a major role in coupling the inventory of constituents in surface sediments with overlying lake water throughout the year. New silty-clay materials erode from bluffs along the shore of Lake Michigan or from exposed glacio-lacustrine clays in relatively shallow waters and form temporary deposits of particles in

patchy, transient reservoirs at the active sediment boundary layer. The materials in these transient reservoirs are biogeochemically transformed within the lake, then redistributed throughout the year by a spectrum of energetic events. Large episodic events resuspend and transport these materials from these temporary sinks to more permanent sinks with a small fraction becoming incorporated annually into the sediments of the depositional basins.



Figure 1. Sediment accumulation patterns in southern Lake Michigan as measured by the thickness of post-glacial sediment. The white region represents zero accumulation and the lightest gray represents accumulation of 0-1 m; the remainder of the contours are in 4m intervals with the darkest region having greater than 14m of accumulation. The sediment trap data discussed are primarily from a 100m deep station approximately 25 km off the eastern shore.

The resultant complex distribution of post-glacial sediment in the southern half of Lake Michigan is asymmetric (Lineback and Gross, 1972, Cahill, 1981), with the greatest accumulations found in a band about 20 km from the eastern shore and decreasing towards the deepest sounding in this basin (Figure 1). There is essentially no accumulation of sediment on the western side of the basin, with generally a thin 1-2 cm layer of 'floc' overlying exposed glacial till, glacio-lacustrine clay, or sand. It is mainly from these areas that portions of the inventory are resuspended during the isothermal period and re-allocated to depositional sites.

The processes of particle flux and resuspension has been examined in Lake Michigan through the use of sediment traps since the mid 1970s (Wahlgren et al., 1980, Eadie et al, 1984). These cylindrical devices are moored at selected depths to intercept materials settling to the bottom. Traps provide an efficient tool for the collection of integrated samples of settling materials for detailed analysis. Measuring the mass collected allows us to calculate the gross downward flux

of particulate matter and associated constituents and to calculate both mass and constituent settling velocities. Here we report on the results of some initial studies with sequencing traps from a station in southeastern Lake Michigan (figure 1) and place them in context with a long time series of earlier results.

2. METHODS

In this report we compare results from two types of traps. Our simple trap, based on reviews of various designs (Bloesch and Burns, 1980; Gardner, 1980a,b), is a cylinder 10 cm in diameter with an aspect ratio of 5:1 above the funnel opening to a 500 ml polyethylene bottle. In 1990 we developed a sequencing trap modified from the designs of Baker et al. (1988), and Jannasch et al., (1980). These are also cylindrical, but with an inner diameter of 20 cm and an aspect ratio of 8:1 above the funnel. A computer-controlled carousel contains 23 sixty ml polyethylene bottles, which rotate under the funnel at preprogrammed intervals. An electric motor rotates the carousel and uses a single-pole detent switch to provide position feedback. A microprocessor-based controller, developed in house, runs the motor based on a schedule and records confirmation of each rotation using non-volatile memory. A battery pack allows up to two years of operation. Cylindrical traps have a high collection efficiency in low current lake environments and have proved satisfactory in many lake studies ((Bloesch and Burns, 1980; Eadie et al, 1984). The accuracy of calculated fluxes is poorly understood, but depends on the trap design, the types of particles in the fluid and the currents at the site (Gardner, 1980; Hawley, 1988; Gardner, 1995).

In order to estimate trap collection precision and intercalibrate between the 10 cm diameter traps and the 20 cm diameter sequencing traps, a series of deployments were made in regions with a wide range of fluxes on specially constructed brackets to assure identical depth and exposure. The 20 cm traps used in these tests did not have sequencing capability, but were identical in other aspects. The traps were deployed as anchored arrays using subsurface buoyed 3/8" steel cable. The 500 ml bottles in the simple traps were poisoned with 25 ml of chloroform and filled with distilled water prior to deployment. The 60 ml polyethylene collection bottles in the sequencing trap were poisoned with 6 ml of chloroform and filled with distilled water immediately prior to deployment. This concentration of chloroform is an effective preservative (Lee et al., 1989) and results in a supersaturated solution, with beads of chloroform remaining after retrieval. The sequencing traps are deployed with the collection funnel feeding to an empty opening (no collection bottle). After a preprogrammed period of time the carousel will move the first collection bottle under the funnel. The remaining 22 bottles will follow in a preprogrammed sequence. After retrieval, the sample bottles are removed from the traps and to the laboratory in cold storage (4°C). The traps have on-board intelligence that records the time of each sequence and various system checks.

