FIELD EVALUATION OF AN INDIRECT METHOD TO ESTIMATE SATURATED HYDRAULIC CONDUCTIVITY

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ABSTRACT

Obtaining accurate saturated hydraulic conductivity values for drainage system design purposes is time consuming and expensive. A unique, indirect estimation method based on visual inspections of undisturbed soil cores from unmeasured soil sites by six persons and previously measured nearby conductivities explained about 50 % of the variations in subsequently measured conductivity data values. The indirect method produced a mean estimated conductivity value that was 28 % smaller than the mean measured value.

Keywords

Conductivity, estimated, field, hydraulic, indirect, saturated

INTRODUCTION

Accurate measurements or estimations of saturated soil hydraulic conductivities are critical for the optimum design of subsurface drainage systems. Drain spacing relationships are of marginal value without the availability of reliable conductivity data. Estimation of field hydraulic conductivity values for soils found in the Lake Plain area in the northern part of the James River Valley of east-central South Dakota is the subject of this paper.

An irrigation project, designated as the Oahe Unit, was proposed for the Lake Plain area (Bureau of Reclamation, 1973). One unique project feature of the proposed irrigation project was the simultaneous installation of a subsurface drainage system and a water distributions system before actual water deliverance to the project area. Soils in the Lake Plain area were derived mainly from silty lacustrine (lakebed) sediments. Project lands were designated for areas where sediments varied from 3 to 12 m in thickness overlying a glacial till. Drainage system installation prior to project water delivery was deemed necessary because drainage system construction costs were anticipated to be prohibitive after the establishment of a water table due to unstable coarse silt materials and very fine sand located about 2 m below the soil surface.

In response to the need for pre-water delivery installation, the Bureau of Reclamation assigned a team of drainage engineers to assess the drainage characteristics of Lake Plain soils. Since direct in-place measurements of saturated hydraulic conductivity is a laborious and expensive process, the Bureau initiated a special program to evaluate an indirect method for conductivity estimation. The objective of this paper is to assess the feasibility of using a visual inspection of undisturbed Oahe Unit soil samples and knowledge of previously measured values from nearby sites to estimate field hydraulic conductivities.

PREVIOUS WORK

Indirect methods of soil hydraulic conductivity estimation have been used for many years with initial approaches based on utilizing physical properties to estimate conductivity. Baver (1939) found a correlation between pore-size distribution and hydraulic conductivity. Aronovici (1946) established a correlation between percent sand and hydraulic conductivity for silt loam to sandy soils in the Imperial Valley of California. Incorporation of detailed field description of soil structure along with soil pores and texture was used as the basis for placement of soils into seven permeability classes ranging from very slow (less than 0.03 m/d) to very rapid (6.0 m/d or more) for soils at 182 locations in the USA (O'Neal, 1952). A more recent study by Suleiman and Ritchie (2001) dealing with the use of effective soil porosity (total porosity minus field capacity) to estimate saturated hydraulic conductivity shows a great deal of promise.

Direct methods have been used to assess the accuracy of indirect methods. Auger hole and pump-in (sometimes called well permeameter) methods are routinely used for measuring soil hydraulic conductivity in the field. Both methods have the limitation of evaluating a relatively small soil volume and conductivity values reflect predominately horizontal flow characteristics (Bouwer and Jackson, 1974). Results of previous studies have shown that the pump-in method produces smaller conductivity values than the auger hole method and that the auger hole values compare favorably with drain line derived conductivities (Table 1). The ratio of pump-in to auger hole values was found to be approximately 0.50 by DeBoer (1979) and Talsma (1960 and 1987) and 0.85 by Winger (1960). The DeBoer (1979) research site, located within the Oahe Unit area, contained a laminated silty clay loam soil above an unconsolidated coarse silt loam material. An auger hole and pump-in comparison was done in the upper laminated portion of the soil profile while the drain line (falling water table condition) and pump-in comparison was done in both segments of the profile because the drain line was positioned in the lower unconsolidated and unstable part of the profile. The Lembke (1967) study site was adjacent to the DeBoer site and a ponded, steady state condition was used to determine the drain line conductivity.

