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An Update on Methods for Measuring the Intragravel Environment of Incubating Salmon Eggs and Larvae

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ABSTRACT

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Although the delivery of oxygenated water to salmonid eggs and larvae buried in river gravel is critical for their survival, intragravel flow rates have been infrequently measured because of the complexity and time consuming nature of the techniques that have been developed. Here we describe modifications of a previously developed technique that makes use of the dilution of a salt solution from a standpipe buried in the river bed. The new flowmeter is lightweight, and rapid determinations of intragravel flow are possible. The flowmeter was calibrated in an experimental flume, and functions for the automated processing of field measurements are given. We also describe a piezometer for the measurement of hydrostatic head associated with salmon redds.

RÉSUMÉ

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Même si l'apport d'eau oxygénée est critique pour la survie des oeufs et des larves des salmonidés enfouis dans le gravier des cours d'eau, les débits dans le gravier ont rarement été mesurés à cause de la complexité et de la longueur des techniques qui ont été élaborées. Nous décrivons ici les modifications apportées à une technique déjà mise au point, qui fait appel à la dilution d'une solution salée provenant d'une colonne plantée droite dans le lit du cours d'eau. Le nouveau débitmètre est léger et permet de déterminer rapidement les débit dans le gravier. L'appareil a été étalonné dans un panache expérimental, et des fonctions sont prévues pour mesurer la pression hydrostatique associée aux nids de frai du saumon.

Introduction

Salmon biologists have been interested in the flow of water through spawning gravels for at least two reasons: first, the survival of incubating eggs and alevins has been positively related to both the oxygen content and the intragravel velocity of water (Cooper 1965). Depleted oxygen levels have also been demonstrated to result in smaller size at emergence, which may affect subsequent survival as free-swimming fry (Silver et al. 1963). Secondly, subsurface flow rates may be an important cue for the selection of spawning areas by adult salmon. Russian scientists have suggested that spawning areas can be classified by the direction of the intragravel flow (Leman 1989), and suggest that chinook prefer downwelling flows (Vronskii and Leman 1991), while sockeye and particularly chum spawn in areas of upwelling. The identification of good spawning habitat for these species might require the measurement of these parameters, as traditionally used measures such as depth, surface water velocity and substrate type can fail to correctly identify preferred spawning areas (Shirvell 1989).

The intragravel environment can be assessed through the measurement of five parameters: water temperature, oxygen concentration, gravel permeability, apparent intragravel velocity and hydraulic head (Leman 1989). Although methods have been developed for the measurement of these parameters (Terhune 1958; Lee and Cherry 1978), with the exception of oxygen and temperature determinations they have not been used frequently, perhaps because of the complexity of the apparatus required. Orchard (1988) notes that less than 400 measurements of sub-surface flow have been made in the 30 years since the development of the methods. The devices we have developed use commonly available materials, and take advantage of modern metering equipment.

Standpipes

Like previous workers, we used a perforated standpipe for sampling at depths where salmon eggs are deposited. The standpipe consisted of a 29 cm length of 25 mm ID PVC pipe, with 48 3 mm drilled holes. The holes were arranged in 6 rows, each row having eight holes evenly distributed around the circumference of the pipe. Rows were 1 cm apart beginning 1 cm above the bottom of the pipe (Fig. 1). A groove was cut between the holes in a row using a bandsaw, following Turnpenny and Williams (1982). The bottom of the standpipe was closed with a glue-on cap, and a 15 cm piece of 1.5 cm steel strapping was attached to serve as an anchoring foot. A threaded female connector was glued to the top of the standpipe. A 75 cm extension tube, fitted with a threaded male adapter was screwed on to the standpipe for sampling; a threaded plug was used to seal the standpipe when not in use. This version of the standpipe was placed in the gravel by first excavating a hole in the river bed using garden hoes, and then refilling it with the standpipe in place, in an attempt to replicate the process female salmon use in the deposition of their eggs. Another version, consisting of a 1 m long solid steel pipe with a hardened pointed tip was used to sample undisturbed gravel beds. The steel standpipe was driven in the riverbed using a steel driving bar.