After arrival at the lab, the trap samples were allowed to settle in a refrigerator for a day, then overlying water was carefully siphoned off and the residual was freeze dried. After drying, samples were weighed and transferred into precleaned scintillation vials for storage in a freezer. All trap samples have been weighed on an analytical balance calibrated to within $\pm 1\text{mg}$ with known standard weights during each weighing session. Virtually all samples are

greater than 100 mg, thus all mass weights have an accuracy and precision of less than 1 % (coefficient of variation).

3. RESULTS and DISCUSSION

Profiles of sediment traps were first deployed at the 100 m deep site (figure 1) in 1978 and sampling has continued with a frequency ranging from biweekly to semi-annually since then. The long-term average mass fluxes measured from 1978-92 at the 100m deep station, 25 km offshore (figure 1), are presented in figure 2. Throughout the year, profiles of mass flux exhibit an exponential increase toward the bottom. From late December through early June, Lake Michigan is virtually isothermal and well mixed. Average fluxes during this period (figure 2) are high throughout the water column, but there is clear evidence of a benthic nepheloid layer (BNL). During the stratified period (June - December), the upper half of the water column becomes isolated from the large inventory of materials in the sediments, although episodic mixing does occur during upwellings. A BNL is still clearly evident from the mass flux profile.

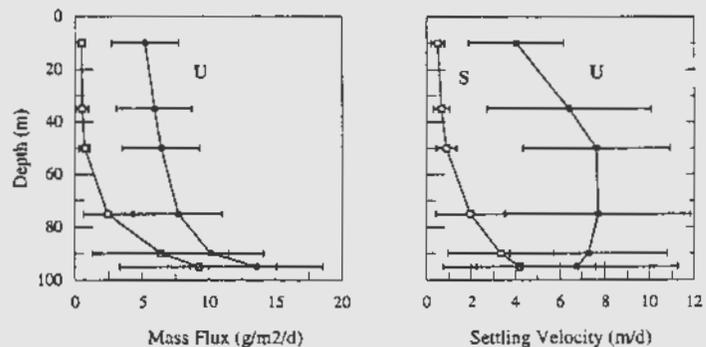


Figure 2. A 14 year synthesis of profiles of trap measured mass fluxes and settling velocities. Error bars represent 1 sd; replicates ranged from 14-54. The stratified and unstratified periods are designated with an S and U respectively.

Ensemble particle settling velocities, estimated from the ratio of mass flux to ambient suspended matter concentration (collected at deployment and retrieval) also show substantial differences between the two thermal periods (figure 2). During the stratified period, these calculated settling velocities in the epilimnion ($0.5-1 \text{ m.d}^{-1}$) agree with those required to model the long-term behavior of fallout radiotracers (Robbins and Eadie, 1991). Settling velocities estimated for the BNL (several m.d^{-1}) shows clearly that frequent recharging of the BNL is required in order to maintain its observed persistence. The BNL is a regular feature in all of the

Great Lakes and appears to be composed primarily of resuspended sediments. In the shallow waters of the shelf and slope, surface and internal waves and occasional strong currents resuspend sediments sorting the particles and transporting them horizontally as well as vertically. The cycle of resuspension and redeposition has the effect of producing a resuspended pool composition which is relatively uniform throughout major basins of the lakes.

