INFILTRATION DATA AND FUNCTIONS, AND SOIL MOISTURE AND MATRIC POTENTIAL DATA DURING WETTING FOR SELECTED SOILS IN THE OAKES AREA,

Dickey County, North Dakota

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Water Resources Investigation No. 18-A
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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

Page

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

Page

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

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INTRODUCTION

During 1984-85 the North Dakota State Water Commission Appropriations Division conducted a field study to collect data for a comprehensive set of soil hydraulic properties and parameters on 11 sites near Oakes, in Dickey County, North Dakota (Fig. 1). The purpose of the data collection was to provide high quality input for modeling studies of natural and artificial recharge. The data-acquisition program was designed to be comprehensive, and to have broad utility, including potential incorporation into a larger state, national and international user base. Data collected included: (1) site description, (2) soil morphology and classification; (3) in-situ measured unsaturated hydraulic conductivity [K (θ/ψ)], water retention (θ/ψ) and diffusivity [$(D(\theta)$] in 6 to 12 inch (15 to 30 cm) depth increments; (4) laboratory water-retention curves, including 15-bar gravimetric water content for each depth increment; (5) laboratory unsaturated hydraulic-conductivity and diffusivity functions for the dry range for each depth increment; (6) soil physical data, including particle-size distribution, organic carbon and bulk density for each depth increment; (7) soil saturation extract water chemistry, including calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, electrical conductivity, sodium-adsorption ratio, saturation water content, and pH for each depth increment; and (8) in-situ infiltration. Except for infiltration data, these were published as North Dakota State Water Commission Water Resources Investigation No. 18 (Schuh, Cline and Sweeney 1991). Many of these data are now included in the EPA's national data-base, compiled by the USDA National Salinity Laboratory, Riverside CA. Eleven sites were measured (labeled A-K) at locations shown on Fig. 2. Site descriptions are on Table 1.

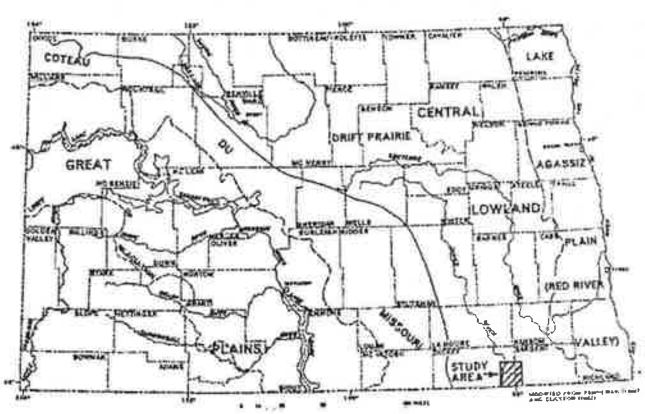

Figure 1. Location of the Oakes study area in relation to North Dakota physiographic provinces (from Bluemle 1979).

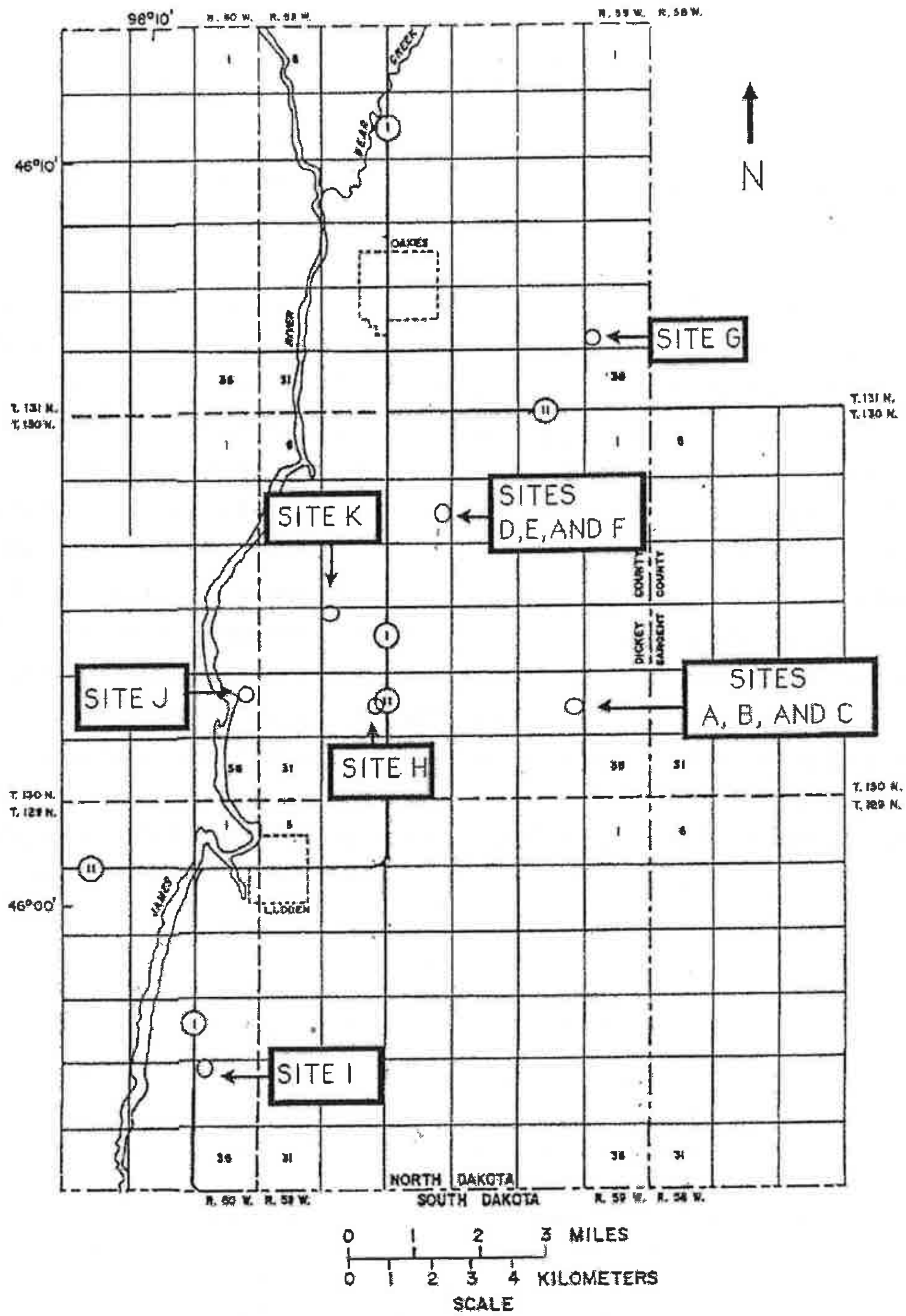

Figure 2. Locations of measurement sites.

Table 1. List of measured soil series, USDA soil classifications, and locations.
USDA classifications provided by Mike Ulmer, USDA-NRCS, Bismarck (From Soil Survey Staff 2003). Previous classifications (in italics) reprinted from WRI No. 18, Schuh, Cline and Sweeney 1991.

	Date	Soil Series	USDA Classification	Location
A	9/28/84 to 10/23/84	Hamar Sand	Sandy, mixed, frigid Typic Endoaquolls *(Sandy, mixed, frigid Typic Haplaquoll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 26, AD [280 feet (85.3 m) south and 100 feet (30.5 m) west of east quarter corner.]
B	9/28/84 to 10/23/84	Hecla Loamy Sand	Sandy, mixed, frigid Oxyaquic Hapludolls *(Sandy, mixed Aquic Haploboroll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 26, AD [280 feet (85.3 m) south and 170 feet (51.1 m) west of east quarter corner.]
C	9/28/84 to 10/23/84	Hecla Loamy Sand	Same as above	Dickey County ND, T 130 N, Range 59 W, Sec. 26, AD [285 feet (86.9 m) south and 360 feet (109.7 m) west of east quarter corner.]
D	6/19/85 to 7/31/85	Hecla Loamy Sand	Same as above	Dickey County ND, T 130 N, Range 59 W, Sec. 9, DAA [66 feet (20.1 m) south and 465 feet (135.6 m) west of east quarter corner.]
E	6/19/85 to 7/31/85	Ulen Loamy-Fine Sand	Sandy, mixed, frigid Aeric Calciaquolls *(Sandy, frigid Aeric Calciaquoll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 9, DAA [355 feet (108.2 m) south and 465 feet (141.7 m) west of east quarter corner.]
F	6/19/85 to 7/31/85	Arveson Fine-Sandy Loam	Coarse-loamy, mixed, superactive, frigid Typic Calciaquolls *(Coarse-loamy frigid Typic Calciaquoll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 9, DAA [525 feet (159.9 m) south and 470 feet (143.3 m) west of east quarter corner.]
G	6/19/85 to 7/31/85	Heimdal Loam	Coarse-loamy, mixed, superactive, frigid Calcic Hapludolls *(Coarse-loamy mixed Udic Haploboroll)*	Dickey County ND, T 131 N, Range 59 W, Sec. 25, CBB [300 feet (90.5 m) south and 100 feet (30.5 m) east of west quarter corner.]
H	8/21/85 to 10/23/85	Stirum Fine-Sandy Loam	Coarse-loamy, mixed, superactive, frigid Typic Natraquolls *(Coarse-loamy, mixed, frigid, Typic Natraquoll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 29, CBB [950 feet (298.8 m) south and 650 feet (198.3 m) west of east quarter corner.]
I	8/21/85 to 10/23/85	*Eckman Loam*	*Coarse-silty, mixed, superactive, frigid Calcic Hapludolls* *(Coarse-silty, mixed, Udic Haploboroll)*	Dickey County ND, T 129 N, Range 60 W, Sec. 25, BBB [125 feet (38.1 m) south and 75 feet (22.8 m) east of northwest corner.]
J	8/19/85 to 10/21/85	Gardena Loam	Coarse-silty, mixed, superactive, frigid Pachic Hapludolls *(Coarse-silty mixed, Pachic Udic Haploboroll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 18, CC [185 feet (56.5 m) south and 90 feet (27.5 m) east of southwest corner.]
K	9/28/85 to 10/21/85	Exline Loam	Fine, smectitic, frigid Leptic Natrudolls *(Fine, montmorillonitic Leptic Natriboroll)*	Dickey County ND, T 130 N, Range 59 W, Sec. 20, BBB [45 feet (13.7 m) south and 90 feet (17.4 m) west of east quarter corner.
RM1	9-10/85	Embden *subsoil only*	Coarse-loamy, mixed, superactive, frigid Pachic Hapludolls	Dickey County ND, T 130 N, Range 58 W, Sec. 20, AAB [25 feet (7.6 m) south of surveyed SWC monitoring well location labeled "13005820AAB"]
RM2	9-10/85	Alymer *subsoil only*	Mixed, frigid Aquic Udipsamments	Dickey County ND, T 130 N, Range 58 W, Sec. 24, AAB [50 feet (15.2 m) east of surveyed SWC monitoring well location labeled "13005824AAB"]
RM3	9-10/85	Unclassified *subsoil only*	Unclassified	Dickey County ND, T 130 N, Range 58 W, Sec. 31, AAB [50 feet (15.2 m) east of surveyed SWC monitoring well location labeled "13005831AAB"]

Most hydrologic models best employ hydraulic data in functional format. For this reason, unsaturated soil hydraulic data were used to derive parameters for the equations of Brooks and Corey (1964) and Van Genuchten (1978, 1980). These parameters were published as appendicized tables to the data report (WRI No. 18). Variability of parameters in relation to soil physical properties was discussed by Schuh et al. (1988) and Schuh and Cline (1991).

WRI No. 18 included only hydraulic data for the desorption phase of the field experiments. It did not include sorption hydraulic data or infiltration values. The purpose of this supplemental report is to provide infiltration and sorption data for each of the measured sites. Also included in this report are supplemental infiltration data measured near Oakes as part of a project examining the feasibility of artificial recharge (Shaver and Schuh 1990). Additional field infiltration and field and laboratory hydraulic data have been measured at the Carrington Research Extension Center, Carrington, North Dakota. These will be published in a separate report.

METHODS

All infiltration measurements were made using a "double-ring" system. The purpose of the double ring is to help assure vertical flow. During infiltration into dry soil, negative capillary pressure tends to draw water horizontally into the surrounding soil matrix. This causes difficulty in interpreting the spatial distribution of infiltrating waters. Swartzendruber and Olson (1961a and 1961b) found that vertical flow was seldom fully realized using a double-ring infiltrometer, but that it was closely approximated under conditions where the diameter (r_n) of the outer ring, and a ring-diameter buffer index are sufficiently large. The proposed ring-diameter buffer index is:

$$B = (r_n - r_i)/r_n \qquad (1)$$

where r_i is the diameter of the inner. They found that the practical validity of the one-dimensional vertical flow assumption for non-layered soils was dependent on time, depth of the wetting front, B, and r_n.

Swartzendruber and Olson (1961a) also found that sensitivity to these parameters varied with soil texture. They found that on sandy soils one-dimensional vertical flow for the inner ring could be assumed for very small B values (very little buffer area) provided that r_n was at least 24 inches (61 cm). For r_n of 12 inches (30 cm) the same assumptions could be made if B was sufficiently large (about 0.5). For $r_n < 8$ inches (20 cm) no buffer index would be sufficient to assure one-dimensional vertical flow. Swartzendruber and Olson (1961b) indicated that the departure from vertical flow was more marked over time and wetting depth for finer soils.

Swartzendruber and Olson (1961b) also demonstrated that wetting depth was important. Based on data from experiments considering a maximum wetting depth of 24 inches (61 cm) they concluded that a good rule of thumb would be to allow for an outer buffer ring radius at least equal to the depth of infiltration.

Field Instrumentation

All measurements were made using a 2-feet (31-cm) diameter inner ring. Surface infiltration measurements at Oakes and Carrington were buffered with a 10-feet (3.1-m) outer ring. A square wooden dike was placed around the infiltration buffer area. Applying the rule of Swartzendruber and Olson, one-dimensional vertical flow assumptions should be valid for about 10 ft. (3.1 m). The maximum depth of measurement on all sites (based on neutron probe and tensiometer instrumentation) was about 6.6 ft. (2 m), and on most sites measurement depths did not exceed 5 ft. (1.5 m).

On all sites care was taken to avoid disturbing or compacting the soil surface. This was done by scaffolding over the measured surface during site construction (Fig. 4). Vegetation on site was left undisturbed within the infiltrometer. Infiltrometers constructed of PVC were placed into carefully cut 4-inch (10-cm) deep vertical grooves (Fig. 3). Inside borders [0.5 inches (1.3 cm)] were packed to within one inch of the surface, as shown on Fig. 3 and on the photo in Fig. 5. The inch nearest the surface was sealed with plaster of Paris (Figures 3 and 6).

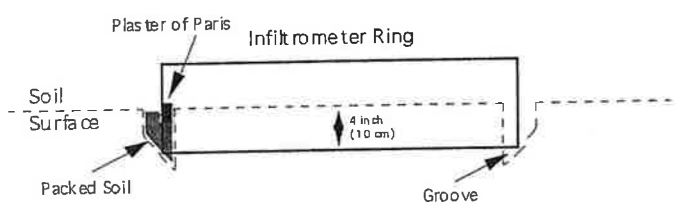

Figure 3. Illustration of infiltrometer placement procedure.

Deep subsoil infiltration measurements were taken after excavation of most soil profiles (Sites D through K) for morphological description. The subsoil surface was smoothed without compacting, and infiltrometers were placed on the excavated surface. A 4-feet (1.22-m) diameter outer ring constructed of steel flashing was used for deep measurements (Fig. 6).

Field Procedures

Infiltration measurements were accomplished by flooding both inner ring and buffer areas to an identical depth using separate water supplies (Fig. 7). Water was delivered to the outer ring through a perforated wooden box which attenuated the erosive force of influent waters on the soil surface. The soil surface of the inner ring was protected by placing burlap on the soil surface. Water was metered and water levels

Figure 4. Construction of hydraulic property measurement apparatus.

Figure 5. Placement of infiltrometer ring.

Figure 6. Placement of deep subsoil infiltrometer.

Figure 7. Operation of surface infiltration measurements.

were controlled using float valves. Water levels were maintained at 3 to 4 inches (7.5 to 10.2 cm) above the soil surface. Infiltration rates were measured using standpipes on cylindrical reservoirs, with calibrated adjustments for the difference between reservoir and infiltrometer areas. Reservoir diameters varied from 4 inches (10.2 cm) for soils with slow infiltration rates to large (50-gallon drums) for sandy soils. Where slow infiltration was occurring reservoirs were covered with polyethylene sheets to prevent evaporative loss from the reservoir. Measurements were maintained until the profile was believed to be fully saturated. Measurement times varied from as little as 6 h on most sandy soils (Sites A through F) to about 30 h on loamy soils (Sites G-J), and 263 hours on a fine-textured sodic Exline soil (Site K). Detailed soil descriptions, and soil physical and chemical data are in Schuh, Cline and Sweeney (1991).

Functional Format

Mathematical transfer functions are useful for application of infiltration data in modeling. All infiltration data were fitted to the functional format of Phillip (1957, 1966). Phillip derived an equation of the form:

$$I = S\,t^{1/2} + A\,t + K\,t + C\,t^{3/2} + D\,t^2 + \ldots.\ X_n\ t^{n/2} \qquad (2)$$

to describe cumulative infiltration (I) into a semi-infinite homogeneous vertical soil column having uniform moisture. This is differentiable for infiltration rates (i) as:

$$i = A + K + S/2\,t^{-1/2} + 3C/2\,t^{1/2} + 2Dt + \ldots\ nX_n/2\,t^{(n/2-1)} \qquad (3)$$

In many cases a two-parameter equation:

$$I = S\,t^{1/2} + A'\,t \qquad (4)$$

is sufficient to fit field data, where A' = (A + K).

In rigorous usage coefficients of the Philip equations have physical significance in their derivations and can be used to estimate soil hydraulic parameters. For example, the S coefficient is called "sorptivity." It is related to the soil moisture status prior to infiltration, and can be used to calculate the [$D(\theta)$] function (Kirkham and Powers 1972). Conventionally, S is estimated by plotting I vs. $t^{1/2}$ using early time data. The slope of the linear curve portion nearest to t=0 is used to estimate S (Smiles and Knight 1976). Varying approaches for determining S have been described by Kirkham and Powers (1972), Smiles and Knight (1976), Talsma (1969) and others.

The approach of Smiles and Knight (1976) for analyzing the two parameter equation consists of plotting:

$$I/t^{1/2} \text{ vs. } t^{1/2} \tag{5}$$

The advantage of this procedure is that information about the soil and infiltration physical attributes can often be inferred. First, the authors specify that the validity of the two-parameter model can be tested using this relationship. In some cases, anisotropy in the measured profile, below the measured surface can be detected. Second, the point at which Phillip's theory (Eq. 2), and long-term behavior (A approaches K) diverge can be discerned. Where Equation 5 is linear, near t=0, Philip theory is valid. Eventually, the curve slope increases asymptotically:

$$I/t^{1/2} = K\,t^{1/2} \tag{6}$$

Thus, both cases can be separated and used to determine appropriate parameters. Where the above graphic conditions do not exist, conditions contrary to Philip's assumptions may exist. It is our experience, and certainly a characteristic of the data presented in this report, that the two-parameter Phillip model works best on sandy soils, and is seldom sufficient on finer soils. The relationship between A' and K has been described as varying from A' = 1/3 to 2/3 K (Smiles and Knight 1976). Talsma (1969) observed that A' was close to 1/3 K. For our data on the R1, R2 and R3 sites (Appendix), a 2/3 factor yielded best results.

At long times, where i approximates a constant value, i itself can sometimes serve as an estimator of K. Infiltration is driven by both gravitational gradients and by matric potential gradients that are determined by the initial moisture disposition of the soil. As the wetting front depth (L) advances over long times (L becomes large) the overall matric potential gradient decreases so that the total gradient asymptotically approaches 1. Under such conditions i must asymptotically approach K according to:

$$i = Q = K\,(\psi+L)/L \sim K(1) \sim K \tag{7}$$

where Q is the internal flow rate through the soil profile. The estimated K is often identified with K_{sat} of the soil saturation zone. However, some caution must be exercised in such interpretations. Under field conditions, even on apparently homogeneous soil profiles, there are usually minor impedances to flow that can desaturate the lower soil profile. Full saturation usually only occurs from a rising water table in response to surface infiltration. Thus, absent a rising water table, K values below the surface zone usually correspond to a matric potential slightly below saturation. These are, however, usually very close to K_{sat}.

The Philip functions used in this report were calculated using a multiple-regression procedure with DataDesk software (Velleman 1997). Least-squares best fits were performed on cumulative infiltration (I vs. t) data (Eq. 2) with the constant omitted.

Parameters for i vs. t (Eq. 3) were derived by differentiating Eq. 2. Because of the omitted constant correlation coefficient values were not computed. Most coarse-soil profiles were adequately fitted for I and i using the two-parameter equation (Eq. 4), while finer soils, and soils having more complex horizonation often required 3 and 4 parameter fits (Eqs. 2 and 3). In almost all cases one of the parametric combinations was sufficient to provide an adequate functional format. Model fits were evaluated by viewing the marginal significance of the added parameter, and by visual fit. Visual fit is the best method for assuring that the model conforms to the data in a desired application range.

It is important that the user recognize that parameters derived using a multivariate least-squares procedure are not identical to those applicable to rigorous Philip theory. The user will see, for example, that sorptivity will change with a difference in the number of parameters in the model. In some cases the (A+K)t term (Eq. 2) is negative. Parameters optimized in this way, while providing good transfer functions for model applications, are non-unique and cannot be used for deriving physical properties, such as moisture retention or diffusivity functions. If the user wishes to use equations of the Philip form to derive or compare soil hydraulic properties, concise descriptions for procedures that can be applied to the data provided can be found in Kirkham and Powers (1972).

Sorption Phase Properties and Parameters (θ, ψ, K_{sat})

Supplementary soil moisture (θ), matric potential (ψ) expressed as cm head, and hydraulic conductivity (K) in cm/h were measured during the sorption phase and are reported in supplementary tables and figures. Soil volumetric water content concurrent with infiltration was measured using a neutron probe for Sites D-K. Pre-wetting and sorption moisture data were non-concurrent with infiltration and were sparse on Sites A-C. No moisture measurements were collected for any of the deep infiltration measurements. Soil water matric potential is reported for all sites. Data was concurrent with infiltration on Sites D-K, but not on Sites A-C.

Soil matric potential was measured using tensiometers with mercury manometers. A calibrated mbar scale (Soil Moisture Equipment Inc.™) was used for all measurements. Matric potential head, $\psi_{j,k}$ (where j and k are depth and time coordinates respectively) for each depth z_j, was calculated as:

$$\psi_{j,k} = 1.02\ \psi^*_{j,k} - 18.24 - z_j \qquad (8)$$

where $\psi^*_{j,l}$ is the mbar scale reading, 1.02 is the conversion from mbar to cm and 18.24 is the height above ground level of the mercury in the supply vat and at the base of the manometer.

Hydraulic gradients are calculated as:

$$\mathrm{Grad}_{1,k} = (H_{o,k} - \psi_{1,k})/ z_1 + 1 \tag{9a}$$
$$\mathrm{Grad}_{(j+1/2,\,k)} = (\psi_{j,k} - \psi_{j+1,k}) / (z_j - z_{j+1}) + 1 \tag{9b}$$

where H_o is the depth of the water in the infiltrometer, $\psi_{j,k}$ is matric potential (expressed as cm head) for depth and time coordinates j and k, and z_j is depth.

K is calculated as:

$$K_{(j+1/2,\,k)} = i_k / \mathrm{Grad}_{(j+1/2,\,k)} \tag{10}$$

where i_k is calculated using the best-fit function for the infiltration data corresponding to tensiometric readings.

Interpretation and reliability of measured K depends on several factors. First, the main water column from infiltration must have reached the bottom of the measured layer such that steady-state flux at that depth is equal to the infiltration rate. If this condition is not met, the measurement is spurious.

Second, it frequently occurs that the steady-state flux condition is met, but the soil layer is not fully saturated. This can occur because of restrictions in overlying layers. In this case a true K is measured, but it may not be a true K_{sat}. Rather, the measurement is the unsaturated $K(\psi)$, corresponding to ψ in the unsaturated layer. Desaturation caused by surface impedance has been described by Bouwer et al. (1972) and Bouma (1975) for sewage and septic tank effluent in drainage fields. Usually the degree of desaturation is small (< 15 cm ψ_m on many sands) under natural conditions. $K(\psi)$ between K_{sat} and air-entry suction is very close to K_{sat}, and is treated as identical to K_{sat} in the models of Burdine (1953) and Brooks and Corey (1964). Other models treat $K(\psi)$ between saturation and air entry suction as a flat portion of an approximately sigmoid curve (Van Genuchten 1980), or as a nearly level linear relationship (Ahuja et al. 1980).