Table 1. Comparison of pump-in, auger hole and drain line derived hydraulic conductivities under field conditions.

Reference	Pump-in	Auger Hole
Broughton and Tu (1975)		~ 0.5 drain line
Camp (1976)		~ 1.0 drain line
DeBoer (1979)	~ 0.5 auger hole	
	~ 1.0 drain line	
DeBoer and Johnson (1967)		~ 1.0 drain line
Hoffman and Schwab (1964)		~ 2.0 drain line
Johnson et al. (1963)		~ 1.0 drain line
Lembke (1967)		~ 0.7 drain line
Talsma (1960, 1987)	~ 0.5 auger hole	
Winger (1960)	~ 0.85 auger hole	

MATERIALS AND METHODS

Bureau of Reclamation drainage engineers with a minimum of two and a maximum of four years field experience conducted the field drainage investigations (Bureau of Reclamation, 1974). Drill crews initiated the field investigations by digging pilot bore holes that were logged and used to delineate areas where the subsoils appeared to be uniform for "in-place" hydraulic conductivity tests. One criterion used in the selection of a test site was that it contained at least a 0.75 m horizon of uniform soil because the conductivity tests were conducted with a 0.6 m test zone and required a minimum of 0.15 m of the same uniform soil below the bottom of the test zone. Test zones varied from 1.2 to 5.7 m below the soil surface.

Very few of the field conductivity tests were conducted where water tables or saturated soil conditions were present when single auger pump-out tests were used. Shallow well pump-in tests (constant head) were used to obtain saturated hydraulic conductivities in the absence of water table conditions (Bureau of Reclamation, 1978). Hence, the data sets used in this paper should be considered as pump-in data sets. Ten-centimeter diameter holes were used for all field tests.

Five-centimeter diameter, undisturbed soil cores from the center of the 0.6 m test zone were used for inspection by the field drainage engineers to make estimates of saturated hydraulic conductivity values. Each of six individuals made an estimate of the conductivity before each field test was conducted. Results of completed tests were then made available to the engineers before another test was initiated. The engineers were provided an opportunity to develop their estimation skills during the 1972 field season. Field data sets composed of measured and estimated conductivity values collect during 1973 and 1974 were used for this paper. Even though the field data sets are about 30 years old, reliable data sets such as these that reflect unchanging field conditions are difficult to obtain.

RESULTS AND DISCUSSION

Drainage engineer estimates explained 51% (R^2 = 0.51) of the 1973 and 1974 measured field data on the average (Table 2). The average standard deviation (error) of estimate for all six regression relationships was 0.164 m/d. A plot of the 1973 and 1974 data sets for person #1 is presented in Figure 1. A large portion of the data points lay below the line of equality (1:1) which indicates that estimated values tended to be smaller than measured values. This estimate bias for person #1 is evident when the mean of the measured data set is 0.300 m/d while the mean of the estimated data set is 0.224 m/d for a difference of -0.076 m/d (Table 2). All six persons had data sets similar to the person #1 data set with an overall average of 0.302 m/d for the measured values, 0.215 m/d for estimated values and a difference of -0.086 m/d. This -0.086 m/d difference represents about 28 % of the measured mean value. Such an under (conservative) estimate of hydraulic conductivity would be expected to produce a 15 % reduction in drain line spacings. In addition, standard deviation values of the engineer estimated data sets were consistently smaller than the measured hydraulic conductivity data sets (Table 2).

Table 2. Measured and estimated hydraulic conductivities "K" (m/d) for the 1973 and 1974 data sets.