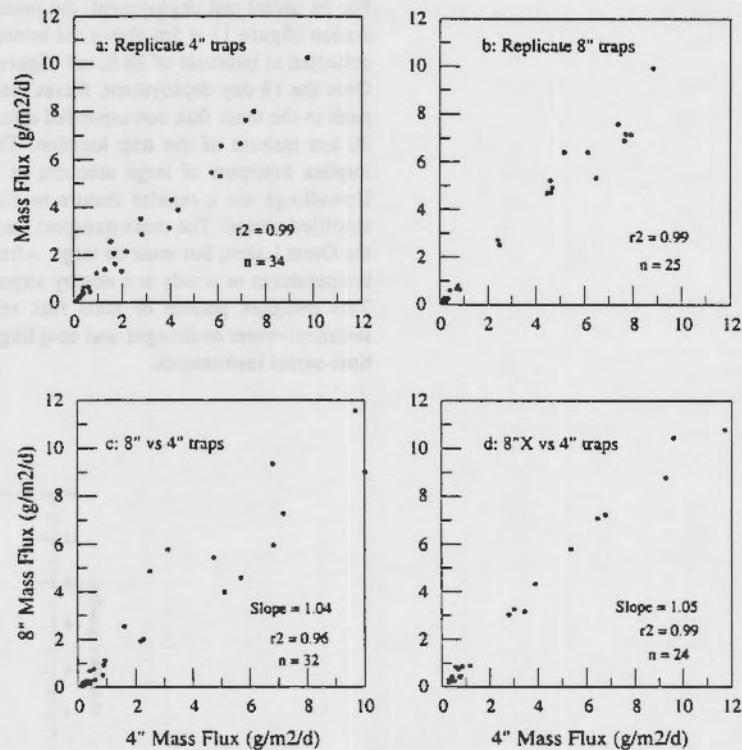


Figure 3. Comparisons of replicate trap flux measurements. a) Replicate 10 cm (4") diameter traps placed on brackets for simultaneous deployments. Correlation coefficient is high and the traps replicate with an average difference between pairs of $\pm 11\%$. b) A similar treatment of 20 cm (8") diameter traps with similar results. c) A comparison of 10 cm and 20 cm traps with 5:1 aspect ratios. The scatter was worse than for individual pairs of the same size. d) Comparison of 10 cm (5:1 aspect) with 20 cm (8:1), extended aspect ratio. There was little bias (slope = 1.05) between these pairs and the scatter was much reduced with the higher aspect ratio.

When deployed in replicate, both the 10 cm and 20 cm traps showed good repeatability with paired t-test showing equal means ($P < 0.05$) in all 4 comparisons (figure 3). The 10 cm traps replicate with an average difference between pairs of $\pm 11\%$ and the 20 cm traps (with and 8:1 aspect ratio) replicate with an average difference between pairs of $\pm 14\%$. An intercomparison of capture efficiency between the 10 and 20 cm traps resulted in a design change from an aspect ratio of 5:1 to 8:1 for the larger diameter traps. A larger trap diameter results in a higher trap Reynolds number, with presumably lower collection efficiency. There was little bias (slope = 1.05) between the two types of traps and the scatter was much reduced with the extended aspect ratio, which became our standard for 20 cm diameter traps.

For its initial test deployment, the prototype sequencing trap was deployed at the 100m deep station (figure 1) at 5m above the bottom (within the BNL) in mid-July, 1990. Samples were collected at intervals of 18 hours (figure 4) in order to examine the variability within the BNL. Over the 18 day deployment, fluxes ranged over an order of magnitude. The first, and largest, peak in the mass flux corresponded directly with a large upwelling recorded at the water intake 20 km inshore of the trap location. The increased mass flux associated with the upwelling implies transport of large amounts of BNL materials from deeper regions further offshore. Upwellings are a regular feature in all of the Great Lakes and occur frequently during the stratified period. The mass transport associated with this process has not been quantified within the Great Lakes, but must be large. After the initial upwelling, fluxes were not related to intake temperatures or winds at a nearby airport; variability is most likely associated with advection. This complex pattern of mass flux reinforces the need for interdisciplinary approaches to sediment-water exchanges and coupling the deployment of traps with current meters and other time-series instruments.