Piezometer

The potential for vertical water flow in the gravel can be estimated by the difference in hydrostatic pressure between the surface and at some depth in the river bed (Lee and Cherry 1978; Sowden and Power 1985; Leman 1989). Hydraulic head can be estimated by comparing the height of water in a pipe that extends from the intragravel environment with the height of the river surface water. If upwelling is occurring, for example, water will be forced up the pipe, and a positive difference will be observed.

The piezometer consisted of a threaded 25 mm PVC nut that was drilled and fitted with a piece of flexible tubing long enough to rise above the river surface (Fig. 1). This tube was mounted on a 75 cm shaft, along with a second tube that extended down to the nut, but was open to river water. Fitted at the top of each tube were small plastic valves; between the tubes a ruler was mounted to measure the difference in water height.

The piezometer was screwed onto the top of an open standpipe and a 50 mm diameter plastic tube was lowered over it to block the river current so that readings were not susceptible to irregularities in river flow. The two valves were closed, and the shielding pipe was removed. When the tubes were turned to face downstream the difference in height was easy to read in the back-eddy created by the river current. The hydrostatic head (Δh) was simply the difference in height between the water in the tube connected to the top of the standpipe and water in the tube open at the river bottom.

Permeability

A pump system similar to that described by Terhune (1958) was used to estimate permeability by measuring the inflow into the standpipe due to a 25 mm reduction in water level at the surface. A brass marine pump with a 0.6 L chamber was connected to a 2 L graduated cylinder (Fig. 1). A 13 mm rubber hose led from the cylinder to a length of 13 mm copper pipe; a ball valve was used to control the flow into the cylinder. To estimate the inflow rate, the pipe was first lowered 25 mm below the water surface in the standpipe extension. Vacuum was initially generated in the cylinder with 2-4 strokes of the pump, and the valve was opened to allow inflow from the standpipe for a fixed length of time (usually 10 s). A slow rate of pumping was required to maintain sufficient vacuum. At the end of the time interval the hose was quickly removed from the standpipe and water in the hose was allowed to drain into the graduated cylinder before a reading of the inflow volume was recorded. To account for the water withdrawn during the initial 25 mm lowering of the water level in the standpipe, 13 mL were subtracted from the inflow total.

Inflow rates (Q, $mL \cdot 10s^{-1}$) from the permeability pump were converted to permeabilities (K), using the calibration curve of Terhune (1958) and Turnpenny and Williams (1982). To automate the calibrations, an empirical function was fit to data read from Fig. 6 of Terhune (1958):

$$\ln K = -15.383 + 11.602 \ln Q - 2.159 (\ln Q)^2 + 0.148 (\ln Q)^3$$

The complex shape of the function required the use of a third order polynomial, which fitted the data well ($r = 0.9997$, $P < 0.0001$).

Permeabilities were converted back to a reference temperature of 10°C using a viscosity factor (Terhune 1958):

$$K_{10} = f K_T$$

where f is the ratio of the viscosity at temperature T and the viscosity at 10°C. Using data provided by Cooper (1965),we derived an empirical function for f:

$$f = \frac{1}{0.7278 + 0.0270T}$$

The function was fitted using temperatures from 0-10°C ($r = 0.9998$); the parameters changed slightly (0.716, 0.0286) for temperatures ranging from 5 to 15°C.

Intragravel Flowmeter

In the original design of the standpipe flowmeter of Pollard (1955) and Terhune (1958) the flow of water in the gravel was estimated by injecting a coloured dye into the bottom of the standpipe, and monitoring its rate of dilution. Turnpenny and Williams (1982) modified this design by using a salt solution, and measuring its dilution with a conductivity bridge. Our design improves on this method through the use of a miniaturized field conductivity meter.