Third, tensiometric measurements must be interpreted carefully. Various problems have been documented, including air bubble formation. When a single tensiometer is clearly malfunctioning we discard the suspected measurement and use composite gradient measurements for the nearest two tensiometers that are functioning properly. For example, given measurements at 15, 30 and 45 cm, if the 30-cm tensiometer is malfunctioning, we perform computations for a 15 to 45 cm composite layer rather than two (15 to 30 and 30 to 45 cm) layers. Mean K values on K tables are determined using only numbers that conform well to these three criteria. K is a soil property and should be stable within a stable grain matrix. But drift in actual K can occur due to air entrapment, oxygen respiration and consequent dissolution of carbonates, particle movement, bacterial clogging, nitrification, dissolution or precipitation of salts, redox changes and filtration phenomena. The soil environment under long-term infiltration is actually a very dynamic environment, and changes in K frequently occur.

Table 2. Summary of data and information included in this report. Y is yes, N is no, S is sparse measurements, F is frequent measurements.

Site	Surface i	Deep i	θ	ψ	Concurrent θ/ψ ?	Other
A	Y	N	S	S	N	
B	Y	N	S	S	N	
C	Y	N	S	S	N	i, θ, and ψ for additional sorption / desorption cycles
D	Y	Y	F	F	Y	
E	Y	Y	F	F	Y	
F	Y	Y	F	F	Y	
G	Y	Y	F	F	Y	
H	Y	Y	F	F	Y	
I	Y	Y	F	F	Y	
J	Y	Y	F	F	Y	
K	Y	Y	F	F	Y	
RM1	N	Y	N	N	N	
RM2	N	Y	N	N	N	
RM3	N	Y	N	N	N	

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DATA SUMMARY

A summary of ancillary site information is provided on Table 1. Sites A, B and C, and sites D, E and F were measured as components of two soil toposequences at two soil locations. The three Carrington measurements were also located in close proximity to one another. Neutron-probe moisture data were collected during sorption on sites D-K. They are not reported on sites A-C. A summary of sorption data and parameters reported for each site is on Table 2. Sorption data and parameters are reported in the following subsections labeled A through K.

SITE A (Hamar Loamy Sand: Sandy, mixed, frigid Typic Endoaquoll)

Site A was located in the non-irrigated corner of a center-pivot irrigated potato field and was covered with a young cover crop of winter barley. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late September and October, 1984. Soil samples and soil profile descriptions were taken approximately two weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture-retention data, soil physical data, soil saturated paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 36-60. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report, Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989). Infiltration rates for Site A (and also Sites B and C) were measured in June of 1985 (eight months after the initial sorption tests) immediately adjacent (within 5 m) of the desorption measurement site. Only surface infiltration rates were measured.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table A.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site A (Hamar loamy sand) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0.00	0.00	0.00	0.00		1.83	30.4	1.78	16.4
*0.142**	*3.59*	*0.0710*	*6.11*		1.90	31.8	1.87	18.1
*0.189**	*4.11*	*0.165*	*11.0*		1.99	33.2	1.95	15.8
0.233	4.80	0.211	15.9		2.08	34.6	2.04	15.2
0.277	5.49	0.255	15.6		2.16	36.0	2.12	17.8
0.326	6.19	0.301	14.2		2.43	40.1	2.29	15.6
0.380	6.88	0.353	12.8		2.55	42.2	2.49	17.1
0.466	8.26	0.423	16.1		2.71	45.0	2.63	16.4
0.562	9.65	0.514	14.4		2.85	47.0	2.78	15.2
0.696	11.7	0.629	15.4		3.03	50.1	2.94	17.5
0.782	13.1	0.739	16.1		3.18	52.6	3.10	16.3
0.913	15.2	0.848	15.9		3.39	56.0	3.28	16.3
1.00	16.6	0.957	15.8		3.58	59.1	3.49	16.2
1.16	19.3	1.08	17.5		4.24	70.4	3.95	18.9
1.25	20.7	1.20	16.2		4.63	76.6	4.44	16.3
1.33	22.1	1.29	15.8		4.99	82.2	4.81	15.2
1.42	23.5	1.38	15.4		5.34	87.7	5.16	16.1
1.49	24.9	1.46	19.2		5.59	91.9	5.47	16.0
1.57	26.3	1.53	17.7		5.86	96.0	5.72	16.0
1.74	29.0	1.66	16.3					

** Italicized data not used for transfer functions*

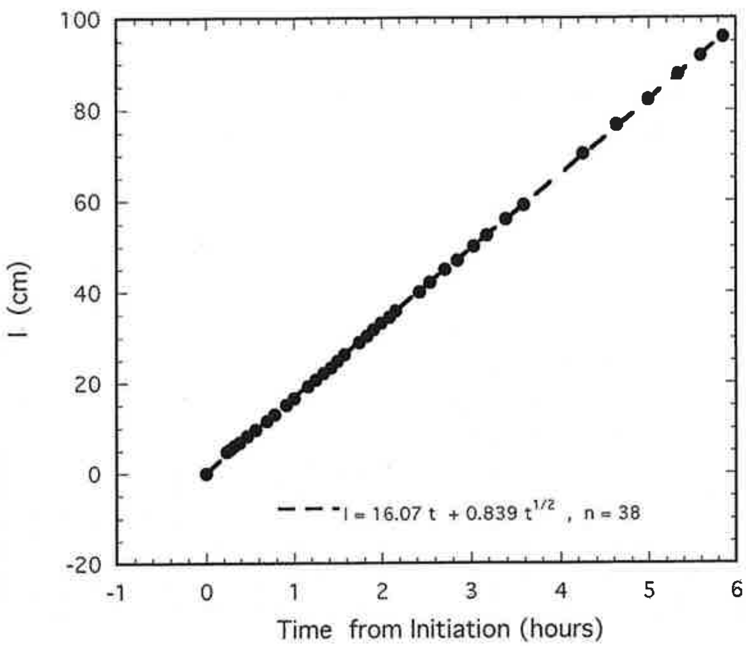

Figure A.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site A.

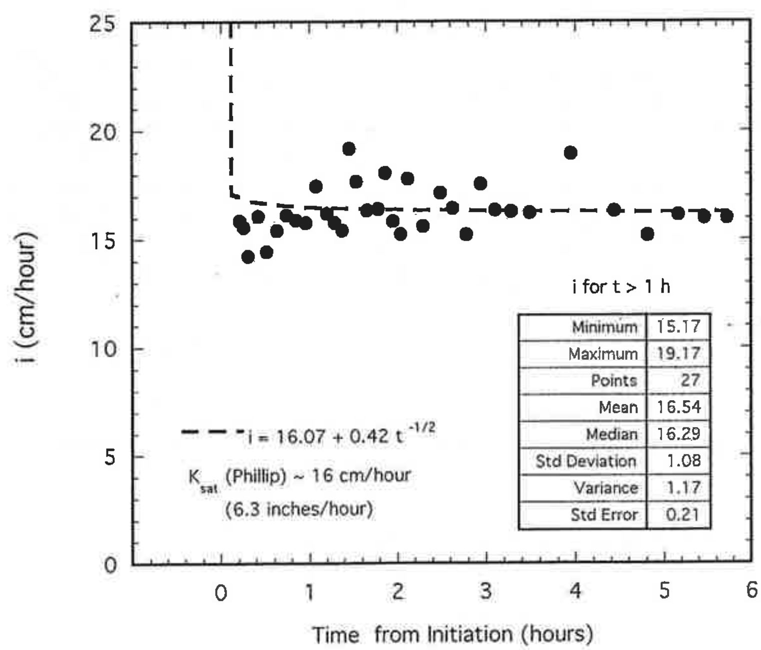

Figure A.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site A.

Table A.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.4	45.7	*60.8*	76.2	91.4	106.7	121.9	137.1
Time (h)									
0	4.9	20	-144.1	*-59.7*	-59.6	-47.4	-40.8	-35.8	-38.4
2.5	11	7.9	-2.4	*65.8*	-13.7	-17.9	-17.9	-16.9	-5.7
7	11	7.9	-3.4	*66.8*	-14.2	-13.8	-7.7	-0.6	10.6
8.73	11	7.9	-4.4	*34.2*	-13.7	-12.8	0.5	13.7	12.7
10.17	11	7.9	-3.4	*17.9*	-4.5	-11.7	-2.6	6.5	22.9
11.4	11	6.8	-2.4	*11.7*	-5.5	-10.7	-1.5	7.6	14.7
12.13	11	7.9	-6.4	*11.7*	-7.6	-11.7	-2.6	7.6	14.7
12.77	-11.4	-2.4	-11.5	*2.6*	-11.6	-12.8	-3.6	4.5	15.7

Replicate 2

Depth (cm) >	15.2	30.4	45.7	60.8	76.2	91.4	106.7	121.9	137.1
Time (h)									
0	-7.4	-106.4	-54.4	-59.7	-59.1	-50	-38.3	-37.3	-36.8
2.48	3.9	4.8	4.8	-7.7	-11.6	-18.9	-20.9	-18	-8.9
6.87	4.9	4.8	4.8	-7.7	-10.6	-15.8	-15.8	-4.7	10.6
8.6	18.2	25.2	2.8	-7.7	-10.6	-14.8	-10.7	-1.6	13.7
10.2	2.9	4.8	0.7	-8.7	-11.6	-13.8	-10.7	-0.6	14.7
11.35	2.9	5.8	0.7	-9.7	-10.6	-13.8	-10.7	-1.6	14.7
12	0.8	3.8	-0.3	-9.7	-10.6	-13.8	-9.7	-0.6	15.7
12.72	-11.4	-7.45	-16.6	-20.9	-13.8	-15.8	-8.7	0.4	14.7

Table A.3. Soil volumetric water content during infiltration (sorption).

Not Measured on Site A

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil-moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Steady-state conditions appear to prevail to 15 cm within two hours, to 76 cm within three hours, and in all layers below at > 10 hours on Replicate 1 and > 8 hours on Replicate 2. Decreasing gradients below 106 cm are likely caused by proximity to the water table.

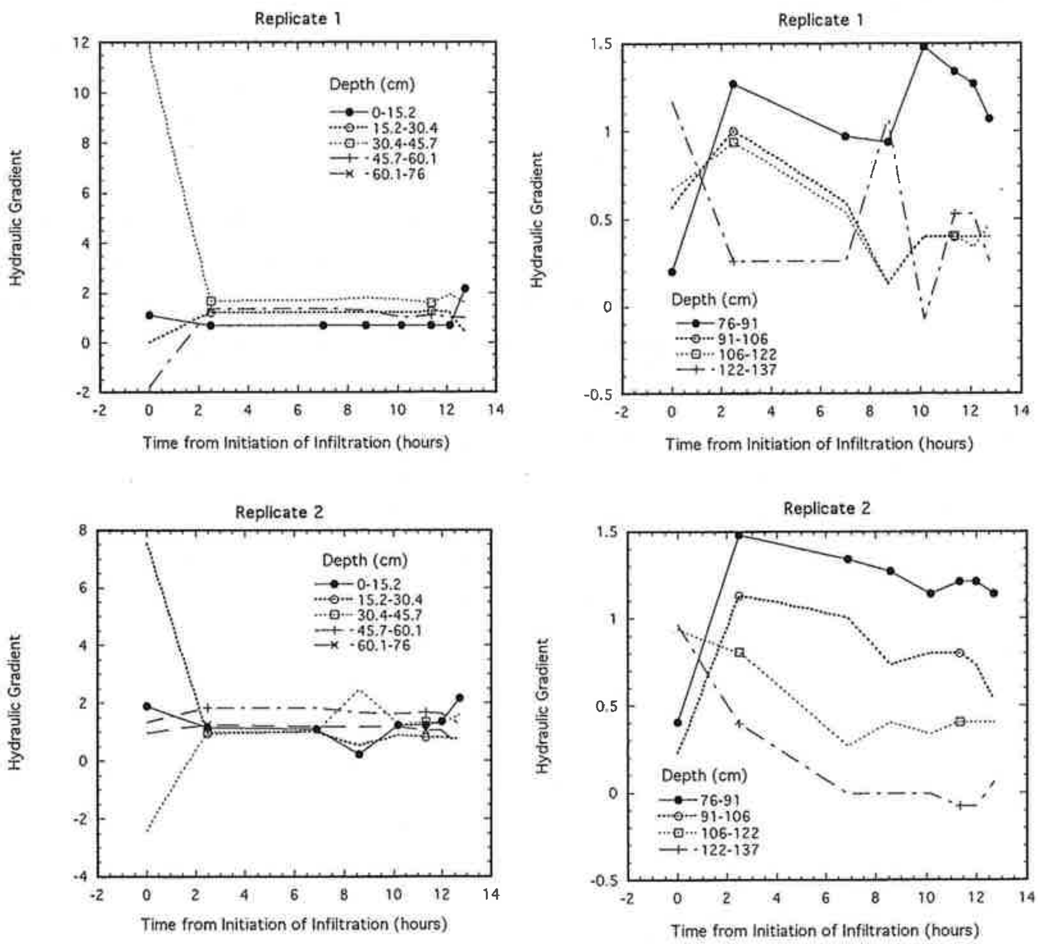

Figure A.3 Vertical hydraulic gradients during wetting and sorption of site A.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site A is measured by matching the i vs. t function (Figure A.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table 4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [$K(\psi)$]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table A.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) is saturated, (-ψ) is corresponding matric potential expressed as cm head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-76.2	76.2-91.4	91.4-106.7	106.7-121.9	121.9-137.1
Time (h)								
7	23.3	4.05	8.96	12.4	-	-	-	-
8.73	23.2	3.24	9.31	15.6	-	-	-	-
10.17	23.2	2.7	10.1	14.7	12.1	40.9	40.2	30.6
11.4	23.2	2.31	8.35	15.6	12.7	40.9	48.2	30.5
12.13	7.46*	2.02	10.1	16.2	15.1	40.9	34.4	61.3
12.77	23.4	8.17*	9.78	11.9	12.9	16.3*	17.4	62.3
K	20.6 (s)	3.75 (s)	9.43 (~0)	14.4 (-7)	13.2 (-10)	34.7 (-7)	35 (s)	46.2 (s)
SE	2.63	0.932	0.284	0.741	0.656	6.15	6.53	9.02
CV	0.313	0.609	0.074	0.126	0.099	0.354	0.373	0.391

Replicate 2

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-60.8	60.8-76.2	76.2-91.4	91.4-106.7	106.7-121.9
Time (h)								
6.87	-	1.25	6.54	-	-	-	-	-
8.6	13.2	1.16	12.8	10	13.6	14.2	20.3	48.2
10.2	13.2	1.08	12.1	9.64	15.3	13.4	20.3	40.2
11.35	11.8	1.01	12.7	9.99	15.3	13.4	22.1	40.2
12	7.46	0.952	10.1	12.6	30.9	14.2	30.5	40.2
12.72	14	1.49	16.3	8.98	13	11	14.5	20.3
K	11.9 (s)	1.16 (s)	11.8 (s)	10.2 (-7)	17.6 (-11)	13.2 (-13)	21.5 (-12)	37.8 (-5)
SE	1.17	0.079	1.33	0.618	3.35	0.588	2.58	4.65
CV	0.22	0.168	0.276	0.135	0.425	0.099	0.268	0.275

SITE B (Hecla Loamy Sand: Sandy, mixed, frigid Oxyaquic Hapludoll)

Site B was located in the non-irrigated corner of a center-pivot irrigated potato field, and was covered with a young cover crop of winter barley. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late September and October, 1984. Soil samples and soil profile descriptions were taken approximately two weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture-retention data, soil physical data, soil saturated-paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 61-82. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report, Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989). Infiltration rates for Site B (and also Sites A and C) were measured in June of 1985 (eight months after the initial sorption tests) immediately adjacent (within 5 m) of the desorption measurement site. Only surface infiltration rates were measured.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table B.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site B (Hecla loamy sand) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0.00	0.00	0.00	0.00		2.13	39.3	2.06	18.6
0.0370	1.61	0.0190	41.5		2.43	44.9	2.28	18.4
0.0880	3.35	0.0630	34.2		2.65	49.0	2.54	19.4
0.152	4.73	0.120	21.8		2.95	54.6	2.80	18.2
0.247	6.11	0.199	14.5		3.34	61.5	3.14	18.1
0.327	7.50	0.287	17.3		3.57	65.6	3.45	18.1
0.399	8.88	0.363	19.2		3.95	72.6	3.76	17.8
0.488	10.3	0.443	15.6		4.24	78.1	4.10	19.0
0.563	11.7	0.526	18.3		4.58	83.6	4.41	16.5
0.713	14.4	0.638	18.5		4.70	86.4	4.64	22.4
0.867	17.2	0.790	18.0		5.06	93.3	4.88	19.5
1.04	20.0	0.955	15.9		5.43	100	5.24	18.5
1.27	24.1	1.16	18.0		5.74	106	5.59	18.1
1.36	25.5	1.32	16.4		6.06	111	5.90	17.0
1.51	28.3	1.44	17.6		6.19	114	6.13	21.9
1.67	31.0	1.59	17.6		6.34	117	6.26	18.3
1.83	33.8	1.75	18.0		6.41	118	6.38	19.2
1.98	36.6	1.90	17.5					

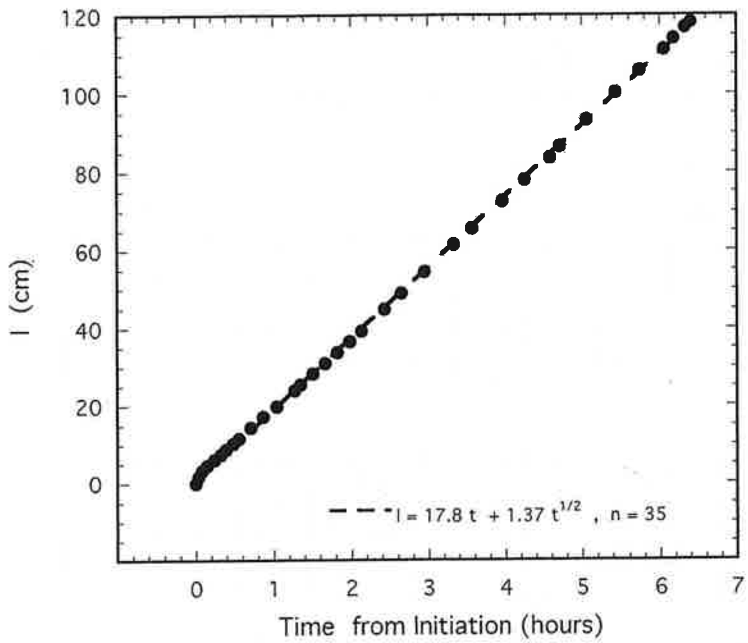

Figure B.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site B.

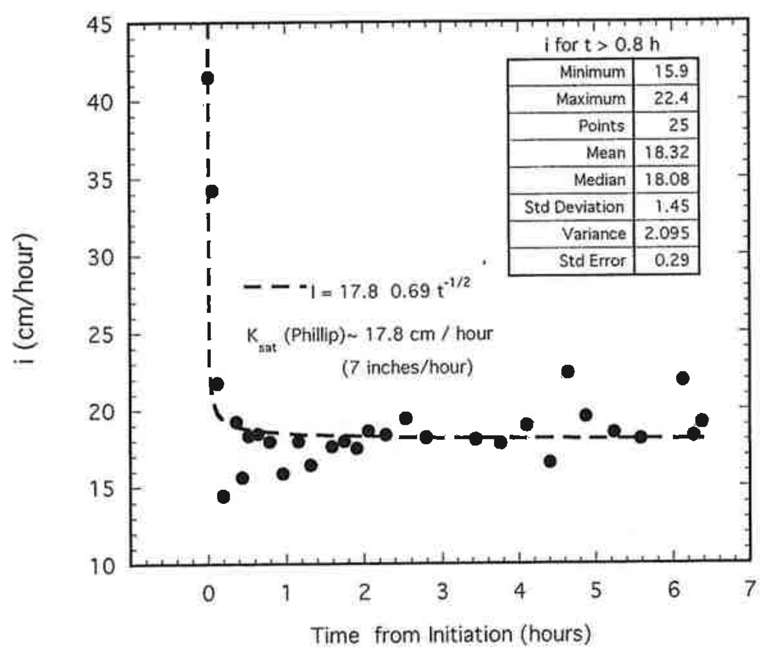

Figure B.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site B.

Table B.2. Soil water matric potential (in cm head units) during infiltration (sorption). Times are referenced to initiation of desorption (infiltration ends) at t=0. The soil profile is saturated to the fullest extent, and approximates steady-state conditions.

Replicate 1

Depth (cm) >	15.2	30.4	45.7	60.8	76.2	91.4	106.7	137.1
Time (h)								
-0.63	3	-6	-8	-15	-18	-19	-24	-15
(t=0)	-19	-19	-18	-19	-18	-22	-25	-18

Replicate 2

Depth (cm) >	15.2	30.4	45.7	60.8	76.2	91.4	106.7	137.1
Time (h)								
-0.63	-19	-27	-	-25	-29	-32	-29	-27
(t=0)	-25	-33	-	-30	-34	-38	-33	-28

Table B.3. Soil volumetric water content during infiltration (sorption). Times are referenced to initiation of desorption (infiltration ends) at t=0. The soil profile is saturated to the fullest extent, and approximates steady-state conditions.

Replicate 1

Depth > (cm)	30.48	45.72	60.96	76.2	91.44	106.7	121.9	137.2
Time (h)								
-0.48	0.3787	0.3607	0.2427	0.35	0.3445	0.3441	0.3492	0.3683
t=0	0.3666	0.3496	0.354	0.3504	0.3329	0.3477	0.35	0.3662

Replicate 2

Depth > (cm)	30.48	45.72	60.96	76.2	91.44	106.7	121.9	137.2
Time (h)								
-0.48	0.3711	0.3567	0.3559	0.3449	0.3508	0.339	0.3719	0.3667
t=0	0.3522	0.3423	0.3396	0.3396	0.3326	0.3443	0.3533	0.3785

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Hydraulic gradients in Table B.4 are at approximate steady state.

Table B.4. Vertical hydraulic gradient during infiltration (sorption). Times are referenced to initiation of desorption (infiltration ends) at t=0. The soil profile is saturated to the fullest extent, and approximates steady-state conditions.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-60.8	60.8-76.22	76.2-91.4	91.4-106.7	106.7-137.1
Time (h)								
-0.63	1.33	1.59	1.13	2.05	1.2	1.07	1.33	0.704
(t=0)	2.78	1	0.934	2.38	0.934	1.26	1.2	0.77

Replicate 2

Depth (cm) >	0-15.2	15.2-30.4	30.4-60.8	60.8-76.2	76.2-91.4	91.4-106.7	106.7-137.1
Time (h)							
-0.63	2.78	1.53	0.934	1.26	1.2	0.803	0.934
(t=0)	3.17	1.53	0.901	1.26	1.26	0.671	0.836

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site B are measured by matching the i vs. t function (Figure B.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table B.5. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table B.5. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). Mean matric potential head (cm), corresponding to measured K for the depth interval, is in parentheses. Times are referenced to initiation of desorption (infiltration ends) at t=0. The soil profile is saturated to the fullest extent, and approximates steady-state conditions.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-60.8	60.8-76.2	76.2-91.4	91.7-106.7	106.7-137.1
Time (h)								
t=0	6.8 (-19)	18.9 (-19)	20.2 (-19)	7.94 (-19)	20.2 (-19)	15 (-20)	15.7 (-24)	24.5 (-22)

Replicate 2

Depth (cm) >	0-15.2	15.2-30.4	30.4-60.8	60.8-76.2	76.2-91.4	91.7-106.7	106.7-137.1
Time (h)							
t=0	5.96 (-25)	12.4 (-29)	21 (-32)	15 (-32)	15 (-36)	28.2 (-35)	22.6 (-31)

SITE C (Hecla Sandy Loam: Sandy, mixed, frigid Oxyaquic Hapludoll)

Site C was located in the non-irrigated corner of a center-pivot irrigated potato field, and was covered with a young cover crop of winter barley. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late September and October, 1984. Soil samples were collected and soil profiles were described approximately two weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil-moisture retention data, soil physical data, soil saturated-paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 83-109. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report, Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989). Infiltration rates for Site C (and also Sites A and B) were measured in June of 1985 (eight months after the initial sorption tests) immediately adjacent (within 5 m) of the desorption measurement site. Only surface infiltration rates were measured.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table C.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site C (Hecla fine sandy loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0.00	0.00	0.00	0.00		3.04	39.8	2.91	11.0
0.0290	2.47	0.0150	47.0		3.27	41.9	3.16	9.01
0.0700	5.24	0.0500	67.8		3.43	43.7	3.35	10.8
0.134	6.62	0.102	21.9		3.55	45.0	3.49	11.8
0.214	8.01	0.174	17.2		3.78	47.8	3.67	11.8
0.304	9.39	0.259	15.5		3.92	49.2	3.85	10.5
0.414	10.8	0.359	12.5		4.06	50.6	3.99	9.44
0.528	12.2	0.471	12.2		4.19	52.0	4.13	10.7
0.654	13.5	0.591	11.0		5.61	67.2	4.90	10.7
0.751	14.9	0.703	14.3		6.00	71.3	5.81	10.6
0.896	16.3	0.824	9.57		6.40	75.5	6.20	10.6
1.13	19.1	1.01	11.9		7.56	88.0	6.98	10.7
1.38	21.9	1.25	11.1		7.69	89.3	7.63	10.8
1.62	24.6	1.50	11.2		8.49	97.7	8.09	10.4
1.78	26.0	1.70	9.15		8.75	100	8.62	10.7
1.89	27.4	1.83	12.2		9.52	109	9.14	10.7
2.02	28.8	1.95	11.0		9.64	110	9.58	12.2
2.27	31.5	2.14	11.0		9.73	111	9.68	8.04
2.53	34.3	2.40	10.5		3.04	39.8	2.91	11.0
2.79	37.1	2.66	10.7					

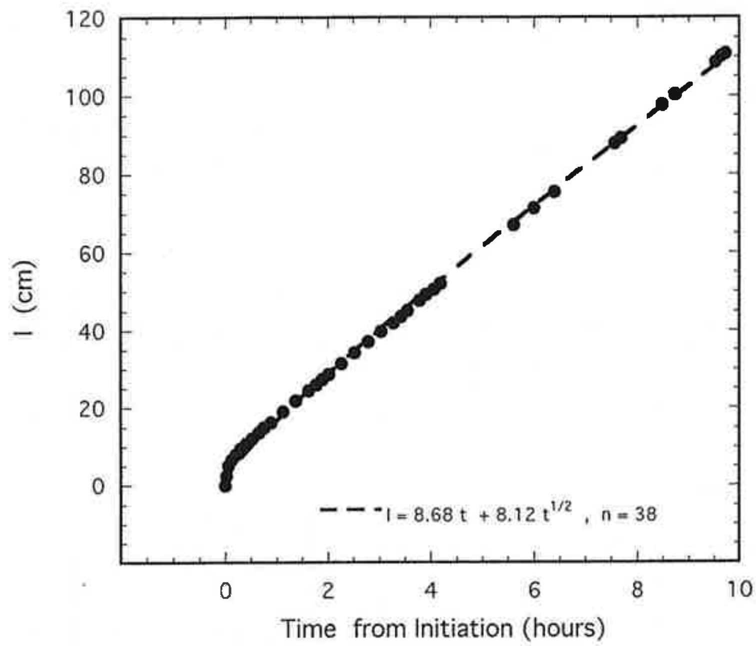

Figure C.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site A.

