The Design and Performance of a Sequencing Sediment Trap for Lake Research

PAPER

Ronald W. Muzzi and Brian J. Eadie
National Oceanic and Atmospheric Administration
Great Lakes Environmental Research Laboratory
Ann Arbor, Michigan

ABSTRACT

Static sediment traps have been successfully used to examine the processes of particle flux and resuspension in large lakes and coastal systems. Although the traps themselves are inexpensive, the deployment and retrieval of them is costly, which restricts both the quantity and frequency of samples. To overcome this, a programmable sequencing sediment trap was designed and tested for use in large lakes and coastal systems. Sediment is collected into a carousel of 23 standard 60 ml (Nalgene™) polyethylene sample bottles. The sequencing design incorporates an electric motor and paddle to rotate the carousel so that one sample bottle at a time is exposed according to a preprogrammed schedule. These traps incorporate a cylindrical design with a 20 cm collection opening and an 8:1 aspect ratio. The micro-controller monitors the operation and records operational parameters allowing confirmation of the exposure time of each bottle. Several field tests were conducted to verify the precision and uniformity of the sediment collection. Improvements made over the 10 years of deployment experience and field testing have resulted in a very reliable and low-cost instrument.

BACKGROUND

In large lakes and coastal systems, the rapid and efficient processes of sorption and settling remove contaminants from the water column. In the vast majority of these systems, the largest fraction of persistent trace contaminant inventories resides in sediments. However, studies of the long-term behavior of certain fallout radionuclides and stable contaminants in the Great Lakes have shown that higher levels than expected persist in the water column and biota if settling and burial were the sole transport process. Materials re-enter the water column from sediments due primarily to resuspension. Constituents initially transferred to sediments are homogenized during transport into regional depositional areas where sediments accumulate. Once there, organisms mix the most recently arrived material with older materials creating a layer corresponding to a decade or more of accumulation.

During the decades that these materials are part of the resuspendable pool, they constitute a major non-point source of nutrients and contaminants to the water column and biota. 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 materials from these temporary sinks to more permanent sinks with a small fraction becoming incorporated annually into the sediments of the depositional basins. Although recognized as a critical process for the cycling of many important constituents, the rates of sediment resuspension and downward flux are difficult to measure. It is now accepted that the internal recycling caused by the coupled processes of mixing and resuspension are responsible for the continuing elevated concentrations of trace contaminants (e.g. PCB, DDT) in fish and the many-year time lag in lake response to nutrient abatement.

Since 1977, NOAA's Great Lakes Environmental Research Laboratory (GLERL) has been examining the processes of particle flux and resuspension through the use of sediment traps (Eadie et al, 1984; Eadie, 1997), passive cylinders deployed 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 settling velocities. We have learned much about the transport of mass, contaminants, and tracers and the results are now routinely incorporated into program sampling and modeling strategies and management considerations. Although the traps themselves are relatively inexpensive, the logistics of deployment and retrieval are quite expensive, restricting both where and how frequently we can sample. In order to address this problem, traps having sequencing capability, for multiple samples per deployment, were developed. Similar devices had been used for some time in aquatic sciences (Bloesch and Burns, 1980; Gardner, 1998) and, after a number of tests, a version was constructed and tested by GLERL for use in large lakes and coastal systems.