The flowmeter consisted of a 1 m, 22 mm diameter tube, with access slots cut in the side at the top and bottom (Figs. 1 and 2). A rubber stopper, shaped to insert into the bottom of the tube, formed a seal when the flowmeter was inserted in the standpipe. Holes were drilled in the stopper for the conductivity probe and a brass stirrer (Fig. 2). A 1 mL syringe was also inserted through the stopper; attached to the syringe plunger was a length of 3 mm brass rod that extended to the top of the flowmeter to serve as a push rod.

The conductivity meter was a model 72 from Engineered Systems and Designs, Delaware, USA, which has a probe 13 mm in diameter and 260 mm in length. The probe was inserted through the rubber plug at the end of the tube, and projected 18 mm into the dilution chamber. A 2.4 m lead extended from the probe to the top of the flowmeter, where it was connected to the meter box.

The stirrer was driven with a Tamiya miniature electric motor, which is available from hobby shops and comes with a set of planetary gears for reducing the driveshaft speed. With one 1.5 volt D cell and the transmission set to 240:1, the final stirrer speed was 0.6-0.7 rps. The motor, battery and on/off switch were mounted in a plastic sandwich box that was attached to the top of the flowmeter shaft. The stirrer driveshaft was a 3 mm brass rod, and was guided by brass tube bushings to the rubber plug at the bottom of the flowmeter. Mixing in the dilution chamber was achieved by bending the shaft to an 'S' shape. We also soldered a 3x3 mm piece of brass to the shaft that served as an extra paddle to circulate water past the conductivity probe (Fig. 2). Extensive trials with a standpipe mounted in a glass beaker using coloured dyes were needed to find the optimal stirrer shape and speed that was able to circulate the water in the dilution chamber, but not create excessive positive pressure that would increase the dilution of the salt solution.

We used a much weaker salt solution than Turnpenny and Williams (1982), to reduce the rate of diffusion of salt from the standpipe. A mixture of 2 g NaCl in 100 ml water, with 9.5 ml of 95% ethanol to correct the specific gravity, raised the conductivity about 1000 $\mu S \cdot s^{-1}$ when 1 mL was injected into the dilution chamber. It was critical that the salt solution be at river water temperature, or the difference in density affected the loss of salt solution from the chamber.

The procedure to measure dilution rate was as follows: first, the syringe was loaded with salt solution and the flowmeter was slowly lowered into the standpipe, through the extension tube. The stirrer was then started and a base conductivity measurement was recorded. The salt solution was injected, and the syringe plunger raised and lowered once more to ensure mixing in the dilution chamber. Conductivity readings were then taken every 5 or 10 s, depending on the rate of dilution, for 0.5 to 1.5 min. For very slow rates of subsurface flow an initial period of mixing (0.5 to 2 min) was required before measurements were taken. The dilution rate was estimated by the slope of the regression of $\log_e$-transformed conductivity on time. Normally the regression was conducted on the final 6 conductivity measurements after the initial mixing period. It is useful to examine plots of the data to ensure there is a constant rate of decay in the salt solution over time.

Flowmeter Calibration

Calibration followed the procedure of Terhune (1958). A 2 m long test flume was constructed and filled with mixed river gravel; four to six standpipes were buried in the gravel. Glass tubes inserted in the sides of the flume 2.4 m apart were used to estimate the slope of the water surface (Terhune 1958). The apparent velocity was estimated from the discharge and the cross section of the flume, and the permeability was derived from the slope and the apparent velocity (see Terhune for details). Flow measurements were made in the standpipes at apparent velocities ranging from 0 to 1200 $cm \cdot hr^{-1}$; 2-3 replicate measurements were made at each standpipe. Five different gravel mixes were used, ranging from a mixture of small pea gravel and sand to clean coarse gravel of the type found in artificial spawning channels.

