Graph for estimating field-scale hydraulic conductivity sampling requirements

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Buckland, G. D. 1988. **Graph for estimating field-scale hydraulic conductivity sampling requirements.** Can. Agric. Eng. 30: 323–324. A graph for estimating the number of saturated hydraulic conductivity measurements required in field studies is developed and described. The graph assumes hydraulic conductivity follows a log-normal distribution. Approximate confidence intervals (95%) around a geometric mean hydraulic conductivity can also be easily determined. Use of the graph does not require knowledge of statistics.

INTRODUCTION

The saturated hydraulic conductivity (K_s) of a soil is important in soil-water studies related to irrigation and drainage. Obtaining reliable estimates of a mean K_s is difficult because K_s is a highly variable property (Warrick and Nielsen 1980) with the degree of variability depending upon soil type (Willardson and Hurst 1965; Topp et al. 1980). Because the variability in K_s is soil dependent, the number of K_s determinations should be based on the variability in K_s encountered in the field.

Dylla and Guitjens (1970) used statistical procedures to develop a graph to estimate sampling requirements. Their work was based on the assumption that K_s follows a normal distribution. However, it has been shown that K_s follows a log-normal distribution (Willardson and Hurst 1965; Nielsen et al. 1973; Lee et al. 1985); the appropriate mean K_s is therefore the geometric mean (Bouwer 1969). Use of an arithmetic mean (normal distribution) results in an overestimate of the mean K_s.

The purpose of this work was to develop a graph, based on a log-normal distribution, which is simple and suitable for estimating K_s sampling requirements in the field.

GRAPH DEVELOPMENT

The confidence interval around a geometric mean hydraulic conductivity ($\bar{K}_s$) is described by

$$CI = \overline{\log K_s} \pm t \left(\frac{SDL^2}{n} \right)^{1/2} \qquad (1)$$

where CI = confidence interval for log transformed data; $\overline{\log K_s}$ = mean of log transformed hydraulic conductivity, K_s; t = Student's-t, associated with $n-1$ degrees of freedom; SDL = standard deviation of log-transformed data; and n = number of K_s determinations. Use of either a log or natural log transformation is a matter of preference; either will result in identical geometric means and confidence intervals on data which has been transformed back to the original units.

Sample size requirements can be estimated using

$$n = t^2\, SDL^2/(\log D)^2 \qquad (2)$$

where D is the desired accuracy. For log-normally distributed means D is the half width of the desired confidence interval (Steel and Torrie 1980) when expressed in terms of transformed (i.e., logarithmic) data. When expressed in terms of untransformed (i.e., nonlogarithmic) data, D takes the form of a multiplication/division factor (Topp et al. 1980).

As an example, assume $\bar{K}_s$ was determined to be 1.0 m d^{-1} from 15 auger-hole tests. The calculated SDL was 0.4. The 95% CI by Eq. 1 is

$$CI = 0.000 \pm 2.145 \left(\frac{0.4^2}{15}\right)^{1/2}$$
$$= -0.222 \text{ to } 0.222$$

which, when untransformed

$$= 0.60 \text{ to } 1.67 \text{ m d}^{-1}$$

The desired accuracy (D) as a multiplier/divisor factor is 1.0/0.60 and 1.0 × 1.67 or 1.67. Substituting log (1.67) into Eq. 2 for D yields:

$$n = (2.145)^2\,(0.4)^2/(0.222)^2$$
$$= 15$$

which is the same number of predicted samples as samples which were taken. Thus, in the graphical solution to Eq. 2, as presented in Fig. 1, D is a multiplication/division factor relative to $\bar{K}_s$.

GRAPH USE

To illustrate the use of the graph the following example is given. Auger-hole K_s tests are to be conducted in an area to assist with the determination of subsurface drain spacing. In this case the number of auger-hole K_s tests (n) to produce an accuracy of 1.5 around the mean is required.