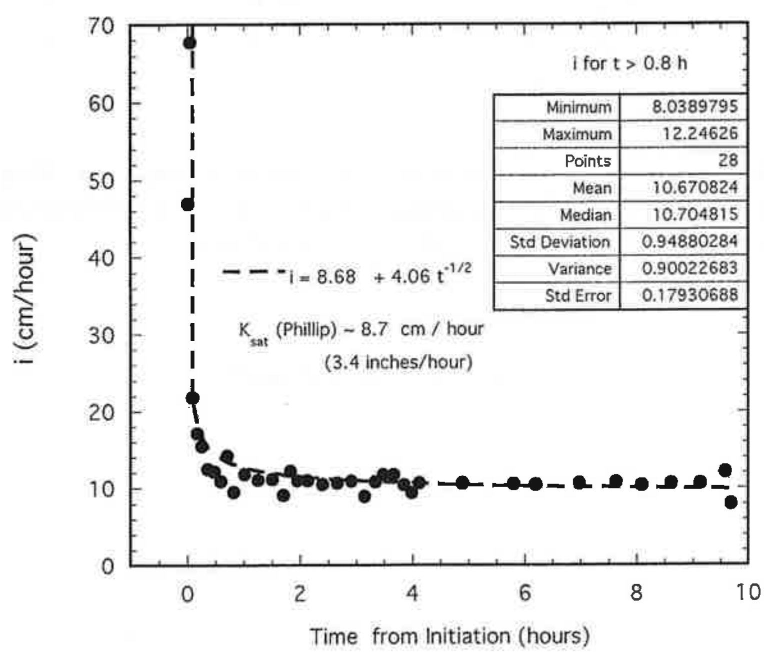

Figure C.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site A.

Table C.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2
Time (h)									
0.52	-12	-36	-40	-39	-70	-72	-68	-68	-78
0.87	-10	-29	-37	-40	-69	-74	-68	-68	-103
1.23	-9.4	-28	-32	-26	-67	-74	-68	-68	-83
1.77	-10	-28	-31	-35	-61	-73	-68	-68	-88
2.3	-11	-29	-31	-35	-36	-59	-67	-68	-89
2.9	-16	-28	-31	-35	-35	-43	-48	-68	-90
3.3	-27	-42	-32	-33	-35	-38	-36	-68	-88

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2
Time (h)									
0.52	-14	-37	-33	-37	-40	-52	-65	-70	-14
0.87	-15	-33	-33	-35	-41	-47	-62	-70	-15
1.23	-15	-31	-30	-33	-38	-43	-56	-69	-15
1.77	-14	-31	-29	-33	-36	-40	-38	-70	-14
2.3	-18	-31	-30	-33	-38	-39	-34	-67	-18
2.9	-18	-32	-30	-33	-38	-39	-32	-54	-18
3.3	-24	-31	-30	-33	-36	-38	-31	-39	-24

Table C.3. Soil volumetric water content during infiltration (sorption). Times are referenced to initiation of desorption (infiltration ends) at t=0. The soil profile is saturated to the fullest extent, and approximates steady-state conditions.

Not Measured on Site C

Hydraulic Gradient Measurements

Hydraulic gradients are shown on Figure C.3. They are at approximate steady state after about 0.8 hours. Most steady-state gradients are near 1. Declining gradients at 91-106 cm on Replicate 1, and at 106 -122 cm on Replicate 2 may indicate ponding near the lower boundary.

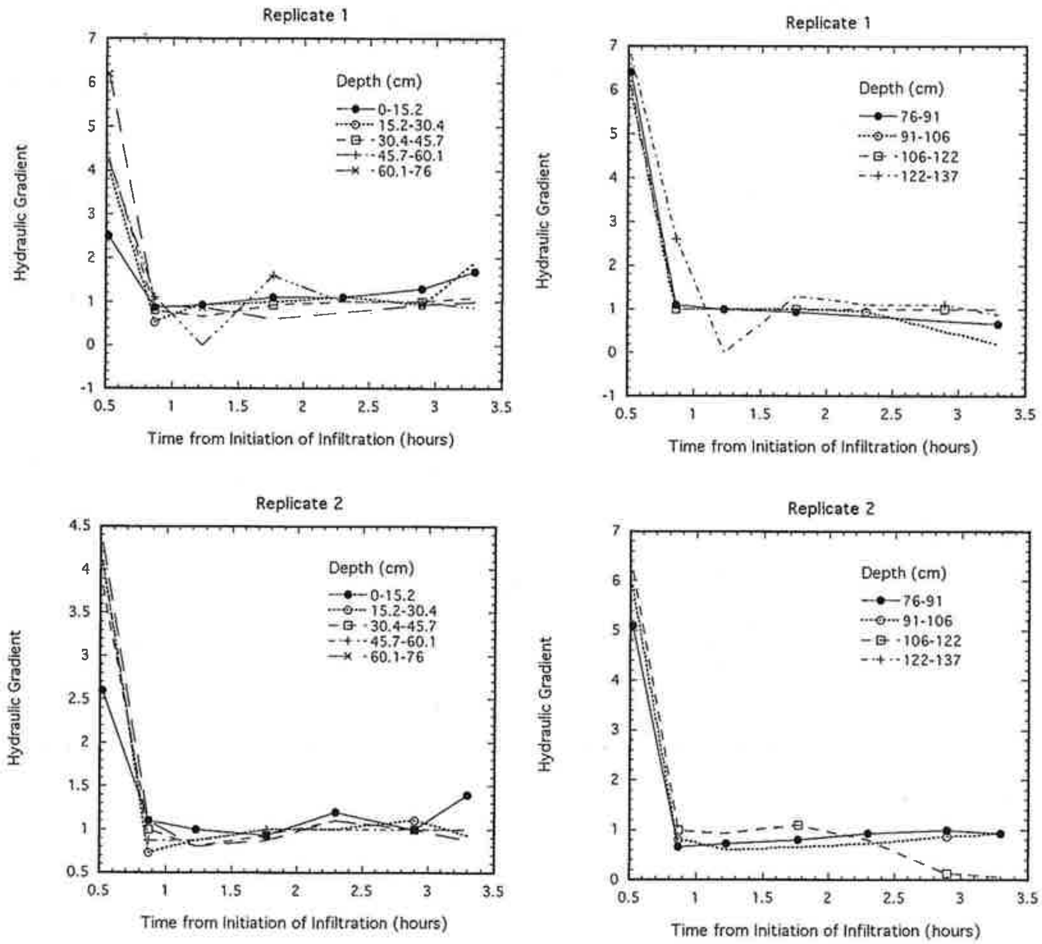

Figure C.3. Vertical hydraulic gradients during sorption of Site C.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site C are measured by matching the i vs. t function (Figure C.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table C.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table C.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) is saturated, (-ψ) is the corresponding matric potential expressed as cm head. SE is standard error, CV is coefficient of variation.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-60.8	60.8-76.22	76.2-91.4	91.4-106.7-	106.7-121.9	121.9-137.2
Time (h)									
1.23	11	11.5	16.1	-	12.4	10.7	10.7	10.7	-
1.77	10	10.7	11.5	6.67	17.9	11.5	10.7	10.7	8.01
2.3	10	10	10.7	10.7	-	-	11.5	10.7	10
2.9	8	11.5	10.7	10.7	11.5	-	-	10.7	10
3.3	6.4	5.52	10	12.4	10.7	16.1	-	10.7	12.4
mean	9.08 (-15)	9.84 (-23)	11.8 (-31)	10.1 (-32)	10.5 (-40)	12.8 (-52)	11 (-57)	10.7 (-63)	10.1 (-78)
SE	0.828	1.12	1.1	1.22	2.91	1.68	0.267	0	0.898
CV	0.2	0.25	0.21	0.24	0.62	0.23	0.042	0	0.18

Replicate 2

Depth (cm) >	0-15.2	15.2-30.4	30.4-45.7	45.7-60.8	60.8-76.22	76.2-91.4	91.4-106.7	106.7-121.9
Time (h)								
1.23	10.7	12.4	13.4	12.4	13.4	14.6	17.9	11.5
1.77	11.5	10.7	11.5	10.7	12.4	13.4	-	10
2.3	8.91	10.7	10	10.7	9.43	11.5	14.6	13.4
2.9	10.7	10	10.7	10.7	10.7	10.7	12.4	-
3.3	7.63	11.5	10.7	10.7	12.4	11.5	11.5	-
mean	9.89 (-18)	11.1 (-25)	11.3 (-30)	11 (-31)	11.7 (-35)	12.3 (-39)	14.1 (-36)	11.6 (-50)
SE	0.706	0.411	0.585	0.34	0.708	0.719	1.42	0.984
CV	0.16	0.083	0.12	0.069	0.14	0.13	0.2	0.15

Soil Profile Response to Infiltration and Drainage Pulses

After completion of the initial wetting and drainage measurements (10:10 A.M. on October 5, 1984), Site C was subjected to two additional pulses of infiltration over a period of 8 hours. These "post-drainage" wetting and drainage regimes were applied on October 10, 1984, five days after completion of the main experiment. The purpose was to collect data on water movement in a pre-wetted soil profile for use in model calibration using field measured hydraulic parameters. The first infiltration treatment was for 1 hour and 16 minutes, followed by 1.5 hours of drainage. A second infiltration treatment was applied for 2 hours and 55 minutes, followed by 1.25 hours of drainage. Volumetric water content and tensiometric data were monitored during these treatments. Resulting matric potentials are on Table C.5. Corresponding soil moisture values are on Table C.6. Second infiltration treatment values on both tables are indicated by italics. Infiltration rates were not measured concurrent with these pulses.

Hydraulic gradients for the "post-desorption" measurements are shown on Figure C.4. Time periods for wetting and the corresponding depth of ponding applied are shown on Figure C.5. Because the maximum gradient for a soil layer usually occurs when the wetting front is at the upper boundary of the layer, we use the time from initiation of infiltration to peak gradient in each layer to measure the rate of advance of the wetting front for both infiltration pulses. Rates of wetting-front advance are shown on Figures C.6. Both advance rates are exponential with depth. The rate of advance of the second pulse is faster, as would be expected from a recently wetted profile.

Table C.5. Soil-water matric potential (in cm head) for infiltration and drainage pulses measured on October 5, 1984.

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137
Time (h)									
-0.837	-111	-100	-91.1	-77.8	-64.7	-63.8	-59.4	-66.8	-75.3
0.297	-29.8	-99.2	-89.1	-79.9	-68.8	-65.8	-59.4	-66.8	-79.4
0.413	-27.8	-99.2	-89.1	-73.8	-58.6	-43.4	-27.8	-12.8	2.24
0.513	-13.5	-98.1	-89.1	-73.8	-58.6	-43.4	-27.8	-12.8	2.24
0.647	-9.4	-85.9	-89.1	-73.8	-58.6	-43.4	-27.8	-12.8	2.24
0.763	-7.36	-66.5	-87	-71.7	-56.5	-41.3	-25.7	-10.7	4.28
0.863	-7.36	-53.3	-88	-79.9	-64.7	-49.5	-33.9	-18.9	-3.88
1.03	-2.26	-42	-86	-79.9	-64.7	-49.5	-33.9	-18.9	-3.88
1.16	-7.36	-36.9	-79.9	-79.9	-68.8	-67.8	-67.5	-67.8	-80.4
1.48	-	-30.8	-50.3	-79.9	-68.8	-53.6	-38	-23	-7.96
1.66	-	-31.8	-44.2	-79.9	-64.7	-49.5	-33.9	-18.9	-3.88
2.06	-	-34.9	-39.1	-68.7	-68.8	-53.6	-38	-23	-7.96
2.43	-	-40	-39.1	-53.4	-68.8	-67.8	-67.5	-52.5	-37.5
3.16	-45.1	-43.1	-39.1	-34	-71.8	-53.6	-66.5	-67.8	-65.1
3.45	*-12.5*	*-35.9*	*-40.1*	*-39.1*	*-69.8*	*-71.9*	*-67.5*	*-67.8*	*-78.3*
3.8	*-10.4*	*-28.8*	*-37*	*-40.1*	*-68.8*	*-74*	*-67.5*	*-67.8*	*-83.4*
4.16	*-9.4*	*-27.8*	*-31.9*	*-25.8*	*-66.7*	*-74*	*-67.5*	*-67.8*	*-83.4*
4.7	*-10.4*	*-27.8*	*-30.9*	*-35*	*-60.6*	*-72.9*	*-67.5*	*-67.8*	*-88.5*
5.26	*-11.4*	*-28.8*	*-30.9*	*-35*	*-36.1*	*-58.7*	*-66.5*	*-67.8*	*-89.6*
5.8	*-16.5*	*-27.8*	*-30.9*	*-35*	*-35.1*	*-43.4*	*-48.2*	*-67.8*	*-90.6*
6.26	*-26.7*	*-42*	*-31.9*	*-33*	*-35.1*	*-38.3*	*-35.9*	*-67.8*	*-88.5*
6.83	*-40*	*-40*	*-36*	*-36*	*-35.1*	*-37.2*	*-33.9*	*-61.7*	*-89.6*
7.25	*-46.1*	*-45.1*	*-40.1*	*-38.1*	*-36.1*	*-38.3*	*-33.9*	*-44.4*	*-89.6*
9.06	*-57.3*	*-54.3*	*-48.3*	*-45.2*	*-41.2*	*-40.3*	*-33.9*	*-39.3*	*-57.9*

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137
Time (h)									
0.297	-19.6	-96.1	-85	-89.1	-86.1	-82.1	-82.8	-67.8	0.297
0.413	-13.5	-94.1	-84	-68.7	-53.5	-38.3	-22.7	-7.66	0.413
0.513	-14.5	-92	-84	-68.7	-53.5	-38.3	-22.7	-7.66	0.513
0.647	-12.5	-84.9	-84	-68.7	-53.5	-38.3	-22.7	-7.66	0.647
0.763	-13.5	-72.6	-82.9	-89.1	-73.9	-58.7	-43.1	-28.1	0.763
0.863	-13.5	-61.4	-82.9	-89.1	-73.9	-58.7	-43.1	-28.1	0.863
1.03	-14.5	-47.1	-76.8	-76.8	-72.8	-70.9	-66.5	-66.8	1.03
1.16	-13.5	-40	-65.6	-77.8	-72.8	-69.9	-66.5	-66.8	1.16
1.48	-13.5	-34.9	-41.1	-73.8	-72.8	-57.6	-42	-27	1.48
1.66	-13.5	-32.9	-36	-68.7	-73.9	-71.9	-66.5	-66.8	1.66
2.06	-15.5	-31.8	-33	-46.2	-68.8	-71.9	-66.5	-66.8	2.06
2.43	-19.6	-32.9	-34	-36	-55.5	-67.8	-66.5	-66.8	2.43
3.16	-33.9	-41	-34	-35	-42.2	-67.8	-65.5	-66.8	3.16
3.45	*-14.5*	*-36.9*	*-33*	*-37*	*-40.2*	*-52.5*	*-64.5*	*-69.9*	*3.45*
3.8	*-15.5*	*-32.9*	*-33*	*-35*	*-41.2*	*-47.4*	*-61.4*	*-69.9*	*3.8*
4.16	*-15.5*	*-30.8*	*-29.9*	*-33*	*-38.2*	*-43.4*	*-55.3*	*-68.9*	*4.16*
4.7	*-14.5*	*-30.8*	*-28.9*	*-33*	*-36.1*	*-40.3*	*-38*	*-69.9*	*4.7*
5.26	*-17.6*	*-30.8*	*-29.9*	*-33*	*-38.2*	*-39.3*	*-33.9*	*-66.8*	*5.26*
5.8	*-17.6*	*-31.8*	*-29.9*	*-33*	*-38.2*	*-39.3*	*-31.8*	*-53.6*	*5.8*
6.26	*-23.7*	*-30.8*	*-29.9*	*-33*	*-36.1*	*-38.3*	*-30.8*	*-39.3*	*6.26*
6.83	*-29.8*	*-32.9*	*-29.9*	*-31.9*	*-37.1*	*-38.3*	*-30.8*	*-40.3*	*6.83*
7.25	*-36.9*	*-38*	*-33*	*-34*	*-37.1*	*-40.3*	*-31.8*	*-38.3*	*7.25*
9.06	*-54.3*	*-50.2*	*-42.1*	*-40.1*	*-40.2*	*-39.3*	*-31.8*	*-37.2*	*9.06*

Table C.6. Soil volumetric water content for infiltration and drainage pulses measured on October 5, 1984.

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137
Time (h)									
-3.09	0.2029	0.2055	0.1931	0.1661	0.1541	0.1416	0.1476	0.1552	0.1845
0.297	0.4404	0.3423	0.2257	0.1674	0.1502	0.1454	0.1446	0.1551	
0.563	0.4611	0.3671	0.2697	-	-	-	-	-	-
0.697	0.4281	0.3558	0.2893	0.1793	-	-	-	-	-
0.847	0.4196	0.3583	0.2925	0.1915	0.1499	-	-	-	-
1.03	0.4158	0.3579	0.3127	0.2081	0.1494	-	-	-	-
1.21	0.4109	0.3659	0.317	0.2272	0.1622	-	-	-	-
1.48	0.4122	0.3563	0.3214	0.2587	0.1685	0.1417	-	-	-
2.06	0.3454	0.3402	0.3115	0.2764	0.2148	0.1532	-	-	-
2.53	0.3236	0.3287	0.3123	0.2708	0.2326	0.1656	-	-	-
3.51	*0.3926*	*0.3625*	*0.3171*	*0.2779*	*0.2537*	*0.2057*	*0.1546*	*0.1516*	*0.1762*
3.86	*0.3895*	*0.3523*	*0.3261*	*0.2852*	*0.2544*	*0.2232*	*0.1696*	*0.1511*	*0.1778*
4.66	*0.3874*	*0.3565*	*0.3256*	*0.2915*	*0.2767*	*0.2591*	*0.2112*	*0.1639*	*0.172*
5.75	*0.3865*	*0.3525*	*0.3309*	*0.2929*	*0.2781*	*0.2762*	*0.2698*	*0.2481*	*0.2088*
6.33	*0.3662*	*0.3602*	*0.3258*	*0.2926*	*0.2807*	*0.2803*	*0.2686*	*0.2697*	*0.2584*
6.78	*0.3288*	*0.3272*	*0.3107*	*0.2921*	*0.2766*	*0.2744*	*0.2635*	*0.2804*	*0.2932*
7.25	*0.3364*	*0.3258*	*0.3159*	*0.2853*	*0.2738*	*0.2773*	*0.2677*	*0.2803*	*0.2977*

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137
Time (h)									
-3.09	0.2184	0.2169	0.1971	0.168	0.1527	0.1486	0.1411	0.1369	0.1583
0.297	0.4687	0.3733	0.2976	0.1852	0.1559	0.1514	0.2223	0.1395	0.1654
0.563	0.4418	0.3719	0.3148	0.2058	-	-	-	-	-
0.697	0.4388	0.368	0.3176	0.1922	-	-	-	-	-
0.847	0.4498	0.3717	0.3323	0.2398	0.1547	-	-	-	-
1.03	0.4365	0.3679	0.3339	0.2631	0.1622	-	-	-	-
1.21	0.4391	0.3672	0.3324	0.2747	0.1846	-	-	-	-
1.48	0.3537	0.3577	0.3289	0.2892	0.2084	0.1485	-	-	-
2.06	0.3421	0.3553	0.325	0.3003	0.247	0.1719	-	-	-
2.53	0.3283	0.3436	0.3154	0.2847	0.2612	0.1994	-	-	-
3.51	*0.4104*	*0.3703*	*0.331*	*0.3053*	*0.273*	*0.245*	*0.1789*	*0.1423*	*0.1629*
3.86	*0.4076*	*0.3649*	*0.3341*	*0.3091*	*0.2848*	*0.257*	*0.1961*	*0.1401*	*0.1635*
4.66	*0.3948*	*0.3612*	*0.3332*	*0.2669*	*0.2881*	*0.2745*	*0.2388*	*0.1708*	*0.16*
5.75	*0.3993*	*0.3582*	*0.3364*	*0.3045*	*0.2822*	*0.2815*	*0.2648*	*0.2508*	*0.2156*
6.33	*0.3492*	*0.3589*	*0.3323*	*0.3086*	*0.2879*	*0.2825*	*0.2736*	*0.2586*	*0.277*
6.78	*0.3435*	*0.3455*	*0.3202*	*0.2954*	*0.2904*	*0.2793*	*0.2655*	*0.2507*	*0.2835*
7.25	*0.3258*	*0.3427*	*0.3161*	*0.2937*	*0.2762*	*0.269*	*0.2648*	*0.2599*	*0.2857*

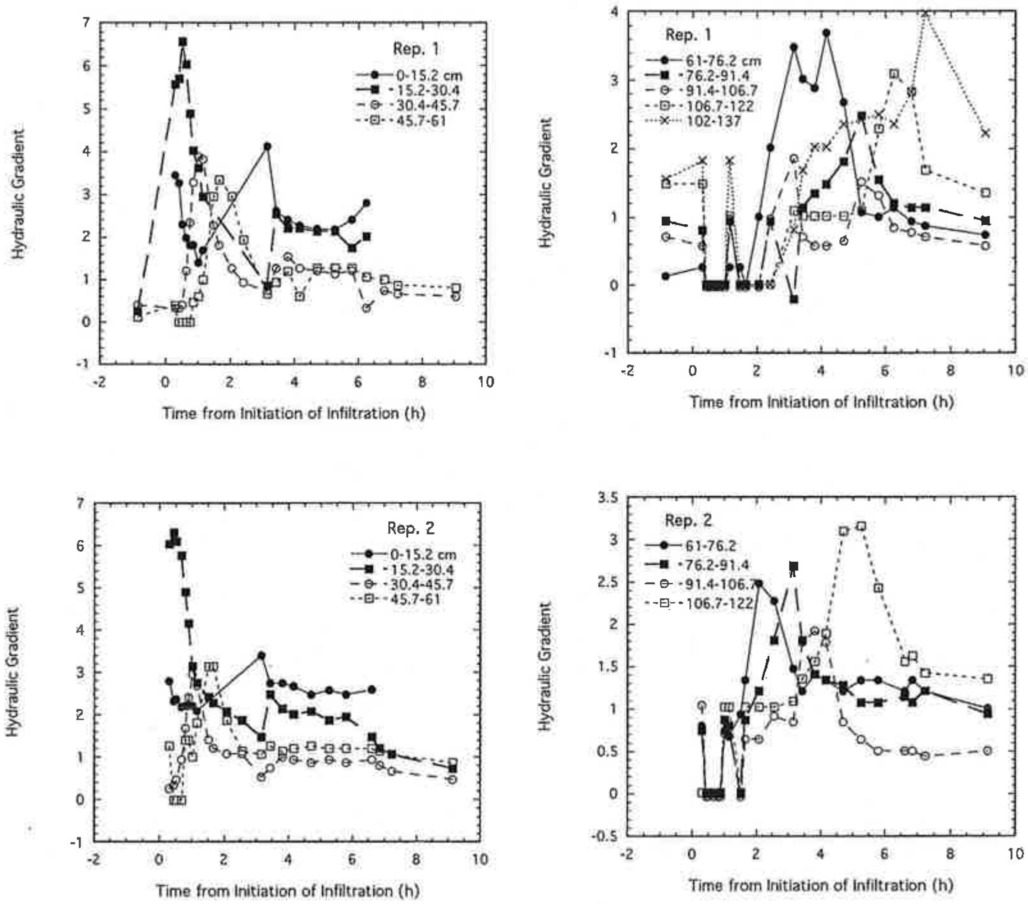

Figure C.4. Hydraulic gradients measured for two infiltration pulses shown on Figure C.5.

