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Scientific Investigation Report 2004-5298

U.S. Department of the Interior
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Gale A. Norton, Secretary

U.S. Geological Survey
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Conversion Factors and Water-Quality Units

Multiply	By	To obtain
Centimeter (cm)	0.3939	inch (in.)
Meter (m)	3.281	feet (ft)
Kilometer	0.6214	mile (mi)
Gallon (gal)	3.785	liter (L)
Liter (L)	103	milliliter (mL)
Kilogram (kg)	2.205	pound, avoirdupois (lb)
Gallon per minute (gal/min)	0.06308	liter per second (L/sec)
Degrees Celsius (ºC)	1.8(ºC)+32	degrees Fahrenheit (ºF)

Chemical concentrations: Chemical concentrations of substances in water are given in metric units of milligrams per liter, micrograms per liter, or nanograms per liter (ng/L). Micrograms per liter µg/L is a unit expressing the concentration of chemical constituents in solution as mass (nanograms) of solute per unit volume (liter) of water. One thousand nanograms per liter is equivalent to one microgram per liter.

Development of a Benthic-Flux Chamber for Measurement of Ground-Water Seepage and Water Sampling for Mercury Analysis at the Sediment-Water Interface

By M.A. Menheer

Abstract

A benthic-flux chamber was constructed to collect data to determine the relation between ground- and surface-water interaction and mercury concentrations in water at the sediment-water interface. The benthic-flux chamber was successfully used to measure the rate of ground water seeping to surface water or surface water seeping to ground water, and to collect water samples for mercury analysis from the sediment-water interface in a lake setting. The benthic-flux chamber was designed to be deployed in relatively calm fresh water lakes, in areas of water less than 2 meters deep. The ground-water seepage rate data were comparable to data from an in-line flow meter in a calibration tank and with data from two 55-gallon drum seepage meters concurrently deployed in two different lakes. The benthic-flux chamber was used to collect possible water samples for analysis of total mercury and methylmercury concentrations.

Introduction

Bioaccumulation of mercury in the aquatic food chain is related to microbial conversion of inorganic mercury to methylmercury near the sediment-water interface. Methylmercury (MeHg) is more toxic and bioaccumulative than inorganic mercury. Therefore, the concentration of methylmercury in water and sediments is a better indicator of mercury concentrations in fish than of total mercury (THg) (Bodaly and others, 1993). Bloom (1992) reports that as much as 95 percent of mercury in fish is MeHg.

Methylation of inorganic mercury and reduction of sulfate are related to microbial processes near the sediment-water interface where anoxic conditions exist (Branfireun and others, 1999). Ground water with low dissolved-oxygen concentrations can create anoxic zones in the sediment-water interface where ground water discharges into the lake. Advection of ground water through the sediments can transport MeHg into the overlying water column. Although the sediment-water interface is known to be an active zone for mercury methylation (Kerry and others, 1991; Gilmour and others, 1992; Pak and Bartha, 1998), the influence of interactions between ground and surface water on the methylation process has not been thoroughly studied.

Sulfate reduction is a key process in the mercury cycle and has important implications at zones of ground-water/surface-water interaction. Gilmour and Henry (1991) suggest an ‘optimal’ relation between sulfate reducing bacteria and mercury methylation efficiency (percent of inorganic mercury that is methylated per unit time). At low concentrations in sediment pore water, sulfate (less than 19 mg/L) is the limiting factor on the growth and biotic activity of sulfate reducing bacteria. At high concentrations of sulfate (greater than 48 mg/L) inhibition of methylation may occur. This may be due to the inhibition of sulfate-reducing bacteria by pore water sulfide (Gilmour and others, 1992), or the increased solubility and decreased availability of mercury to bacteria in sulfide-rich pore-water (Paquette and Helz, 1997; Benoit and others, 1999; Jay and others, 2000).

Transport rates of THg and MeHg from sediments in the past have been estimated using diffusive flux models, not direct measurement of the discharge of ground water to surface water. The models are based on concentration gradients between sediment pore water and overlying water between pore water concentrations at different sediment depths. Two difficulties exist with this approach: diffusive fluxes are subject to considerable uncertainty in model coefficients, and even modest ground-water-discharge rates yield advective fluxes that typically are much greater than diffusive fluxes.

There are two common problems in studying benthic processes with a benthic-flux chamber (hereinafter termed flux chamber). The first is the water contained within the flux chamber is isolated from the surrounding lake water. This creates a stagnant zone where the benthic currents that mix the water at and above the bottom sediments are eliminated, which in turn can induce marked changes in reduction oxidation chemistry.

The second problem encountered by flux chambers is that biologic respiration and water-sediment processes may progressively reduce the dissolved-oxygen concentration of the water. Over time the water in the flux chamber no longer represents the chemistry of the ambient water at the sediment-water interface. Dissolved oxygen commonly is used

as a surrogate measurement to determine when water samples collected from flux chambers may be compromised (Gill and others, 1999).

Purpose and Scope

To address these problems with flux chambers, the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency (USEPA) and Minnesota Department of Health (MDH), conducted a study to design a flux chamber that could be used to measure seepage rates and collect water samples from the sediment-water interface that minimizes the disturbance of ambient conditions. The data would be used to measure benthic fluxes of trace concentrations of water-quality parameters such as THg and MeHg. The purpose of this report is to describe (1) the design of the flux chamber, (2) ground-water seepage data collected using the flux chamber, and (3) mercury data from water samples collected using the flux chamber. Data were collected during November 2003 and January 2004. Flux chambers and 55-gallon drum seepage meters were deployed in Long Lake and Square Lake in Minnesota (fig. 1). Data from the two types of seepage measurements are compared.

Acknowledgments

The author extends thanks to Carl Herbandson, Minnesota Department of Health, Dr. Robert Ford, U.S. Environmental Protection Agency, Office of Research and Development, and Mark Brigham, U.S. Geological Survey, Minnesota District; for their technical assistance. Thanks also are given to Dave Krabbenhoft, U.S. Geological Survey, Wisconsin District; Don Rosenberry, U.S. Geological Survey, National Research Program; Dr. Gary Gill and Ron Lehman of the University of Texas, A&M, Galveston; and to Dave Shelander of Logix Engineering, Inc for the fabrication of the flux chamber. The author is grateful to a private landowner for generously allowing his property to be used to deploy and test the flux chamber.

Description of the Flux Chamber

A flux chamber (figs. 2 and 3) was designed to route ground water seeping from sediments through an ultrasonic-flow meter. The flux chamber was made of a polycarbonate (vivac) plastic that was molded and welded into a 38.1-cm diameter by 20.3-cm high cylinder. Vivac was used because