The variability in replicate dilution rate measurements tended to increase with the mean; however, when log transformed, the variance was independent of the mean. The average within-standpipe variance (estimated by PROC VARCOMP in SAS [SAS inst. 1988]) for log-transformed slopes was $0.030 \cdot h^{-1}$ (SD = 0.17), corresponding to an average error for individual readings of about 18%.

The average dilution rate at zero velocity was $2.15 \pm 0.24 \cdot h^{-1}$, which is the loss rate of the salt solution due to the action of the stirrer and diffusion. This value was subtracted from the other dilution rates before the calculation of the calibration curve.

The results of the calibration trials are shown in Fig. 3. For many of the gravel mixtures an asymptote in dilution rate was reached at the higher flow rates. Terhune (1958) notes that at high flows, turbulence will break the relationship between dilution rate and interstitial water velocity. Also, for the coarsest gravel, the data deviated from the expected linear relationship at lower flows. Therefore, a number of data were not used in the fitting of the multiple regression predicting velocity as a function of dilution rate and permeability. In Fig. 3 the excluded points are those beyond the regression lines indicated. The fitted equation was:

$$\ln(V) = -7.555 + 0.860 \ln(D) + 0.803 \ln(K),$$

where V is the intragravel velocity ($cm \cdot h^{-1}$), D is the dilution rate (h^{-1}) and K is the permeability ($cm \cdot h^{-1}$). The explained variation was high ($r = 0.99$, $P < 0.0001$, $N = 25$), however for some of the test gravels the fitted line deviated slightly from the data. This is probably partially due to the difficulty in accurately determining the permeability of the test gravels; a difference in water levels of only 1-2 mm was observed in many cases because of the short length of the flume. In using this function, care must be taken in ensuring that the input data do not exceed beyond the range used in the regression equation, or very erroneous estimates of velocity will result.

Conclusions

The equipment described provides relatively simple means for the characterization of the movement of water through salmon redds. With the exception of an oxygen meter, the remaining devices can be constructed for well under $1000CDN. Some field results, detailing the distribution of variability for 15 standpipes located in chinook redds in Slim Ck. BC are shown in Table 1. Although there is considerable variation among pipes, reasonable estimates for the study site as a whole are possible.

Replicate variability for piezometric head and permeability are relatively low; the flow measurements are the most variable. For permeability measurements, the replicate variation (CV = 19%) is lower than reported by Young et al. (1989), but higher than values obtained using a gas-powered vacuum pump system developed by Mason et al. (1992). The number of replicates can be increased if more precise estimates at individual standpipes are required; this is probably the simplest alternative in remote locations where transporting a heavier pump system may be difficult. The variance estimates in Table 1 can also be used for power calculations for determining sample size in other studies.

With a crew of 3, the full set of measurements (subsurface flow, dissolved oxygen, water temperature, permeability, and hydraulic head) for 15 standpipes can be completed in 2-2.5 h, which is a considerable saving over the older dye-dilution method (Terhune 1958).

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References Cited

Cooper, A.C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. Int. Pac. Salmon Fish. Comm. Bull. 18:71p.

Lee, D.R., and J.A. Cherry. 1978. A field exercise on groundwater flow using seepage meters and minipiezometers. J. Geol. Educ. 27:6-10.

Leman, V.M. 1989. Classification of salmon (genus *Oncorhynchus*) redds in the Kamchatka river basin. J. Ichthyol. 30:148-158.

Mason, J.C., T. Sweeton and W.E. McLean. 1992. Modifications to improve the standpipe method of determining the permeability of spawning gravels for stream salmonids. Can. Tech. Rept. Fish. Aquat. Sci. 1877:11p.

Orchard, R.D. 1988. New method for measuring water seepage through salmon spawning gravel. U.S. Forest Serv. Res. Note PNW-RN-483, Portland, OR. 18p.

Pollard, R.A. 1955. Measuring seepage through salmon spawning gravel. J. Fish. Res. Board Can. 12:706-741.

SAS 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 1028pp.