DESIGN

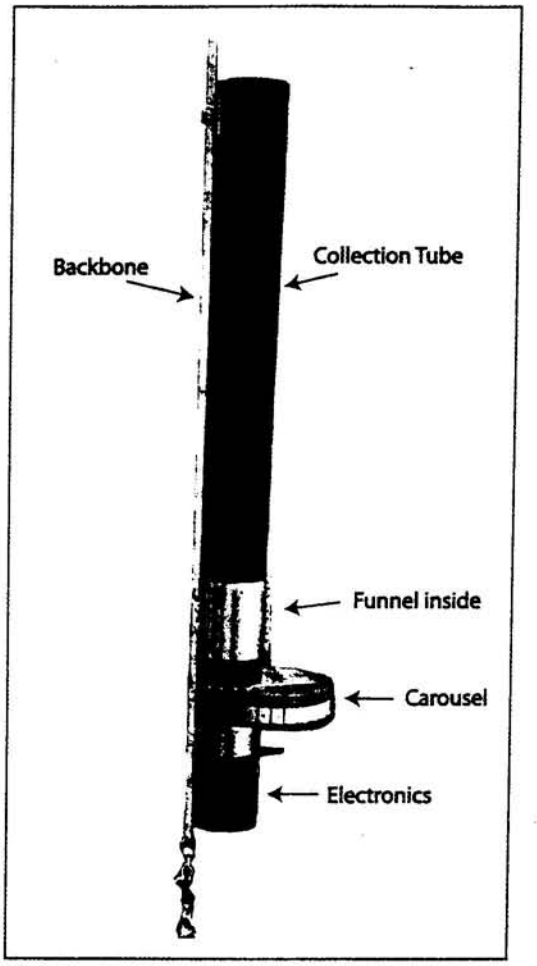
We had several major design goals in the development of the sequencing traps:

1. A large enough cross-sectional area to collect sufficient material for constituent analyses,
2. A sufficient number of sample bottles to provide useful time-series samples over the course of an annual cycle,

3. Sufficient robustness to withstand rough handling and function in an environment where biofouling could occur,
4. A feedback and recording mechanism to confirm the exposure time of each bottle, and
5. A relatively low cost to meet budget constraints.

We already had several years of trapping experience in the Great Lakes using non-sequencing cylindrical traps. These data, combined with a review of various designs (Bloesch, 1982; Butman, 1986; Butman et al., 1986; Gardner et al., 1997; Gardner, 1998), allowed us to converge on a cylindrical design with a 20 cm cross-section and an 8:1 aspect ratio above the funnel. Cylindrical traps have a high collection efficiency in low current lake environments and have proved satisfactory in many lake studies (Bloesch, 1982; Eadie et al., 1984; Robbins and Eadie, 1991). 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. The trap was constructed from standard 8-inch diameter gray PVC pipe with a length of 160 cm (figure 1). A nominal 8" diameter powder funnel (Nalgene™), with 45 degree sloped sides and relatively large diameter stem, is located at the bottom of the pipe. The top lip of the funnel was beveled to eliminate a shelf where materials might accumulate. The trap was attached to a backbone consisting of a 3/8 x 1 inch stainless steel bar. The steel bar provides structural support for the sampler and bears the mooring load.

Figure 1. Annotated photograph of sequencing sediment trap.



Carousel for Holding Sample Bottles

A carousel to hold the sediment collection bottles was made with 24 positions. Twenty-three of these positions are filled with standard 60 ml (Nalgene™) polyethylene sample bottles. 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 moves the first collection bottle under the funnel. The remaining 22 bottles will follow in a preprogrammed sequence. The carousel then returns to the open position so that all the bottles are sealed upon retrieval.

The carousel consists of three 1/2-inch PVC plates, cut into 38 cm diameter circles. The top plate is stationary and attached to the funnel housing. The upper carousel plate and the lower carousel plates are coupled together. The sample bottles are sandwiched between these two plates, which rotate together when the carousel is turned (figure 2). A threaded rod mechanism operated by a screwdriver is provided to increase the distance between the two carousel plates so that sample bottles can be loaded into and removed out of the carousel without tipping. The same mechanism will also tighten the bottles against their o-ring seals.

The bottles are covered by the upper PVC plate until time for exposure. The carousel rotates the bottles so that one bottle at a time is placed under a hole in the upper plate exposing the bottle under the base of the funnel. Each bottle uses a nylon insert with a foam ring to seal it against the upper plate. The foam ring provides both a spring action to hold the nylon insert against the upper plate as well as a seal to block sediment from seeping into the collection bottle. The foam is open cell in order to reduce the amount of compression under water. Nylon is used to reduce friction against the PVC plate and, therefore, reduce the load requirement of the motor. Early field tests, however, revealed that sediment leakage into the sealed bottles was occurring around the mouth of the bottle. This was resolved by adding an o-ring seal at the mouth of the bottle.

