ground water

Technical Note/

Errors with Small Volume Elastic Seepage Meter Bags

by Robert A. Schincariol[1] and John D. McNeil[1]

Abstract

The use of small volume elastic collection bags (condoms) has become popular in seepage meter studies in recent years, despite minimal field or laboratory validation of their use and, specifically, the impact of their elasticity on seepage measurements. A laboratory study was initiated after field results using small elastic collection bags produced seepage data that did not correlate with hydrometric data. The laboratory data demonstrate that condoms undergo significant mechanical relaxation during seepage measurement times typically observed in field settings. Unlike conventional nonelastic collection bags, which mechanically relax over several minutes, the condoms suffered from a slow mechanical relaxation or equilibration. Over nine hours, condoms gained 43 mL of water, ~50% of maximum workable volume (between mechanical relaxation effect and elastic limit), under stagnant flow conditions. This long-term equilibration invalidates simple subtraction of equilibration volumes from collection volumes as a correction technique. Previously published studies using flexible small-volume elastic measurement bags (condoms) have not reported a mechanical relaxation effect. Overall, because the condom's small workable volume and inherent variability, we would not recommend any small-volume elastic measurement bags for quantitative seepage measurements.

Introduction

Ground water seepage directly into rivers and lakes is potentially important for assessing water budgets and water quality. Ground water seepage can also be an important parameter in hyporheic biogeochemical processes (Hendricks and White 1995), ecological problems such as algal blooms and eutrophication (Corbett et al. 1999), and spawning areas of cold water fish (Blanchfield and Ridgway 1996). In general, the impacts of ground water quantity and quality on surface water ecosystems are motivating researchers to examine these ecosystems using an integrated (watershed) perspective.

The spatial and temporal distribution of ground water seepage to a small perennial stream in Ontario, Canada, was examined in an attempt to link variations in seepage with sediment heterogeneities. Streambed material varied locally from dense vegetative mats and decomposed plant material to silt and sand. To better assess this variability, a miniaturized version (area 0.0082 m^2) of the conventional seepage meter (Lee 1977) was used. However, seepage results did not agree with hydrometric data. Looking for potential sources of error, a laboratory investigation was conducted testing the miniaturized meters and small-volume elastic measurement bags (condoms). The laboratory investigation is the focus of this technical note.

The typical seepage meter is simply an open-bottomed chamber (end section of steel drum, 0.25 m^2) with a collection bag attached (Lee 1977; Corbett et al. 1999). Seepage meters must be deployed with care or errors can occur (Lee 1977). Meter errors include frictional resistance and head loss along meter walls, attachment tubing, and collection bag. With the 0.15 m $\times$ 0.57 m (0.25 m^2) seepage meter, the collection bag is typically a 4 L (thickness 0.017 mm) inelastic membrane plastic bag. These bags suffer from a mechanical relaxation effect that causes an anomalous short-term influx of water into the bags (Shaw and Prepas 1989; Belanger and Montgomery 1992; Blanchfield and Ridgway 1996). In essence, the bag is collapsed to evacuate air and water prior to attachment, after which it attempts to regain its original shape. These effects are reduced by prefilling the bags with 1000 mL of water before they are attached to the seepage meters (Shaw and Prepas 1989). Recently, a miniaturization of this meter has been used in hydrogeology and stream ecology field studies, including Fryar et al. (2000) and Duff et al. (2000). The meter employed by Fryar et al. (2000) has an area of 0.0082 m^2, whereas Duff et al. (2000) used meters with an area of 0.0314 m^2. Both studies used a latex capture bag (condom). The smaller meter has the advantage of enhanced portability and the ability to sample smaller sediment features (e.g., vegetative mats and riffle pool sequences). The smaller size and cost also make it easier to employ a larger number of meters at any given site. Furthermore, given that the ratio of seepage meter collection area to collection bag volume is similar between the "typical" and miniature seepage meters, field deployment times remain similar.

Laboratory Studies and Discussion

The miniaturized seepage meter used in this study was based on the design used in Fryar et al. (2000). In field applications, the open beveled end of the 101.6 mm diam-

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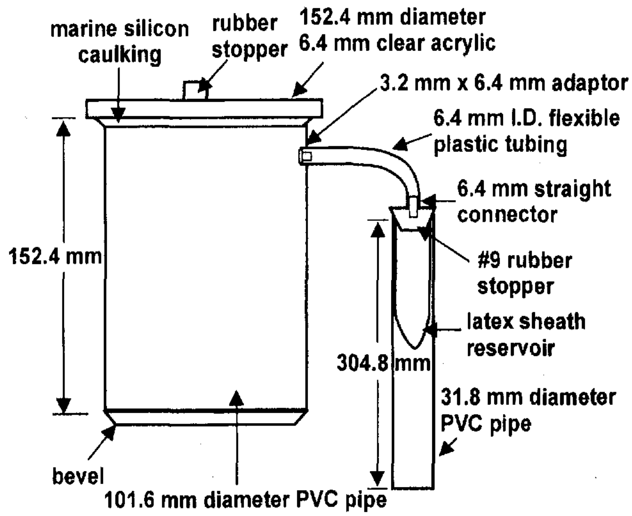

Figure 1. Seepage meter construction details.