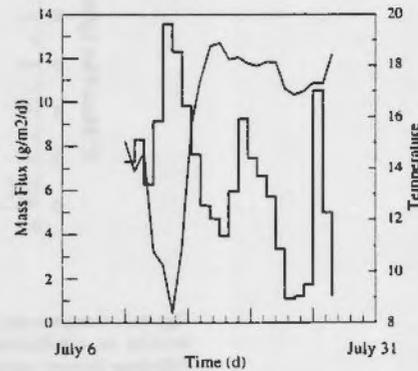


Figure 4. Mass flux (solid line) results from the first deployment of the sequencing traps at 5m above bottom at the 100m deep station. The traps sampled at 18 hour intervals and captured startling variability in flux compared with the long-term average (9.2 ± 5.9) for the summer period.

Interpretation of trap data has led to an increased understanding of particle (and associated constituent) behavior including water column residence times, settling velocities, sediment-water exchange via resuspension long-term removal rates via burial and geochemical properties of mobile materials. Analysis of trapped materials also provides information on sources, fluxes and degradation rates of natural and contaminant organic compounds in the water column. Throughout this long time series, approximately 80% of the primary production has been remineralized within the epilimnion; less than 5% reaches traps at 5m above bottom and approximately 2% is finally incorporated into surface sediments.

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REFERENCES

- Baker, E.T., Milburn, H.B., and Tennant, D.A.: 1988, *J. Mar. Res.* 46:573-592.
- Bloesch, J. and Burns, N.M.: 1980, *Schweiz. Z. Hydrol.* 42(1) 16-55.
- Cahill, R.A.: 1981, *Il. Geol. Surv. Circular no 517*, 96pp, Champaign, IL.
- Chambers, R.L. and Eadie, B.J.: 1981, *Sedimentology* 28:439-447.
- Eadie, B.J., Chambers, R.L., Gardner, W.S., and Bell, G.L.: 1984, *J. Great Lakes Res.* 10(3):307-321.
- Eadie, B.J. and Robbins, J.A.: 1987, *Sources and Fates of Aquatic Pollutants*, (R. Hites and S. Eisenreich, eds.), *Advances in Chemistry Series No.216*, American Chemical Society, Washington, D.C., p. 319-364.
- EPA: 1987, *The Great Lakes: An Environmental Atlas and Resource Book*, EPA-905/9-87-002, Chicago, IL.
- Gardner, W.D.: 1980a, *J. Mar. Res.* 38:17-39.
- Gardner, W.D.: 1980b, *J. Mar. Res.* 38:41-52.
- Gardner, W.D.: 1996, *Report on the JGOFS symposium in Villefranche sur Mer*, May, 1995.
- Hawley, N.: 1988, *J. Great Lakes Res.* 14:76-88.
- Jannasch, H.W., Zafriou, O.C., and Farrington, J.W.: 1980, *Limnol. Oceanogr.* 25:939-943.
- Lee, C., Wakeham, S. and Hedges, J.: 1989, *JGOFS Report 10*, WHOI, Woods Hole, MA.
- Lerman, A.: 1979, *Geochemical Processes Water and Sediment Environments*, John Wiley and Sons, Inc., New York, 481 pp.
- Lineback, J.A. and Gross, D.L.: 1972, *Il. Geol. Survey Environmental Notes no 58*, 25pp, Champaign, IL.
- Quinn, F.H.: 1992, *J. Great lakes Res.* 18:22-28.
- Robbins, J.A. and Edgington, D.: 1975, *Geochim. Cosmochim. Acta* 39:285-304.
- Robbins, J.A.: 1982, *Hydrobiologia* 92:611-622.
- Robbins, J.A. and Eadie, B.J.: 1991, *J. Geophys. Res.* 96:17081-17104.
- Wahlgren, M.A., Robbins, J. A. and Edgington, D.N.: 1980, *Transuranic Elements in the Environment*, (Hanson, W.C.,ed), Technical Information Center/U.S. Department Energy, Washington, D.C.,