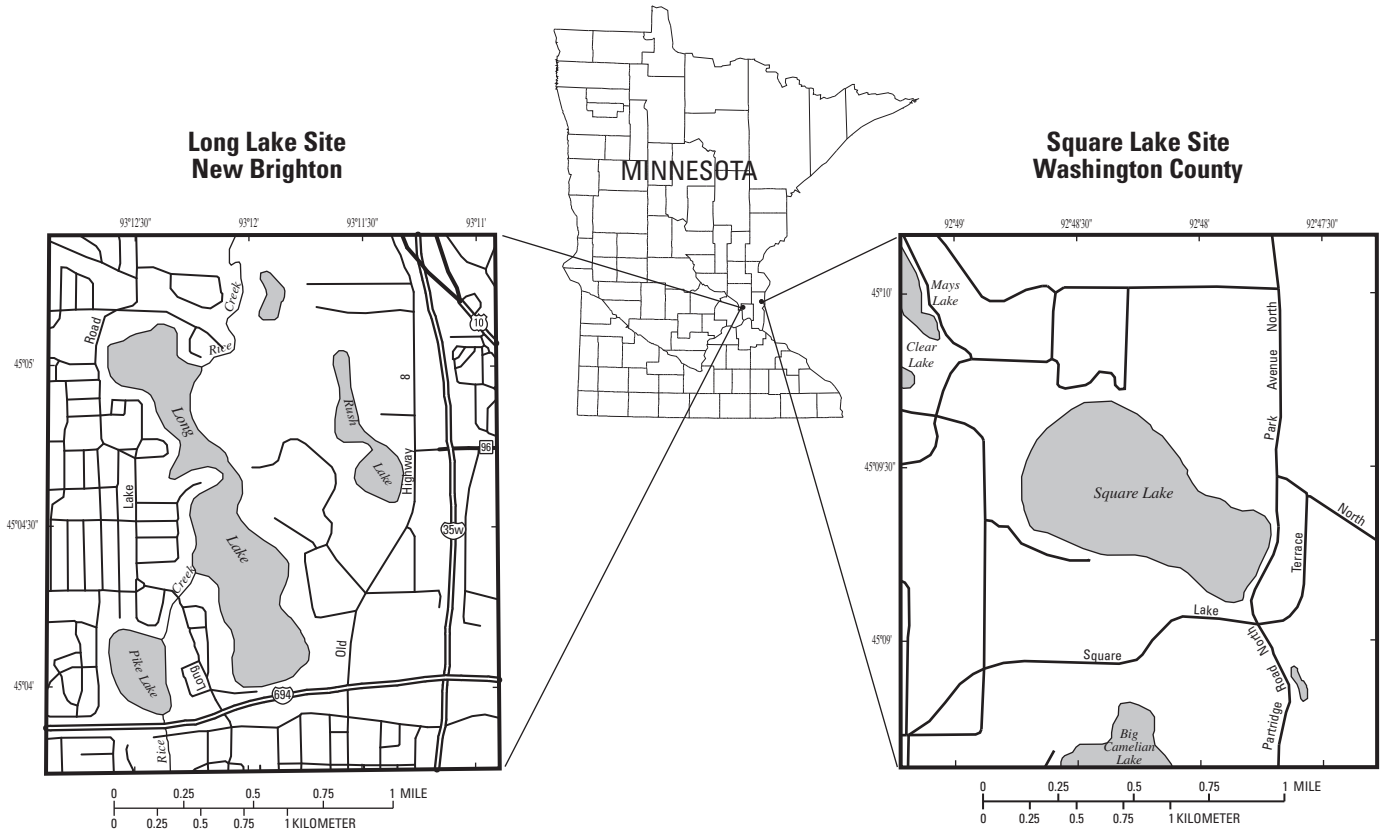


Figure 1. Test site locations at Long Lake and Square Lake in Minnesota

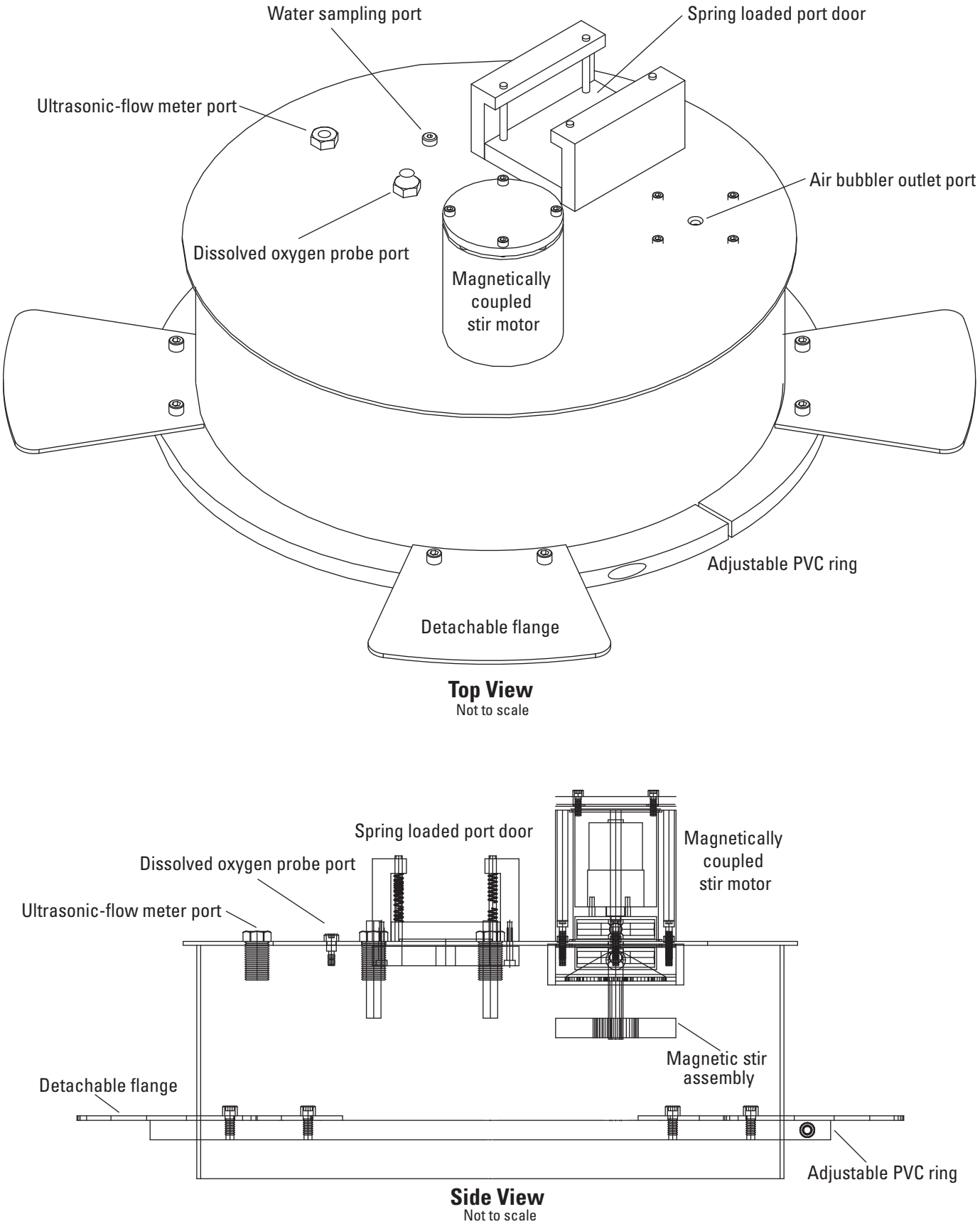
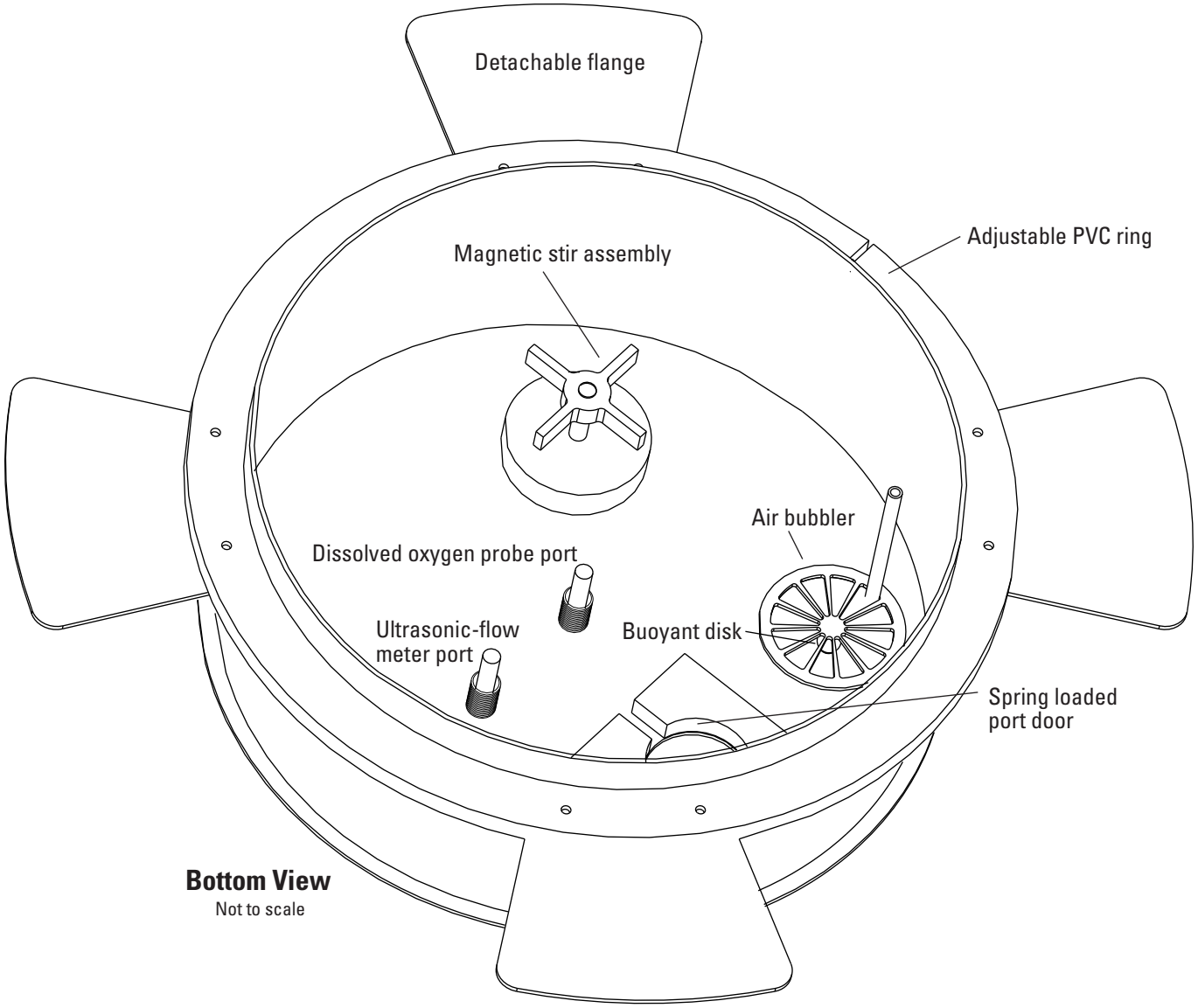


Figure 2. Schematic of the top and side views of the flux chamber.