Motor Assembly

To rotate the carousel reliably, the mechanism had to be sufficiently robust to

overcome potential biofouling. This cannot be done with standard gears, as the small tolerances are prone to failure when fouled, but is best accomplished by keeping the mechanisms large. This was achieved with the use of a paddle (figure 3), which in essence constituted a two-tooth gear. A 180 degree rotation of the paddle moves the carousel 15 degrees or exactly one bottle position. The motor is encased in a watertight housing with the paddle mounted directly on its shaft. A spring detent is employed to hold the carousel in position until moved by the paddle. Since movement of this detent indicates movement of the carousel, a magnet was placed on the pivot arm of the detent and a reed switch mounted in proximity to detect the movement. This would work as follows: the motor is turned on and the paddle rotates. As the paddle makes contact with the notch in the side of the carousel it begins to rotate the carousel. This causes the detent to be pushed out of its notch on the side of the carousel. The movement of the detent is detected by the closing of the reed switch. The paddle rotates the carousel to the next bottle position. At the next bottle position, the detent slips back into a notch, causing the reed switch to open. The motor is then kept on for another 0.25 seconds to allow the paddle to clear the carousel. The total time for this whole operation is typically about 3 seconds. The sampler uses a common 24 volt DC permanent magnet motor with a 733:1 reduction planetary gearhead resulting in a loaded operating speed of about 20 rpm.

The last batch of traps that were manufactured by our contractor were slightly modified. The detent feedback mechanism was replaced with a magnet on the motor shaft. This was simpler to manufacture because the magnet and reed switch could be mounted inside the pressure housing instead of exposed to the water. However, while it provides enough feedback to properly rotate the motor 180 degrees, it does not independently confirm rotation of the carousel. In practice this has rarely been a problem since a situation that would prevent the carousel from rotating should also keep the motor shaft from rotating.

Controller Electronics

The sampler is controlled by a low-power micro-controller. The first designs used a custom-built circuit board based on the 80C51 micro-controller chip. Power consumption was kept low by powering down the micro-controller and using a real-time clock to wake it up on schedule. A 512 byte serial electrically-erasable PROM was used to provide nonvolatile memory, and the board included multiple A/D inputs and digital I/O. Commercially available micro-controllers now come with low standby power features; we are currently using an off-the-shelf

Figure 2. A cutaway view of the bottle sealing used in the carousel.

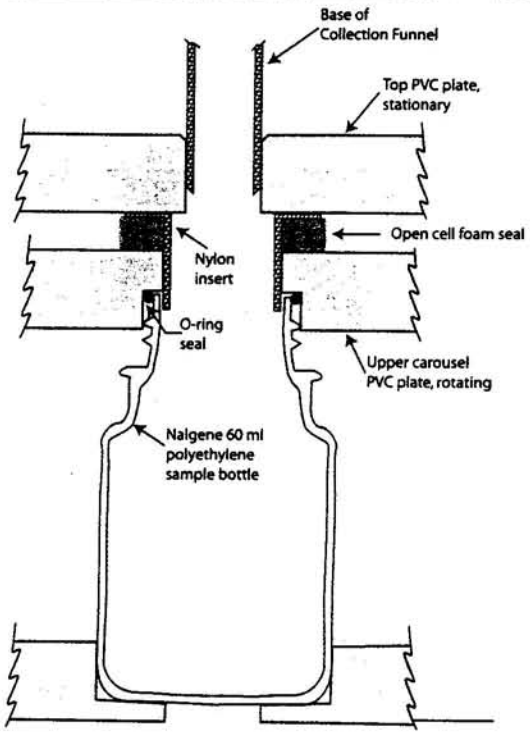
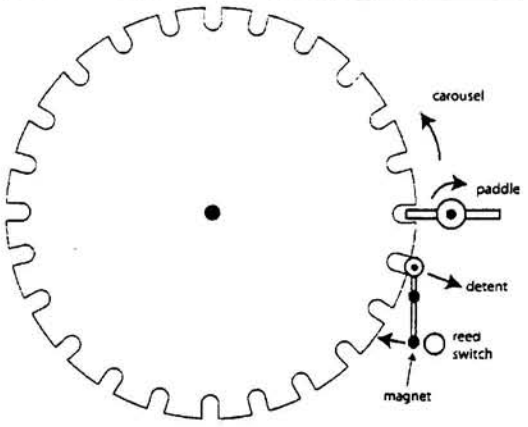