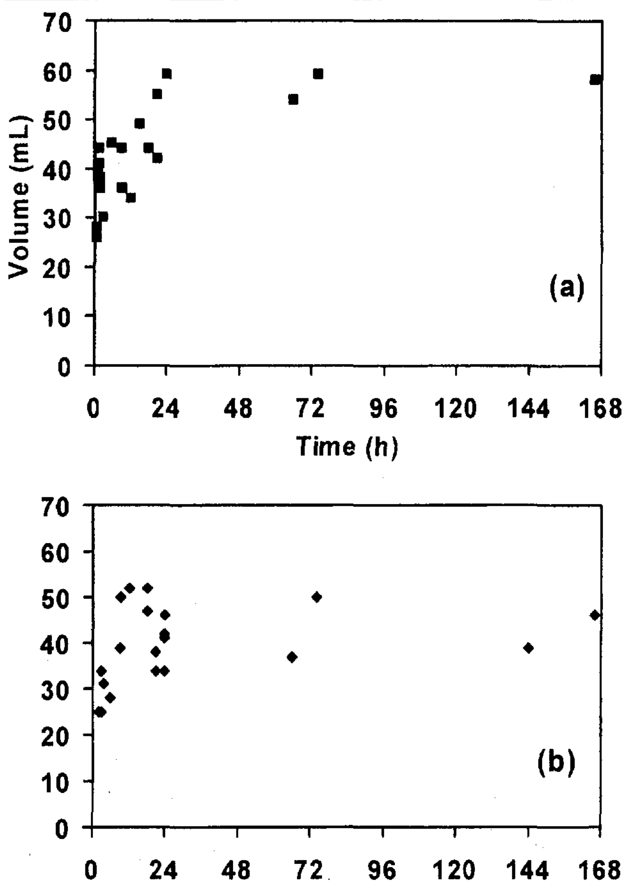

Figure 2. Volume of water collected by initially empty latex (condom) collection bags submerged in a stagnant water filled tank versus time interval (hours [h]): (a) seepage meter bottom open to water (no sand); (b) seepage meter seated in sand.

eter cylinder is pushed into the sediment to a depth of ~ 120 mm (Figure 1). In most applications, this depth is sufficient to stabilize the meter. However, in loose sediments or higher stream velocities, the meter can be stabilized by placing rocks or weight on the cylinder top. The side adapter and thick-walled tubing (Figure 1) prevent the cylinder top from pressing against the sediment. Once all air bubbles have been removed from the cylinder and tubing, the top rubber stopper is replaced and a wetted evacuated latex capture bag (condom) is placed over the #9 stopper while the stopper hole is covered. The headspace between the tubing connected to the reservoir and the top of the meter allows ample room for any gases to collect without influencing seepage flow. The clear acrylic top allows a confirmation of the extent of any gas accumulation. The empty condom is then placed in the 31.8 mm diameter PVC pipe that provides a secure seal and protects it from damage. After deployment times ranging from one to 10 days, the flexible plastic tubing leading to the condom is pinched and the condom removed so the volume of water can be measured. To reduce memory effects, a new condom was used for each measurement period. In addition, the latex condoms become less elastic with time and cannot be easily removed from the stopper without breakage. Thus, the top of the condom is pinched closed and then torn off from the stopper. Collection times were selected so volumes were below the amount where elastic effects would come into play. The condoms (Durex Ramses® nonlubricated) have a relaxed lay flat width of 52 mm and a length of 178 mm. Using these measurements, the relaxed volume is 150 mL. However, field equilibration tests showed elastic effects occur when the volume of water exceeds approximately 100 mL.

