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HYDRAULIC CONDUCTIVITY MEASUREMENT FOR SUBSURFACE DRAINAGE SYSTEM

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ABSTRACT

Hydraulic conductivity is an important parameter in the design of subsurface drainage system. The measurement of hydraulic conductivity is complicated by sampling size, distance between sampling points and methods of measurement. The objective of this study was to compare drainage system (Ks), Porchet (Kp), and saturated Porchet (Kps) for measuring hydraulic conductivity. Furthermore, the sampling distance and size for Porchet method was examined. The results indicated that the distance between measurement points should not be less than 300 m due to inter-dependency of the observations. The total number of observations for a 25% error tolerance was 138. The equation Kps = 0.46 + 0.39 Kp described the relationship between hydraulic conductivity measured by Porchet and saturated Porchet methods. The K value from the drainage system, Porchet, and saturated Porchet methods (previous equation) were 2.73, 4.48 and 2.2 m d^{-1}, respectively. Thus, for practical purposes in the study area, hydraulic conductivity can be measured by Porchet procedure and then the result can be converted to the saturated Porchet K value, which is nearly similar to the K value obtained from the drainage system.

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چکیده

هدایت هیدرولیکی یکی از عوامل مهم برای طراحی زهکشی زیر زمینی است. انـدازه گیری هدایت هیدرولیکی به علت مشخص نبودن اندازه نمونه، فاصلـه بیـن محـل هـای نمونـه بـرداری و روش های تعیین آن پیچیده است. در این پژوهش، روش های زهکش زیر زمینـی، پورشـه (Kp) و پورشه اشباع شده (Kps) برای اندازه گیری هدایت هیدرولیکی مقایسه شدند. هم چنیـن فاصلـه بیـن محل های نمونه برداری و تعداد نمونه، برای روش پورشه تعیین شد. نتایج نشان داد کـه بـه علـت وابسته بودن نمونه ها فاصله بین آن ها نبایستی از ۳۰۰ متر کمتر باشـد. بـرای خطـای ۲۵ درصـد، عدد ۱۳۸برای تعداد نمونه ها به دست آمـد. معادلـه Kps = 0.46 + 0.39 Kp رابطـه بیـن هدایـت هیدرولیکی حاصل از روش های پورشه و پورشه اشـباع شـده را نشـان مـی دهـد. مقـادیر هدایـت هیدرولیکی حاصل از روش های زهکش زیر زمینی، پورشه و پورشه اشباع شده (معادلـه قبلـی) بـه ترتیب ۲/۷۳، ۴/۴۸و ۲/۲ متر در روز بـود. بنـابراین، در مطالعـات صحرایـی، بـرای طراحـی زهکشی زیر زمینی در منطقه مورد نظر، ابتدا می توان هدایت هیدرولیکی را از روش پورشه تعییـن و سپس آن را به ضریب K مربوط به پورشـه اشـباع شـده تبدیـل کردکـه تقریبـا" برابـر ضریـب K بدست آمده از روش زهکش زیر زمینی است.

INTRODUCTION

The design spacing between the lateral drains determines the efficiency of subsurface drainage which requires the saturated hydraulic conductivity of soil. Some efforts have been made in measuring saturated hydraulic conductivity for subsurface drainage design in Khuzestan province, Iran, by different procedures (4, 5). However, the measurement of hydraulic conductivity is complicated by its high spatial variability, especially in alluvial soils and is a time-and labor-consuming task.

Very little information is available on the sampling size, distance between sampling points and the methods of K measurement in the study area. Gallichand *et al.*(3) used the geostatistics to improve the representation of K for subsurface drainage design.

The best choice of method(s) for the K measurement must optimize several interrelated factors including accuracy, speed, simplicity, variability, manpower and capital cost (1). With these criteria in mind, this research compares three techniques for measuring Ks for a drainage design. These methods are drainage system (2) Porchet and saturated Porchet (6).