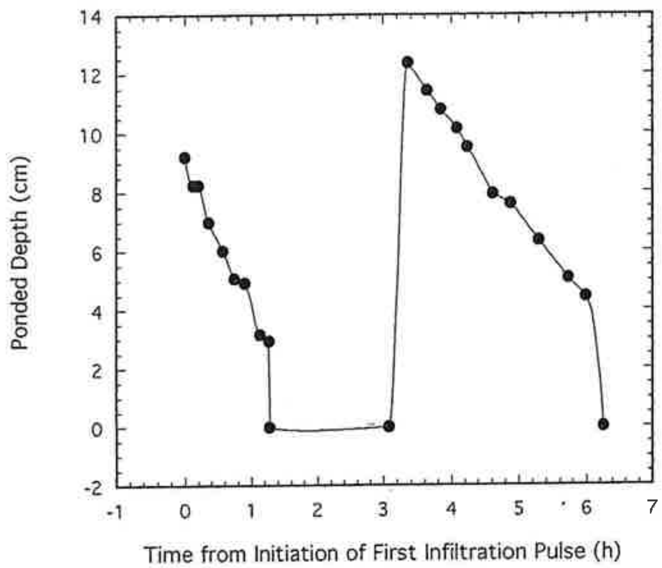

Figure C.5. Time and ponded depth for two infiltration pulses on Site C.

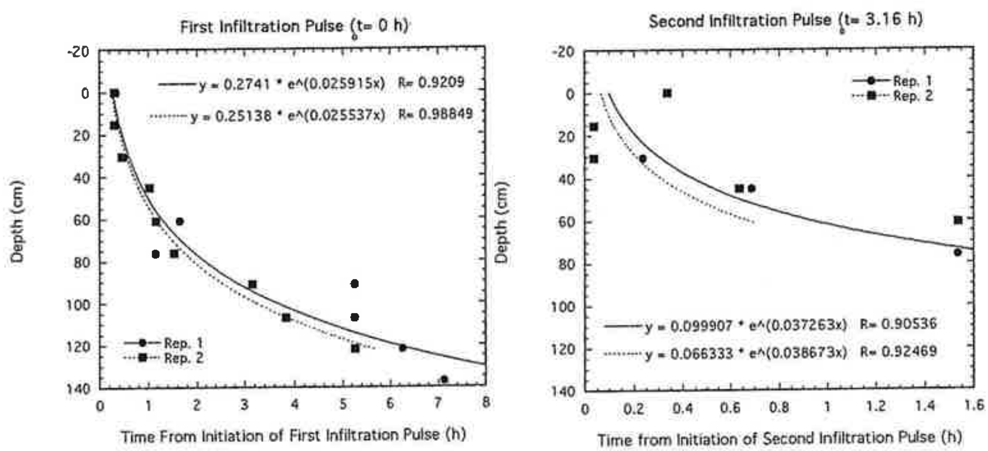

Figure C.6. Rate of wetting front advance for first and second infiltration pulses.

SITE D (Hecla Loamy Sand : Sandy, mixed, frigid Oxyaquic Hapludoll)

Site D was located in a non-irrigated wheat field. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples were collected and soil profiles were described approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture-retention data, soil physical data, soil saturated-paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 110-138. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Unlike Sites A, B and C, surface infiltration on Site D (and Sites E-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table D.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site D (Hecla sandy loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0.00	0.00	0.00	0.00		4.93	61.2	4.85	13.8
0.0330	0.229	0.0170	6.86		5.24	64.2	5.09	9.70
0.0800	0.839	0.0570	13.0		5.38	65.1	5.31	6.85
0.136	2.67	0.108	32.9		5.43	65.4	5.40	6.13
0.162	3.89	0.149	46.7		5.60	68.1	5.51	15.0
0.238	4.96	0.200	14.1		5.64	68.5	5.62	14.3
0.275	5.26	0.256	8.19		5.79	70.1	5.71	10.1
0.411	7.78	0.343	18.5		5.88	71.0	5.83	9.47
0.462	8.46	0.436	13.4		5.96	71.6	5.92	7.47
0.551	9.68	0.506	13.7		6.01	72.2	5.99	12.3
0.667	11.4	0.609	14.5		6.17	74.0	6.09	12.0
0.684	11.8	0.675	26.6		6.29	75.3	6.23	9.76
0.768	12.7	0.726	10.9		6.48	77.1	6.38	9.92
0.841	13.6	0.805	12.5		6.71	79.2	6.59	9.20
0.941	14.6	0.891	9.20		6.90	81.7	6.81	12.4
1.10	16.9	1.02	15.2		7.09	83.5	7.00	9.82
1.19	18.1	1.14	12.4		7.24	85.0	7.16	10.3
1.27	19.1	1.23	12.9		7.37	86.2	7.30	9.36
1.34	20.0	1.30	12.5		7.46	86.8	7.41	6.84
1.44	21.2	1.39	12.2		7.49	87.0	7.47	5.38
1.53	22.1	1.49	9.89		7.76	91.2	7.62	15.0
1.65	23.9	1.59	15.5		10.4	124	9.08	12.4
1.77	25.8	1.71	15.1		10.6	127	10.5	18.3
1.82	26.4	1.79	13.3		11.1	133	10.8	13.3
1.89	27.3	1.85	12.5		11.5	138	11.3	10.5
2.00	28.5	1.95	11.0		11.6	139	11.5	17.1
2.06	29.4	2.03	16.3		12.1	147	11.9	12.3
2.13	30.3	2.10	11.8		12.5	151	12.3	13.0
2.26	31.3	2.20	7.40		13.1	158	12.8	11.9
2.38	33.6	2.32	18.3		13.2	160	13.2	10.4
2.46	34.5	2.42	12.0		13.4	162	13.3	15.1
2.56	35.6	2.51	11.2		13.8	167	13.6	11.0
2.68	36.9	2.62	11.3		14.2	171	14.0	11.1
2.82	38.8	2.75	12.9		14.4	174	14.3	13.8
2.86	39.4	2.84	16.3		14.7	177	14.5	12.3
3.01	40.9	2.93	9.80		14.8	179	14.7	12.1
3.21	43.0	3.11	10.5		15.0	181	14.9	12.4
3.40	44.6	3.31	8.13		15.2	184	15.1	11.2
3.55	46.8	3.47	15.5		15.4	186	15.3	12.5
3.72	48.6	3.63	10.3		15.5	188	15.5	11.5
3.84	49.8	3.78	10.1		15.7	189	15.6	12.1
3.91	50.4	3.87	9.89		15.9	192	15.8	13.3
4.01	51.3	3.96	8.90		16.1	195	16.0	12.0
4.09	52.0	4.05	7.71		16.4	198	16.3	12.0
4.24	54.1	4.16	13.7		16.7	201	16.5	10.7
4.31	54.7	4.28	9.31		18.6	226	17.6	12.8
4.43	55.9	4.37	10.1		18.7	227	18.6	15.0
4.62	57.8	4.53	9.63		19.2	232	18.9	10.2
4.74	58.7	4.68	7.34		19.9	242	19.5	14.3
4.77	59.0	4.76	12.2		20.4	249	20.1	14.3

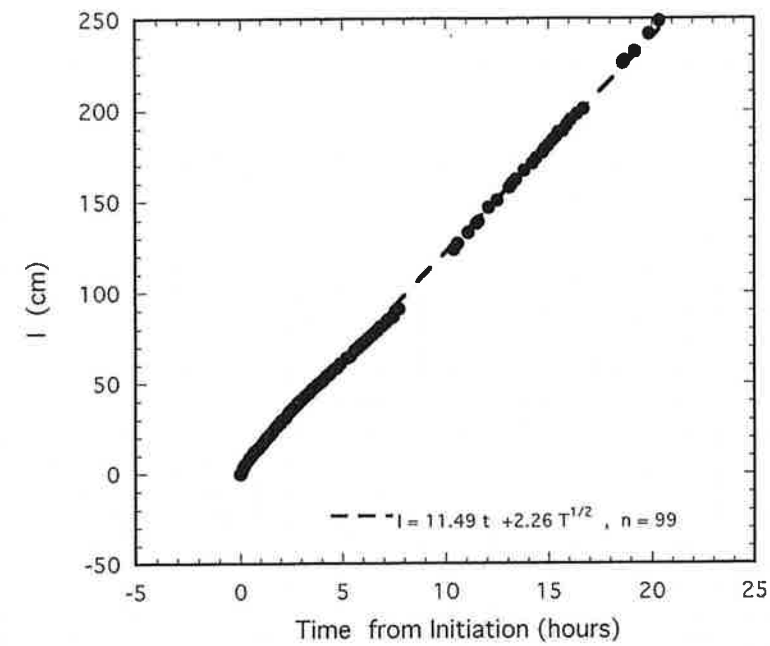

Figure D.1. Cumulative infiltration (I) and Phillp (1957) parametric function for soil surface on Site D.

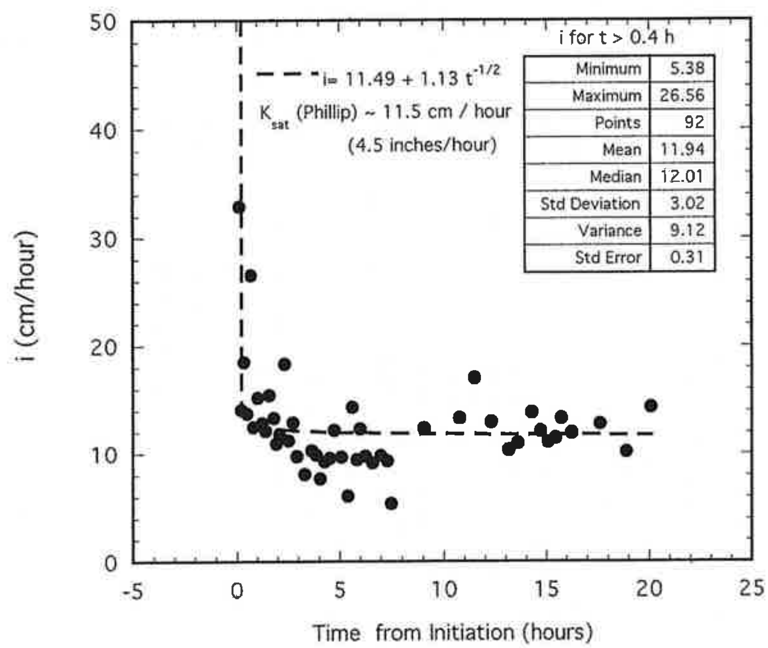

Figure D.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site D.

Table D.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8	274.3
Time (h)											
0.02	-140	-161	-165	-118	-90	-97	-66	-62	-40	-45	-
0.12	-130	-166	-169	-120	-90	-97	-66	-62	-40	-45	-
0.35	-3.3	-172	-169	-123	-94	-97	-66	-62	-40	-45	-
0.55	0.81	-145	-53	-123	-	-101	-78	-53	-31	-44	-8
0.67	0.81	-25	-26	-123	-96	-101	-78	-53	-31	-44	-8
0.88	30	0.8	-3.4	-35	-94	-101	-80	-64	-42	-45	-40
1.22	2.8	2.8	1.7	-8.5	-97	-101	-80	-64	-42	-45	-40
1.52	1.8	3.9	2.7	-2.3	-35	-101	-80	175	-42	-45	-40
1.87	1.8	5.9	2.7	-0.31	-18	-66	-80	-64	-42	-48	-40
2.28	2.8	4.9	2.7	2.7	-8.7	-4.7	-80	-64	-42	-48	-40
2.53	4.9	4.9	2.7	2.7	-4.6	0.4	-22	-65	-43	-49	-40
3.78	4.9	17	2.7	5.8	-3.6	1.4	-22	-25	-21	-48	-45
5.35	5.9	6.9	2.7	1.7	-4.6	-1.6	-21	-24	-19	-20	-44
6.85	4.9	6.9	2.7	3.8	-8.7	-4.7	-20	-24	-18	-19	-28
14	5.9	10	3.8	2.7	-8.7	-5.7	-17	-25	-19	-15	-26
15.2	6.9	10	3.8	1.7	-8.7	-5.7	-17	-25	-19	-14	-22
16	5.9	10	3.8	2.7	-7.1	-4.7	-17	-25	-20	-13	-22
19.9	5.9	11	3.8	1.7	-8.7	-3.7	-25	-29	-20	-11	-22

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4
Time (h)							
0.02	-124	-170	-164	-126	-90	-111	-68
0.12	-7.3	-163	-169	-128	-92	-111	-68
0.35	-1.2	-16	-171	-131	-94	-115	-76
0.55	-1.2	-4.3	-169	-131	-92	-113	-76
0.67	-4.3	-0.21	-7.4	-47	-92	-115	-75
0.88	0.81	0.81	2.7	-17	-92	-115	-75
1.22	0.81	1.8	2.7	-9.5	-15	-111	-77
1.52	0.81	-0.21	2.7	-11	-41	-117	-78
1.87	0.81	1.8	2.7	-9.5	-15	-111	-77
2.28	0.81	7.9	2.7	-8.5	-2.5	-25	-79
2.53	0.81	1.8	3.3	-5.4	1.5	-9.8	-17
3.78	1.8	1.8	4.8	-5.4	3.6	-11	-11
5.35	13	2.8	4.8	-4.4	4.6	-8.8	-12
6.85	1.8	-0.21	3.8	-5.4	3.6	-11	-15
14	3.9	2.8	2.7	-1.3	1.5	-13	-15
15.2	3.9	2.8	0.71	-2.3	0.51	-13	-18
16	4.9	2.8	1.7	-2.3	0.51	-13	-18

Table D.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8	274.3
Time (h)											
-0.71	0.0665	0.0647	0.0622	0.0611	0.0655	0.0918	0.0913	0.0952	0.0752	0.064	0.0637
0.62	0.2779	0.123	0.0791	0.0616	0.0672	0.0924	0.0927	0.0952	0.0752	0.064	0.0637
1.11	0.6132	0.4542	0.2942	0.1233	0.0667	0.0918	0.0927	0.0952	0.0752	0.064	0.0637
1.39	0.6421	0.4722	0.3885	0.2872	0.0761	0.0931	0.0902	0.0952	0.0752	0.064	0.0637
1.69	0.6186	0.4502	0.3559	0.332	0.1873	0.0931	0.0913	0.0952	0.0752	0.064	0.0637
2.01	0.6097	0.4408	0.3602	0.3657	0.2872	0.1055	0.0904	0.0984	0.0752	0.064	0.0637
2.37	0.6062	0.4583	0.3559	0.3591	0.3527	0.2431	0.092	0.0938	0.0749	0.065	0.0634
2.94	0.644	0.4189	0.3602	0.3735	0.3411	0.2969	0.2368	0.0986	0.0733	0.064	0.0622
3.52	0.615	0.4583	0.3391	0.3804	0.357	0.2951	0.2556	0.2618	0.0805	0.0624	0.0627
4.62	0.6257	0.4502	0.3506	0.3657	0.3463	0.2846	0.241	0.2771	0.2208	0.2127	0.0697
5.94	0.6257	0.4488	0.3422	0.3804	0.3484	0.289	0.2395	0.2787	0.2078	0.234	0.2526
8.23	0.6312	0.4227	0.3474	0.3657	0.336	0.2721	0.2374	0.2729	0.209	0.2189	0.2641
19.6	0.6608	0.4638	0.3624	0.392	0.3474	0.2978	0.2595	0.2812	0.2163	0.224	0.2579
20.9	0.6514	0.4982	0.3691	0.4304	0.3516	0.3078	0.2556	0.2907	0.2049	0.2227	0.2618

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8	274.3
Time (h)											
-1.12	0.1061	0.1003	0.09308	0.08676	0.0989	0.1487	0.1544	0.1672	0.1354	0.0989	0.09841
0.38	0.4898	0.4576	0.2639	0.1634	0.09938	0.1511	0.1549	0.1672	0.1354	0.0989	0.09841
0.78	0.5166	0.4738	0.4009	0.3556	0.1008	0.1544	0.1525	0.1672	0.1354	0.0989	0.09841
1.1	0.5037	0.4778	0.4025	0.3957	0.2102	0.1558	0.1553	0.1672	0.1354	0.0989	0.09841
1.4	0.7634	0.4526	0.4073	0.4015	0.3571	0.1643	0.1539	0.1686	0.1354	0.0989	0.09841
1.72	0.5025	0.4559	0.3983	0.4036	0.3719	0.2763	0.1511	0.1676	0.1325	0.0989	0.09841
2.12	0.5142	0.4744	0.4062	0.3962	0.402	0.3734	0.1988	0.1662	0.1311	0.1042	0.09841
2.75	0.5166	0.4727	0.403	0.4041	0.392	0.3744	0.3591	0.2816	0.1263	0.09648	0.09841
3.43	0.5118	0.4649	0.4115	0.4009	0.4025	0.3637	0.3591	0.3521	0.3118	0.1032	0.09987
4.43	0.5019	0.4705	0.4173	0.4131	0.3946	0.3739	0.3566	0.3612	0.342	0.3246	0.161
5.77	0.5013	0.4716	0.4015	0.4078	0.3952	0.3663	0.3556	0.3495	0.3286	0.332	0.343
7.4	0.5019	0.4688	0.4232	0.4157	0.3978	0.3709	0.3657	0.3571	0.3295	0.3226	0.346
19.2	0.5195	0.4767	0.4147	0.4308	0.4041	0.3724	0.3581	0.3571	0.331	0.3246	0.342
20.6	0.5113	0.4716	0.4163	0.4152	0.4036	0.3755	0.3612	0.3526	0.332	0.3281	0.344

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur, steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture above the boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Steady-state conditions prevail to 91 cm within two hours, and for all depths > 91 cm at 3 to 4 hours.

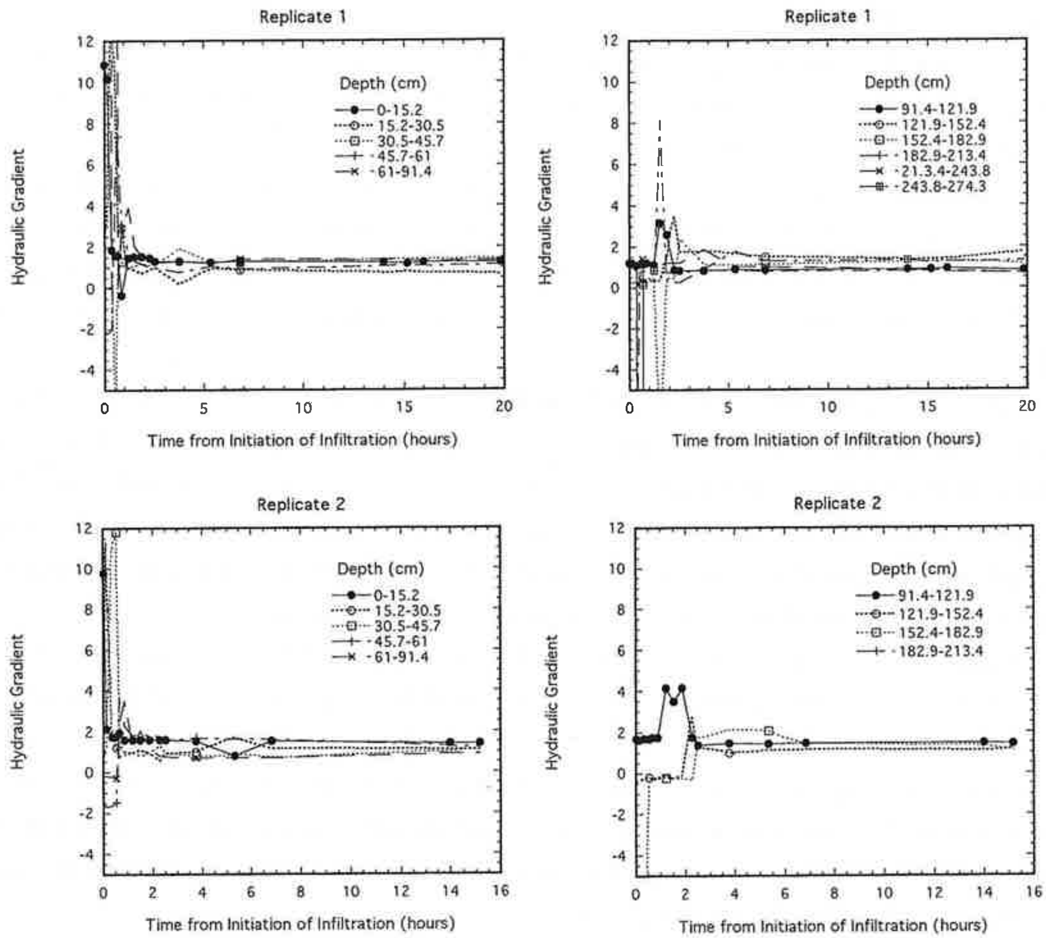

Figure D.3. Vertical hydraulic gradients during wetting and sorption of Site D.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site A are measured by matching the i vs. t function (Figure D.2) to the time sequence of the measured gradients. $K(sat/\psi)$ are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and $K(sat/\psi)$ can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table D.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [$K(\psi)$]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table D.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) is saturation and (-ψ) is the corresponding matric potential expressed cm head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-121.9	121.9-152.4	152.4-182.9	182.9-213.4	213.4-243.8	243.8-274.3
Time (h)											
1.22	8.6	13	-	-	-	-	-	-	-	-	-
1.52	8.1	14	-	-	-	-	-	-	-	-	-
1.87	8.1	17	10	10	-	-	-	-	-	-	-
2.28	8.4	14	11	12	8.9	-	-	-	-	-	-
2.53	9.2	12	11	12	9.8	-	-	-	-	-	-
3.78	9.1	-	6.2	15	9.2	14	6.8	11	14	-	-
5.35	9.5	13	9.4	11	9.9	13	7.3	11	14	12	9.5
6.85	9	14	9.4	13	8.5	14	7.9	10	15	12	9
14	9.3	16	8.4	11	8.6	13	8.6	9.3	15	14	9.3
15.2	9.9	15	8.4	10	8.8	13	8.6	9.3	15	14	9.9
16	9.3	16	8.4	11	8.9	13	8.4	9.3	14	15	9.3
mean	9 (s)	14 (s)	9.1 (s)	12 (s)	9.1 (-8)	13 (-11)	7.9 (-12)	10 (-23)	15 (-22)	13 (-20)	9.4 (-25)
SE	0.18	0.5	0.5	0.53	0.18	0.21	0.31	0.34	0.22	0.6	0.15
CV	0.065	0.11	0.16	0.14	0.058	0.039	0.094	0.083	0.038	0.1	0.035

Replicate 2

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-121.9	121.9-152.4
Time (h)							
1.2	7.8	13	-	-	-	-	-
1.5	7.8	11	-	-	-	-	-
1.9	7.7	13	-	-	-	-	-
2.3	7.6	23	9.4	7.2	15	-	-
2.5	7.6	13	13	7.6	16	-	-
3.8	8.0	12	15	7.1	17	8	12
5.3	15	7	14	7.5	17	8.6	11
6.8	7.9	11	16	7.5	17	7.9	11
14	8.4	11	12	9.1	13	7.9	11
15	8.4	11	11	9.8	13	8.4	9.8
16	9.1	11	11	9.1	13	8.4	9.8
mean	8.7 (s)	12 (s)	13 (s)	8.1 (-1)	15 (-6)	8.2 (-8)	8.7 (-13)
SE	0.65	1.2	0.7	0.37	0.67	0.12	0.65
CV	0.25	0.32	0.17	0.13	0.12	0.037	0.25

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site D was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table D.5. Cumulative infiltration and infiltration rate are shown on Figures D.4 and D.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table D.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site D (Hecla sandy loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		0.634	48.8	0.616	74.9
0.004	0.667	0.002	185		0.668	51.6	0.651	81
0.007	1.28	0.005	183		0.705	54.4	0.687	75
0.011	1.89	0.009	146		0.746	57.1	0.726	68.3
0.017	2.5	0.014	110		0.778	59.9	0.762	85.2
0.021	3.11	0.019	146		0.814	62.7	0.796	77.3
0.03	3.72	0.025	68.6		0.857	65.6	0.836	68.8
0.037	4.33	0.034	78.4		0.891	68.2	0.874	75.4
0.046	4.94	0.042	73.2		0.893	68.4	0.892	89
0.054	5.55	0.05	78.4		1.06	80.8	0.976	75.1
0.062	6.16	0.058	68.6		1.09	83.6	1.077	79.1
0.072	6.77	0.067	66.5		1.13	86.4	1.113	74.4
0.08	7.38	0.076	70.8		1.17	89.1	1.15	73.8
0.098	8.04	0.089	38.1		1.21	91.9	1.188	71.7
0.129	10.8	0.113	88.2		1.24	94.7	1.225	77.9
0.136	11.4	0.132	84.5		1.28	97.4	1.261	75.5
0.145	12	0.14	70.8		1.35	103	1.315	78.2
0.154	12.6	0.149	64.6		1.39	106	1.369	76.7
0.164	13.2	0.159	64.6		1.44	110	1.414	76.7
0.177	14.1	0.17	67.2		1.5	115	1.471	80.8
0.19	15.1	0.184	71.6		1.53	117	1.514	77.1
0.2	15.7	0.195	61		1.57	120	1.548	69.2
0.201	15.8	0.201	85.8		1.61	123	1.588	75.8
0.248	19.7	0.225	84.3		1.69	129	1.65	78.7
0.266	21.1	0.257	79.1		1.72	132	1.707	82.4
0.3	23.9	0.283	80.4		1.76	135	1.742	74.9
0.337	26.7	0.319	75.5		1.8	137	1.78	73.8
0.375	29.4	0.356	73.3		1.84	140	1.817	75.5
0.413	32.2	0.394	71.7		1.87	143	1.854	72.8
0.448	35	0.431	79.1		2.3	165	2.085	52.2
0.522	40.5	0.485	75.5		2.71	196	2.503	75.8
0.559	43.3	0.541	73.3		3.07	224	2.89	76.4
0.597	46.1	0.578	73.3					

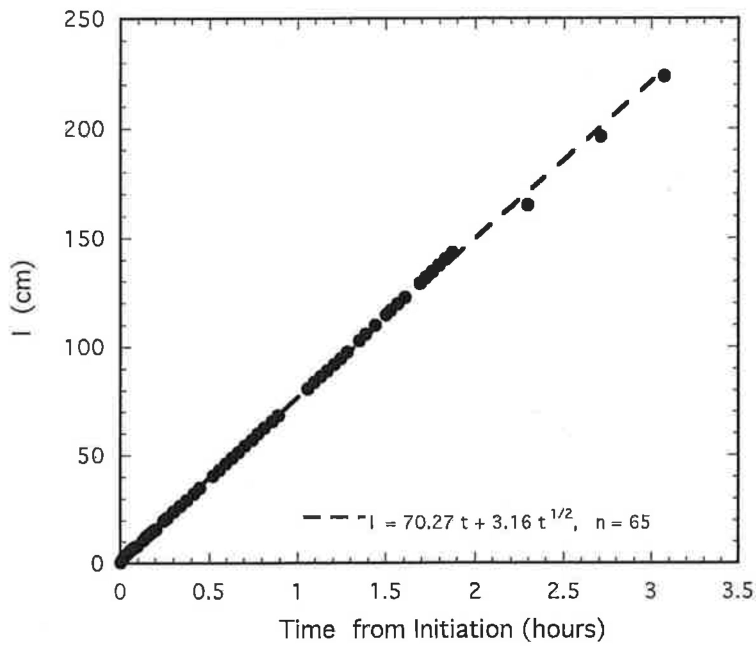

Figure D.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site D.