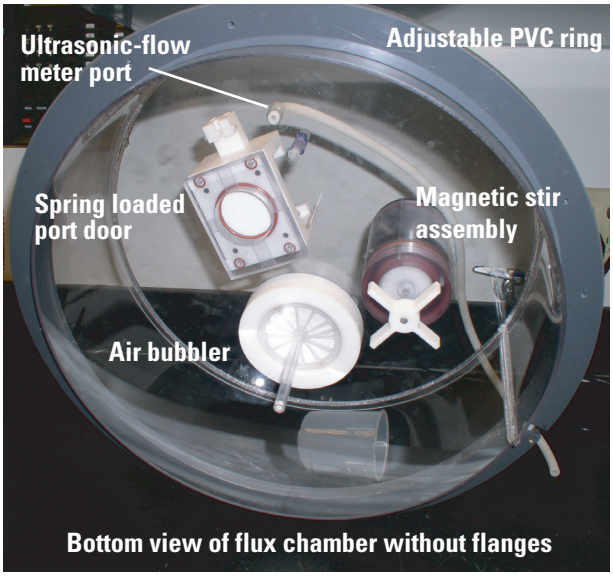


Figure 3. Schematic of the bottom view and photograph of bottom view of the flux chamber (photograph by Michael Menheer).

it can be adequately cleaned to sample for trace levels of mercury. Teflon also was used for several of the ports and other parts of the flux chamber that came into contact with the water inside the flux chamber.

The ultrasonic-flow meter (Controlotron 1010) has two main parts, a flow tube and a flow computer (figs. 4 and 5). The flow tube is a rigid 1.3-cm outside diameter Teflon tube, 24.5 cm long. The flow tube was connected to the flow computer by electrical cables with barrel nut connectors on both ends of the flow tube. Densyl Tape, a water resistant fabric, was wrapped around the barrel nut connectors on the flow tube so it could be submerged in water. An ultrasonic-flow-meter port on the top of the flux chamber was used to route water through the flow tube. The flow tube contains two ultrasonic pulse transducers directed towards each other. Ultrasonic pulses are sent between the two transducers. The direction and rate of the water flowing through the tube varies the time delay of the signals. The signals sent in the same direction of the flow are received at a shorter time interval than the pulses sent in the opposite direction of flow; this time difference is proportional to the rate of flow. These data are measured and compiled as a flow rate in the flow computer (Paulsen and others, 2001).

An adjustable polyvinyl chloride (PVC) ring 1.3-cm thick by 3.2-cm wide was fitted around the outside of the flux chamber. The ring was used as a guide to indicate when the flux chamber was pushed far enough into the sediment and to seat the meter at a consistent depth in the sediment. This ring also served as a reference to calculate the volume of water that was in the flux chamber. Attaching flanges (10.2 cm widening to 15.6 cm wide and 12.4 cm long) to the ring facilitated deployment in lakes with silty, soft sediments with minimal settling of the flux chamber over time.

A 5-cm circular hole was made in the top of the flux chamber to allow water to seep through the top of the flux chamber during deployment, thereby minimizing disturbance of the sediments. When the flux chamber is properly deployed, a pin is pulled and a spring-loaded port door made

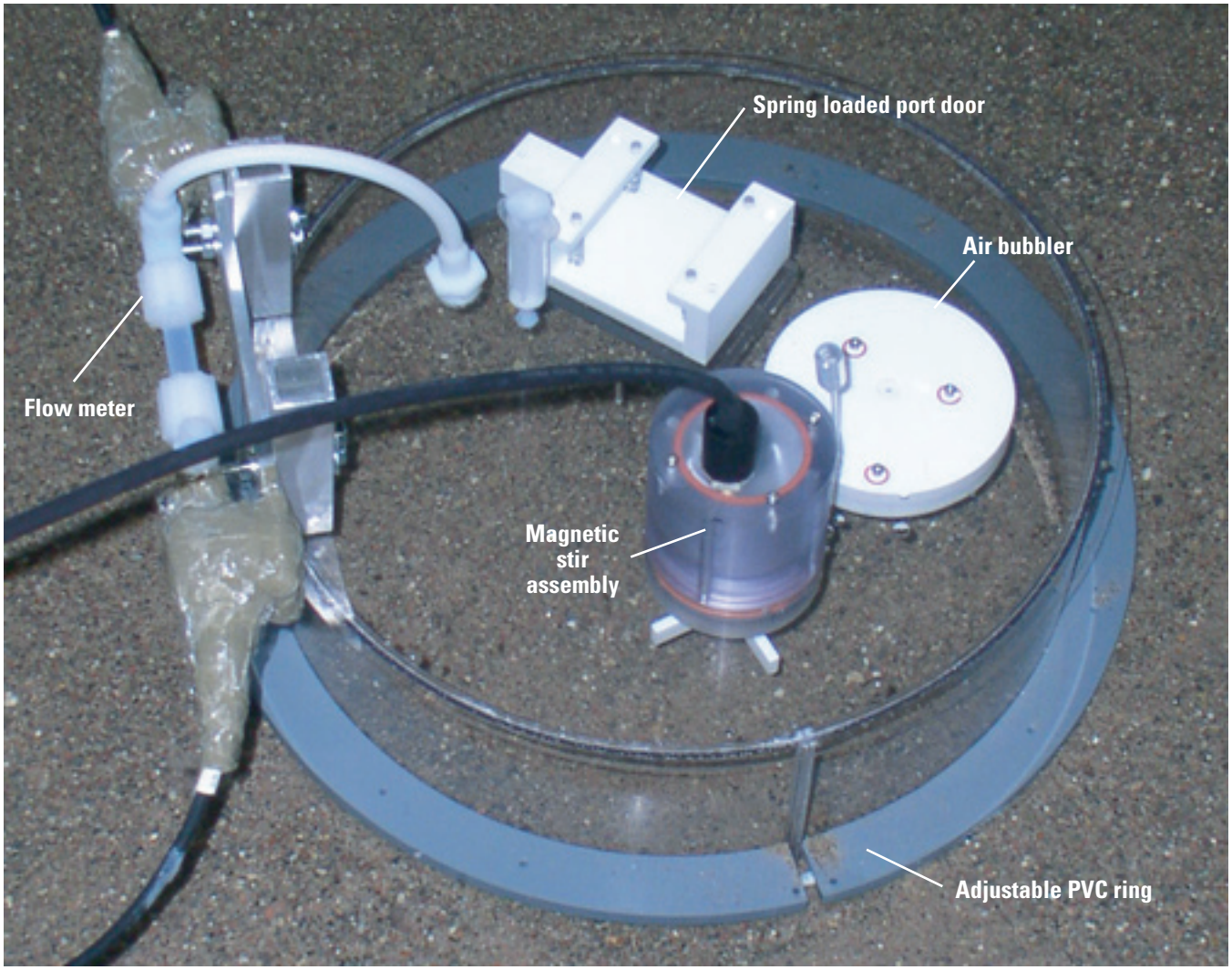


Figure 4. Top view of flux chamber showing flow meter (photgraph by Michael Menheer).

from a piece of Teflon tightly closes this hole. This is done from the water surface.

The flux chamber was designed to slowly mix the water and to maintain ambient dissolved-oxygen concentrations to minimize the artificially induced changes in reduction-oxidation chemistry. A polycarbonate and Teflon magnetic stir assembly was designed to slowly circulate the water in the flux chamber to simulate benthic currents. A small motor was mounted outside the flux chamber and encased in polycarbonate plastic. The motor turned a magnet on the outside of the flux chamber that was partnered with another Teflon-coated magnet inside the flux chamber. The magnet inside the flux chamber was attached to the stirrer. This design avoids contamination from the motor, and prevents the motor from warming the water in the flux chamber.

A dissolved-oxygen meter with a Teflon probe was used to monitor the dissolved-oxygen concentrations inside the chamber. The data from the dissolved-oxygen meter were recorded by a datalogger. A small-volume, battery-powered air pump was connected to the datalogger and to an air bubbler on the flux chamber. The datalogger was programmed to monitor the dissolved-oxygen concentration. When the dissolved-oxygen concentration dropped to a user-defined percentage of the initial level, the air pump would turn on. The pump would run the air bubbler until the dissolved-oxygen concentration approached the initial concentration. The air could be pumped through a gold trap to remove any mercury that might contaminate the water in the flux chamber. The top of the flux chamber, above the air input, had an air bubbler outlet port that was kept closed with a buoyant disk. When air was pumped into the flux chamber, it would accumulate in this area and the disk would fall away from the opening, allowing air to leave the flux chamber.

An ultrasonic-flow-meter port on the top of the flux chamber was used to attach to Teflon tubing so water could be pumped from the flux chamber for collection of water samples. The ultrasonic-flow-meter port had a luer loc fitting threaded into it. When water samples were not collected, this port was closed with a luer plug.