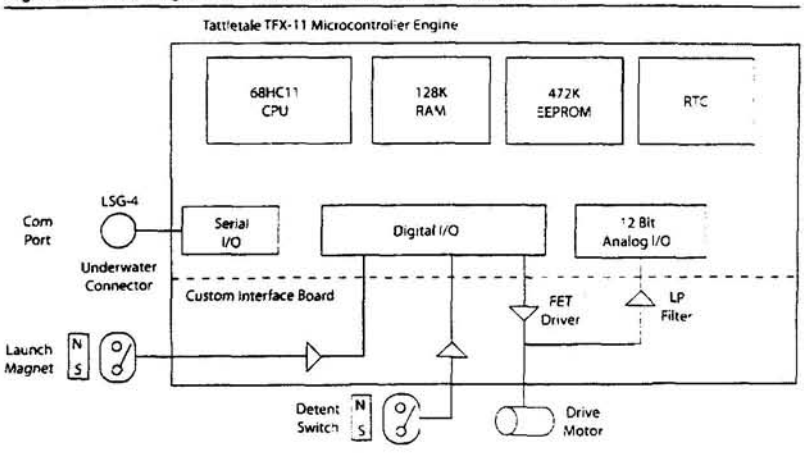
Figure 3. Schematic of drive mechanism, detent, and reed switch.



TattleTale™ model TFX-11 manufactured by Onset Computer Corporation. This features programming in BASIC, a 100 μA low-power standby mode, real-time clock, 128K RAM, 472K nonvolatile memory, multiple A/D inputs and digital I/O.

The motor is controlled by a single digital output line driving an N-channel power field effect transistor (figure 4). The motor voltage and current are lowpass filtered and measured on two of the A/D channels. In addition, the detent switch state and battery voltages are monitored. Two battery stacks are used to power the sampler: a 12 volt stack for the elec-

Figure 4. Block diagram of micro-controller and interface circuits.



tronics and a 24 volt stack for the motor. We have found it best to use two stacks of D-cell alkaline batteries wired in parallel and isolated by diodes for each supply even though this is more than double the power requirement. The redundancy provides assurance of operation in the event that one of the battery stacks fail.

In our first designs we had problems with the micro-controller failing because of electromagnetic interference from the motor. The micro-controller would randomly lock up when the motor was energized. This was resolved by increasing the spatial distance between the motor and the circuit board and adding inductor chokes to the motor lead wires.

Software Operation

The software provides a command driven user-interface to allow full operation of the sampler and testing of all the sub-components. The serial access to the controller is brought outside the pressure housing to an underwater connector permitting easy access. The sampler is connected to a computer's RS-232 serial port. A simple terminal emulator may be used as an interface and an MS-DOS™ user interface was written to provide menu-based operation. The standard setup procedure involves setting the real-time clock and loading the schedule table. This table contains the rotation time for each sample bottle with a resolution of one minute. The one minute resolution is helpful for bench testing.

In operation, the TattleTale™ would wake up every minute and scan the operation table to see if anything needed to be done. If the real-time clock was equal to or had passed any time entry in the table, then the carousel would be moved one bottle. Movement of one bottle position includes three phases: the rotation of the paddle before it contacts the carousel, the rotation of the paddle as it moves the carousel, and the rotation of the paddle for 0.25 seconds to clear the carousel. The time of the rotation, the controller battery voltage, and motor information for each phase of the paddle rotation was recorded to the table entry. The motor information includes the motor battery voltage, motor current, elapsed time, and number of stalls. A stall occurred when the motor current exceeded a threshold value after an 0.2 second start-up delay. If the motor stalled, it would be turned off for 15 seconds to cool it down, and then another attempt would be made. After 255 successive stalls, the program simply gives up and sets a stall error flag.

