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

PAPER

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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

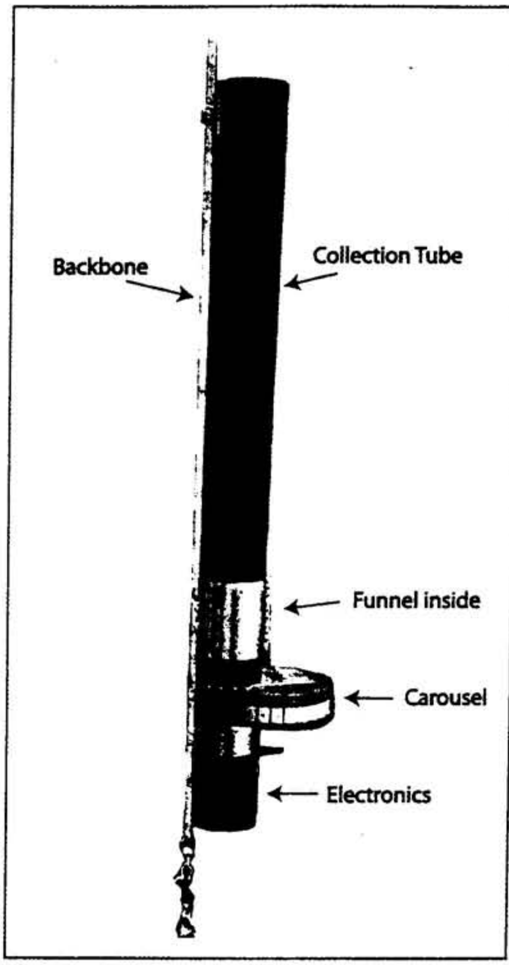
We had several major design goals in the development of the sequencing traps:

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.

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

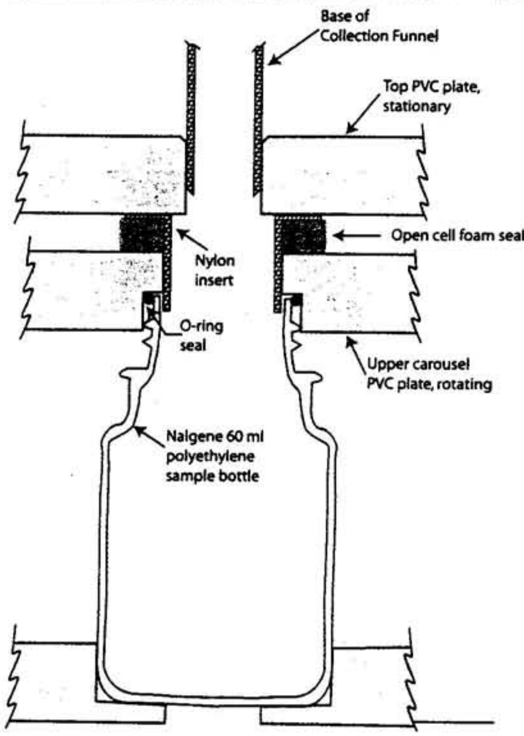
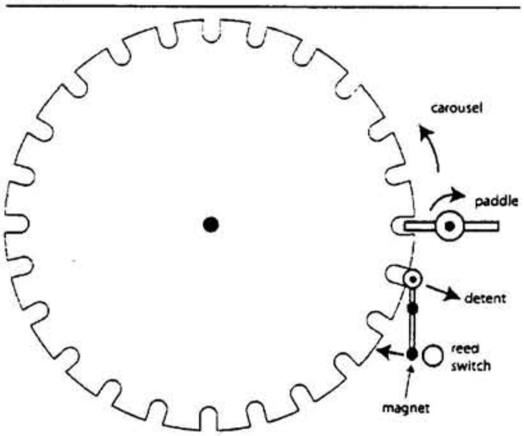


Figure 3. Schematic of drive mechanism, detent, and reed switch.



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 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-