A floating data collection platform, consisting of two pontoons and an aluminum frame, was used to hold the equipment needed to collect the seepage data (figs. 5 and 6). The equipment consisted of a datalogger, a dissolved-oxygen meter, an air pump, a battery for the datalogger, the flow

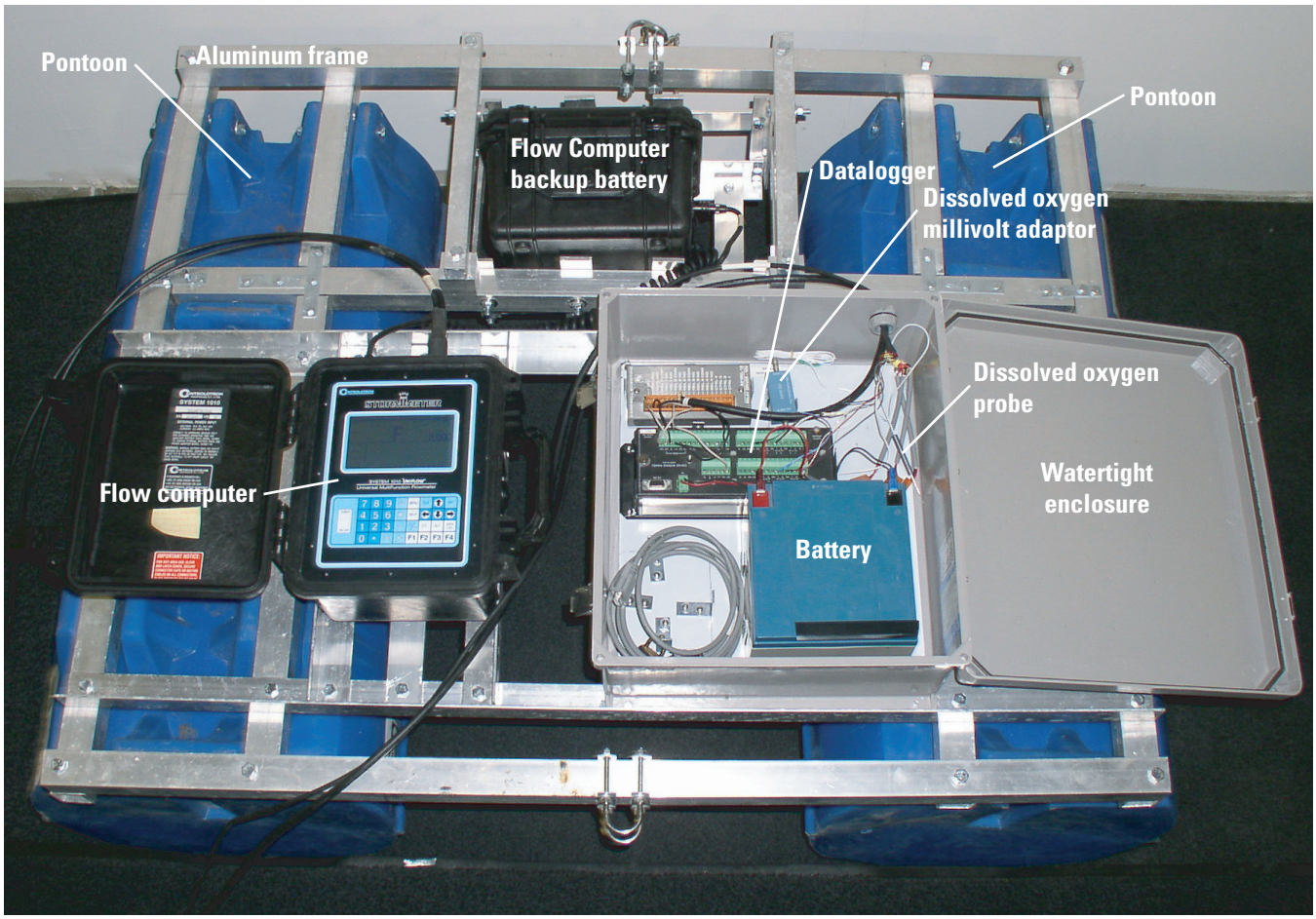


Figure 5. Photograph of the data collection platform (photograph by Michael Menheer).

computer, and a backup battery for the flow computer (fig. 5). The combined weight of the equipment was 35 kilograms. The data-collection platform was anchored in place, near the deployed flux chamber, using two aluminum rods on either side of the data-collection platform, and was chained to an earth anchor for added security. The aluminum rods allowed the data-collection platform to move up and down in response to wave activity.

Methods

Seepage-rates and mercury concentration data were collected to evaluate the performance of the flux chamber. The flux chamber was tested in a calibration tank to determine the accuracy of the ultrasonic-flow meter. The flux chamber was then deployed in two lakes. Seepage data were collected during fall 2003 concurrently using the flux chamber and two traditional 55-gallon drum seepage meters at two lakes (Lee, 1977). Water samples were collected from one of the two lakes, during fall 2003. The flux chamber was tested and recalibrated in a calibration tank during January 2004 after the field deployment.

Seepage Measurements

The seepage meter was attached to the flux chamber and was tested in a sand-bed calibration tank (fig. 7). The tank was designed so the seepage of water moving through the sand could be accurately measured and varied. A George Fischer (GF) Signet micro-flow (0.113 - 2.65 L/min.) in-line flow meter was used to measure the seepage rate of the water moving through the sand and across the sand-water interface. Raising or lowering the head of the water source provided control of the seepage rate to test the flow meter over a range of seepage rates. The water overflowed from the tank through a spigot into a basin. The seepage rate could be verified by measuring the water coming from the spigot using a graduated cylinder. A peristaltic pump was used to pump the water from the basin back into the water source. The pump and the trans-

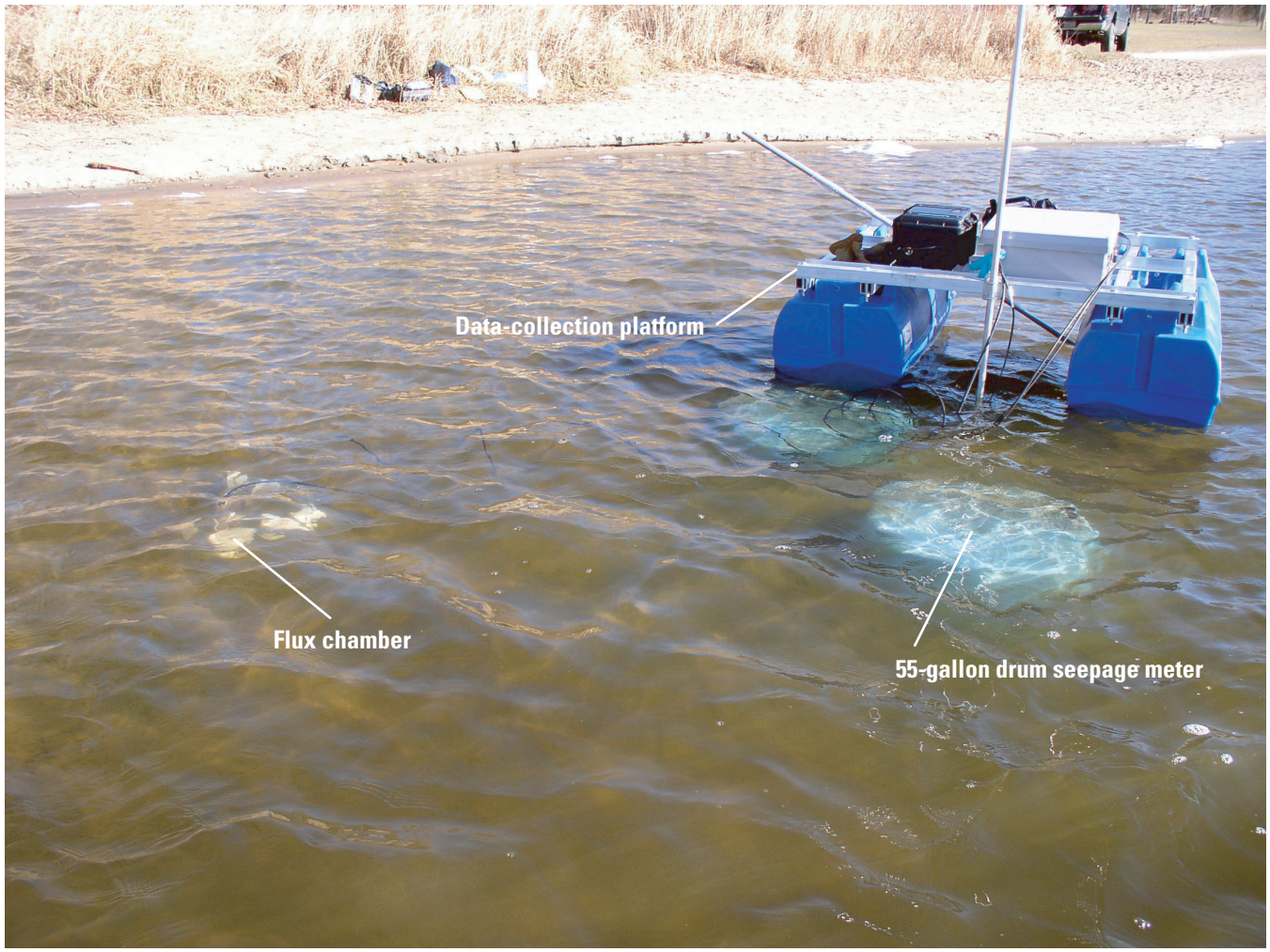


Figure 6. Flux chamber and 55-gallon drum seepage meter deployed at Long Lake (photograph by Michael Menheer).

ducer were connected to a datalogger that was programmed to turn the pump on and off to maintain a constant water level in the water source. This allowed calibration tests to be conducted for extended periods of time at a constant seepage rate.