From the information recorded in the table, it is possible to determine the exposure time of each bottle even in the event of multiple anomalies in the operation. Furthermore, care was taken in writing and testing the software to consider possible error conditions, record the error, and recover from them as fully as possible. Thoroughly considering error conditions was critical in providing reliable operation in unattended, hostile conditions and contributed greatly to the success of the sampler.

Sampler Operation

Traps are deployed as anchored arrays using 3/8" steel cable and subsurface buoys. The 60 ml polyethylene collection bottles in the sequencing trap are poisoned with 6 ml of chloroform and filled with distilled water immediately prior to deployment. This concentration of chloroform is an effective preservative (Lee, 1992) and results in a supersaturated solution, with beads of chloroform remaining after retrieval. The carousel can be easily removed from the sampler and reinstalled, providing easy transportation of the sampler. After filling the bottles with distilled water and chloroform and loading them in, the carousel is typically installed into the sampler while the sampler is hanging vertically on the mooring line. As a last system integrity check, a launch plug is placed on the sampler's underwater connector. This launch plug contains a short that sends a signal to the micro-controller to rotate the carousel exactly one position. Observation of this movement confirms that the sampler is operating properly. This setup was later modified to use a reed switch and an external magnet. The magnet is taped to the outside of the electronics housing at a marked location. When the magnet is pulled off, the carousel will rotate one bottle position to confirm proper operation.

Upon collection, the sample bottles are removed from the traps and transported to the laboratory in cold storage at 4° C. After arrival at the lab, the trap samples are allowed to settle in a refrigerator for 1 day, then overlying water is carefully siphoned off and the residual is freeze dried. After drying, samples are weighed

and transferred into pre-cleaned scintillation vials for storage in a freezer. All trap samples are weighed on an analytical balance calibrated to within ± 1 mg with known standard weights during each weighing session. Virtually all samples are greater that 100 mg, thus all mass weights have an accuracy and precision of less than 1% (coefficient of variation). Samples are subsequently parsed out for various constituent analyses.

RESULTS

We present the results of two field experiments designed to examine some of the properties of these traps. The first experiment was designed to examine the correspondence of mass collected in the traps with water column turbidity, as measured with a Sea-Tech transmissometer (figure 5) recording single measurements at 20 minute intervals. The trap was deployed Oct. 18, 1999 in Lake Michigan and began sampling on Dec 6. Trap samples collected prior to 4/16/00 are for 6 day intervals. The relatively short duration of flux events would be very difficult to sample with non-sequencing traps. After 4/16/00, the preprogrammed sampling interval was increased to 12 days. The transmissometer record (fig 5) shows that the turbidity events are very short, on the order of 1 day and are well correlated with available wind data (not shown). The mass of resuspended materials collected by the traps corresponded well with the turbidity, with highest trap fluxes collected during the maximum integrated turbidity. Short-interval trap data are very valuable in order to interpret the consequences of episodic events, including the reintroduction of nutrients and contaminants from sediments into the pelagic food web.

The second experiment was designed to test the replication of sample collection by these traps. Two deployments were made with pairs of traps mounted 2 m apart horizontally on a bracket with a large (0.5 m^2) vane between them to keep the traps perpendicular to the currents. One pair of 20 cm diameter traps was deployed in 1992 at 35 m below the surface at a 100 m deep station in southeastern Lake Michigan. The total time of the deployment was greater than 10 months, with traps collecting at equal intervals of 14 days. The average mass flux (mass collected / (length of deployment * trap cross sectional area)), shown in figure 6a, ranged from 0.10 to 7.70 g/m^2/d for the 22 intervals. The figure also shows the range of the mass fluxes in each pair of traps. An estimate of the average replication of trap collections can be calculated as a value of 100 times half the paired differences divided by the average mass flux. For this set of traps that value is 10.5%.

Figure 5. Comparison of trap-collected mass (shaded step intervals) and the beam attenuation coefficient of a transmissometer (continuous line) deployed at the same location.