MATERIALS AND METHODS

This study was conducted at the Kooshkak Agricultural Experiment Station, College of Agriculture, Shiraz University, located 60 km north of Shiraz, Iran. The soils are predominantly silty clay loam to clay loam of alluvial origin (8). A subsurface drainage system was installed in this area about two decades ago. The distance between drains is 88 m with drain depth and diameter of 1.65-2.35 m and 0.3 m, respectively. Drain length and slope are 1165 m and 0.0022 m m^{-1}, respectively. At each side of three manholes along the drain (at the beginning, in the middle, and at the end) bore holes (2.3 m depth) were installed. The walls of these holes were reinforced by PVC tubes with 5 cm inside diameter. The distance between PVC tube and the hole wall was filled with sand filter. The water table depth in bore holes was measured by an electrical sensor and the discharge of water at the outlet of drain was measured by volumetric procedure. These measurements were made at different times after each rain during winter of 1991.The amount of rain was also measured at the meteorological station located in the experimental area.

Saturated hydraulic conductivity (Kp) was measured in the summer of 1991 at 70 points on 50×50 m grids in 2 m bore holes using the inverted-hole method of Porchet without any water infiltration before measurement (6). The hole diameter was 9 cm and the wall was reinforced by PVC tube with holes of 6 mm diameter on the tube wall with 2.5×2.5 cm grids. The total area of holes on the tube wall was about 5% of total area. A 10-cm layer of sand filter was placed at the bottom of bore holes. The ground water was used for Kp measurements and the chemical properties of this water are shown in Table 1.

Table 1. Some chemical properties of the ground water.

EC, dS m^{-1}	1.2
Sum of anions, meq l^{-1}	8.27
Sum of cations, meq l^{-1}	11.97
Sodium adsorption ratio	2.25
Water type	chloride-carbonate

Saturated hydraulic conductivity (Kps) was measured at 6 of these bore holes after 7 hr of water infiltration by the inverted hole method of Porchet (6). This method is called "saturated Porchet".

In all of the K measurements, water temperature was measured by a thermometer to adjust the measured K to the K value at 20° C by using water viscosity ratio at measured temperature of water and 20° C.

Theory

K from drainage system. The solution of Boussinesque equation has been reported by Dieleman (2) as follows:

$$q(t) = (8R/\pi^2)[(-\exp(-t/j))+(\exp(-(t-tr)/j)] \quad [1]$$

$$h(t) = (4Rj/\pi\mu)[(-\exp(-t/j))+(\exp(-(t-tr)/j)] \quad [2]$$

in which:

q(t)=discharge intensity (m d^{-1}), h (t)=hydraulic head in middle of the drains (m), R=recharge intensity (m d^{-1}), tr = duration of steady recharge (d), t = time from beginning of recharge (d) and μ = drainable porosity.

$$j = (1/a)=(\mu L^2)/(\pi^2 Kd) \quad [3]$$

in which:

j = storage coefficient (d), d = equivalent depth (m) and L = drain spacing (m). The Eqs. [1] and [2] are valid at t greater than tr+0.4j. Replacing $t=t_1$ and t=t2 greater than tr+0.4j in Eqs. [1] and [2] will result:

$a = (l/j)=[\ln q(t_1)-\ln q(t_2)]/(t_2-t_1)$ [4]

$a = (l/j)=[\ln h(t_1)-\ln h(t_2)]/(t_2-t_1)$ [5]

Then, by using Eq. [3] and L, μ and d the field hydraulic conductivity was obtained.

Semivariogram

For further analysis, it is necessary to identify the spatial correlation structure from the experimental semivariogram, which shows the relationship between the semivariance and the distance between sampling pairs.

$$\gamma^*(h) = (1/2n)\sum_{i=1}^{n} [z(xi) - z(xi+h)]^2 \qquad [6]$$

where $\gamma^*(h)$=estimated value of the semivariance for lag(h); n = number of sample pairs separated by h; z(xi) and z(xi+h) = values of variable z at xi and xi+h, respectively; xi, and xi+h = position in two dimensions; and h =distance vector between sample points (lag).

Observation Number for K Measurement

Here the question is that with confidence level of α and a given tolerance for error, how many measurements in a sample should be taken. The number of measurements in a sample can be determined by the following equation:

$N=(X^2_{\alpha}\cdot \sigma^2)/e^2$ [7]

in which e is the tolerance for error (difference between the real value of mean and measured mean of sample), σ^2 is the sample variance and $X\alpha$ is related to probability for the confidence level , α, obtained from t-student table (11) . Log-normal distribution has been considered in this analysis.