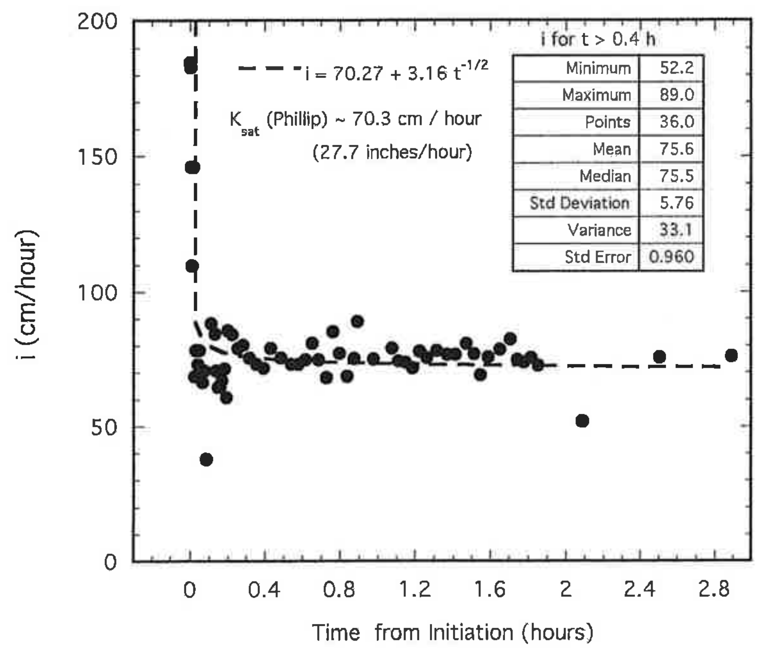

Figure D.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site D.

SITE E (Ulen Sandy Loam : Sandy, mixed, frigid Aeric Calciaquoll)

Site E was located in a non-irrigated wheat field downslope from Site D. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples and soil profile descriptions were taken approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture retention data, soil physical data, soil saturated-paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 140-162. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Unlike Sites A, B and C, surface infiltration on Site E (Sites -K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table E.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site E (Ulen sandy loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0.00	0.00	0.00			1.83	30.4	1.78	16.4
0.142	3.59	0.071	6.11		1.90	31.8	1.87	18.1
0.189	4.11	0.165	11.0		1.99	33.2	1.95	15.8
0.233	4.80	0.211	15.9		2.08	34.6	2.04	15.2
0.277	5.49	0.255	15.6		2.16	36.0	2.12	17.8
0.326	6.19	0.301	14.2		2.43	40.1	2.29	15.6
0.380	6.88	0.353	12.8		2.55	42.2	2.49	17.1
0.466	8.26	0.423	16.1		2.71	45.0	2.63	16.4
0.562	9.65	0.514	14.4		2.85	47.0	2.78	15.2
0.696	11.7	0.629	15.4		3.03	50.1	2.94	17.5
0.782	13.1	0.739	16.1		3.18	52.6	3.10	16.3
0.913	15.2	0.848	15.9		3.39	56.0	3.28	16.3
1.00	16.6	0.957	15.8		3.58	59.1	3.49	16.2
1.16	19.3	1.08	17.5		4.24	70.4	3.95	18.9
1.25	20.7	1.20	16.2		4.63	76.6	4.44	16.3
1.33	22.1	1.29	15.8		4.99	82.2	4.81	15.2
1.42	23.5	1.38	15.4		5.34	87.7	5.16	16.1
1.49	24.9	1.46	19.2		5.59	91.9	5.47	16.0
1.57	26.3	1.53	17.7		5.86	96.0	5.72	16.0
1.74	29.0	1.66	16.3					

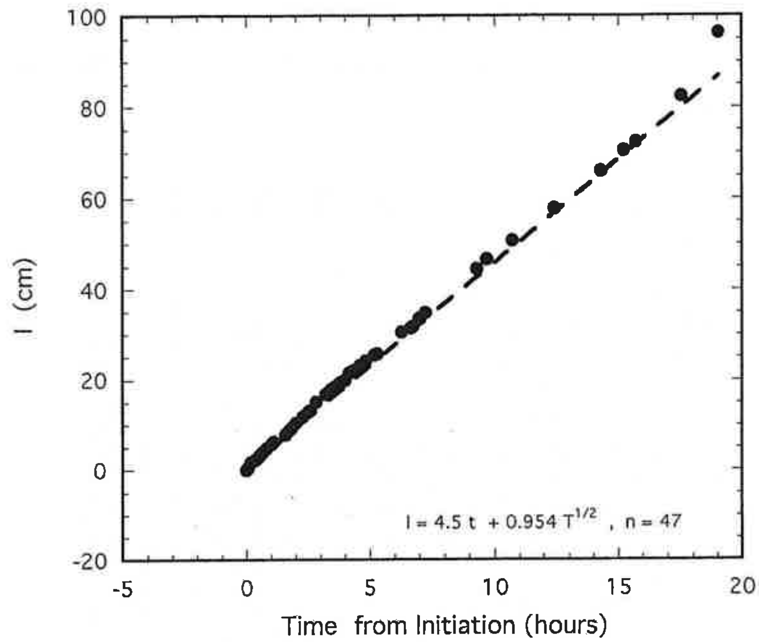

Figure E.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site E.

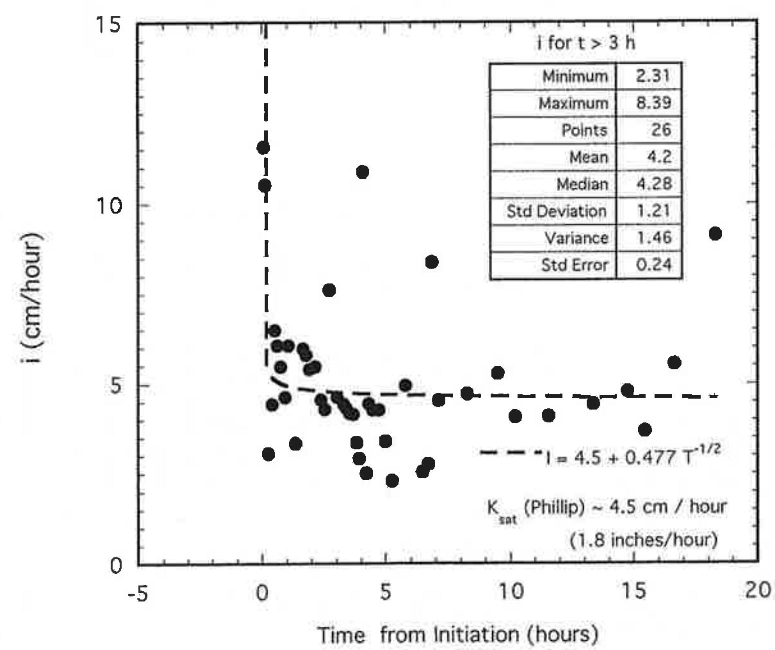

Figure E.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site E.

Table E.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4
Time (h)							
-0.46	-134	-129	-118	-103	-78	-43.5	-36.4
-0.09	-15.5	-129	-120	-104	-78	-46.5	-37.4
0.2	23.2	6.82	-62.5	-106	-80.1	-48.6	-36.4
0.39	24.3	8.86	-10.5	-45.2	-82.1	-49.6	-36.4
0.5	23.2	8.86	-5.42	-22.8	-79.1	-49.6	-36.4
0.87	25.3	8.86	-3.38	-10.5	-63.8	-49.6	-37.4
1.61	26.3	7.84	-3.38	-0.32	-14.8	2.44	-37.4
2.7	25.3	6.82	-4.4	-2.36	-12.8	-26.1	-19.1
3.27	25.3	6.82	-5.42	-3.38	-13.8	-26.1	-17
3.78	25.3	5.8	-6.44	-5.42	-12.8	-25.1	-17
3.19	25.3	5.8	-8.48	-6.44	-13.8	-35.3	-16
5.74	25.3	3.76	-8.48	-8.48	-2.56	-20	-16
9.38	26.3	2.74	-11.5	-10.5	-25	-24.1	-15
11.5	26.3	3.76	-11.5	-9.5	-12.8	-22	-16
17.5	25.3	5.8	-13.6	-9.5	-12.8	-22	-18.1
20.5	25.3	4.78	-8.48	-7.46	-21.9	-30.2	-19.1
21.2	15.1	-0.32	-9.5	-9.5	-12.8	-24.1	-17

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8
Time (h)										
-0.41	-93	-146	-132	-131	-100	-84.3	-50.7	-37.5	-42.7	-10.3
-0.02	-9.4	-26.8	-133	-140	-111	-87.3	-55.8	-44.7	-34.6	-7.24
0.27	-2.26	1.72	-63.6	-149	-113	-87.3	-54.8	-49.8	-42.7	-9.28
0.44	-1.24	2.74	-22.8	-151	-115	-87.3	-53.8	-48.8	-42.7	-9.28
0.55	-0.22	2.74	-16.6	-135	-116	-88.3	-53.8	-49.8	-42.7	-9.28
0.94	-1.24	1.72	-11.5	-14.6	-119	-89.4	-54.8	-53.9	-43.8	-9.28
1.22	3.86	1.72	-10.5	-9.5	-10.7	-25.1	-39.5	-57.9	-44.8	-9.28
2.74	2.84	2.74	-10.5	-9.5	-10.7	-18	-29.3	-61	-43.8	-9.28
3.32	6.92	4.78	-9.5	-8.48	0.5	-18	-26.2	-50.8	-42.7	-9.28
3.82	6.92	4.78	-10.5	-8.48	-9.7	-18	-26.2	-41.6	-42.7	-8.26
4.23	6.92	4.78	-10.5	-8.48	-9.7	-16.9	-26.2	-40.6	-42.7	-8.26
5.77	6.92	5.8	-11.5	-10.5	-8.68	-18	-26.2	-49.8	-24.4	-6.22
9.42	6.92	6.82	-9.5	-9.5	-8.68	-16.9	-27.2	-40.6	-24.4	-5.2
11.6	5.9	6.82	-8.48	-7.46	-7.66	-18	-27.2	-39.6	-24.4	-3.16
14.2	8.96	7.84	-6.44	-6.44	-6.64	-18	-28.3	-39.6	-24.4	-3.16
17.5	9.98	6.82	-5.42	-5.42	-2.56	-19	-29.3	51.2	-26.4	-5.2
20.5	11	7.84	-4.4	-4.4	-2.56	-20	-29.3	-40.6	-25.4	-5.2

Table E.3. Soil volumetric water content (θ)during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4
Time (h)									
-0.8	0.196	0.1837	0.1596	0.1544	0.1757	0.097	0.0999	0.1095	0.1273
21.91	0.392	0.3678	0.3801	0.375	0.3515	0.2524	0.2639	0.2734	0.2696
22.8*	0.3894	0.376	0.3734	0.3791	0.2744	0.2562	0.2836	0.2768	0.272
23.04	0.377	0.3632	0.3765	0.3719	0.3445	0.2529	0.26	0.2807	0.2759

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4
Time (h)									
-0.57	0.1988	0.1932	0.1823	0.1572	0.2277	0.1941	0.1052	0.1134	0.122
20.6	0.4693	0.4216	0.3703	0.2457	0.351	0.3108	0.2624	0.2812	0.2691
21.38*	0.427	0.412	0.378	0.3946	0.3435	0.3162	0.2533	0.2763	0.2648
21.64	0.3848	0.3755	0.3703	0.3832	0.3566	0.3128	0.2471	0.2773	0.2653

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Steady-state conditions prevail to 45.7 cm on Replicate 1 and to 91 cm on Replicate 2 within 2 hours. All deeper layers approximated steady state at 4 hours on Replicate 1 and at 5 hours on Replicate 2.

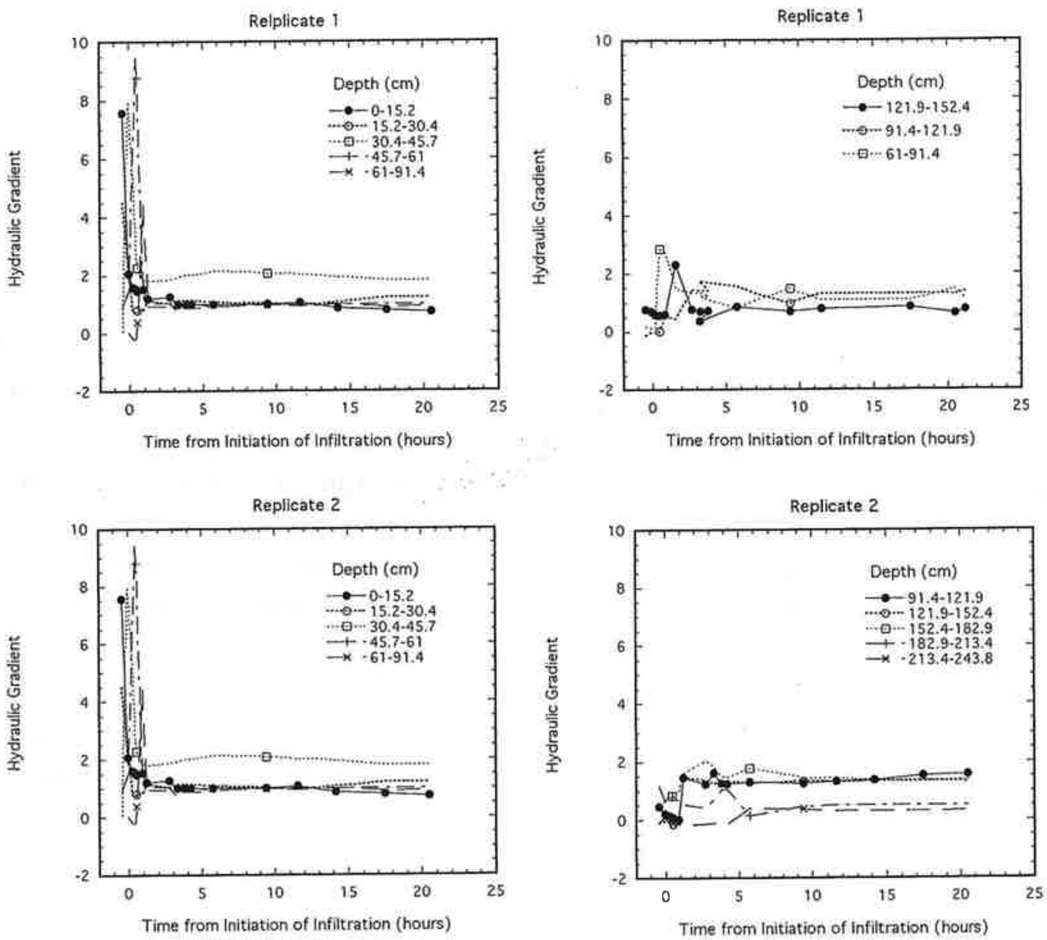

Figure E.3. Vertical hydraulic gradients during wetting and sorption of Site E.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site E is measured by matching the i vs. t function (Figure E.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table E.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table E.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) indicates saturation and (-ψ) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-30.5	30.5-45.7	45.7-61	61-91.4	91.4-121.9	121.9-152.4
Time (h)						
2.7	4.8	2.8	-	-	-	-
3.27	4.8	2.6	-	-	-	-
3.78	4.6	2.6	-	-	-	-
3.19	4.6	2.5	-	-	-	-
5.74	4.3	2.6	4.7	5.8	3	5.4
9.38	4.1	2.4	5	3.2	4.8	6.6
11.5	4.2	2.3	5.4	4.2	3.6	5.8
17.5	4.5	2	6.3	4.2	3.5	5.3
20.5	4.3	2.5	4.9	3.1	3.6	7.3
21.2	3.7	2.9	4.6	4.2	3.4	6
mean	4.39 (s)	2.52 (-9)	5.15 (-10)	4.12 (-12)	3.65 (-18)	6.07 (-21)
SE	0.11	0.08	0.26	0.4	0.25	0.31
CV	0.08	0.1	0.12	0.24	0.17	0.13

Replicate 2

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-121.9	121.9-152.4	152.4-182.9	182.9-213.4	213.4-243.8
Time (h)										
2.74	3.8	4.8	2.6	5.1	4.6	-	-	-	-	-
3.32	4.8	4.2	2.5	5.1	6.8	-	-	-	-	-
3.82	4.8	4.2	2.4	5.5	4.6	-	-	-	-	-
4.23	4.7	4.1	2.4	5.5	4.5	-	-	-	-	-
5.77	4.7	4.4	2.2	5	5	3.6	3.7	2.6	29	12
9.42	4.7	4.6	2.2	4.7	4.8	3.7	3.5	3.2	10	13
11.6	4.4	4.9	2.3	5	4.6	3.5	3.6	3.3	9.3	15
14.2	5.4	4.3	2.4	4.6	4.6	3.4	3.5	3.4	9.3	15
17.5	5.8	3.8	2.6	4.6	5.1	3	3.4			15
20.5	6.3	3.8	2.6	4.6	4.9	2.9	3.5	3.4	9.2	14
mean	4.94 (s)	4.31 (s)	2.42 (~0))	4.97 (-8)	4.95 (-7)	3.35 (-12)	3.53 (-23.1)	3.18 (-27)	13.4 (-26)	14 (-15)
SE	0.23	0.12	0.05	0.11	0.22	0.13	0.04	0.15	3.91	0.52
CV	0.15	0.09	0.06	0.07	0.14	0.1	0.03	0.11	0.66	0.09

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site E was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table E.5. Cumulative infiltration and infiltration rate are shown on Figures E.4 and E.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table E.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site E (Ulen Sandy Loam) measured near Oakes, ND.

0.5	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0			0.486	41.6	0.47	86.7
0.009	0.61	0.005	64.6		0.518	44.4	0.502	85.9
0.014	0.915	0.012	61		0.55	47.2	0.534	86.7
0.021	1.52	0.018	87.8		0.582	49.9	0.566	86.7
0.03	2.44	0.029	122		0.678	58.3	0.661	79.1
0.036	3.05	0.033	110		0.707	61	0.692	95.9
0.039	3.36	0.037	99.8		0.804	69.3	0.756	85.2
0.041	3.66	0.04	110		0.873	75	0.856	89
0.044	3.96	0.043	110		0.97	83.3	0.921	85.7
0.047	4.27	0.046	99.8		1.049	90.3	1.01	86.8
0.051	4.57	0.049	91.5		1.113	95.8	1.081	87.4
0.054	4.88	0.052	91.5		1.203	104	1.158	92.3
0.057	5.18	0.056	91.5		1.266	110	1.234	88.2
0.061	5.49	0.059	91.5		1.3	113	1.283	91.2
0.064	5.8	0.062	91.5		1.422	124	1.361	90.6
0.071	6.41	0.068	81.3		1.461	127	1.441	80.1
0.074	6.71	0.073	99.8		1.525	132	1.493	81.3
0.078	7.01	0.076	84.5		1.59	138	1.557	84.5
0.082	7.32	0.08	84.5		1.624	140	1.607	81
0.085	7.62	0.083	91.5		1.667	144	1.646	80.9
0.088	7.93	0.087	91.5		1.692	146	1.68	83.1
0.094	8.31	0.091	62.4		1.726	149	1.709	82.4
0.145	12.9	0.12	91.6		1.759	152	1.743	82.4
0.148	13.2	0.147	99.8		1.803	155	1.781	78.9
0.155	13.9	0.151	91.5		1.832	157	1.817	73.3
0.17	15.1	0.162	81.3		1.866	160	1.849	81.7
0.177	15.7	0.174	78.4		1.9	163	1.883	81
0.185	16.3	0.181	84.5		1.968	168	1.934	81.4
0.186	16.4	0.185	91.5		2.021	173	1.994	84.8
0.262	22.3	0.224	76.7		2.108	180	2.064	79.6
0.292	25	0.277	93.2		2.177	185	2.142	80.1
0.324	27.8	0.308	85.2		2.211	188	2.194	80.4
0.357	30.6	0.341	83.8		2.228	189	2.22	81.7
0.388	33.3	0.373	89.8		2.263	192	2.246	80.4
0.454	38.9	0.438	86.7		2.301	195	2.282	73.3

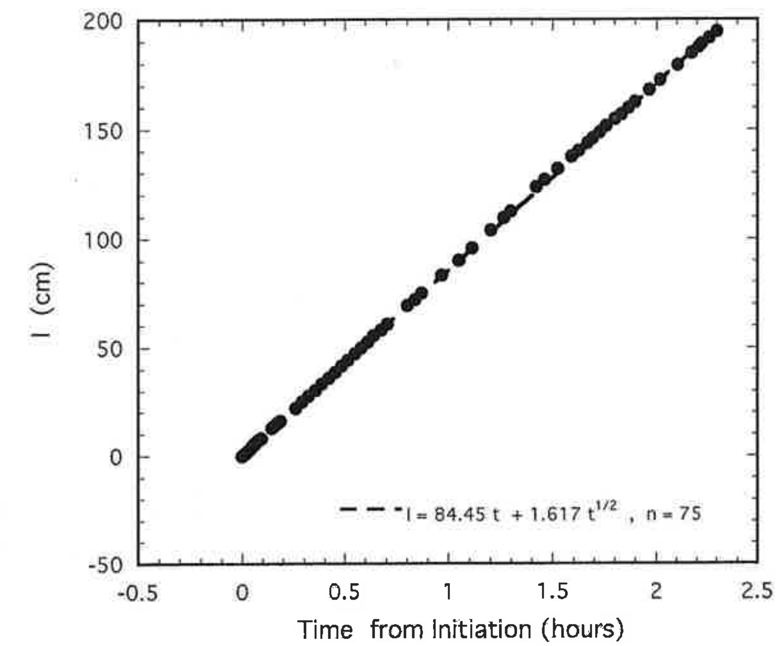

Figure E.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site E.