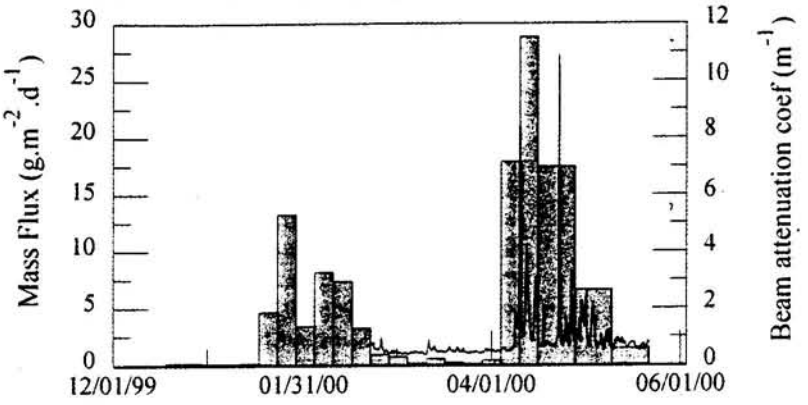
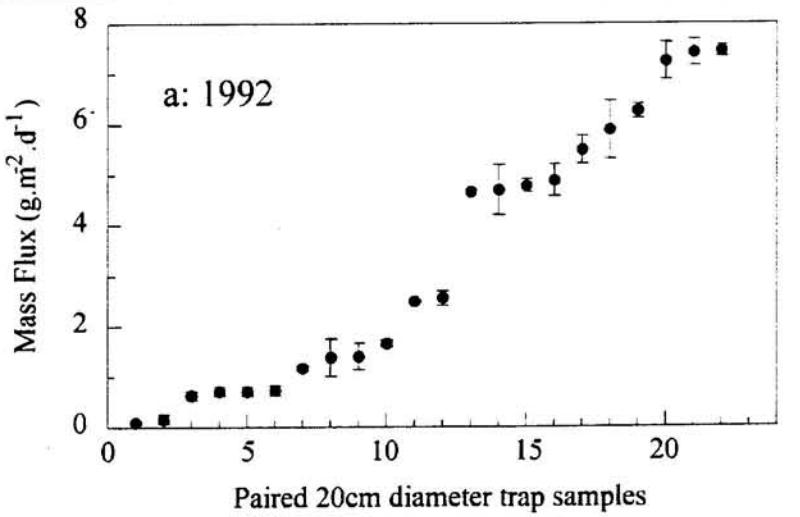
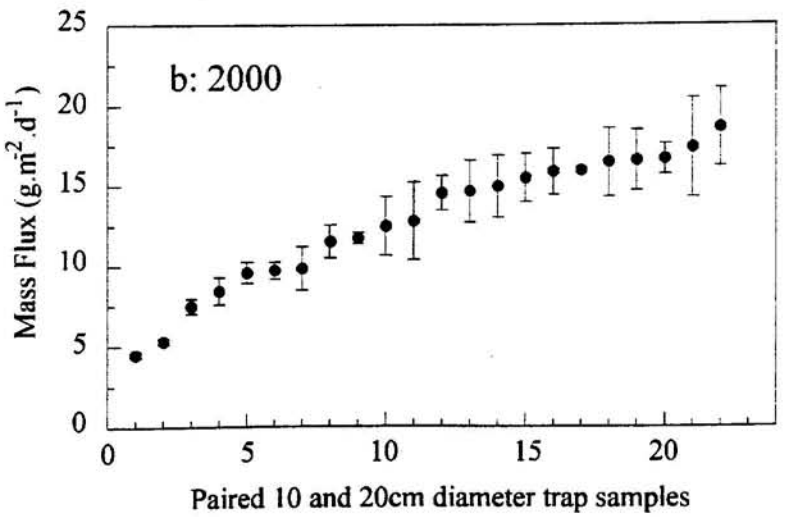


Figure 6. a) Mass fluxes measured at a near-surface offshore station in Lake Michigan. The sampling interval was a uniform 14 days, and fluxes spanned an order of magnitude. Solid symbols represent the average of the trap pair and the vertical bars represent the range of fluxes measured by the pair of traps. b) Mass fluxes measured at a near-bottom offshore station in Lake Michigan. Fluxes ranged from 4.4 to 18.5 g/m^2/d. Symbols the same as 6a.





