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Evaluation of Variation in Permeability Measurements when Using the MARK VI Standpipe

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Using the MARK VI standpipe in a substrate-filled flume under constant flow conditions, we found significant differences in permeability readings made by different people at four of five sites. Coefficients of variation at each site ranged from 27 to 79%. Readings usually varied greatly for each person at each site. To detect a 10% change in the mean permeability at single sites (α = 0.05) would require from 34 to 90 samples; for a 30% change, the range was 4 – 10. Repeated sampling at a site did not produce directional changes in permeability estimates, nor did the performance of individuals change during the test. We propose a sampling strategy based on repeated readings taken by one person.

Avec une colonne montante MARK VI dans un canal rempli d'un substrat et où l'écoulement est régulier, on a observé des différences significatives dans les lectures de perméabilité faites par différentes personnes à quatre stations sur cinq. Les coefficients de variation par station s'étalaient entre 27 et 79 %. Habituellement, les lectures variaient considérablement selon chaque personne et selon chaque station. Pour détecter une variation de 10 % de la perméabilité moyenne à des stations uniques (α = 0,05), il fallait 34 à 90 échantillons. Pour une variation de 30 %, il en fallait de 4 – 10. Des échantillonnages répétés à des stations données n'ont pas produit d'indications de changements directionnels dans les évaluations de la perméabilité, et la performance des personnes qui ont fait les mesures n'a pas changé durant le test. Nous proposons une stratégie d'échantillonnage fondée sur des lectures répétées par une seule personne.

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The impact of fine sediment on salmonids has been studied for more than 60 yr (Harrison 1923). In a relation that is not precisely understood, increases in fine sediment lead to decreases in the embryonic intragravel survival of numerous species (Cordone and Kelly 1961; Iwamoto et al. 1978). Among the suggested influences of fine sediment on spawning substrates is a reduction in permeability (Cooper 1965).

Permeability and hydraulic head directly determine intragravel water velocity, as demonstrated by Darcy's Law (Pollard 1955). Estimates of permeability have focused on two methods, laboratory estimates based on permeameters (McNeil and Ahnell 1964) and field estimates based on the use of standpipes (Gangmark and Bakkala 1958). Because the laboratory estimates require that substrate be removed from a streambed, the true permeability cannot be measured because the substrate loses its instream arrangement and compaction (Pollard 1955). Consequently instream measurement of permeability is preferred.

Wickett (1954), Pollard (1955), and Terhune (1958) developed the standpipe method to measure permeability of the spawning substrates of salmonids. By applying suction in the standpipe at a point 2.5 cm below the surface of the water inside the pipe, the operator draws water through the perforated tip buried in the substrate. The volume of water collected is an index of the permeability of the substrate. Terhune (1958) demonstrated remarkable precision with this technique; coefficients of variation ($c(v)$ = standard deviation/mean × 100) ranged from 1 to 5%. In contrast, Pollard (1955) found greater scatter about the predicted mean permeabilities, and his test substrates seemed much more representative of salmonid redds than those of Terhune.

After evaluating the available techniques for directly or indirectly evaluating intragravel flow in salmonid redds, Chapman and McLeod (1987) suggested that the standpipe measurement of permeability was the most desirable method. Previous studies of salmonid spawning habitats have relied on this method of permeability estimation (Wickett 1958; Turnpenny and Williams 1980). Several investigators (e.g. Coble 1961; Hansen 1975) failed to demonstrate a relation between permeability and survival of salmonid embryos to emergence, despite the theoretical support for this relation (Shumway et al. 1964; Vaux 1968). Few researchers have reported means and variances for their measurements, apparently assuming that single readings were adequate descriptors of permeability (Koski 1966; Reiser and Wesche 1977). Our field observations of this technique

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TABLE 1. Means of permeability readings (mL·s^{-1}) for each combination of person and sampling site. All cell means are based on three observations per cell except cells I–3 (one observation) and V-1 (two observations). Sample standard deviations are given in parentheses.

	Site				
Person	1	2	3	4	5
I	2 (1)	23 (5)	12 (0)	27 (16)	38 (12)
II	4 (2)	15 (7)	57 (5)	45 (4)	38 (3)
III	5 (5)	21 (7)	42 (3)	39 (2)	23 (10)
IV	2 (2)	12 (9)	42 (6)	30 (15)	33 (6)
V	4 (0)	25 (2)	40 (4)	39 (2)	32 (5)
Means	3 (3)	19 (7)	43 (12)	36 (11)	33 (9)

made us less certain of its precision and led to the present laboratory study.

We wished to assess the variability in permeability estimates made by different people, at different sites, and through time under laboratory conditions. By replicating measurements by individuals at given sites, we hoped to estimate the precision of this technique.

Materials and Methods

We conducted the experiment from 0800 to 1200 on 18 May 1987. We used a 21.3-m flume, containing a substrate typical of that found in the Big Laramie River of southeastern Wyoming, in the Hydraulics Laboratory of the University of Wyoming Department of Civil Engineering. The materials and technique used for determining permeability closely followed those used by Terhune (1958). We drove a standpipe 25 cm into the substrate once at each of five randomly selected sites that had different substrate compositions and hydraulic characteristics (i.e. pools or riffles). Flow through the flume was 0.07 m^3·s^{-1}. Water temperature was held constant (at 18°C), since changes in water temperature alter viscosity and hence permeability (Terhune 1958).