PERSON	DATA SET SIZE	REGRESSION		MEASURED "K" DATA SET		ESTIMATED "K" DATA SET		DELTA "K"	STD DEV FROM 1:1 LINE
		R^2	STD DEV	MEAN	STD DEV	MEAN	STD DEV		
1	555	0.52	0.187	0.300	0.434	0.224	0.269	-0.076	0.313
2	468	0.58	0.158	0.303	0.453	0.224	0.243	-0.078	0.320
3	469	0.44	0.189	0.303	0.460	0.224	0.252	-0.079	0.358
4	472	0.41	0.178	0.302	0.461	0.212	0.233	-0.090	0.369
5	504	0.63	0.127	0.304	0.450	0.207	0.209	-0.097	0.325
6	483	0.49	0.145	0.299	0.451	0.201	0.204	-0.098	0.353
MEAN		**0.51**	**0.164**	**0.302**	**0.452**	**0.215**	**0.235**	**-0.086**	**0.340**

There was consistency among the engineer-estimated values with a range of 0.201 to 0.224 m/d and an overall average of 0.215 m/d. A concentration of data values exists for measured values of 1.0 m/d or less. Figure 2 shows a magnified view of the 1974 data using values less than 1.0 m/d for person #1. The under estimate bias is also evident for these values at the smaller end of the data spectrum with a mean estimated value of 0.240 m/d in contrast to a mean measured value of 0.317 m/d. A similar trend was found for the 1973 data set.

The 1974 data were recorded and grouped into 21 weekly data sets for time trend analyses. It was assumed that the drainage engineers would have honed

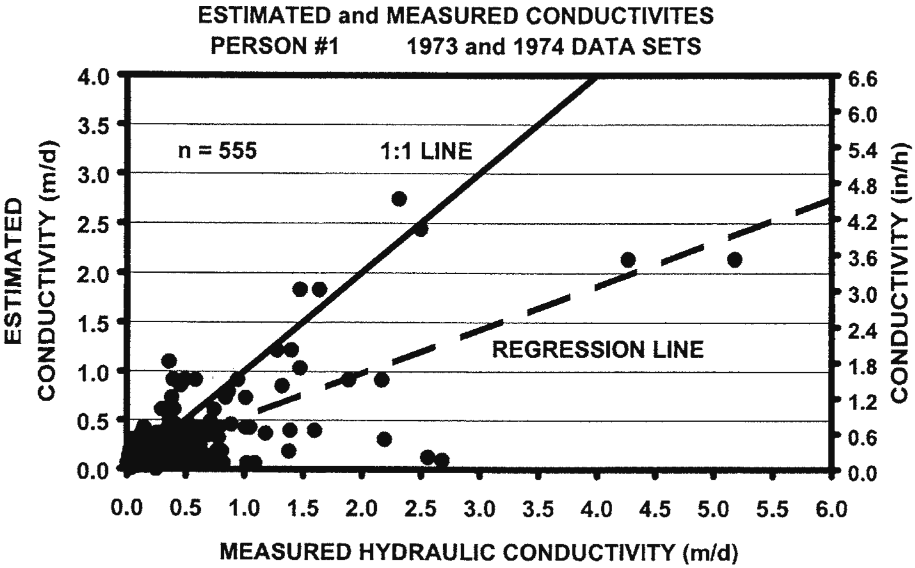

Figure 1. Estimated hydraulic conductivity values for person #1 versus measured conductivity values using the combined 1973 and 1974 data sets.