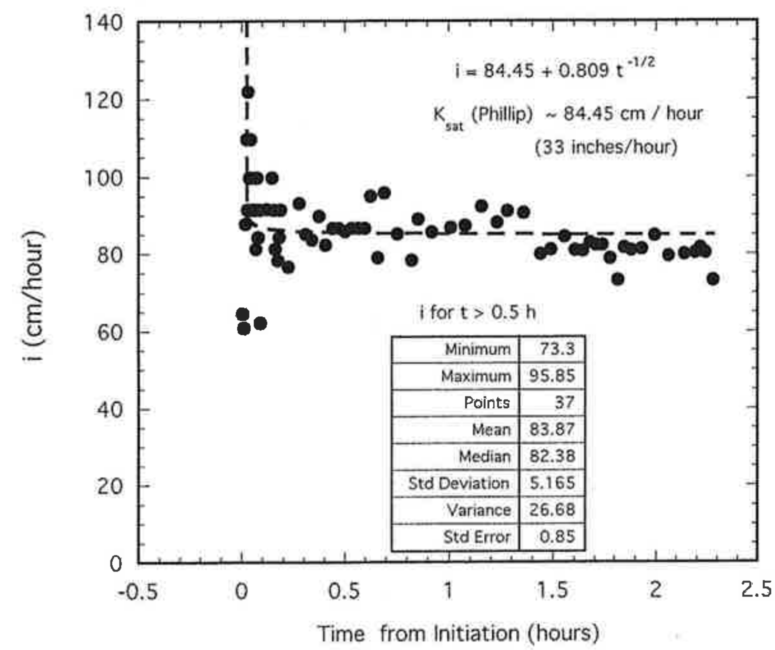

Figure E.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site E.

SITE F (Arveson Sandy Loam : Coarse-loamy, mixed, superactive, frigid Typic Calciaquoll)

Site F was located in a depressional area of a non-irrigated wheat field down slope from Sites D and E. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples and soil profile descriptions were taken approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in situ and laboratory soil moisture retention data, soil physical data, soil saturated paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 163-181. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Unlike Sites A, B and C, surface infiltration on Site F (Sites D-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table F.1. Cumulative infiltration (I), and infiltration rate (i) for the soil surface Site F (Arveson sandy loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		2.006	15	1.941	1.78
0.038	0.763	0.019	20		2.139	15.8	2.072	5.44
0.108	2.53	0.073	25.2		2.519	17.2	2.329	3.8
0.151	3.13	0.129	14.4		2.846	18.4	2.683	3.74
0.21	3.9	0.18	12.9		3.043	19	2.944	3.09
0.279	4.51	0.244	8.85		3.231	19.6	3.137	3.25
0.378	5.12	0.328	6.15		3.799	21.5	3.515	3.22
0.499	6.64	0.438	12.6		4.146	22.4	3.972	2.63
0.575	7.25	0.537	8.01		4.398	23	4.272	2.42
0.697	8.17	0.636	7.47		4.645	23.6	4.522	2.47
0.779	8.78	0.738	7.47		5.199	24.8	4.922	2.2
0.872	9.39	0.825	6.59		5.275	25	5.237	2
0.987	9.85	0.929	3.98		8.891	32.9	7.083	2.2
1.15	10.7	1.068	5.14		10.43	35.7	9.658	1.81
1.308	12	1.229	8.19		11.91	38.5	11.16	1.87
1.425	12.6	1.367	5.22		13.56	41.8	12.73	1.99
1.6	13.5	1.513	5.24		14.19	42.6	13.88	1.37
1.743	14.2	1.672	4.79		14.96	44	14.58	1.81
1.877	14.8	1.81	4.56					

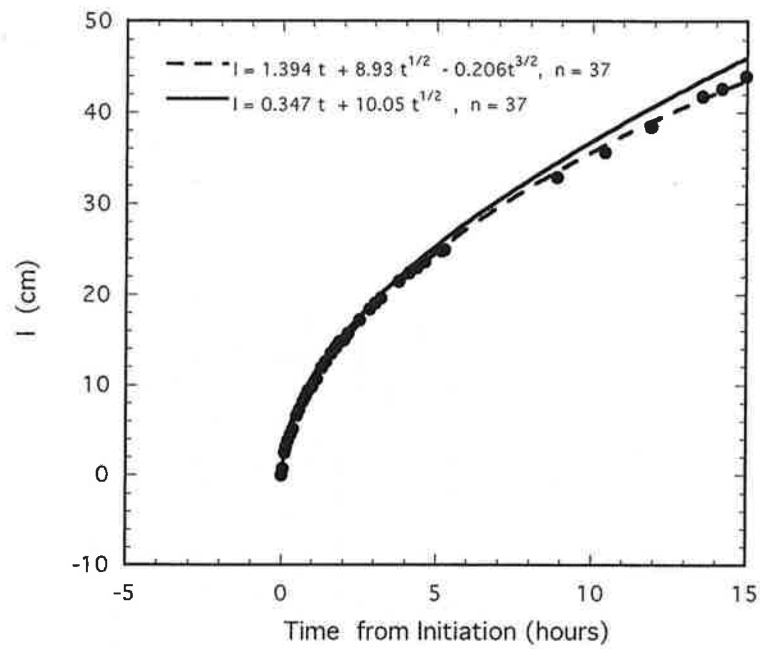

Figure F.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site F.

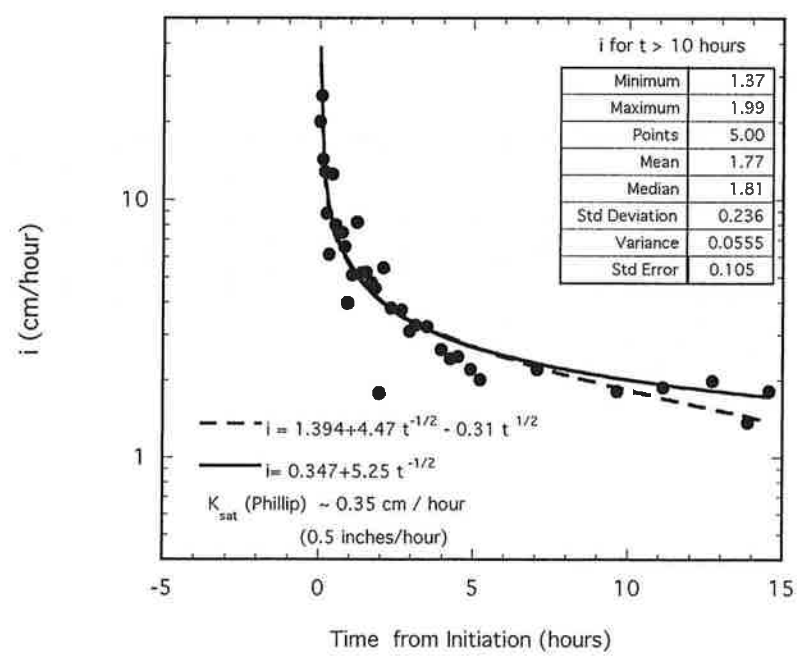

Figure F.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site F.

Table F.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4
Time (h)							
-0.49	-317	-332	-262	-116	-95.4	-98.4	-83.7
0.16	-102	-345	-282	-126	-100	-104	-105
0.46	-9.4	-186	-293	-129	-100	-113	-104
0.63	-9.4	-9.4	-297	-129	-100	-102	-102
0.94	-7.36	-8.38	-44.2	-127	-100	-102	-98
1.26	-8.38	-6.34	-16.6	-56.4	-100	-100	-97
1.57	-7.36	-6.34	-12.6	-20.7	-102	-100	-95
1.85	-6.34	-6.34	-10.5	-7.46	-100	-100	-93.9
2.1	-6.34	-6.34	-8.48	-4.4	-99.5	-100	-92.9
2.9	-3.28	-5.32	-7.46	-2.36	-42.3	-102	-90.9
4.36	-0.22	-3.28	-7.46	-3.38	-40.3	-35.2	-84.8
8.99	6.92	-0.22	-3.38	-5.42	-36.2	-31.1	-37.8
10.7	5.9	1.82	-3.38	-7.46	-36.2	-31.1	-37.8
12.1	6.92	1.82	-2.36	-8.48	-37.2	-32.1	-39.9
14.2	14.1	3.86	0.7	-8.48	-36.2	-32.1	-39.9
15.4	14.1	4.88	0.7	-9.5	-37.2	-33.2	-39.9
18.2	8.96	1.82	-2.36	-13.6	-37.2	-34.2	-36.8

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8
Time (h)										
-0.43	-303	-313	-245	-147	-115	-102	-73.5	-52.7	-23.8	7.24
0.12	-129	-331	-138	-155	-121	-105	-76.6	-51.7	-23.8	7.24
0.34	-20.6	-337	-59.5	-159	-123	-108	-76.6	-52.7	-23.8	7.24
0.61	-7.36	-241	-35	-159	-123	-109	-76.6	-52.7	-23.8	7.24
0.88	-5.32	-342	-31.9	-157	-122	-108	-75.6	-52.7	-23.8	7.24

Table F.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	207
Time (h)									
-0.37	0.261	0.2438	0.2064	0.1676	0.1378	0.1624	0.2372	0.1563	0.2759
13.7	0.4571	0.3868	0.3607	0.3167	0.2648	0.2768	0.3622	0.2908	0.329
15.4	0.4471	0.392	0.3581	0.3211	-	0.2821	0.3668	0.2899	0.329
18.3*	0.4532	0.3926	0.3566	0.3172	0.2701	0.2802	0.3556	0.2908	0.338

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9
Time (h)								
-0.26	0.2467	0.2267	0.2064	0.1658	0.1435	0.1425	0.2918	0.1506
14	0.471	0.3791	0.3515	0.3266	0.2812	0.2855	0.4073	0.2918
15.6	0.4755	0.3848	0.3526	0.3172	0.2821	0.2874	0.4004	0.2845
18.4*	0.4565	0.3822	0.3596	0.3271	0.2869	0.2739	0.412	0.2865

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Steady-state conditions are approximated to 60 cm after 2 hours, to 91 cm after 3 hours, and below 91 cm after 5 hours on replicate. On Replicate 2 steady state is approximated after 0.6 hours to 31 cm. Because of short measurement times, deeper steady-state approximations for deeper layers cannot be ascertained. Initial gradients near 0 deep in the soil profile indicate likely equilibrium with the water table. Most final steady-state gradients are near 1.

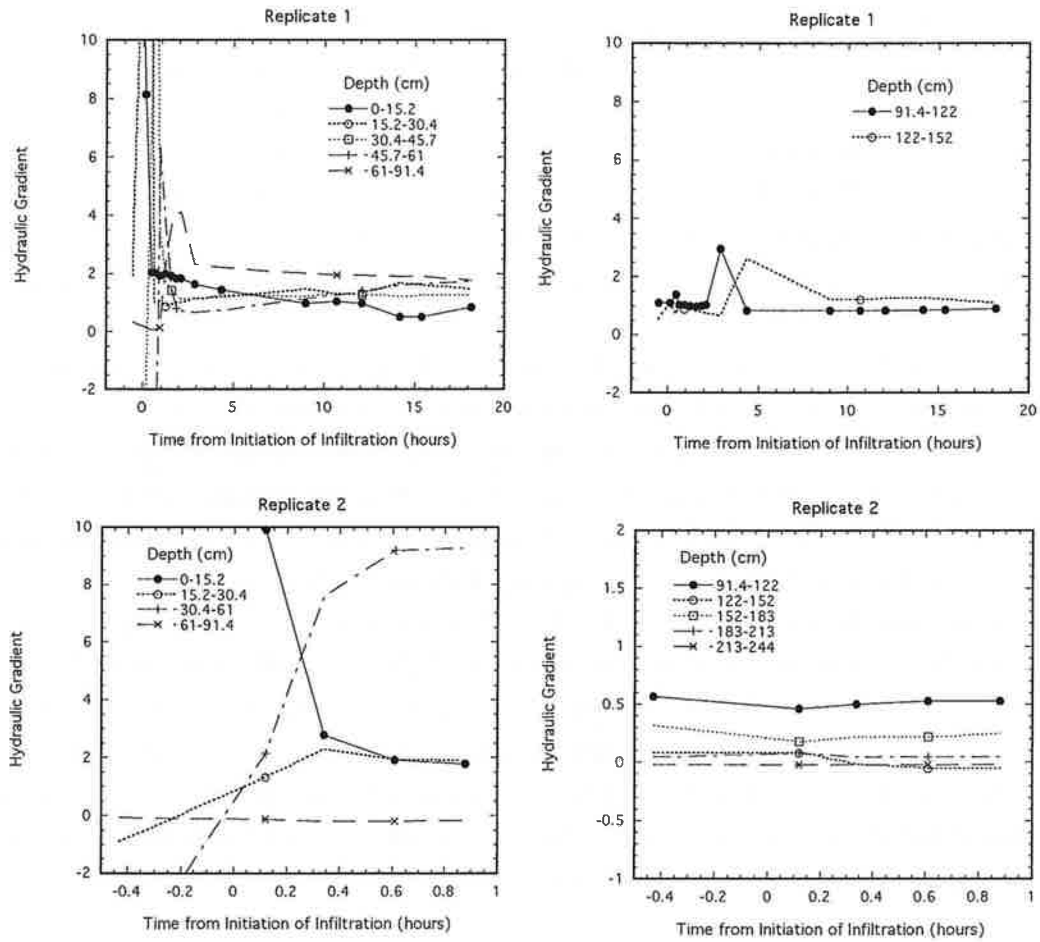

Figure F.3. Vertical hydraulic gradients during wetting and sorption of site F.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site F are measured by matching the i vs. t function (Figure F.2) to the time sequence of the measured gradients. $K(sat/\psi)$ are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and $K(sat/\psi)$ can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table F.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [$K(\psi)$]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table F.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) indicates saturation and ($-\psi$) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-121.9	121.9-152
Time (h)							
2.9	2.08	3.02	3.01	-	-	-	-
4.36	1.98	2.38	2.24	3.91	1.29	-	-
8.99	2.14	1.43	1.74	1.85	1.04	2.52	1.09
10.7	1.87	1.54	1.45	1.54	1	2.35	1.72
12.1	1.9	1.39	1.46	1.32	0.954	2.23	1.6
14.2	3.42	1.04	1.44	1.08	0.91	2.01	1.48
15.4	3.31	1.05	1.32	1.01	0.882	1.95	1.39
18.2	1.87	1.07	1.24	0.907	0.887	1.75	1.38
mean	2.3 (s)	1.88 (s)	1.93 (-1)	1.66 (-6)	0.995 (-23)	2.13 (-35)	1.44 (-36)
SE	0.204	0.344	0.27	0.395	0.054	0.116	0.0883
CV	0.266	0.55	0.419	0.63	0.144	0.133	0.15

Replicate 2

Not Measured on Site F.

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site E was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table F.5. Cumulative infiltration and infiltration rate are shown on Figures F.4 and F.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table F.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil Site F (Arveson sandy loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		2.01	69.2	1.972	35.9
0.009	0.865	0.004	97.3		2.086	72	2.048	36.5
0.046	3.63	0.028	74.4		2.175	74.8	2.13	31.2
0.105	6.4	0.075	47.2		2.26	77.5	2.217	32.6
0.18	9.17	0.142	36.8		2.422	83.1	2.341	34.2
0.258	11.9	0.219	35.6		2.53	86.5	2.476	31.9
0.351	14.7	0.304	29.8		2.59	88.6	2.56	34.8
0.43	17.5	0.39	35.1		2.702	92.4	2.646	34
0.523	20.2	0.476	29.8		2.831	96.9	2.767	34.7
0.609	23	0.566	32		2.927	100	2.879	36.2
0.696	25.8	0.653	31.9		2.985	102	2.956	35.6
0.83	28.6	0.763	20.7		3.066	105	3.025	34.5
0.869	31.3	0.849	71.2		3.157	108	3.111	34
0.951	34.1	0.91	33.9		3.222	111	3.19	37.3
1.035	36.9	0.993	32.9		3.299	114	3.26	36.2
1.129	40	1.082	33.2		3.404	117	3.372	56.2
1.198	42.4	1.163	34.8		3.472	120	3.438	41
1.29	45.5	1.244	34.1		3.935	137	3.703	37.4
1.366	47.9	1.328	31.8		4.468	155	4.201	34.1
1.451	50.7	1.408	32.7		4.718	163	4.593	28.4
1.545	53.5	1.498	29.2		5.151	178	4.935	34.7
1.646	56.9	1.596	34.2		5.718	196	5.435	32.7
1.668	57.6	1.657	32.8		1.933	66.5	1.893	34.1
1.785	61.6	1.726	33.9		2.01	69.2	1.972	35.9
1.852	63.7	1.818	31		2.086	72	2.048	36.5
1.933	66.5	1.893	34.1					

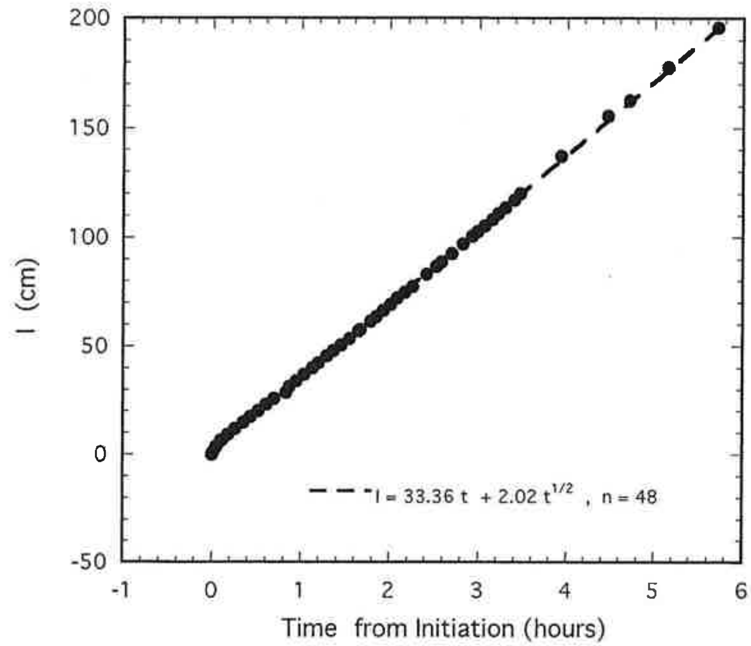

Figure F.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site F.

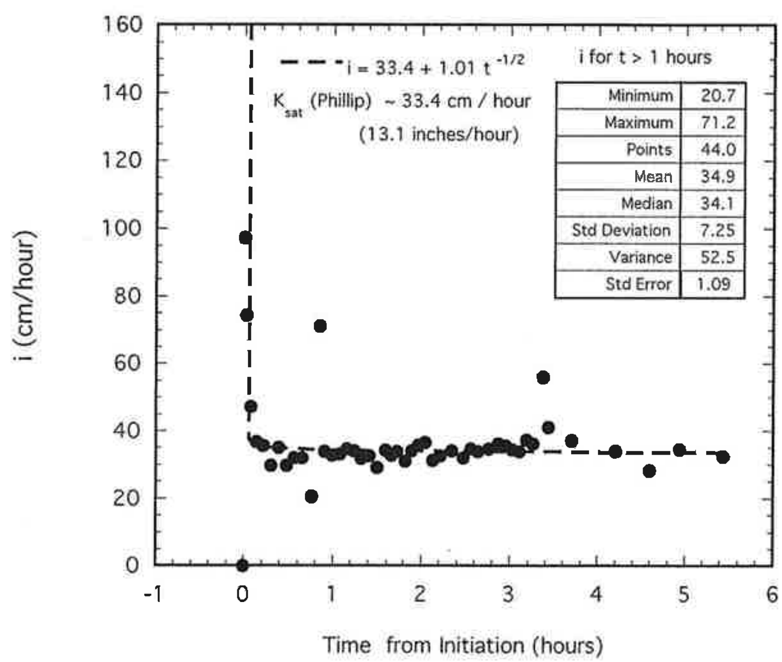

Figure F.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site F.

SITE G (Heimdal Loam : Coarse-loamy, mixed, superactive, frigid Calcic Hapludoll)

Site G was located on an elevated knob in a non-irrigated cornfield. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples and soil profile descriptions were taken approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture-retention data, soil physical data, soil saturated paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 182-201. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Unlike Sites A, B and C, surface infiltration on Site G (and Sites D-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table G.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site G (Heimdal loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0.202	1.37	0.187	45.3		1.106	21.7	0.994	18.4
0.229	2.29	0.215	34		1.484	26.5	1.295	12.8
0.274	3.81	0.252	33.3		1.852	30.7	1.668	11.3
0.319	5.03	0.297	27.3		5.436	48	3.644	4.83
0.342	5.64	0.33	27.1		5.725	48.7	5.58	2.39
0.581	11.4	0.461	24.2		7.486	53.7	6.605	2.85
0.699	14.2	0.64	23.2		9.35	57.7	8.418	2.14
0.731	14.8	0.715	19.3		10.75	61.1	10.05	2.47
0.779	15.7	0.755	18.9		11.42	62.5	11.09	2.08
0.831	16.6	0.805	17.9		12.99	63.9	12.2	0.883
0.881	17.5	0.856	18.2		1.106	21.7	0.994	18.4
0.202	1.37	0.187	45.3		1.484	26.5	1.295	12.8
0.229	2.29	0.215	34		1.852	30.7	1.668	11.3
0.274	3.81	0.252	33.3		5.436	48	3.644	4.83
0.319	5.03	0.297	27.3		5.725	48.7	5.58	2.39
0.342	5.64	0.33	27.1					

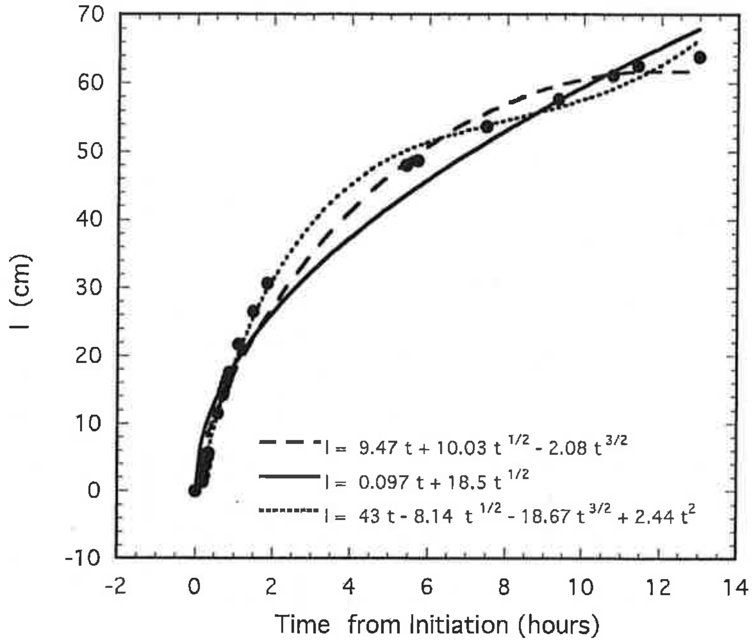

Figure G.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site G.

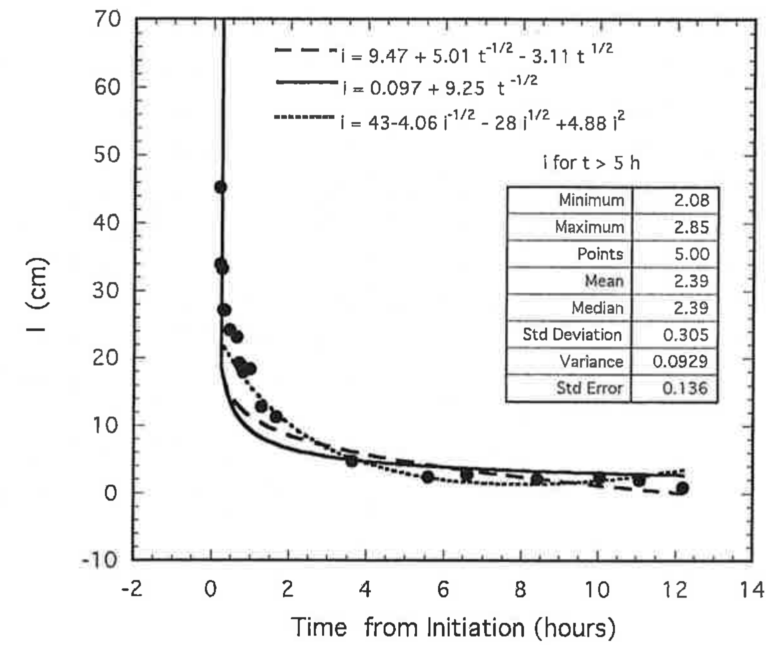

Figure G.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site G.