The flux chamber was field tested by deploying it in two lakes in east-central Minnesota known to have measurable ground-water discharge, Long Lake in Ramsey County and Square Lake in Washington County (Alexander and others, 2001; J. Lundy, hydrologist, Minnesota Pollution Control Agency, oral commun., 2003). Seepage measurements were made in both lakes.

The in-lake test deployments were made in firm, sandy bottom sediments at locations free of vegetation to avoid loss of ground-water seepage from obstructions or poor contact with the sediment. The flux chamber and two 55-gallon drum seepage meters were inverted under water to ensure all the air was removed, then pressed into the lake sediments approximately 5 cm. The flux chamber and the 55-gallon drum seepage meters were deployed 2-3 m from shore in water approximately 1 m deep. The ultrasonic-flow meter tube was submerged next to the chamber, and a piece of vinyl tubing 38-41 cm in length was used to connect the chamber to the ultrasonic-flow meter. The 55-gallon drums were fitted with a garden hose threaded fitting. Plastic (polyethylene) bags were secured to a threaded ball valve using electrical tape. The bags were prefilled with 500 to 600 mL of lake water and the air was removed before they were attached to the drums. The fittings on the bags were then threaded onto the drums. Once they were securely attached, the starting time was noted when the valves were opened. The volume of water in the bags was measured using an electronic scale before and after deployment. It was assumed that 1 mL of water equaled 1 gram. The end time of the test was noted when the valve was closed, and the bag was removed from the drum and weighed.

The 55-gallon drum seepage rate was calculated with the following formula:

$$\text{Seepage} = dV/dt \quad (1)$$

where $dV = V_2 - V_1$, (2)

V_2 = ending bag volume, in milliliters,

V_1 = starting bag volume, in milliliters, and

dV = difference in volume in milliliters.

$$dt = t_2 - t_1 \quad (3)$$

t_2 = test ending time, in minutes,

t_1 = test start time, in minutes, and

dt = length of test, time in minutes.

The seepage rates were converted from milliliters per minute (mL/min) to centimeters per day (cm/day). This was done to normalize the seepage to area. It made the data directly comparable between the two types of seepage meters used which had different diameters. The following formula was used:

$$(\text{mL/min})*(1{,}440 \text{ min/day})/(3.14159*r^2) = (\text{cm/day}) \quad (4)$$

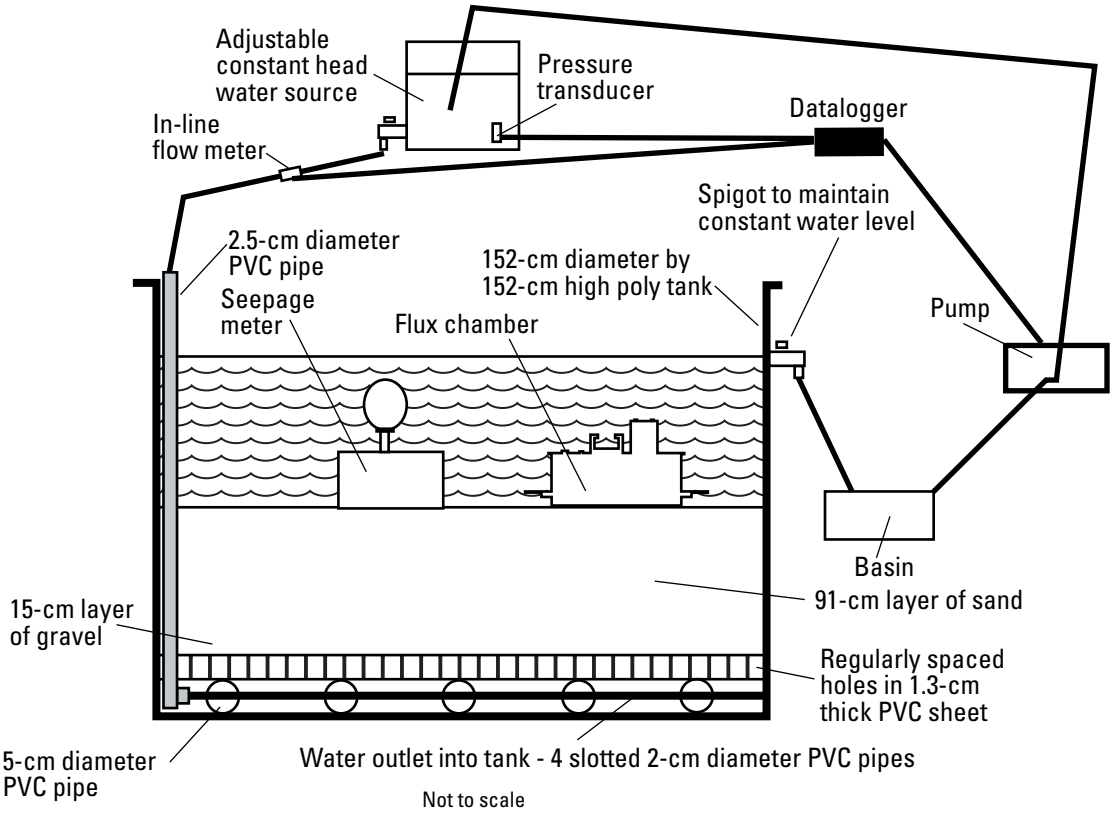


Figure 7. Schematic of the calibration tank.

where r is the radius, in centimeters, of the drum or flux chamber being used.

The flux chamber and the seepage meters were given time to equilibrate before initial measurements were made (Rosenberry and Morin, 2004). The time period required before stable flow was established varied based on seepage rate and the size of the flux chamber. The flux chamber was deployed for a minimum of 30 minutes before tests began. The flux chamber was left deployed overnight and seepage rates were measured the following day. Several tests of different lengths of time were done before the flux chamber and the 55-gallon drums were moved to determine an average seepage rate. Field tests of flux chamber operation were made during November 2003. The weather conditions were windy with rough, cold water (4–7 degrees Celsius). Fifty-five-gallon drum seepage meters were concurrently deployed within 1-2 m of the flux chamber to obtain comparable measurements. The water was clear in both lakes so it was possible to visually inspect the 55-gallon drum seepage meters and the flux chamber (fig. 6) to ensure they were pressed deeply enough into the lake sediments.

Water Sampling

Water samples were collected in Square Lake. A water sample was collected outside of the flux chamber to establish an ambient background concentration. A replicate sample was collected from the flux chamber. An equipment blank was collected in the office following the sample collections. Blank water was obtained from the USGS, Wisconsin District Mercury Laboratory, Middleton, Wisconsin.

Water samples were collected from the flux chamber using a peristaltic pump and following a “dirty hands” and “clean hands” protocol (Olson and DeWild, 1999). This involved two individuals who collected the samples. The equipment had been cleaned prior to sampling. This cleaning was in accordance with the USGS National Field Manual (U.S. Geological Survey, 1998) cleaning procedures and included a 10 percent hydrochloric acid (HCl) rinse by the personnel who were to collect the samples. Each sampler wore shoulder-length polyethylene gloves and wrist-length nitrile gloves. The two samplers waded upwind to the flux chamber, a section of acid cleaned Teflon tubing was connected to the top of the flux chamber and to an acid cleaned section of C-Flex pump head tubing. Water was pumped from the flux chamber using a peristaltic pump. Laboratory-cleaned Teflon sample bottles were double-bagged in resealable plastic bags. The “dirty hands” sampler opened the outside bag. The “clean hands” sampler touched only the inside bag and the sample bottle. A lake sample was collected by submerging the bottles to a depth of 0.2 m. A multiparameter meter was used to measure the water temperature, specific conductance, dissolved oxygen, and pH of the lake water surrounding the flux chamber. The THg and MeHg samples were preserved with 10 mL and 5 mL of 6N HCl, respectively. Preservation was done within several hours of sample collection. Samples were then stored in a laboratory refrigerator until shipped, on ice, to the USGS, Wisconsin District Mercury Laboratory (DeWild and others, 2001).

Measurement of Ground-Water Seepage and Water Sampling

Seepage Measurements

The trial deployment of the flux chamber was done in Long Lake in Ramsey County, Minnesota (fig. 6). The water temperature varied from 3 to 5 degrees Celsius during the trial period. The specific conductivity of the water was 568 micro-Siemens per centimeter (μS/cm) at 25 degrees Celsius. There were moderate sized waves. A seepage rate was recorded every 5 seconds by the ultrasonic-flow meter. These were averaged and one value per minute was recorded. The data are presented in figure 8. It was noticed during this deployment that the ultrasonic-flow meter drifted over time. The initial flow rates reported by the ultrasonic-flow meter fell within the range that was concurrently measured using two 55-gallon drums. The downward trend in seepage shown in figure 8 continued and later measurements drifted to zero and negative flows. It did not appear that the drift in the meter was due to wave effects as is discussed in several papers (Shum, 1992; Libelo and MacIntyre, 1994; Taniguchi and Fukuo, 1996). The drift in the ultrasonic-flow meter was linear over the entire period of deployment. It did not vary cyclically as one would expect if it were wave induced. Also, the drift continued even after the wind calmed and the waves lessened. The minimum, maximum, and average flow rates for the ultrasonic-flow meter were 1.55, 39.47, and 18.06 cm/day, respectively. The minimum, maximum, and average seepage rates for the two 55-gallon drum seepage meters were 1.84, 26.0, and 11.20 cm/day, respectively. The ultrasonic-flow meter would occasionally report a noticeably anomalous value, either considerably higher or lower than the average flow reading.