RESULTS AND DISCUSSION

The hydraulic conductivity by Porchet procedure (Kp) in the area ranged from 0.05 to 18.39 m d^{-1} with a mean of 4.48 m d^{-1} and variance of 22.7 (m $d^{-1})^2$ and skewness coefficient of 1.378 (m $d^{-1})^3$. The high positively skewed distribution of Kp can be observed in Fig. 1. The mean and variance in log-transformed observations were 0.85 and 1.62 (Fig. 2). The Kp data were found to be better described by log-normal frequency distribution than by the normal frequency distribution (7).

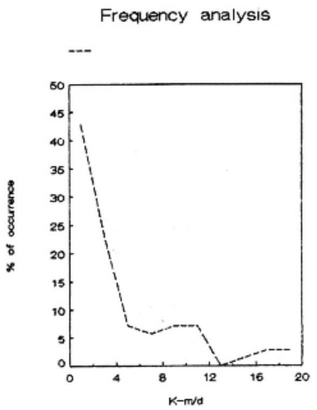

Fig. 1. Distribution of 70 hydraulic conductivities measured by the Porchet procedure.

Semivariogram

The shape of experimental semivariogram in Fig. 3 suggested an exponential model. The exponential model which best fitted the experimental semivariogram (R^2 =0.998) is represented by the curve in Fig. 3 as follows (12):

$$\gamma^*(h) = C_o + C_1 \, [1\text{-}\exp(-h/a_o)] \qquad [8]$$

Semivariogram analysis was carried out on the natural logarithm transformation of the hydraulic conductivity [Y=ln K].

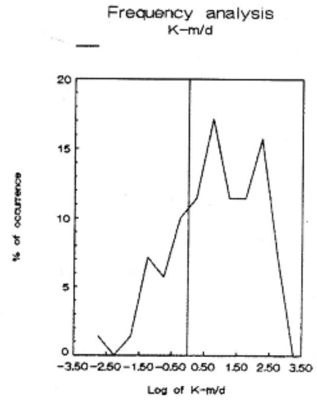

Fig. 2. Distribution of 70 log-transformed values of hydraulic conductivities measured by Porchet procedure.

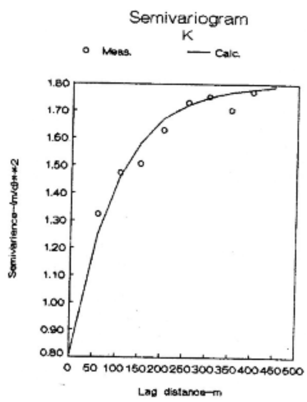

Fig. 3. Experimental and calculated semivariogram for hydraulic conductivity measured by Porchet procedure.

The nugget effects (C_o) reflects measurement errors and variations that occur over distances shorter than the sample spacing. The high nugget effect is most likely the result of the high variability of the hydraulic conductivity for the heavy soils in the project area.

For the exponential model, a_o is a range parameter equal to one-third of the apparent range (A), which represents the intersample distance with significant autocorrelation. The following equation has been obtained for semivariogram:

$\gamma^* (h) = 0.8+1.0[1-\exp(-h/100)], R^2 = 0.998$ [9]

in which the nugget effect (C_o) is 0.8 $(m\ d^{-1})^2$, the sill (C_o+C_1) is 1.8 $(m\ d^{-1})^2$ and the apparent range value (A) is 300 m.

Sample Size

By the confidence level of 95% (α = 0.05), the probability is 97.5 [F(x)=1-1/2(0.05)] and the corresponding $X\alpha'$ is 1.96 from Student's t table (11). With the error tolerance of 25% (0.25×mean) the number of observations in a sample is 138. The number of observations for different error tolerances are shown in Table 2. As the error tolerance decreases, the number of observation increases.

Table 2. Number of observations as a function of error tolerance.

Error tolerance %	Number of observations
5	3445
10	861
15	383
20	215
25	138

K from Drainage System

The ratio of total rainfall before water table descending to the hydraulic head at the point between drains was considered as drainable porosity. These values varied between 0.0586 to 0.087 (Table 3, mean = 0.073, and SD = 0.012) as measured in bore holes A to F. These values are comparable to those measured by hanging column under tension of 100-150 cm of water in core samples from depth of 0-60 cm as 0.067 (9).

Table 3. Drainable porosities and reflection coefficients at different bore holes.