Table G.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	122	152	244	274
Time (h)									
-1.24	-330	-102	-371	-358	-341	-217	-295	-234	-205
0.99	-7.36	6.92	-9.5	26.2	15.8	-300	-25.2	-197	-19.6
1.69	-4.3	11.0	6.82	38.4	35.2	-132	0.3	-20.5	-4.28
2.61	-0.22	15.1	12.9	42.5	43.3	11.6	47.2	40.7	1.84
3.97	-1.24	14.1	14	42.5	45.4	46.3	69.7	72.3	-1.22
5.85	0.8	16.1	21.1	46.6	55.6	66.7	85	76.4	2.86
6.51	0.8	16.1	19.1	46.6	55.6	70.8	88	68.2	8.98
9.49	1.82	17.1	21.1	46.6	57.6	71.8	86	64.2	11
11.3	1.82	17.1	20.1	46.6	57.6	71.8	82.9	61.1	11
13.3	2.84	17.1	22.1	47.6	59.7	74.9	96.2	62.1	15.1
17.8	2.84	16.1	23.1	46.6	58.6	74.9	83.9	64.2	16.1
19.7	0.8	15.1	22.1	44.6	60.7	70.8	97.2	63.1	26.3

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	122	152	244	274
Time (h)									
-1.24	-290	-343	-341	-341	-306	-282	-274	-197	-179
0.99	16.1	24.2	27.2	52.7	70.9	-317	78.8	66	63
1.69	17.1	26.2	30.3	51.7	72.9	-125	93.1	62.9	62
2.61	19.2	28.2	35.4	54.8	79	26.9	111	97.6	56.9
4.02	20.2	25.2	36.4	54.8	80.1	63.6	131	129	132
5.9	23.2	28.2	41.5	52.7	84.1	83	142	156	158
7.51	23.2	25.2	40.5	56.8	84.1	89.1	143	158	160
9.39	23.2	35.4	42.5	57.8	84.1	90.2	143	159	161
11.3	21.2	24.2	42.5	55.8	81.1	90.2	141	158	160
13.3	23.2	27.2	46.6	57.8	83.1	90.2	143	159	162
17.8	23.2	25.2	46.6	54.8	82.1	89.1	143	159	161
20.4	20.2	34.4	48.6	58.8	83.1	92.2	140	159	160

Table G.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8
Time (h)										
-0.88	0.2490	0.2957	0.302	0.3142	0.2908	0.3113	0.3206	0.3345	0.3551	0.3724
19.4	0.4973	0.4152	0.4324	0.4716	0.4389	0.391	0.3873	0.3842	0.3926	0.3868
21.7	0.5002	0.4179	0.4297	0.4643	0.4291	0.3905	0.3863	0.3827	0.3822	0.3873
22	0.4904	0.42	0.4265	0.4587	0.4168	0.3905	0.3817	0.3848	0.3905	0.3926
22.7	0.4789	0.4088	0.4346	0.4699	0.4104	0.3827	0.3842	0.378	0.3832	0.3894

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8	250
Time (h)											
-0.73	0.2500	0.2923	0.2889	0.3345	0.2952	0.3128	0.3182	0.351	0.3617	0.376	
19.6	0.4927	0.4184	0.4389	0.4598	0.4041	0.4131	0.376	0.3822	0.3842	0.3899	0.3962
20.9	0.4852	0.4157	0.4772	0.4548	0.4094	0.3978	0.3724	0.3755	0.3796	0.3837	0.3899
21.1	0.4852	0.4094	0.4367	0.4521	0.3978	0.4051	0.3714	0.3775	0.3765	0.3739	0.391
21.3	0.4967	0.412	0.4291	0.4526	0.3983	0.4115	0.3744	0.3806	0.3837	0.3868	0.3837

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Steady-state conditions are approximated to 91 cm within 2 hours on both replicates. Below 91 cm all layers approximate steady state after 7 hours.

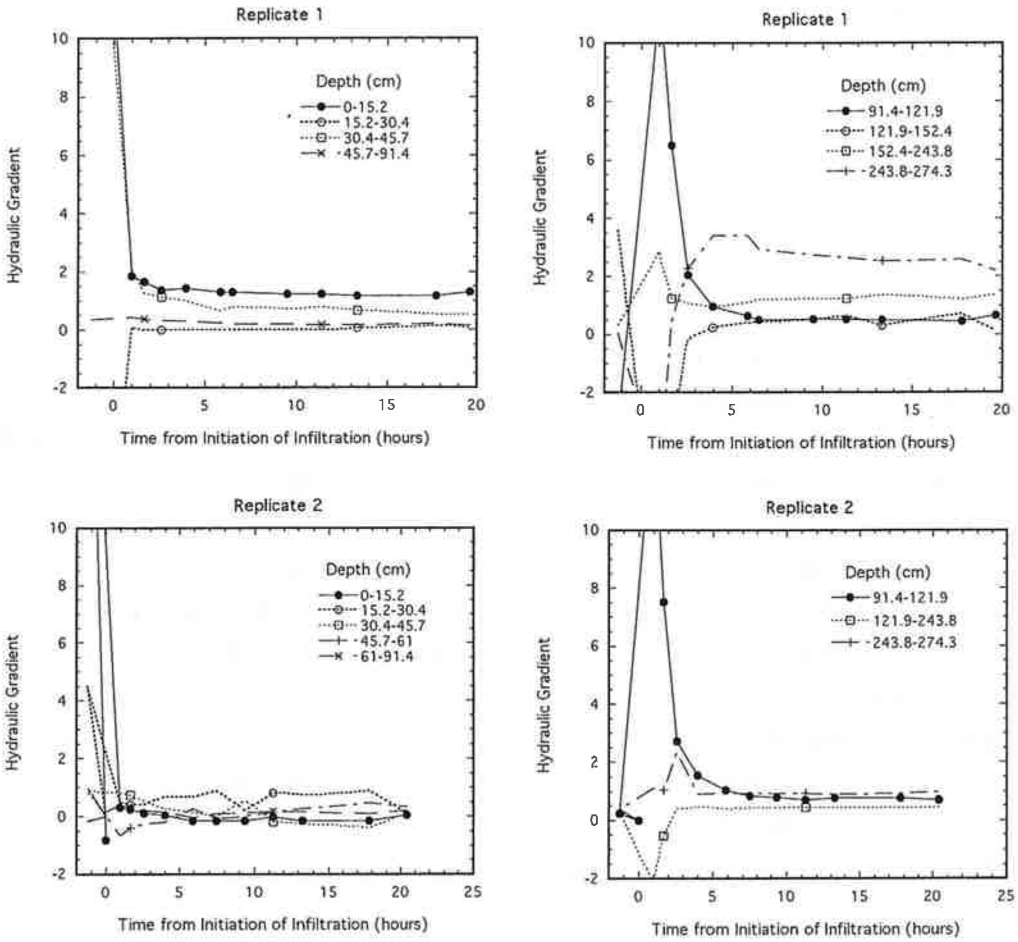

Figure G.3. Vertical hydraulic gradients during wetting and sorption of Site G.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site G are measured by matching the i vs. t function (Figure G.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table G.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table G.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) indicates saturation and (-ψ) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-91.4	91.4-122	122-152	152.4-244	244-274
Time (h)								
2.61	4.21	-	5.13	15.2	-	-	-	-
3.97	3.27	-	4.74	16	-	-	-	-
5.85	*2.98*	-	5.9	*18.5*	-	-	-	-
6.51	*2.83*	-	*4.66*	*15.4*	5.81	5.81	2.5	1.13
9.49	*2.48*	-	*4.24*	*15.9*	5.33	4.48	2.29	1.08
11.3	*2.28*	-	*3.56*	*14.7*	5.26	8.8	1.91	1.04
13.3	*2.23*	39.2	*3.96*	*10.3*	4.91	3.26	1.88	0.889
17.8	*1.94*	17	*4.32*	*14*	3.27	16.7	1.59	0.99
19.7	*1.66*	32.5	*4.12*	*21*	0.824	-	3.26	-
mean	2.65 (s)	29.6 (s)	4.51 (s)	15.7 (s)	4.23 (s)	7.81 (s)	2.24 (s)	1.03 (s)
SE	0.258	6.57	0.231	0.982	0.769	2.41	0.243	0.041
CV	0.291	0.385	0.154	0.188	0.445	0.689	0.266	0.09

Replicate 2

Depth (cm) >	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-122-	122-244	244-274
Time (h)							
4.02	7.02	18	-	28.1	-	-	-
5.9	5.82	30.6	14.9	-	-	-	-
7.51	3.98	-	-	34.5	4.16	7.94	3.74
9.39	15.5	5.88	-	23.2	*3.88*	*7.13*	*3.35*
11.3	3.54	-	22.3	*17*	*4.07*	*6.4*	*3.07*
13.3	3.57	-	10.1	*15.7*	*3.43*	*6.03*	*2.94*
17.8	2.62	-	4.94	*22.7*	*2.98*	*5.34*	*2.46*
20.4	-	-	6.52	*10.6*	*3.06*	*4.72*	*2.23*
mean	6.01 (s)	7.78* (s)	11.8* (s)	21.7* (s)	3.6 (s)	6.26 (s)	2.96 (s)
SE	1.68	4.55	3.14	3.04	0.21	0.479	0.228
CV	0.741	1.55	0.598	0.371	0.143	0.187	0.188

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site G was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table G.5. Cumulative infiltration and infiltration rate are shown on Figures G.4 and G.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table G.5. Cumulative infiltration (I), and infiltration rate (i) for deep subsoil of Site G (Heimdal loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		2.811	6.96	2.608	0.798
0.07	2.63	0.035	37.4		3.283	8.18	3.047	2.58
0.094	3.09	0.082	18.9		3.713	8.41	3.498	0.533
0.137	3.39	0.116	7.22		6.647	9.7	5.18	0.442
0.196	3.62	0.166	3.87		6.876	9.74	6.762	0.166
0.216	3.7	0.206	3.71		7.148	9.82	7.012	0.281
0.286	3.93	0.251	3.28		7.375	9.89	7.262	0.336
0.409	4.19	0.372	3.56		7.607	9.93	7.491	0.164
0.522	4.5	0.466	2.7		10.41	10.7	9.009	0.265
0.856	5.11	0.766	3.36		12.73	11.3	11.57	0.263
1.103	5.41	0.98	1.24		14.47	11.8	13.6	0.275
1.366	5.72	1.235	1.16		16.29	12.1	15.38	0.188
1.639	6.02	1.502	1.12		19.11	12.8	17.7	0.237
1.99	6.33	1.814	0.868		19.89	13	19.5	0.292
2.405	6.63	2.197	0.735					

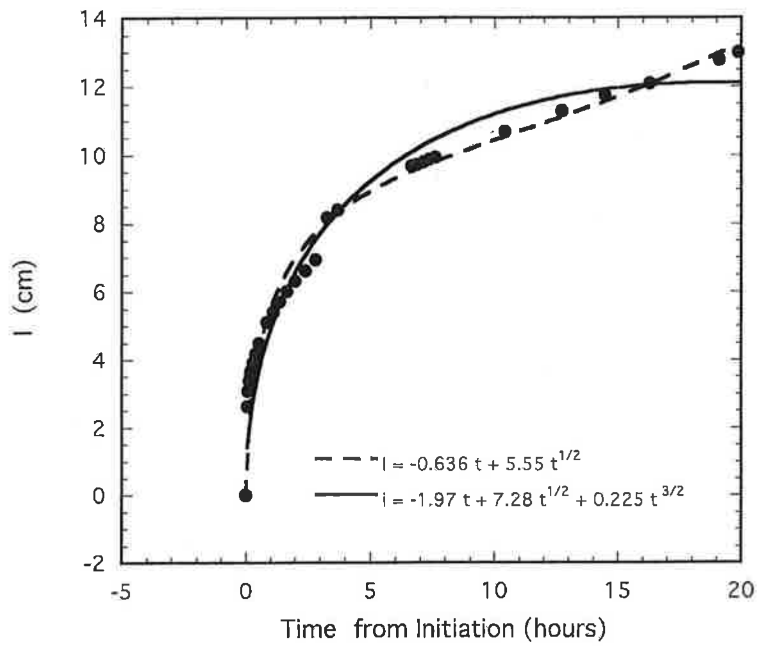

Figure G.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site G.

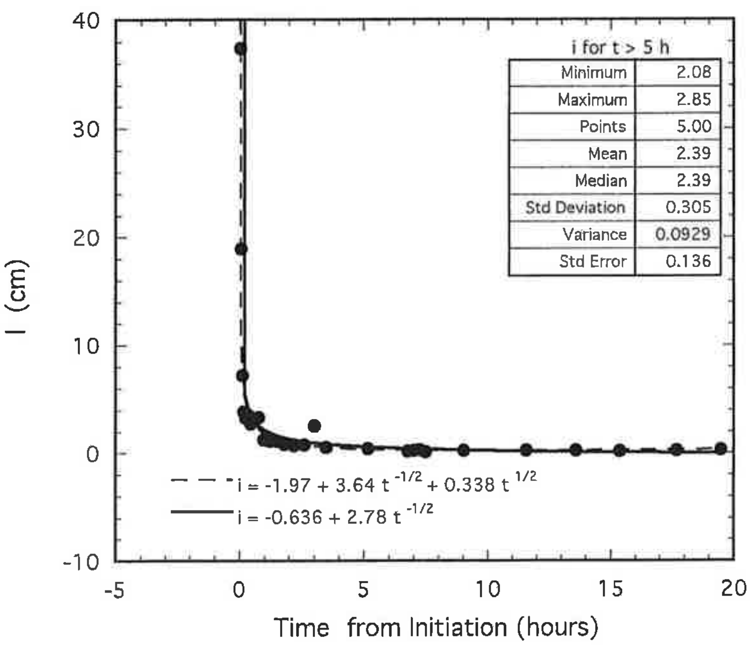

Figure G.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site G.

SITE H (Stirum Sandy Loam : Coarse-loamy, mixed, superactive, frigid Typic Natraquoll)

Site H was located on a broad, nearly depressional area in a fallow field. The location and description are summarized on Table 1. In situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples and soil profile descriptions were taken approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in-situ and laboratory soil moisture-retention data, soil physical data, soil saturated-paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 202-225. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Infiltration on Site H (Sites D-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table H.1. Cumulative infiltration (I), and infiltration rate (i) for the soil surface of Site H (Stirum sandy loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		2.531	4.47	2.427	0.366
0.581	3.42	0.291	0.295		2.714	4.52	2.622	0.313
0.698	3.61	0.64	1.63		3.583	4.73	3.149	0.241
0.828	3.7	0.763	0.733		3.927	4.79	3.755	0.166
1.284	3.91	1.056	0.46		9.241	5.53	6.584	0.14
1.386	3.97	1.335	0.559		11.69	6.03	10.47	0.202
1.581	4.07	1.483	0.49		14.78	6.41	13.24	0.123
1.748	4.16	1.664	0.57		18.27	6.91	16.52	0.142
1.953	4.26	1.85	0.464		22.72	7.54	20.5	0.141
2.185	4.35	2.069	0.411		34.54	11.1	28.63	0.302
2.322	4.39	2.254	0.277					

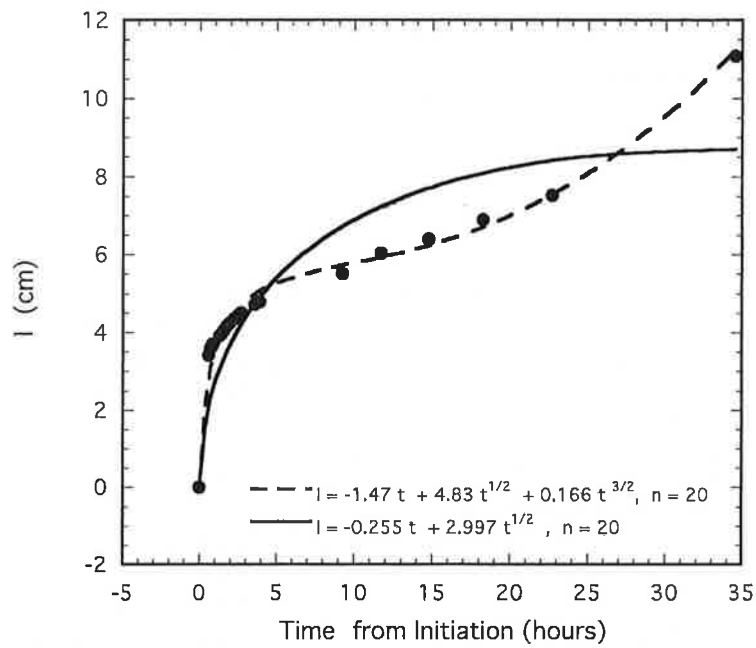

Figure H.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site H.

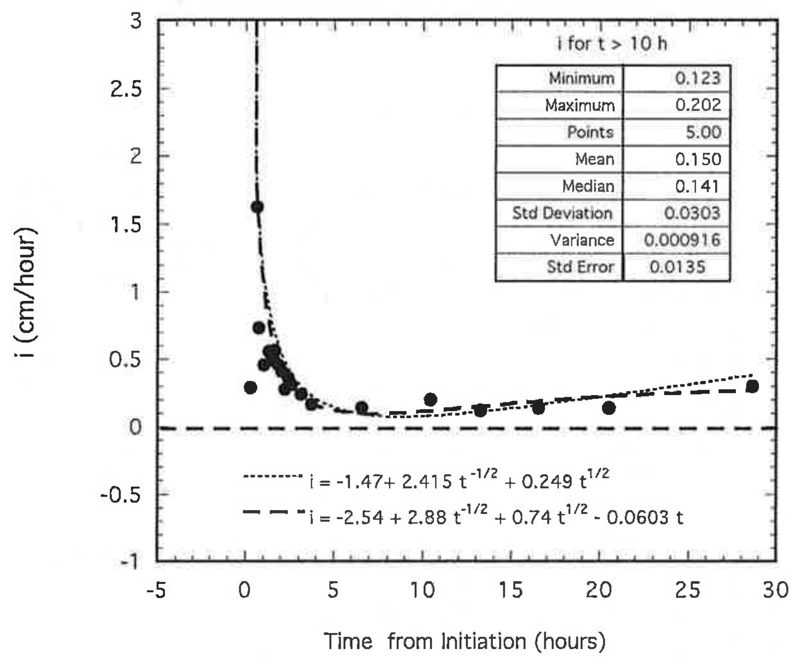

Figure H.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site H.

Table H.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	152
Time (h)								
-1.66	-224	-238	-160	-131	-109	-90.3	5.9	-5.2
0.34	-8.38	11	-158	-130	-105	-89.3	0.8	-5.2
0.63	3.86	25.3	-136	-131	-106	-90.3	-1.24	-5.2
1.31	15.1	25.3	-62.5	-131	-106	-91.3	1.82	-5.2
1.82	17.1	26.3	-43.2	-130	-105	-90.3	0.8	-5.2
2.21	18.1	27.3	-41.1	-128	-106	-90.3	-0.22	-5.2
3.62	19.2	28.3	-42.1	-97.2	-105	-89.3	1.82	-5.2
4.41	19.2	28.3	-44.2	-81.9	-101	-91.3	-0.22	-5.2
9.32	21.2	25.3	-41.1	-42.1	-38.2	-66.8	-6.34	-6.22
12.9	21.2	22.2	-38.1	-37	-25.9	-23	-11.4	-5.2
18.3	23.2	22.2	-36	-35	-21.8	-15.8	8.96	-5.2
34.2	21.2	20.2	-36	-35	-24.9	-15.8	20.2	-5.2
22.4	30.4	20.2	-37	-34	-21.8	-14.8	15.1	-3.16
50.2	30.4	12	-36	-36	-21.8	-14.8	22.2	-5.2
77.3	21.2	1.82	-37	-34	-20.8	-14.8	20.2	-4.18
125	27.3	-1.24	-36	-33	-25.9	-16.8	-16.5	-4.18
126	27.3	-0.22	-36	-33	-26.9	-15.8	-17.6	-4.18

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	152
Time (h)									
-1.66	-339	-247	-171	-136	-131	-89.3	-68.6	-42.3	-9.28
0.39	-11.4	-235	-168	-133	-129	-89.3	-64.5	-40.3	-8.26
0.67	9.98	4.88	-142	-134	-126	-89.3	-65.5	-40.3	-9.28
1.35	18.1	20.2	-38.1	-134	-123	-89.3	-66.5	-40.3	-11.3
1.84	22.2	20.2	-28.9	-131	-122	-88.2	-66.5	-39.3	-9.28
2.43	24.3	20.2	-27.9	-87	-126	-90.3	-62.4	-40.3	-9.28
2.65	27.3	19.2	-27.9	-41.1	-124	-88.2	-64.5	-39.3	-9.28
4.44	27.3	19.2	-26.8	-33	-119	-88.2	-66.5	-40.3	-11.3
9.37	28.3	18.1	-15.6	-5.42	-41.2	-27	-64.5	-40.3	-11.3
12.9	28.3	16.1	-11.5	-10.5	-35.1	-8.68	-45.1	-40.3	-11.3
18.3	28.3	12	-12.6	-9.5	-31	-4.6	-22.7	-40.3	-11.3
34.2	28.3	7.94	-13.6	-12.6	-33.1	-5.62	-19.6	-17.9	-8.26
46.4	29.4	7.94	-14.6	-12.6	-31	-5.62	-21.6	-35.2	-9.28
50.2	28.3	5.9	-16.6	-10.5	-24.9	-5.62	-19.6	-17.9	-5.2
77.4	25.3	3.86	-18.7	-10.5	-22.9	-6.64	-20.6	-17.9	-7.24
141	27.3	3.86	-16.6	-8.48	-7.56	-3.58	-19.6	-16.8	-7.24
126	25.3	4.88	-17.7	-9.5	-8.58	-4.6	-22.7	-16.8	-5.2

Table H.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137	152
Time (h)										
-1	0.196	0.289	0.232	0.224	0.299	0.184	0.124	0.121	0.162	0.29
0.87	0.392	0.345	0.298	0.227	0.301	0.179	0.125	0.128	0.16	0.293
28.7	0.407	0.357	0.331	0.472	0.365	0.268	0.213	0.186	0.194	0.301
34.3	0.414	0.358	0.334	0.331	0.378	0.264	0.216	0.189	0.197	0.311
77.4	0.416	0.363	0.344	0.335	0.372	0.265	0.216	0.184	0.198	0.304
125	0.411	0.368	0.341	0.343	0.372	0.272	0.213	0.188	0.197	0.32
126*	0.423	0.378	0.347	0.342	0.376	0.271	0.214	0.184	0.204	0.322

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137	152
Time (h)										
-1.47	0.228	0.284	0.21	0.238	0.269	0.266	0.164	0.133	0.177	0.305
1.03	0.405	0.342	0.303	0.244	0.257	0.263	0.16	0.134	0.175	0.316
28.9	0.432	0.35	0.324	0.334	0.322	0.327	0.234	0.184	0.2	0.315
34.4	0.428	0.347	0.33	0.341	0.327	0.337	0.234	0.187	0.201	0.317
77.5	0.429	0.36	0.338	0.347	0.333	0.38	0.228	0.19	0.207	0.321
125	0.435	0.363	0.339	0.341	0.335	0.323	0.232	0.192	0.2	0.327
126*	0.424	0.361	0.342	0.347	0.334	0.335	0.237	0.195	0.208	0.325

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Low initial gradients near the surface appear to be caused by ponding over the Bt horizon. The 15.2 to 30.4 cm layer tranverses the Bt upper boundary, which likely impedes water movement at the upper boundary. Decreasing gradients within the 30.4 to 45.7 cm layer are also likely a response to the overlying impedance and wetting within the layer. Approximate steady state is reached in the top layer after 5 hours and to 76 cm after 20 hours (except for 15 to 30 cm which occur after 50 hours).

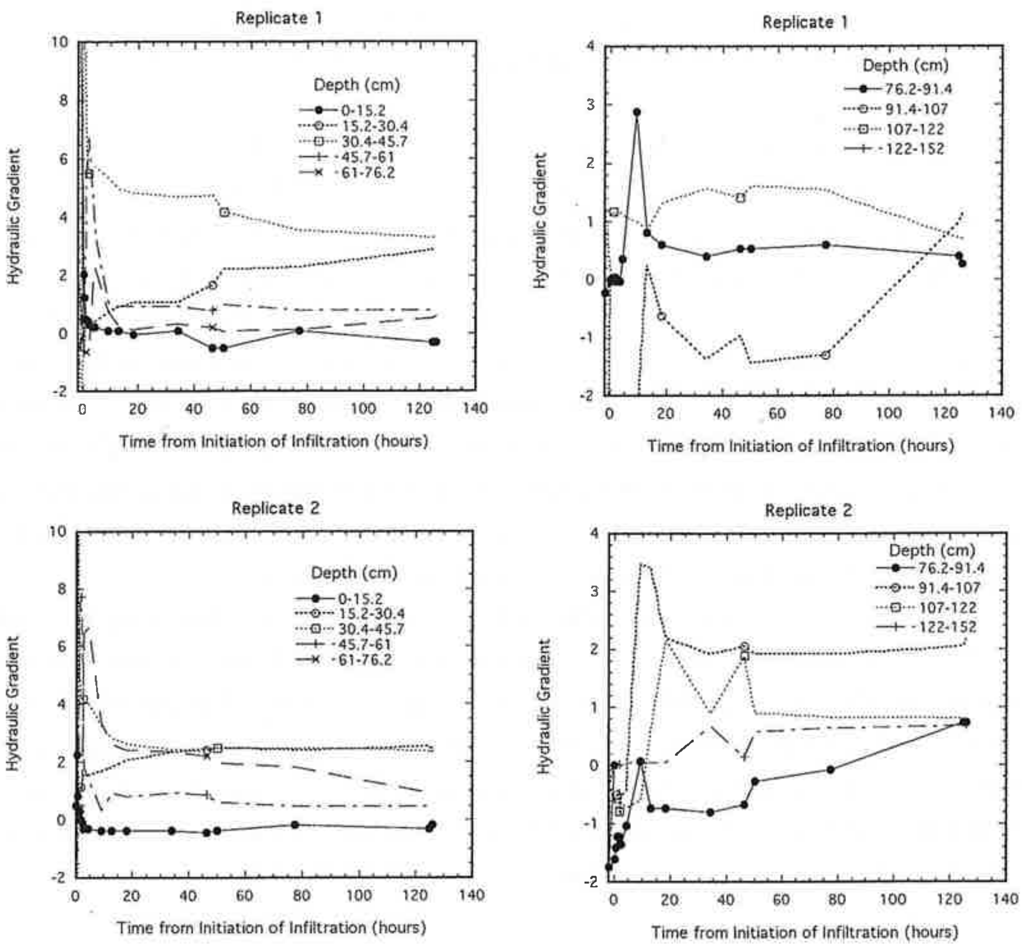

Figure H.3. Vertical hydraulic gradients during wetting and sorption of Site H.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site H are measured by matching the i vs. t function (Figure H.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table H.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table H.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). (s) indicates saturation and (-ψ) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-76.2	76.2-91.4	107-152
Time (h)							
9.32	1.12	-	-	-	-	-	-
12.9	1.56	-	-	-	-	-	-
18.3	-	-	-	0.221	1.57	0.341	0.157
34.2	2.4	-	-	0.249	0.692	0.579	0.148
22.4	-	-	-	0.289	1.18	0.43	0.165
50.2	-	0.0451	0.024	0.0996	1.51	0.185	0.0619
mean	1.69 (s)	0.0451 (s)	0.024 (-36)	0.215 (-36)	1.24 (-29)	0.384 (-19)	0.133 (s)
SE	0.375	-	-	0.0408	0.201	0.0825	0.0239
CV	0.384	-	-	0.38	0.325	0.43	0.36

Replicate 2

Depth (cm) >	15.2-30.5	30.5-45.7	45.7-61	61-76.2	91.4-107	107-122	122-152
Time (h)							
18.3	-	-	*0.259*	*0.085*	*0.094*	*0.096*	*4.48*
34.2	-	-	*0.249*	*0.099*	*0.121*	*0.261*	*5.04*
46.4	*0.059*	*0.057*	*0.164*	*0.064*	*0.069*	*0.075*	*0.208*
mean	0.059 (s)	0.057 (-3)	0.224 (-13)	0.0827 (-22)	0.0947 (-13)	0.144 (-26)	3.24 (-20)
	-	-	0.0301	0.0102	0.015	0.0588	1.53
	-	-	0.233	0.213	0.275	0.707	0.815

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site H was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table H.5. Cumulative infiltration and infiltration rate are shown on Figures H.4 and H.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table H.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site H (Stirum Sandy Loam) measured near Oakes, ND.