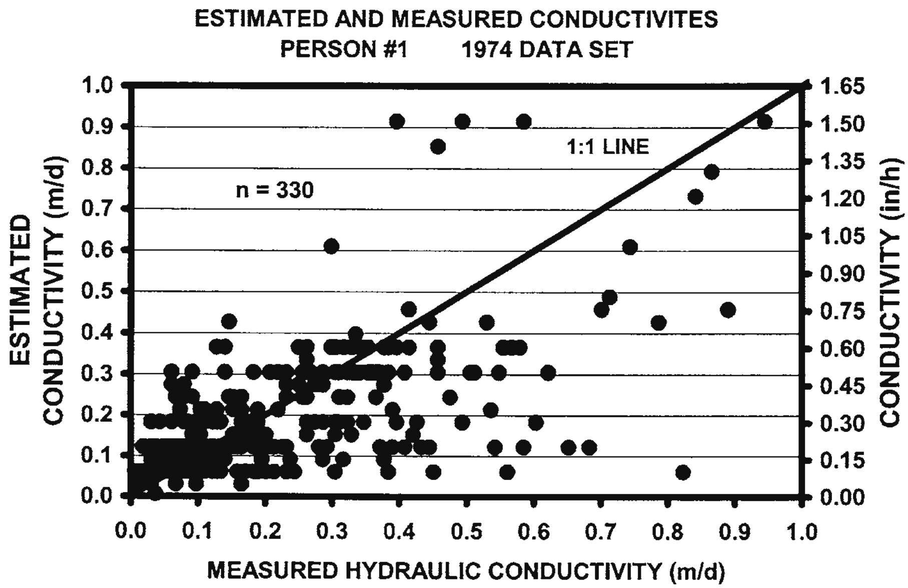

Figure 2. Estimated hydraulic conductivity values for person #1 versus measured conductivity values of less than 1.0 m/d for the 1974 data set.

their estimation skills after their 1972 and 1973 field experiences. Variations in mean weekly measured and estimated conductivity values for person #1 are illustrated in Figure 3 with values ranging from 0.1 to 0.6 m/d. Mean estimated

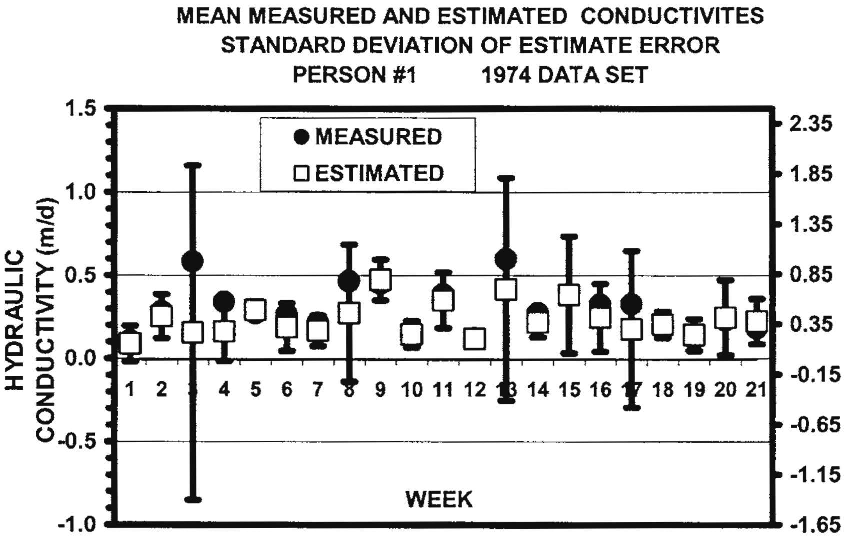

Figure 3. Mean measured and estimated weekly hydraulic conductivity values and standard deviation of estimated error for person #1 and the 1974 data set.

values are consistently equal to or less than measured values. Standard deviation of estimate errors are also presented in Figure 3 with large variations in values ranging from 0.05 m/d for weeks 5 and 12 to 1.0 m/d for week 3. The large standard deviations are associated with measured values equal to or greater than 0.5 m/d. Data sets for the other five persons were similar to the person #1 data set. No time trends with regards to changes in standard deviations of estimated errors are evident from the data presented in Figure 3 which indicates a lack of estimation improvement over time.

Engineer-estimated hydraulic conductivity values tended to be conservative when compared with measured pump-in derived values, which will cause design drain line spacings to be smaller than if measured values were used. In addition, pump-in values on the average, tend to be much smaller than auger hole derived conductivity values (Table 1). So a drainage system designed on the basis of pump-in and/or engineer-estimated conductivity values would have a probability of success due to the conservative nature of the average conductivity values.

While the smaller "engineer-estimated" values were on the conservative side, natural variations in soil conditions can only be accommodated by measuring the conductivity for a soil mass larger than that represented by a 5-cm soil core. The drain line method (Hoffman and Schwab , 1964) produces an integrated conductivity value over a large soil volume while the auger-hole methods measure the conductivity for a soil mass many times the size of a soil sample. An indirect method, such as presented in this paper, should only be used by drainage professionals who have extensive field experience.

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