The second test deployment of the flux chamber was along the west shore of Square Lake in Washington County, Minnesota the following week. The water was calm. The temperature of the water was 4 to 6 degrees Celsius. The specific conductivity of the water was 282 μS/cm at 25 degrees Celsius. A flow rate was recorded every 5 seconds by the ultrasonic-flow meter. These were averaged and one value per minute was calculated. The ultrasonic-flow meter rates again slowly drifted linearly, slowly decreasing over time. The data are presented in figure 9. The seepage rates were closely comparable between the ultrasonic-flow meter and the 55-gallon drum seepage meter. The minimum, maximum, and the average values for the ultrasonic-flow meter were 5.90, 18.29, and 13.06 cm/day, respectively. The minimum, maximum, and

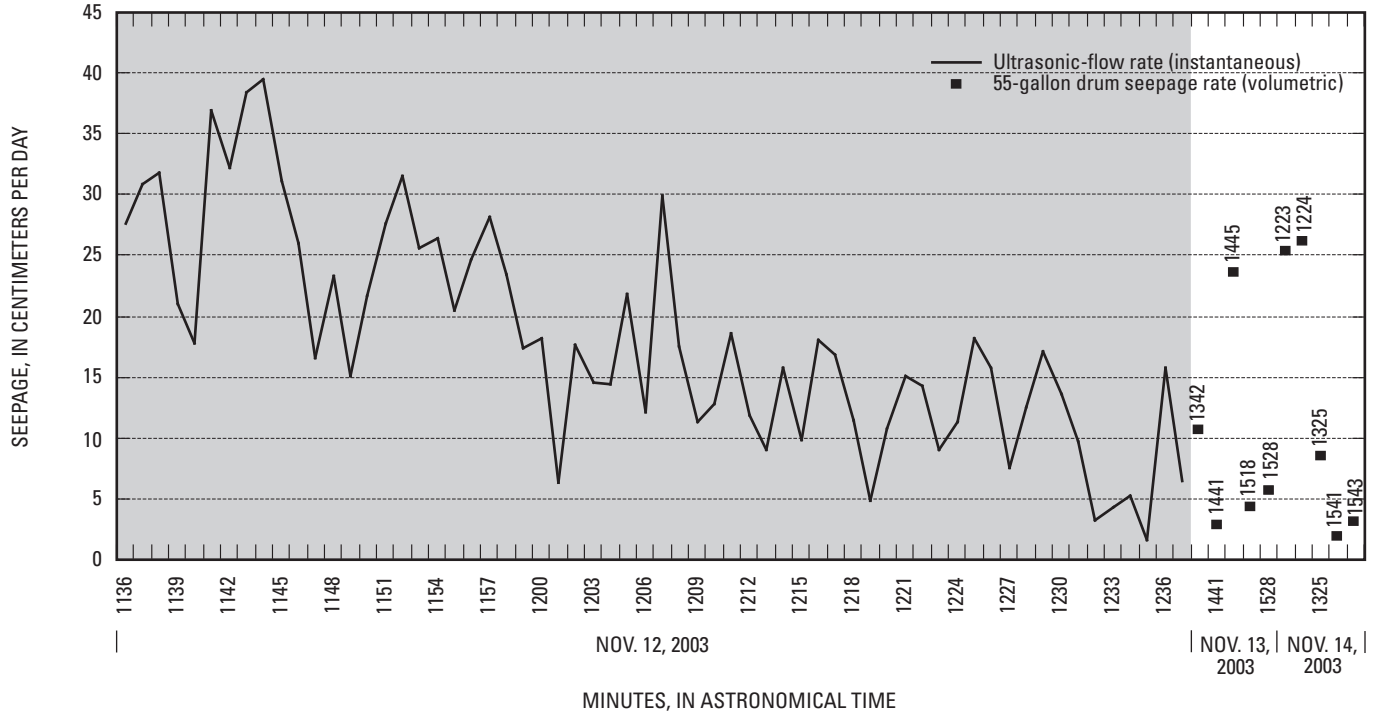


Figure 8. Long Lake seepage from ground water.

the average values for the two 55-gallon drum seepage meters were 10.99, 16.80, and 11.16 cm/day, respectively.

The ultrasonic-flow meter was tested and recalibrated in the calibration tank after it had been field tested. A flow rate was recorded every minute by both the ultrasonic- and the in-line- flow meter. Several times during calibration the flow was stopped and the ultrasonic-flow meter was manually reset to zero flow. The range of in-line flow rates on the January

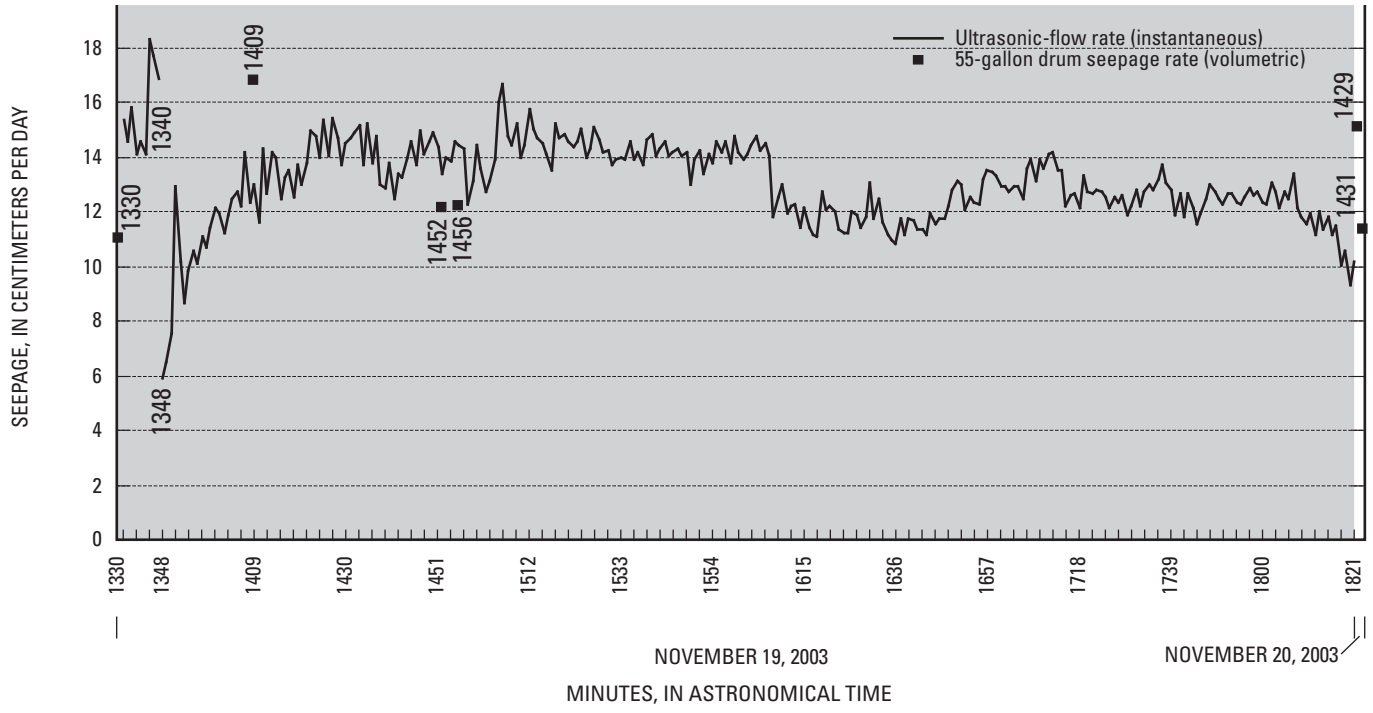


Figure 9. Square Lake seepage from ground water.

23, 2004 test varied between 10 and 35 cm/day (fig. 10). The duration of the test was 338 minutes. When compared, 88 percent of the ultrasonic-flow rates and the in-line flow meter rates were within 20 percent (table 1). The rates varied on the January 27, 2004 calibration test between 5 and 39 cm/day (fig. 11). The duration of the test was 1,407 minutes. When compared 55 percent of the readings were within 20 percent, 69 percent were within 30 percent (table 1). The data from these two tests are presented in figures 10 and 11, and table 1. The zero values when the flow was turned off were not included in this summary.

Water Sampling

A sequential replicate water sample was collected to test the design of the flux chamber. A dip sample was collected directly from the lake to establish background concentrations. The water samples were collected at Square Lake, November 20, 2003. The replicate sample was collected from the flux chamber immediately following the collection of the lake sample. The flux-chamber samples yielded THg concentrations of 0.47 and 0.53 nanograms per liter (ng/L). The lake sample was 0.27 ng/L. The MeHg concentrations for all three of the samples were below the detection limit of 0.04 ng/L.