Bore holes	Drainable porosity	Reflection coefficient (1/j) d^{-1}
A	0.067	-
B	0.075	0.16*
C	0.062	0.15*
D	0.059	0.31*
E	0.086	0.31*
F	0.087	0.27*
Mean	0.073	0.24
Standard deviation	0.012	0.079
From q-t		0.34

* These values were obtained from h-t relationships.

Considering the L=88 m, D (distance between drain and the impermeable layer below it) = 10 m, drain diameter of 30 cm (ID) and trench width of 40 cm, the wetted perimeter was estimated as 1.1 m. So, by using the Ernest formula (10) the equivalent depth was estimated as 6.1 m.

Timely variation of drain discharge and hydraulic head at points between the drains (in bore hole C, as sample) are shown in Figs. 4 and 5. Since the Eqs. [4] and [5] are valid at tr+0.4j, therefore, the slope of descending limb (reflection coefficient, a d^{-1}) were obtained by regression analysis. The mean values of reflection coefficient from h-t and q-t relationships were 0.24 and 0.34 d^{-1}, respectively, with an overall mean of 0.29 d^{-1} (Table 3).

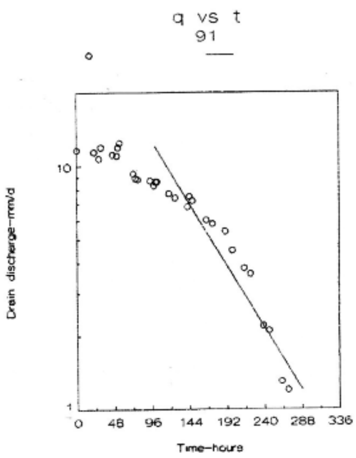

Fig. 4. Variation of drain discharge with time.

Considering the above parameters in Eq. [3], the values of Kd and K were obtained as 16.6 $m^2 d^{-1}$ and 2.73 $m d^{-1}$, respectively.

K from Saturated Porchet

The measured values of K by saturated Porchet (Kps) with the corresponding K values measured by Porchet procedure (Kp) in the same bore holes are shown in Fig. 6. The regression analysis resulted in the following equation:

$$Kps = 0.46+0.39Kp, \quad R^2 = 0.936, \quad P<0.001 \qquad [10]$$

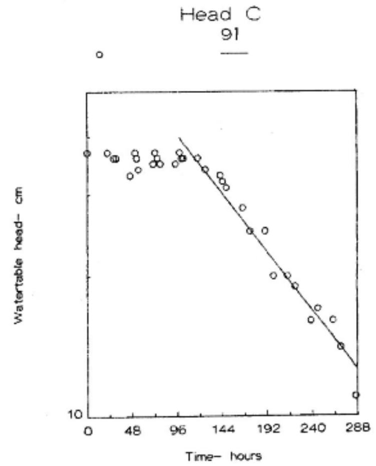

Fig. 5. Variation of hydraulic head at the mid point between drains with time.

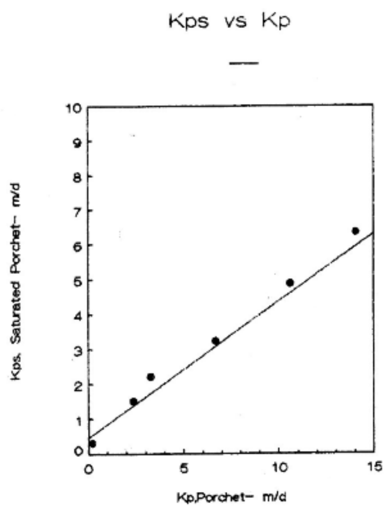

Fig. 6. Relationship between Kps (saturated Porchet) and Kp (Porchet).

The mean value of Kp (4.48 m d^{-1}) results in a Kps value of 2.21 m d^{-1} from Eq. [10]. This value is comparable with that obtained from drainage system as a whole (2.73 m d^{-1}). Therefore, when K measurement from a drainage system is not possible in a similar area, it may be measured by the Porchet procedure and then be converted to the Kps by Eq. [10]. In this way, a K value close to the K value from drainage system may be obtained.

CONCLUSION

For practical purposes in the study area, K value can be measured by Porchet procedure and then it may be converted to the saturated Porchet value by Eq. [10] which is nearly similar to the K value from a drainage system. The distance between measurement points should not be less than 300 m due to the inter-dependency of the observations. The total number of observations for 25% error tolerance was 138.

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