Shirvell, C.S. 1989. Ability of phabsim to predict chinook salmon spawning habitat. Regulated Rivers: Res. & Mngmt. 3:277-289.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92:327-343.

Sowden, T.K., and G. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. Trans. Am. Fish. Soc. 114:804-812

Terhune, L.B. 1958. The mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Board Can. 15:1027-1063.

Turnpenny, A.W.H., and R. Williams. 1982. A conductiometric technique for measuring the water velocity in salmonid spawning beds. Water Res. 16:1383-1390.

Young, M.K., W.A. Hubert and T.A. Wesche. 1989. Evaluation of variation in permeability measurements when using the MARK VI standpipe. Can. J. Fish. Aquat. Sci. 46: 447-450.

Vronskii, B.B., and V.N. Leman. 1991. Spawning stations, hydrological conditions and survival of progeny in the redds of chinook salmon, *Oncorhynchus tshawytscha*, in the Kamchatka R. basin. J. Ichthyol. 31:282-291.

Table 1: Summary of intragravel data for 15 standpipes located in Slim Ck., B.C. Two replicates were taken, except for the hydraulic head data which were not replicated. Shown is the SD for both among and within pipe variation estimated by PROC VARCOMP (SAS 1988), and the percent of the total variability among replicates (i.e. measurement error). Units are mm for hydrostatic head, $cm \cdot h^{-1}$ for others.

Variable	Mean	SE	SD(pipes)	SD(reps)	% Variance within pipes
Hydrostatic head	9.47	1.20	-	-	-
Permeability	29724	3856	20703	5679	7
Intragravel Velocity	132.6	26.1	135.1	45.0	13