A second deployment in 2000 consisted of one 20 cm diameter and one 10 cm diameter trap on the same bracket. The reduced cross section was necessitated by very high fluxes (experienced elsewhere in near-shore deployments) that apparently clogged the tip of the funnel and led to a few failures in prior deployments of 20 cm samplers. The 10 cm diameter trap was subsequently deployed specifically to sample large storm events and worked very well. The average and range of mass fluxes is shown in figure 6b. These results are similar to those attained with non-sequencing traps of the same 10 and 20 cm designs (Eadie, 1997) and show that the samplers are collecting at the same rate. This pair was deployed at a depth of 5 m above the bottom at a 105 m deep station. Fluxes into the near-bottom trap ranged from 4.4 to 18.5 g/m^2/d. In this case, the estimate of average replication, described above, was 9.5%.

CONCLUSION

Thus far we have over 100 trap deployments over the past 10 years with only 8 failures in the electronics. Overall, 1839 samples have been collected; a success rate approaching 90%. Using the sequencing traps has allowed us to confirm that much of the particle transport in the lake is associated with storms during the six month unstratified period (Eadie et al., 1996; 2002), and while the fluxes are episodic, they also span a wide interannual range. The consequences of these findings are still being evaluated. We see this instrument as a major tool in our investigations of lake processes (such as sediment transport during winter, high frequency bottom boundary fluxes, and other logistically difficult experiments) and a valuable integrating sampler for monitoring programs. This is GLERL contribution No. 1235.

REFERENCES

Bloesch, J. and N.M. Burns (1980). A critical review of sedimentation trap technique. *Schweiz. Z. Hydrol.* 42(1): 16–55.

Bloesch, J. 1982. Inshore-offshore sedimentation differences resulting from resuspension in the eastern basin of Lake Erie. *Canadian Journal of Fisheries and Aquatic Sciences*, 39 (5): 748–759.

Butman, C.A. 1986. Sediment trap biases in turbulant flows: Results from a laboratory flume study. *Journal of Marine Research*, 44: 645–693.

Butman, C.A., W.D. Grant, et al. 1986. Predictions of sediment trap biases in turbulant flows: A theoretical analysis based on observations from the literature. *Journal of Marine Research*, 44: 601–644.

Eadie, B.J. 1997. Probing particle processes in Lake Michigan using sediment traps. *Water, Air, and Soil Pollution*, 99: 133–139.

Eadie, B.J., R.L. Chambers, et al. 1984. Sediment trap studies in Lake Michigan: Resuspension and chemical fluxes in the southern basin. *Journal of Great Lakes Research*, 10 (3): 307–321.

Eadie, B.J., D.J. Schwab, et al. 1996. Development of recurrent coastal plume in Lake Michigan observed for the first time. *EOS, Transactions, American Geophysical Union*, 77 (35): 337–338.

Eadie, B.J., D.J. Schwab, et al. 2002. Particle transport, nutrient cycling, and algal community structure associated with a major winter-spring sediment resuspension event in Southern Lake Michigan. *J Grt Lakes Res.* 28 (3): 324–337.

Gardner, W.D., P.E. Biscaye, et al. 1997. A sediment trap experiment in the Vema Channel to evaluate the effect of horizontal particle fluxes on measured vertical fluxes. *Journal of Marine Research*, 55: 995–1028.

Gardner, W.D. Sediment trap technology and sampling in surface waters. College Station, TX, Department of Oceanography, Texas A&M University: 19 pp.

Lee, C. 1992. Controls on organic carbon preservation: The use of stratified water bodies to compare intrinsic rates of decomposition in oxic and anoxic systems. *Geochimica et Cosmochimica Acta*, 56: 3323–3335.

Robbins, J.A. and B.J. Eadie 1991. Seasonal cycling of trace elements 137Cs, 7Be, and 239+240Pu in Lake Michigan. *Journal of Geophysical Research*, 96 (C9): 17,081–17,104.