Five people, with varying physical abilities and differing amounts of experience in using this technique, collected the samples. To collect a sample, a person pumped water for 5 or 10 s through a copper tube (inside the standpipe) into a graduated cylinder using a modified bicycle pump (Terhune 1958). The workers usually took three samples at each site; the sequence of sampling for each person and each site was randomized. Because one person took only one reading at site 3 and two readings at site 1, the total number of readings was 72. All analyses were performed on a standardized sample of discharge (mL·s^{-1}) into the graduated cylinder, less the 25 mL introduced by the sampling technique. We used two-way ANOVA, performed by the GANOVA-4 program (Courtesy of D. G. Bonett, Department of Statistics, University of Wyoming, Laramie, USA), to assess differences between people and sites; pairwise comparisons were made between all individual sampler combinations within sites and across all sites. Tests for runs up and down and binomial probabilities (Mosteller and Rourke 1973) were used to determine if permeability changed at each site through time. Finally, we calculated estimates of the sample sizes needed to detect possible changes of 10, 20, or 30% in the permeability means at each site (Sokal and Rohlf 1981). An α of 0.05 was accepted as indicating significance.

TABLE 2. Pairwise comparisons of samples taken by different individuals at each site based on F-tests (NS indicates no significant difference; * indicates significance at an $\alpha = 0.05$; ** indicates significance at an $\alpha = 0.01$).

		Person			
Site	Person	I	II	III	IV
1	II	NS			
	III	NS	NS		
	IV	NS	NS	NS	
	V	NS	NS	NS	NS
2	II	NS			
	III	NS	NS		
	IV	NS	NS	NS	
	V	NS	NS	NS	*
3	II	**			
	III	**	*		
	IV	**	*	NS	
	V	**	**	NS	NS
4	II	**			
	III	*	NS		
	IV	NS	**	NS	
	V	*	NS	NS	NS
5	II	NS			
	III	*	*		
	IV	NS	NS	NS	
	V	NS	NS	NS	NS

TABLE 3. Number of permeability samples necessary to detect potential changes of 10, 20, or 30% in the mean permeability ($\alpha = 0.05$) at the five sites.

	Sites					
Potential change (%)	1	2	3	4	5	Mean
10	90	68	38	44	34	55
20	23	17	9	11	9	14
30	10	8	4	5	4	6

Results

Mean permeability readings ranged from 3 to 43 mL·s^{-1} over the five sites; coefficients of variation at each site ranged from 27 to 79%. Means between individuals varied greatly within and between sites (Table 1). We were unable to detect overall differences among people by applying two-way analysis of variance, but we did identify significant differences among sites. A significant interaction between people and sites suggested that people performed differently at different sites. Nonetheless, when we transformed the measured values to ranks, we found the majority of people gave the same rank to a given site.

Pairwise comparisons of samples withdrawn by different people across all sites yielded only one significant difference (between samples collected by persons I and II), but pairwise comparisons of samples taken by different people at each site revealed several significant differences (Table 2). Only for site 1 did we find no significant differences between the samples removed by all possible pairs of individuals, which may be attributable to the variance associated with samples at this site rather than to a lack of differences between people. At site 3, seven of the 10 pairwise comparisons were significant, but a low single reading by sampler 1 influenced this result. Nonetheless, the samples withdrawn by each individual differed significantly from those taken by at least one other person at one or more sites.

Permeability did not exhibit a directional shift at any site during the experiment (test for runs, $P > 0.05$). The probabilities that readings by specific samplers at each site had successively increased (sample 1 < sample 2 < sample 3) or decreased (sample 1 > sample 2 > sample 3) were not significant. The number of samples needed to detect a 10% change in the mean permeability of a site varied from 34 to 90, to detect a 20% change, from 9 to 23, and to detect a 30% change, from 4 to 10 (Table 3).

Discussion

We demonstrated the need to take replicate samples for permeability estimates. Yet single samples taken at various intervals have been used to evaluate temporal variation in permeability (e.g. Reiser and White 1981). Typically, researchers attributed this variation to fluctuation in permeability, rather than to imprecision of the technique and the individual sampler (Moring 1982). Furthermore, sampling by different people at a single site should be cautiously interpreted, and we question the comparison of permeabilities between different streams when readings are collected by different people whose sampling biases are unknown (e.g. Moring 1982).

Terhune (1958) stated that the probable error in predicting mean permeability when using his calibration curve was 1.1%, and that a liberal allowance for error would be 10%. Conversion of our samples to permeability estimates by using the figure published by Terhune (1958) exacerbated the variability, since the calibration curve is based on a log–log plot and one performs the conversion graphically. Thus we believe that the standpipe technique is best adapted to assessing relative differences or changes, rather than providing precise estimates of permeability. Replicated readings by one person taken at various sites or times will probably reflect true changes in permeability.

Pollard (1955) suggested that permeability readings did not change over the course of sampling. Our results confirm this conclusion and suggest that individual samplers behaved consistently during the test, despite the strenuous sampling effort. From these perspectives, the standpipe method has potential for detecting temporal or spatial changes in permeability.

Proposed Sampling Strategy

We demonstrated limitations of the standpipe technique for measuring permeability, but we also identified advantages of this method and believe it can be successfully used to assess permeability. We offer the following sampling strategy:

(1) Drive a single standpipe into the specific location of interest, e.g. the egg pocket of a salmonid redd. If spatial differences are of interest, the standpipe can be removed after sampling. If temporal changes are of concern, then the standpipe should not be removed or disturbed because doing so could alter future readings.

(2) Select the percentage change in the mean permeability that one wishes to be able to detect. Our results suggest that about 15 samples should enable one to recognize a 20% change in mean permeability at an α of 0.05, but variability among sites may require a different number of samples to detect a similar change.

(3) One person should collect all the readings, following the technique developed by Terhune (1958). Intervals between sampling may vary, but all samples should be collected at similar water temperatures and flows.

(4) Results should be interpreted as an index of permeability, rather than as an accurate estimator.

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