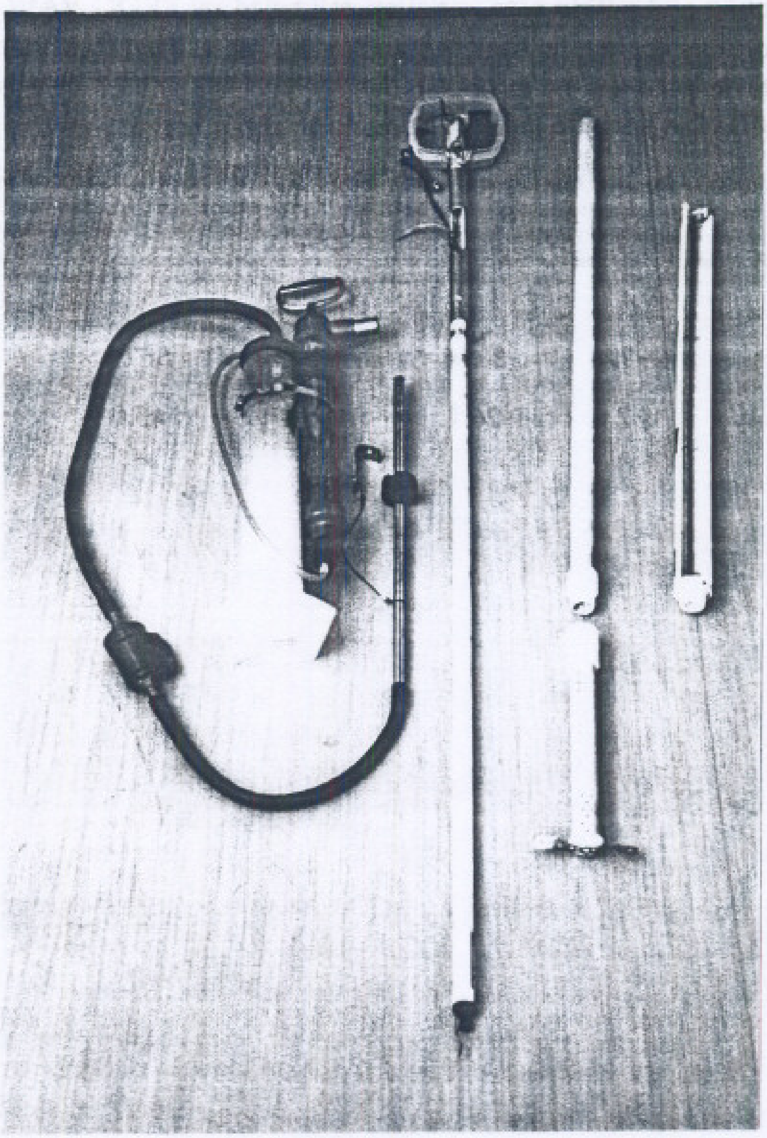

Figure 1: From left to right: the permeability pump, intragravel flowmeter with the plastic box containing stirring motor and batteries, standpipe with extension tube and the peizometer.