The use of small-volume elastic collection bags has become popular in seepage meter studies in recent years, despite minimal field or laboratory validation of their use and, specifically, the impact of their elasticity on seepage measurements. Initially, it was thought the condoms would not have a mechanical relaxation effect, although it was known that elastic measurement bags, by their very nature, create a resistance to inflow and an aid to outflow. The thin and flexible latex condom (thickness 0.065 mm) did not seem to change shape once evacuated and attached to the meters. In addition, previous studies using condoms as collection bags did not report any problems with mechanical relaxation or preload condoms when positive (gaining) seepage was expected (Duff et al. 2000; Fryar et al. 2000; Isiorho and Meyer 1999). However, a discussion by Harvey and Lee (2000) on Isiorho and Meyer (1999) indicated some serious concerns regarding the use of small-volume elastic measurement bags.

To investigate any mechanical relaxation effects, we ran two series of experiments (22 trials in total) in a laboratory tank. In the first series, the seepage meter (Figure 1) was placed in a stagnant tank seated on a plastic grill to allow free movement of water into the condom. After a given time interval from one to 166 hours, the condom was removed and the volume of water collected was measured. A new condom was used for each trial. The data show a definite mechanical relaxation effect with the collection bag equalizing after approximately six hours (Figure 2a). The mean collected volume of the nine tests of three hours or less duration is significantly different from the mean collected volume for the remaining 13 tests of six hours or more (≤ 3 hours, mean [SE] = 35.3 [2.0] mL; > 3 hours, mean [SE] = 47.9 [2.3] mL; $t = 3.8$, $df = 20$, $p = 0.01$). To better reproduce field conditions, additional laboratory simulations were conducted where the seepage meters were seated in sand in a stagnant tank. Results were similar (Figure 2b); however, the mechanical relaxation, or equilibration, was slowed down because of

Table 1
Prefilled Volume Tests in Stagnant Sand-Filled Tank

Initial Prefilled Volume (mL)	Final Volume after 24 h (mL) Mean (standard deviation)
50	62.6 (11.1)
75	77.5 (2.7)
100	99.1 (2.3)
150	104.8 (9.5)

the hydraulic resistance of the sand. Equilibration appears to be complete after nine hours with a mean (SE) volume of 43.1 (1.6) mL. Mean volume collected prior to nine hours (mean [SE] = 28.5 [1.4]) was significantly different from the ≥9 hours data ($t = 5.32$, $df = 19$, $p = 0.01$).

The relatively long period of time to attain equilibration is probably due to the very thin and flexible nature of the condom. Shaw and Prepas (1989) found the volume of water in the standard polyethylene plastic bags (3.5 L capacity) increased and stabilized at ~ 300 mL after 45 minutes in a stagnant tank. Furthermore, they found that prefilling with 1000 or 2000 mL of water decreased but did not eliminate equilibration as bags still gained an additional 160 mL. Additional stagnant tank tests with the seepage meter (Figure 1) seated in sand with prefilled condoms showed similar results to Shaw and Prepas (1989). Condoms prefilled with 50 and 75 mL of water gained additional water (Table 1). Prefilling with 100 and 150 mL of water confirmed our earlier field studies that the inelastic range of the condom is ~ < 100 mL.

Although our field deployment times (22 to 309 hours) exceeded the equilibration time, applying a seepage correction rate based on an additional 43 mL of water over the collection period did not fix the noncorrelation of our field seepage and hydrometric data. Although some authors (e.g., Shaw and Prepas 1989) were able to correct early time seepage data, the relatively long mechanical relaxation time of the condom creates problems with these types of corrections. Most likely, the error lies in the complicating effect of natural flow rates. Over the nine hours that relaxation creates a negative pressure gradient within the condom, ground water seepage is also entering the condom at varying rates.

Conclusions

A laboratory study testing the utility of small-volume elastic seepage collection bags (condoms) was initiated after field data employing these bags did not match hydrometric data. Condoms attached to miniature seepage meters, seated in sand in a stagnant tank, were found to have a slow mechanical relaxation (equilibration volume) effect. In addition, condoms prefilled with a volume of water equal to or greater than the relaxation volume still gained additional water. The long equilibration time, on the order of nine hours, does not allow the simple subtraction of mechanical relaxation volumes from collected volumes to correct field data. Although more complex and representative techniques could be developed that correlate mechanical relaxation to seepage rate, the use of small-volume elastic collection bags (condoms) does not seem to warrant this effort. The workable volume of the condoms, ~ 50 mL between the mechanical relaxation effect and the elastic limit, leaves little room for additional errors or meter variability. Overall, although miniature seepage meters are smaller and easier to use than the conventional seepage meter, we would not recommend the use of the small-volume elastic measurement bags (condoms) for quantitative seepage flux measurements. We would recommend inelastic bags and that each bag type be tested in the laboratory for variability, mechanical relaxation errors, and additional fluid gained when preloaded.

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