The flux chamber was cleaned by rinsing it with 10 percent HCl acid. The sample tubing was cleaned by pumping similar acid through it. The flux chamber was not cleaned by soaking it in an acid bath because of the size of the chamber and the amount of acid that would be required. An office equipment blank was collected several weeks after the environmental samples. The flux chamber and tubing were cleaned prior to collection of the equipment blank. The blank was collected in the office laboratory by inverting the flux chamber, pouring blank water into the flux chamber, rinsing the water around in the flux chamber, and then using the sample tubing to pump it into the sample bottles. The office equipment blank concentration for THg was 0.79 ng/L, and for MeHg was below the detection limit of 0.04 ng/L.

The data indicates that the flux chamber is suited for sampling water with mercury concentrations greater than 0.1 ng/L. At sites where concentrations are low (<1.0 ng/L), greater attention needs to be given to cleaning protocols and collecting quality-control and quality-assurance data to verify the accuracy of the data.

Potential Improvements to the Flux Chamber

The following is a discussion of design changes that would improve the flux chamber. These changes were beyond the scope of this study.

The physical dimensions of the flux chamber could be larger. This would have integrated data and seepage from a larger area. The material used for the flux chamber could be thicker making it more durable. This would also make it

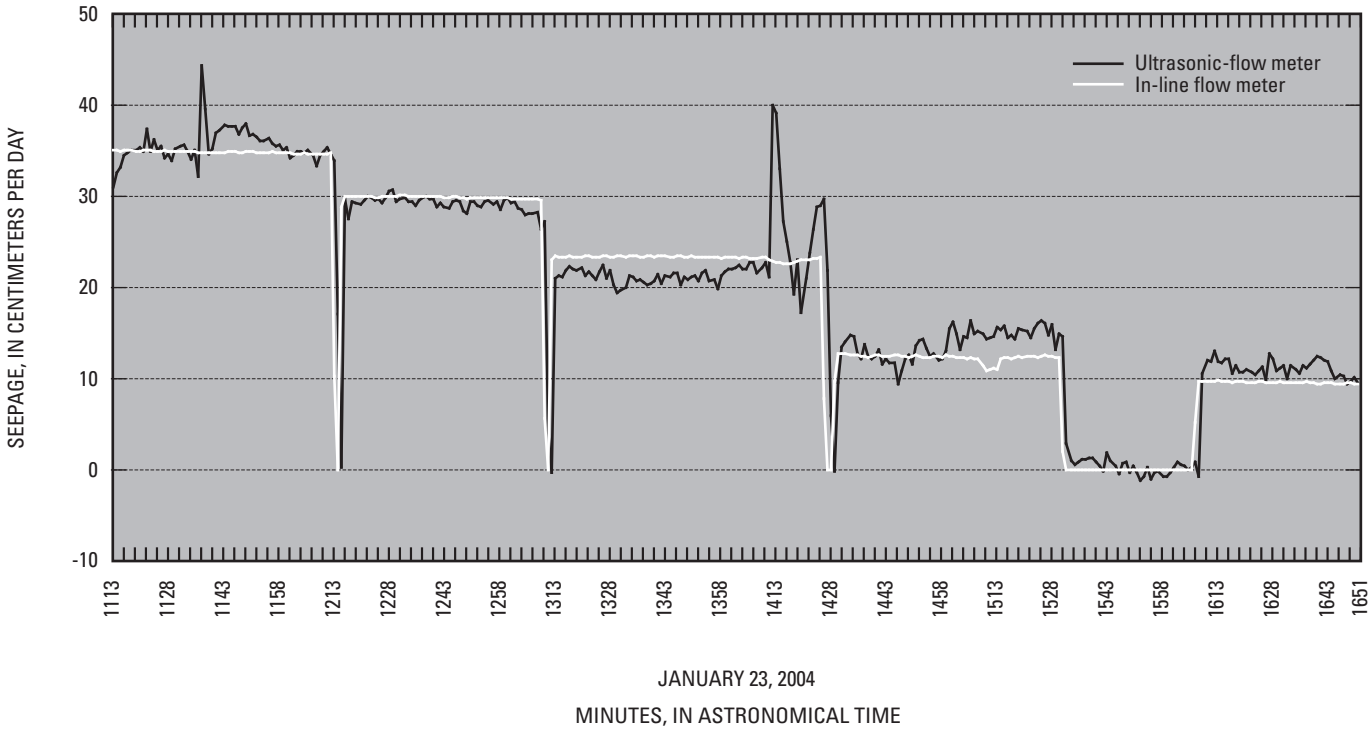


Figure 10. Calibration tank seepage, January 23, 2004.

Table 1. Summary of flow data from calibration tests done in a calibration tank.

January 23, 2004 Calibration Test Start: 1/23/2004 11:13:00 AM End: 1/23/2004 4:51:00 PM Test duration: 338 minutes (5 hours 38 minutes)			January 27, 2004 Calibration Test Start: 1/27/2004 9:12:00 AM End: 1/28/2004 8:39:00 AM Test duration: 1,407 minutes (23 hours 27 minutes)		
Percent difference between Inline and ultrasonic-flow meters	Number of recorded flow rates	Percent of total measurements made during test	Percent difference between Inline and ultrasonic-flow meters	Number of recorded flow rates	Percent of total measurements made during test
0 - 10	202	67	0 - 10	493	35
11 - 20	64	21	11 - 20	278	20
21 - 30	22	7	21 - 30	202	14
31 - 40	1	0	31 - 40	133	10
41 - 50	2	1	41 - 50	95	7
51 - 60	0	0	51 - 60	99	7
61 - 70	1	0	61 - 70	76	5
71 - 80	2	1	71 - 80	5	0
81 - 90	2	1	81 - 90	5	0
>90	4	1	>90	13	1
total:	300	100	total:	1399	100

easier to make the ports in the flux chamber, some of which were threaded.

The ultrasonic-flow meter drifts over time. A closeable valve on the flux chamber or inline with the tubing from the flux chamber to the flow tube would be useful to set the seepage to zero. A valve could be attached to the datalogger so it would automatically be closed at regular intervals. This would allow the drift to be quantified over time. An alternative would be to install a valve that could be manually closed and the meter could be reset to zero at regular intervals.

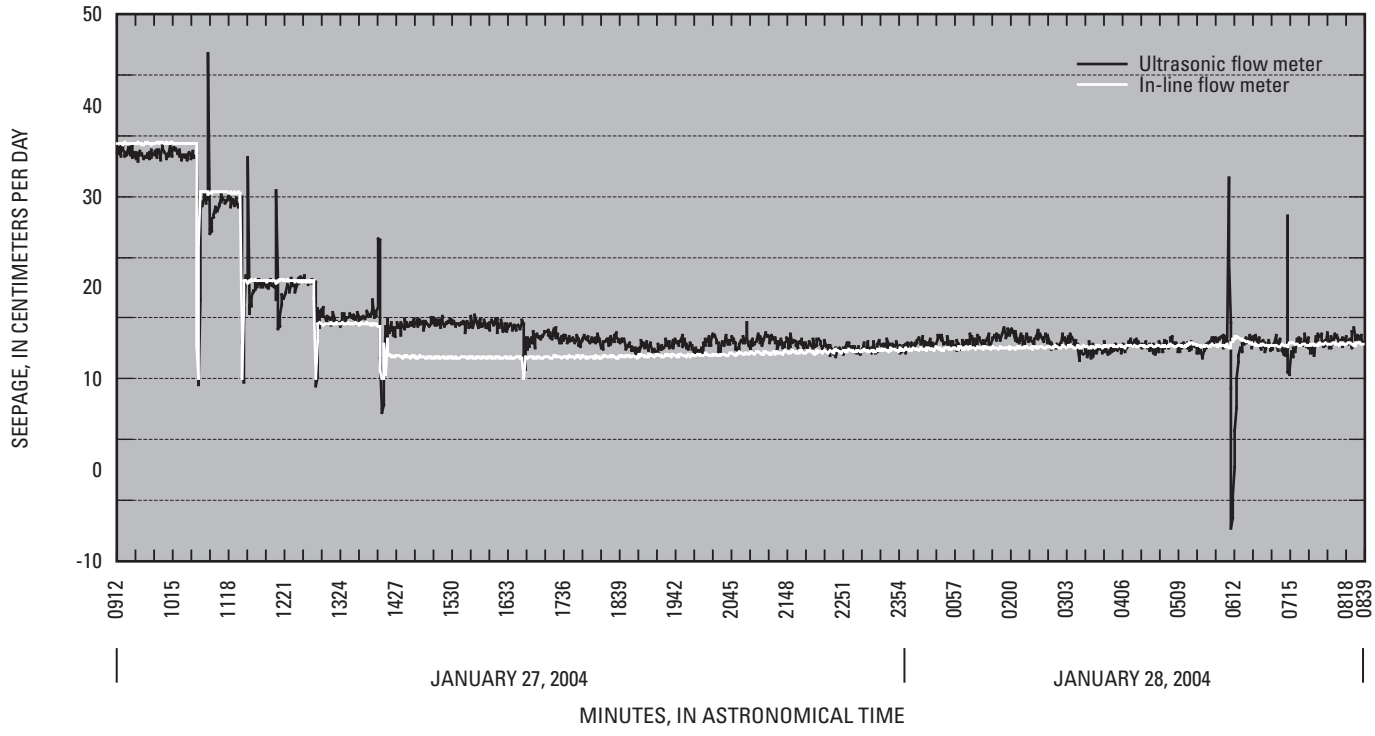


Figure 11. Calibration tank seepage, January 27-28, 2004.