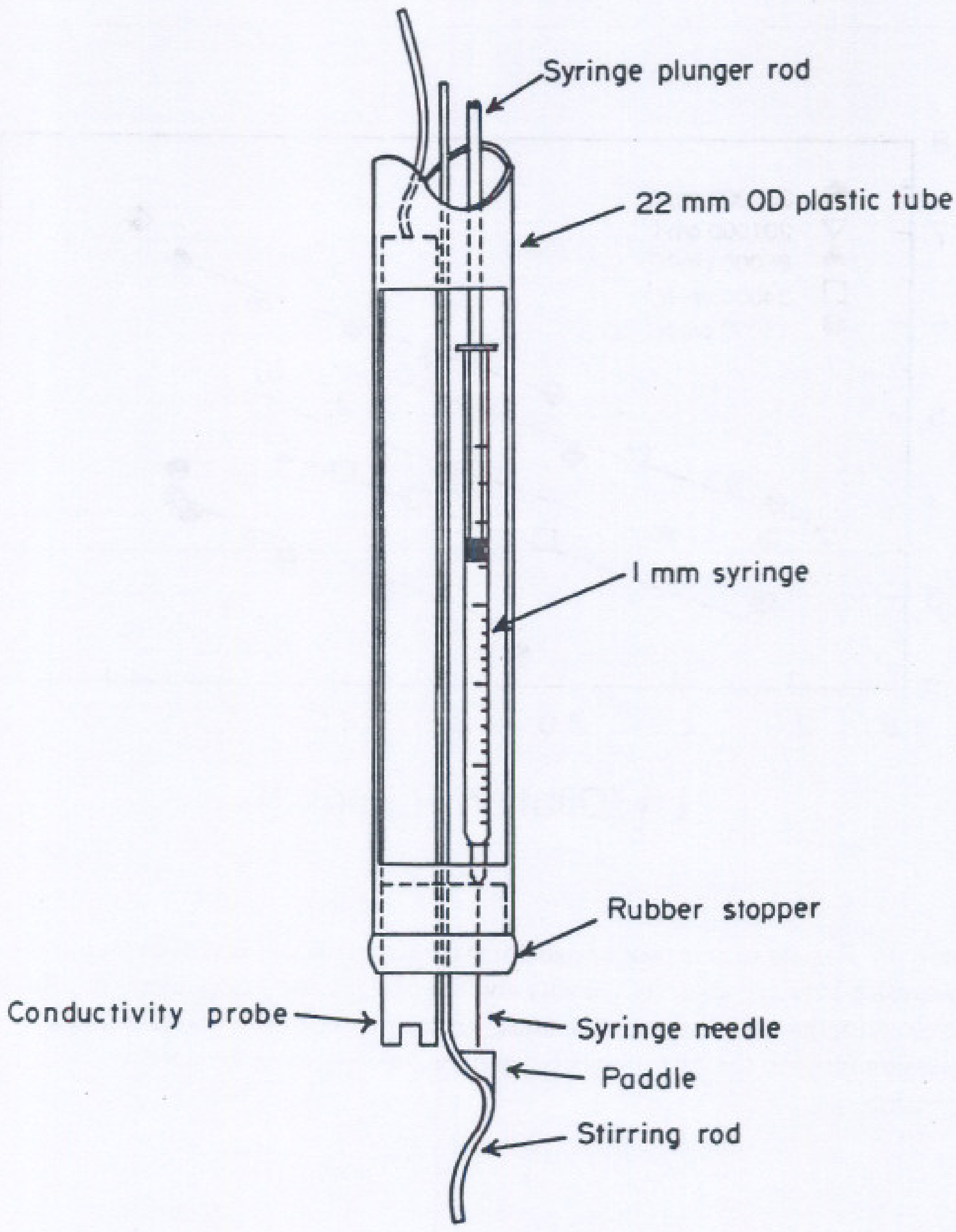

Figure 2: Lower end of the flowmeter, showing the conductivity probe and stirrer projecting from the bottom. Visible in the cut-out is the 1 mL syringe used to inject the salt solution.

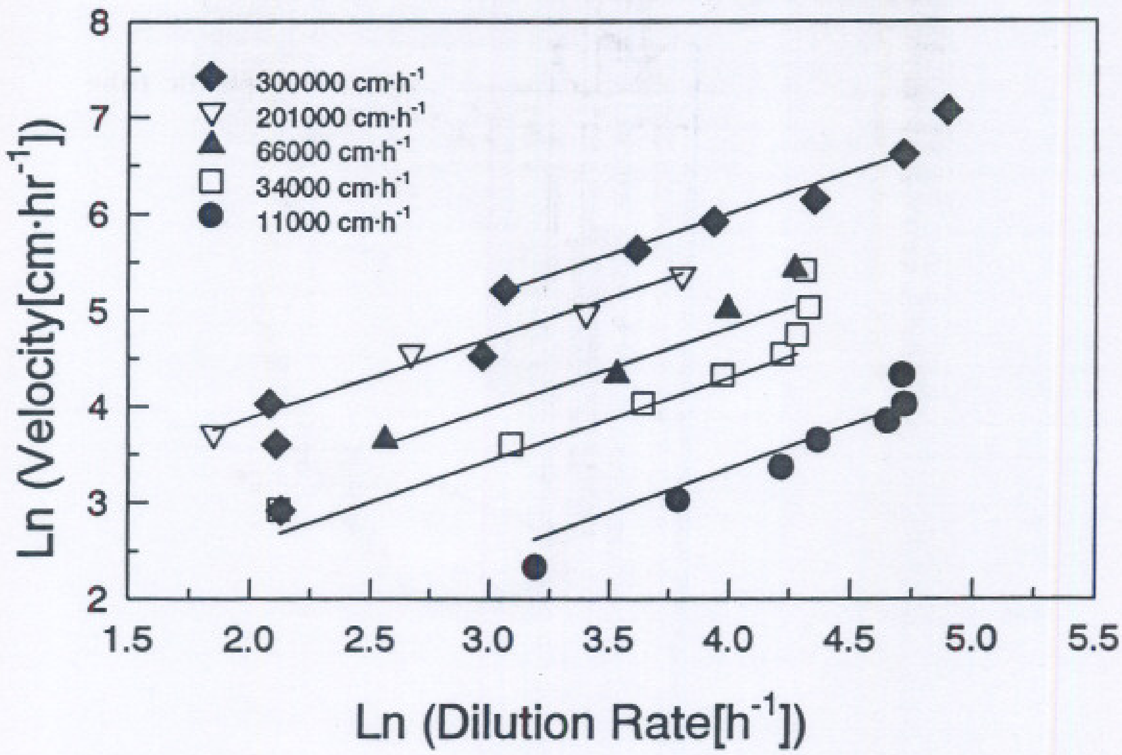

Figure 3: Results of calibration trials for the intragravel flowmeter. Shown is the relationship between apparent velocity and the dilution rate in $\log_e$ units (h^{-1}) for five gravels, with the indicated permeabilities. Lines are predicted from the multiple regression fitted to the data; points beyond the lines were not included in the regression.