Five K_s determinations were conducted on the first day (Table I). $\bar{K}_s$ and SDL were calculated to be 0.13 m d^{-1} and 0.20, respectively (Table I). Using the graph, select a desired accuracy of 1.5, move to an SDL of 0.2, and read across to n = 8. Therefore, at least three more determinations are required to obtain the desired accuracy. Alternatively, with n = 5 and SDL = 0.2, read a desired accuracy of about 1.8. The 95% CI is 0.13/1.8 to 0.13 × 1.8 or about 0.07–0.23 m d^{-1}. Five addi-

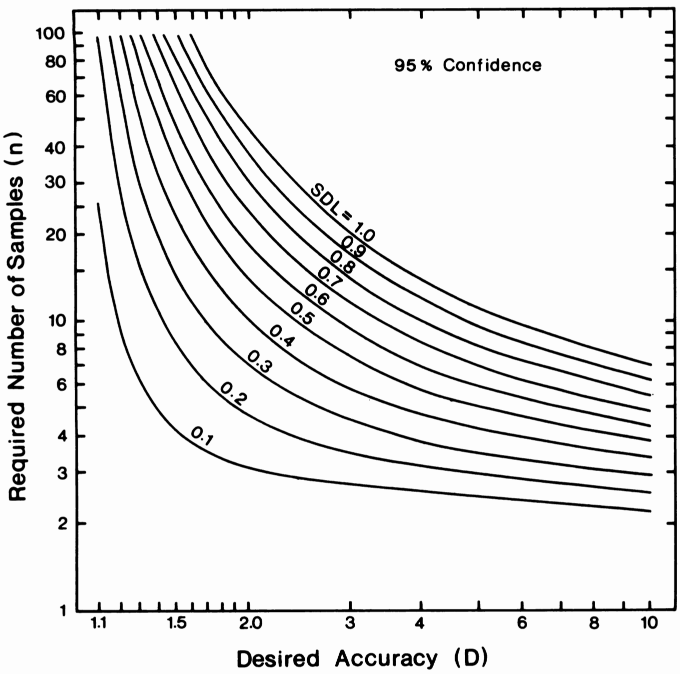

Figure 1. Graph for estimating hydraulic conductivity sample requirements.

tional K_s tests are conducted on the second day (Table I). Recalculation of $\bar{K}_s$ and *SDL* yield 0.13 and 0.24, respectively. For $n = 10$, the desired accuracy is 1.5 (from Fig. 1); hence, a sufficient number of determinations has been made. The 95% *CI* is 0.13/1.5–0.13 × 1.5 or about 0.09–0.20 m d^{-1}.

OTHER CONSIDERATIONS

The *SDL* of Fig. 1 is independent of the units in which K_s is expressed (e.g.: m d^{-1} or m s^{-1}). If a natural log (ln) transformation is used, the *SDL* of Fig. 1 can be multiplied by 2.3 to obtain the appropriate ln *SDL* (i.e., a log *SDL* of 0.1 corresponds to a ln *SDL* of 0.23).

Table I. Hydraulic conductivity determinations used in the example

n	K_s (m d^{-1})	log K_s	$\bar{K}_s$ of cumulative samples (m d^{-1})	*SDL* of cumulative samples
1	0.10	−1.00	–	–
2	0.24	−0.62	–	–
3	0.08	−1.10	0.12	0.25
4	0.12	−0.92	0.12	0.21
5	0.19	−0.72	0.13	0.20
6	0.25	−0.60	0.15	0.21
7	0.05	−1.30	0.13	0.26
8	0.07	−1.15	0.12	0.26
9	0.13	−0.89	0.12	0.24
10	0.21	−0.68	0.13	0.24

At least three samples are necessary to obtain an initial estimate of *SDL*. If the field is heterogeneous, stratified random sampling (Petersen and Calvin 1986) should be used to delineate areas of different K_s corresponding to different soils. This will result in a lower *SDL* for each soil type and thus a smaller *n* requirement for each soil type, but not necessarily a smaller *n* for the field.

Selection of *D* depends upon the intended use. For subsurface drainage studies Bouwer and Jackson (1974) suggest a $\bar{K}_s$ within 30% ($D = 1.3$) of the true field mean is reasonable. For variable soils, however, use of high accuracy (i.e., low *D*) may result in impractical or prohibitive sample requirements. For example, if $SDL = 0.4$ and $D = 1.3$, then $n = 50$. If *D* is increased to 1.5, however, then *n* decreases to 23. It therefore would require about one-half the time to determine $\bar{K}_s$ using $D = 1.5$ compared to $D = 1.3$. Because subsurface drain spacing is proportional to the square root of $\bar{K}_s$ (for example, see drain spacing equations cited by Buckland et al. (1987)), use of $D = 1.5$ compared to $D = 1.3$ would result in marginal sacrifice of confidence in drain spacing: that is $(1.5)^{1/2} \times 100 = 122\%$ versus $(1.3)^{1/2} \times 100 = 114\%$, or an 8% difference. Similar comparisons can be done using other *D* values.

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