The ultrasonic-flow meter was powered by an internal 12-volt battery. An external battery extended the length of continuous operation to about 48 hours. A solar panel could be mounted on the floating platform to further extend the battery life of the meter.

The stirrer moved in jerky movements and was stopped if it encountered an obstruction. Stronger magnets could be used to produce a dependable, smoother operation.

The dissolved-oxygen probe was labor intensive to maintain and became an ongoing effort of time and supplies and was not used when field testing the flux chamber. There was concern about damaging the fragile probe. Because the dissolved-oxygen probe was not used, air was not pumped into the flux chamber. To monitor the dissolved-oxygen concentration in the flux chamber, either small volumes of water could be withdrawn periodically and tested with a dissolved-oxygen meter, or the water coming from the flow tube could be routed into a standard multiparameter meter to continuously monitor the dissolved-oxygen concentration of the water coming from the flux chamber. This would avoid the contamination issues from the dissolved-oxygen probe and allow pH, specific conductivity, and water temperature data to be collected.

The springs on the spring loaded port door snapped the cover in place, closing the opening forcefully. This could agitate the sediments, which the port door was designed to avoid. This could have been lessened, if not completely alleviated, by a change in design that would not have lifted the Teflon cover as high. Over time the springs had a tendency to rust. This could have been resolved by using stronger springs and replacing them on a routine basis.

The buoyant disk to close the outlet for the air that was pumped into the chamber worked, but the seal was not tight. Water was able to leak from this port. The issue with water leaking from various ports was noticed when the chamber was inverted and filled with water. When deployed in the field, the water pressure against the ports would only be a fraction of what this experiment showed. A Teflon coated O-ring around the buoyant disk would have given it a tighter seal.

Prior to water sampling, careful cleaning of the flux chamber and the sampling tubing is needed. This includes soaking them in a 10 percent HCl acid bath or rinsing them with acid. Collection of numerous quality-control and quality-assurance samples, especially equipment blanks, is needed to monitor the flux chamber performance, specifically to monitor any contamination that might result from inadequate cleaning procedures.

Summary

The U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency and the Minnesota Department of Health conducted a study during November 2003 and January 2004 at Long Lake and Square Lake in Minnesota to measure ground-water seepage rates. A benthic-flux chamber was constructed and used to measure ground-water seepage rates and to collect water samples. The ground-water seepage rate data was verified by testing the flux chamber in a calibration tank and by deploying it in two fresh water lakes alongside other 55-gallon drum seepage meters. The flux chamber seepage rate data were comparable to rates measured concurrently in the calibration tank by an in-line flow meter. The seepage rate in the calibration tank also was verified by measuring the seepage over time using a graduated cylinder. The seepage rate data from two lakes also were comparable between the flux chamber and two concurrently deployed 55-gallon drum seepage meters. The minimum, maximum, and average flow rates for the ultrasonic-flow meter at Long Lake were 1.55, 39.47 and 18.06 cm/day compared to 1.24, 26.0, and 11.20 cm/day for the 55-gallon drum seepage meter. The minimum, maximum, and average flow rates for the ultrasonic-flow meter at Square Lake were 5.90, 18.29, and 13.06 cm/day compared to 10.94, 16.80, and 11.16 cm/day for the 55-gallon drum seepage meter. The flux-chamber samples yielded THg concentrations of 0.47 and 0.53 nanograms per liter (ng/L). The lake sample was 0.27 ng/L.

The flux chamber was successfully used to (1) measure ground-water seepage rates and (2) collect water samples for analysis of mercury concentrations at the nanogram per liter level. Several modifications could improve the general performance and the accuracy of the flux chamber, most notably: increasing the size of the flux chamber; manually setting the seepage to zero and resetting the ultrasonic-flow meter to evaluate meter drift; routing the outflow from the ultrasonic-flow meter through a multiparameter (dissolved oxygen, pH, specific conductivity, and water temperature) meter; and soaking or copiously rinsing the flux chamber and the sample tubing in a 10 percent hydrochloric acid solution in the cleaning procedure.

References

Alexander, S., Setterholm, D., Tipping, R., and Meyer, G., 2001, The influence of ground water on the quality of lakes in the Carnelian-Marine watershed district: Minnesota Geological Survey, CD ROM, 33 p.

Benoit, J.M., Gilmour, C.C., Mason, R.P., and Heyes, A., 1999, Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment pore waters: Environmental Science and Technology, v. 33, p. 951-957.

Bloom, N.S., 1992, On the chemical form of mercury in edible fish and marine invertebrate tissue: Canadian Journal of Fisheries and Aquatic Science, v. 49, p. 1010-1017.

Bodaly, R.A., Rudd, J.W.M., Fudge, R.J.P., and Kelly, C.A., 1993, Mercury concentrations in fish related to size of remote Canadian Shield lakes: Canadian Journal of Fisheries and Aquatic Sciences, v. 50, p. 980-987.

Branfireun, B.A., Roulet, N.T., Kelly, C.A., and Rudd, J.W.M., 1999, In situ sulphate stimulation of mercury methylation in a boreal peatland: Toward a link between acid rain and methylmercury contamination in remote environments: Global Biogeochemical Cycles, v. 13, no. 3, p. 743-750.

DeWild, J.F., Olson, M.L., and Olund, S.D., 2001, Determination of methylmercury by aqueous phase ethylation, followed by gas chromatographic separation with cold vapor atomic fluorescence detection: U.S. Geological Survey Open-File Report 01-445, 14 p.

Gill, G.A., Bloom, N.S., Cappellino, S., Driscoll, C.T., Dobbs, C., McShea, L., Mason, R., and Rudd, J.W.M., 1999, Sediment-water fluxes of mercury in Lavaca Bay, Texas: Environmental Science and Technology, v. 33, no. 5, p. 663-669.

Gilmour, C.C., and Henry, E.A., 1991, Mercury methylation in aquatic systems affected by acid deposition: Environmental Pollution, v. 71, p. 131-169.

Gilmour, C.C., Henry, E.A., and Mitchell, R., 1992, Sulfate stimulation of mercury methylation in freshwater sediments: Environmental Science and Technology, v. 26, no. 11, p. 2281-2287.

Jay, J.A., Morel, F.M.M., and Hemond, H.F., 2000, Mercury speciation in the presence of polysulfides: Environmental Science and Technology, v. 34, no. 11, p. 2196-2200.

Kerry, A., Welbourn, P.M., Prucha, B., and Mierle, G., 1991, Mercury methylation by sulphate-reducing bacteria from sediments of an acid stressed lake: Water, Air, and Soil Pollution, v. 56, p. 565-575.

Lee, D.R., 1977. A device for measuring seepage flux in lakes and estuaries: Limnology and Oceanography, v. 22, no. 1, p. 140-147.

Libelo, E.L., and MacIntyre, W.G., 1994, Effects of surface-water movement on seepage-meter measurements of flow through the sediment-water interface: Applied Hydrogeology, v. 2, no. 4, p. 49-54.

Olson, M.L., and DeWild, J.F., 1999, Techniques for the collection and species-specific analysis of low levels of mercury in water, sediments, and biota, in Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the technical meeting, Charleston, North Carolina, March 8–12, 1999, volume 2 of 3—Contamination of hydrologic systems and related ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 191–200.

Pak, K.R., and Bartha, R., 1998, Mercury methylation and demethylation in anoxic lake sediments and by strictly anaerobic bacteria: Applied and Environmental Microbiology, v. 64, no. 3, p. 1013-1017.

Paquette, K.E., and Helz, G.R., 1997, Inorganic speciation of mercury in sulfidic waters—The importance of zero-valent sulfur: Environmental Science and Technology, v. 31, no. 7, p. 2148-2153.

Paulsen, R.J., Smith, C.F., O'Rourke, D., and Wong, T., 2001, Development and evaluation of an ultrasonic ground water seepage meter: Ground Water, v. 39, no. 6, p. 904-911.

Rosenberry, D.O., and Morin, R.H., 2004, Use of an electromagnetic seepage meter to investigate temporal variability in lake seepage: Ground Water, v. 42, no. 1, p. 68-77.

Shum, K.T., 1992, Wave-induced advective transport below a rippled water-sediment interface: Journal of Geophysical Research, v. 97, no. C1, p. 789-808.

Taniguchi, M., and Fukuo, Y., 1996, An effect of seiche on groundwater seepage rate into Lake Biwa, Japan: Water Resources Research, v. 32, no. 2, p. 333-338.

U.S. Geological Survey, 1998, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chapters A1-A9, variously paged, http://water.usgs.gov/owq/FieldManual.

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