T (h)	I (cm)	t (h)	i (cm/h)		T (h)	I (cm)	t (h)	i (cm/h)
0	0	0	0		1.404	80.6	1.391	52.5
0.041	4.42	0.021	46.3		1.428	81.9	1.416	58
0.058	5.8	0.05	80.4		1.453	83.3	1.441	56.6
0.095	8.57	0.085	71.2		1.503	86.1	1.491	54.8
0.119	9.95	0.107	58		1.528	87.5	1.516	56.6
0.185	14.1	0.164	65.6		1.575	90.3	1.563	56.6
0.211	15.5	0.198	51.9		1.602	91.6	1.589	50.9
0.263	18.3	0.249	49.3		1.625	93	1.614	60.8
0.291	19.6	0.277	49.8		1.776	99.9	1.701	46
0.318	21	0.305	50.9		1.819	103	1.797	63.9
0.4	25.2	0.385	48.4		1.914	108	1.891	59.7
0.431	26.6	0.416	43.7		1.967	111	1.941	51.9
0.477	29.3	0.454	61.2		2.016	114	1.992	56.6
0.533	32.1	0.519	48.9		2.204	125	2.169	59.8
0.559	33.5	0.546	53		2.302	130	2.253	56.2
0.587	34.9	0.573	49.3		2.398	136	2.35	57.8
0.64	37.6	0.627	54.2		2.495	141	2.447	57
0.668	39	0.654	48.4		2.597	147	2.546	54.6
0.691	40.4	0.679	62.3		2.69	153	2.643	59.5
0.743	44.6	0.73	110		2.781	158	2.736	60.4
0.796	47.3	0.77	51.9		2.886	164	2.833	53.2
0.821	48.7	0.809	55.4		2.979	169	2.932	59.2
0.928	54.3	0.902	52.7		3.161	180	3.114	59
0.956	55.6	0.942	48.9		3.251	186	3.206	61.5
0.978	57	0.967	63.1		3.354	191	3.302	53.7
1.031	59.8	1.005	52.2		3.46	197	3.407	52.1
1.057	61.2	1.044	53.6		3.526	201	3.493	63.1
1.082	62.6	1.07	54.8		3.879	222	3.702	58.9
1.133	65.3	1.12	53		3.926	225	3.902	58.6
1.163	66.7	1.148	46.1		4.016	230	3.971	61.3
1.182	68.1	1.173	73.3		4.111	236	4.063	58.6
1.209	69.5	1.196	51.9		4.205	241	4.158	58.6
1.257	72.3	1.245	56.6		4.351	249	4.278	57
1.282	73.6	1.27	55.4		4.398	252	4.374	58.6
1.308	75	1.295	53		4.44	255	4.419	66.5
1.331	76.4	1.32	60.1		4.486	258	4.463	60.4
1.355	77.8	1.343	58.6					

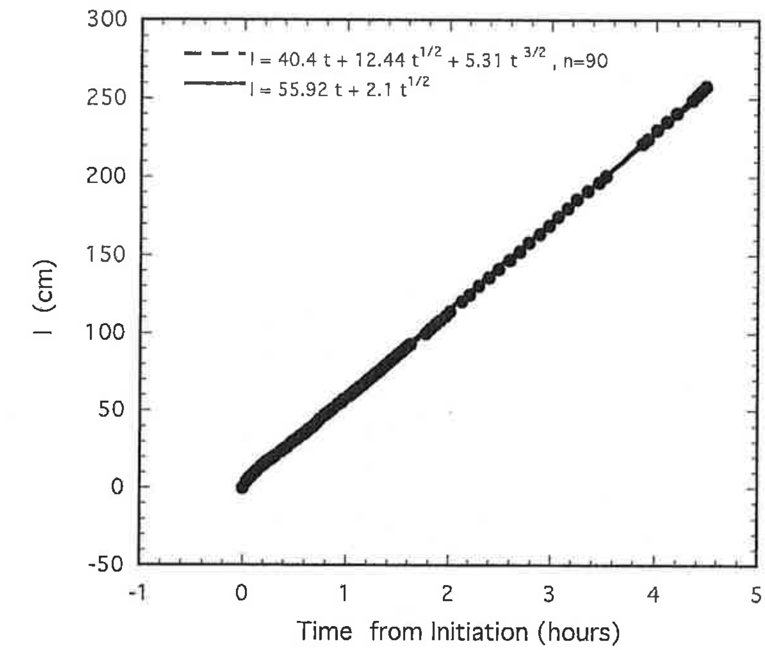

Figure H.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site H.

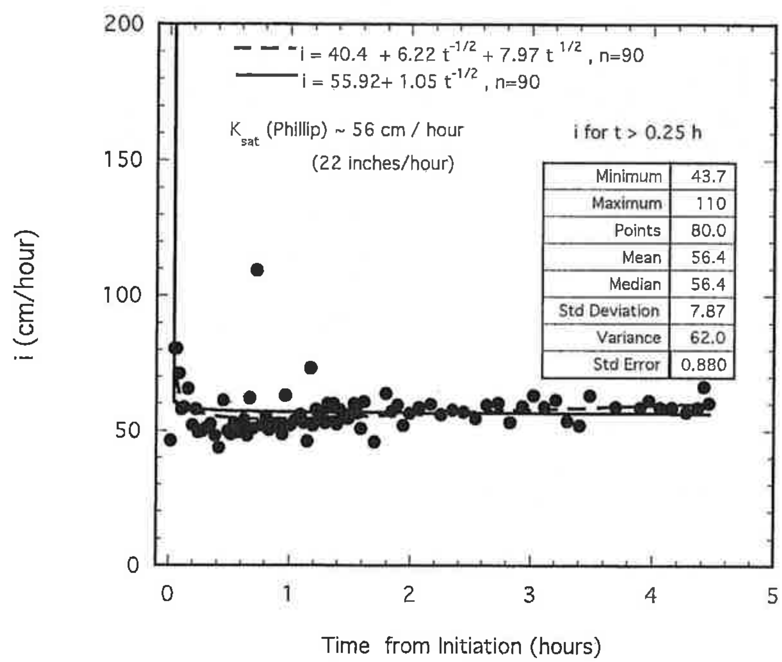

Figure H.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site H.

SITE I (Eckman Silt Loam : Coarse-silty, mixed, superactive, frigid Calcic Hapludoll)

Site I was located in the non-irrigated corner of a center-pivot irrigated cornfield. . The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during late June and July, 1985. Soil samples and soil profile descriptions were taken approximately four weeks after completion of soil hydraulic measurements. Soil morphology, in situ and laboratory soil moisture-retention data, soil physical data, soil saturated paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 226-246. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Infiltration on Site I (Sites D-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Site I, as for all of Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table I.1. Cumulative infiltration (I), and infiltration rate (i) for the soil surface of Site I (Eckman silt loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		1.048	4.91	0.987	1.41
0.022	0.624	0.011	13.2		1.131	5.05	1.089	1.6
0.033	0.929	0.027	28.2		1.275	5.2	1.203	1.06
0.049	1.23	0.041	18.3		1.41	5.35	1.342	1.13
0.069	1.54	0.059	15.5		1.553	5.5	1.481	1.07
0.102	1.84	0.085	9.31		1.892	5.94	1.821	3.09
0.146	2.15	0.124	6.91		2.059	6.09	1.976	0.91
0.188	2.45	0.167	7.22		2.251	6.25	2.155	0.797
0.246	2.91	0.217	7.84		2.468	6.4	2.359	0.703
0.336	3.37	0.291	5.13		4.788	7.87	3.628	0.633
0.443	3.75	0.389	3.56		6.721	9.13	5.754	0.651
0.587	4.13	0.515	2.63		8.179	9.62	7.45	0.34
0.661	4.28	0.624	2.06		13.53	11	10.85	0.264
0.757	4.46	0.709	1.8		17.09	13.1	15.31	0.577
0.833	4.59	0.795	1.74		26.7	13.4	21.9	0.0278
0.926	4.74	0.879	1.65		37.82	13.4	32.26	0.00343

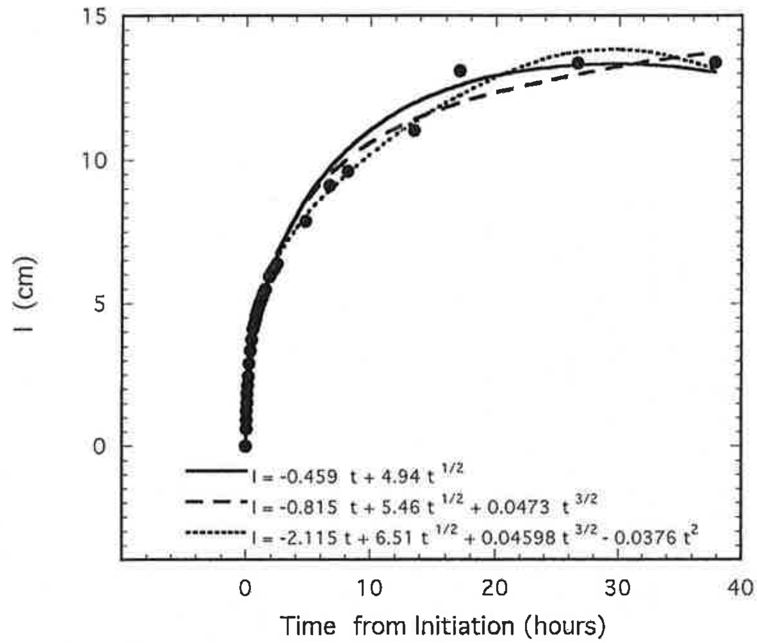

Figure I.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site I.

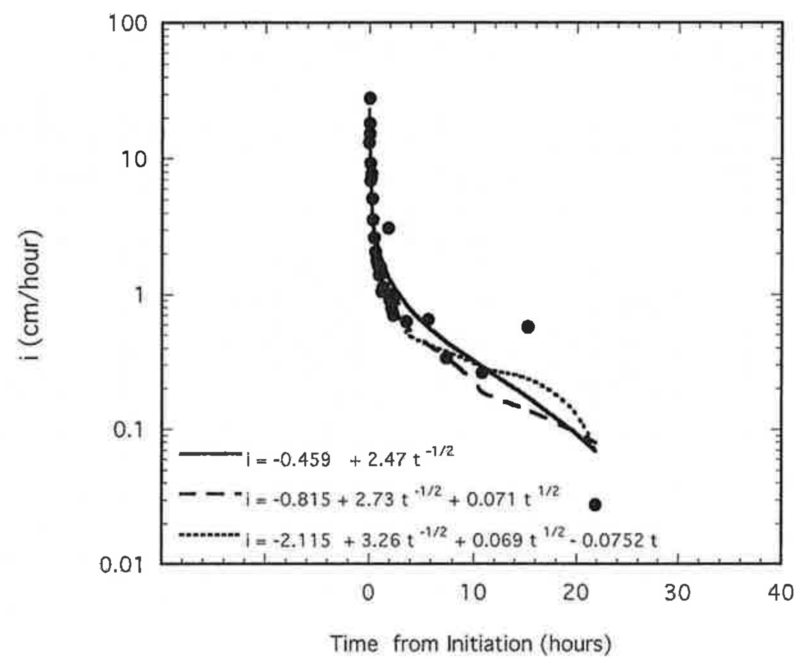

Figure I.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site I.

Table I.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	152
Time (h)									
-1.01	-261	-163	-131	-104	-	-69.9	-53.3	-38.3	-11.3
0.37	-15.5	-1.24	-113	-101	-	-65.8	-42	-25	-10.3
0.69	3.86	2.84	-116	-99.3	-	-62.7	-36.9	-19.9	-8.26
1.06	5.9	3.86	-91.1	-96.2	-	-61.7	-33.9	-17.9	-7.24
1.33	6.92	3.86	-48.3	-88	-	-60.7	-30.8	-16.8	-6.22
1.76	6.92	3.86	-21.7	-62.5	-	-58.7	-28.8	-15.8	-6.22
2.09	6.92	3.86	-14.6	-49.3	-	-56.6	-27.8	-14.8	-5.2
4.94	7.94	1.82	-8.48	-15.6	-	-34.2	-13.5	1.52	19.3
8.07	11	-1.24	-5.42	-3.38	-	12.7	30.4	44.4	61.1
9.46	8.96	-2.26	-4.4	2.74	-	26	44.7	54.6	73.3
13.6	9.98	-2.26	-2.36	7.84	-	36.2	51.8	62.7	81.5
17.2	7.94	-3.28	2.74	7.84	-	42.3	56.9	69.9	89.7
26.4	7.94	-2.26	4.78	17	-	41.3	55.9	69.9	90.7
38.5	-7.36	-8.38	3.76	15	-	30.1	43.6	57.6	80.5
39.3	-15.5	-19.6	-5.42	5.8	-	31.1	44.7	59.7	80.5

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	152
Time (h)									
-0.93	-189	-161	-129	79.2	-92.2	-80.1	-64.5	-49.5	-22.5
0.4	0.8	-65.5	-128	-103	-85.1	-77	-59.4	-40.3	-19.5
0.73	3.86	-19.6	-127	-101	-83	-75	-53.3	-36.2	-17.4
1.09	2.84	-12.5	-96.2	-97.2	-80	-72.9	-47.1	-31.1	-15.4
1.36	3.86	-11.4	-63.6	-89.1	-74.9	-66.8	-45.1	-29.1	-14.4
1.79	2.84	-11.4	-38.1	-58.5	-67.7	-58.7	-44.1	-29.1	-13.4
2.13	2.84	-11.4	-28.9	-45.2	-58.6	-54.6	-43.1	-30.1	-13.4
4.99	4.88	-12.5	-21.7	-10.5	-9.6	1.52	6.92	13.8	23.4
8.13	4.88	-9.4	-13.6	7.84	14.9	29.1	36.5	47.4	62.1
9.51	2.84	-9.4	-9.5	12.9	19	33.1	42.6	54.6	70.3
13.6	5.9	-9.4	-7.46	14	23	34.2	44.7	58.6	74.4
17.2	8.96	-6.34	-0.32	18	27.1	40.3	51.8	63.7	82.5
26.4	5.9	-5.32	4.78	23.1	28.1	39.3	48.7	61.7	84.6
38.6	1.82	-6.34	-0.32	19.1	29.2	39.3	49.8	61.7	84.6
39.3	-3.28	-8.38	3.76	19.1	31.2	41.3	51.8	64.8	86.6

Table I.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2	152.4
Time (h)										
-0.9	0.2889	0.3177	0.3246	0.3926	0.3946	0.4367	0.4576	0.4632	0.4789	0.5002
14.6	0.3868	0.4173	0.4189	0.4373	0.4554	0.4637	0.4863	0.4755	0.4915	0.5183
26.4	0.3868	0.4173	0.4356	0.4471	0.4521	0.466	0.4835	0.4932	0.4881	0.5177
38.4	0.3962	0.427	0.4152	0.446	0.4565	0.4559	0.4881	0.4738	0.4944	0.5083
39.2*	0.3884	0.4184	0.4281	0.4433	0.4515	0.4688	0.4875	0.4909	0.4892	0.5172

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2	152.4
Time (h)										
-0.76	0.3201	0.3315	0.3355	0.3627	0.4157	0.446	0.4727	0.471	0.4744	0.5201
14.8	0.3967	0.3983	0.402	0.4211	0.4543	0.4716	0.4823	0.4835	0.4927	0.5177
26.5	0.3952	0.4147	0.4088	0.4297	0.4587	0.4858	0.4863	0.4881	0.499	0.5183
38.5	0.3973	0.412	0.4088	0.4259	0.4504	0.4222	0.4795	0.4863	0.4927	0.5357
39.4*	0.3858	0.4141	0.4088	0.4384	0.4532	0.4812	0.4904	0.4915	0.5025	0.516

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Approximate steady state was reached to 15 cm after 2 h, 30 cm after 4 hours on Replicate 2, and 7 hours on Replicate 1, to 91 cm after 12 hours on Replicate 1, 10 hours to 76 cm and 20 hours to 91 cm on Replicate 2, and after 25 hours for depths greater than 91 cm. After 25 hours increasing gradients in the surface layer indicate clogging, likely due to particulate movement. Increasing gradients in the 76 to 91 cm layer indicate clogging, possibly involving particulate movement, but more likely involving swelling. We note (Schuh, Cline and Sweeney, 1991, Table I-1.3) that elevated SAR (> 8) values begin at 61 cm, and increase with depth).

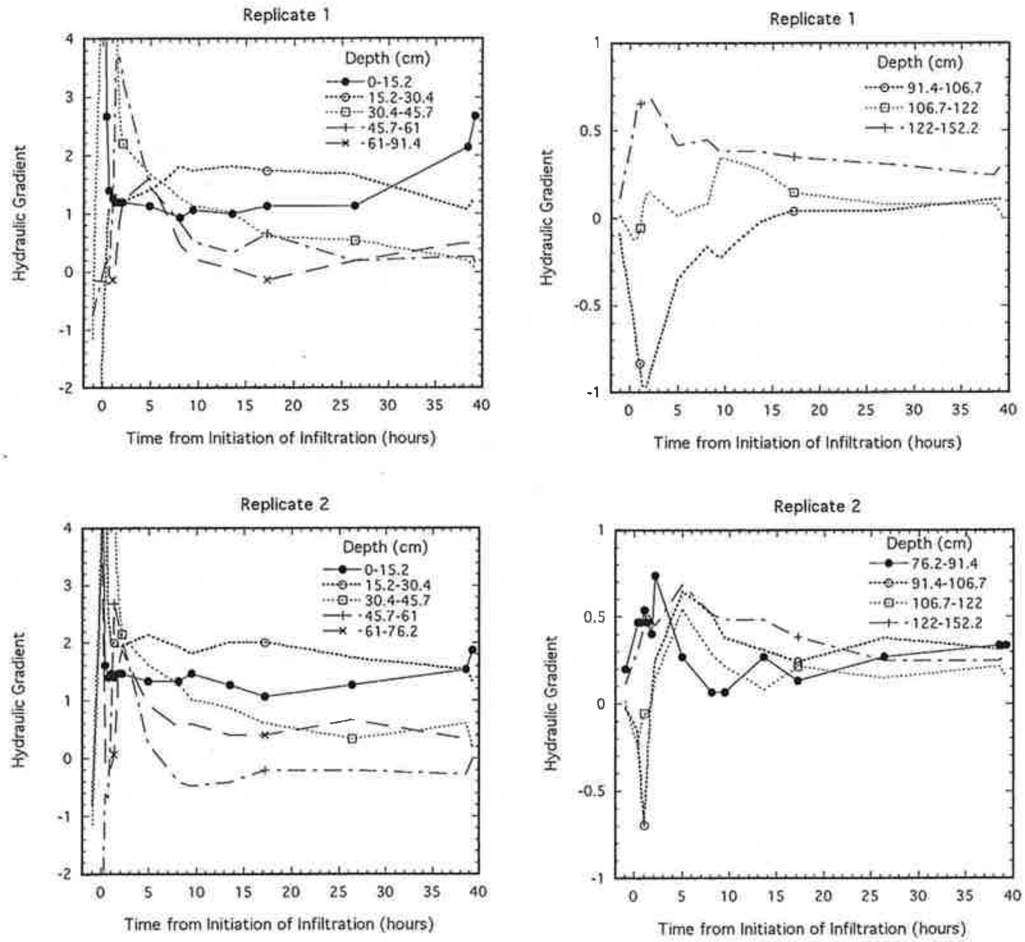

Figure I.3. Vertical hydraulic gradients during wetting and sorption of site I.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site I are measured by matching the i vs. t function (Figure I.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table I.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table I.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). Mean matric potential head (cm), corresponding to measured K for the depth interval, is in parentheses. (s) indicates saturation and (-ψ) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-107	107-122	122-152
Time (h)								
0.37	1.39	61.4	-	-	-	-	-	-
0.69	1.8	2.37	-	-	-	-	-	-
1.06	1.5	1.68	-	-	-	-	-	-
1.33	1.36	1.36	-	-	-	-	-	-
1.76	1.11	1.11	-	-	-	-	-	-
2.09	0.978	0.979	-	-	-	-	-	-
4.94	0.503	0.407	-	-	-	-	-	-
8.07	0.372	0.193	-	-	-	-	-	-
9.46	0.272	0.167	-	-	-	-	-	-
13.6	0.187	0.104	0.186	0.57	2.79	-	-	-
17.2	0.122	0.0794	0.229	0.208	-1.03	3.38	*0.937*	0.396
26.4	0.0716	0.0486	0.151	0.417	*0.404*	1.99	*1.01*	*0.258*
38.5	0.0306	0.0614	0.325	*0.25*	*0.13*	*0.607*	*0.816*	*0.264*
39.3	0.0245	0.0517	0.977	*0.25*	*0.391*	*0.608*	4.98	*0.208*
mean	*	*	0.374 (s)	0.339 (s)	0.537 (s)	1.65 (s)	1.94 (s)	0.282 (s)
SE	-	-	0.154	0.068	0.622	0.663	1.02	0.0402
CV	-	-	0.92	0.448	2.59	0.806	1.05	0.285

Replicate 2

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	61-76.2	76.2-91.4	91.4-107	107-122	122-152
Time (h)								
2.13	0.788	0.598	-	-	-	-	-	-
4.99	0.423	0.264	-	-	-	-	-	-
8.13	0.258	0.178	0.271	-	-	-	-	-
9.51	0.197	0.16	0.287	0.479	-	-	-	-
13.6	0.148	0.0937	0.215	0.467	-	-	-	-
17.2	0.129	0.0686	0.228	0.342	-	-	-	-
26.4	0.0639	0.0467	0.242	0.121	0.302	0.216	0.551	0.327
mean	*	*	0.249 (-8)	0.352 (-3)	0.302 (s)	0.216 (s)	0.551 (s)	0.327 (s)
SE	-	-	0.013	0.083	-	-	-	-
CV	-	-	0.12	0.472	-	-	-	-

* K estimates decreasing. Systematic rather than random error renders mean values meaningless.

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site I was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table I.5. Cumulative infiltration and infiltration rate are shown on Figures I.4 and I.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table I.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site I (Eckman Loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0.00	0.00	0.00	0.00		5.92	1.54	5.48	0.345
1.22		0.607	0.0628		6.05	1.58	5.99	0.286
1.38		1.30	0.351		6.30	1.68	6.18	0.381
1.74	0.058	1.56	0.210		6.64	1.77	6.47	0.286
2.20	0.210	1.97	0.334		6.97	1.89	6.80	0.343
2.44	0.286	2.32	0.319		7.30	2.00	7.14	0.343
2.64	0.363	2.54	0.366		7.64	2.08	7.47	0.229
2.97	0.477	2.81	0.350		16.8	4.71	12.2	0.287
3.30	0.591	3.14	0.347		17.1	4.78	17.0	0.253
3.63	0.706	3.47	0.343		17.5	4.90	17.3	0.276
3.97	0.858	3.80	0.458		20.5	5.72	19.0	0.272
4.30	0.973	4.14	0.343		20.9	5.82	20.7	0.258
4.64	1.12	4.47	0.458		21.1	5.85	21.0	0.241
5.03	1.24	4.84	0.286					

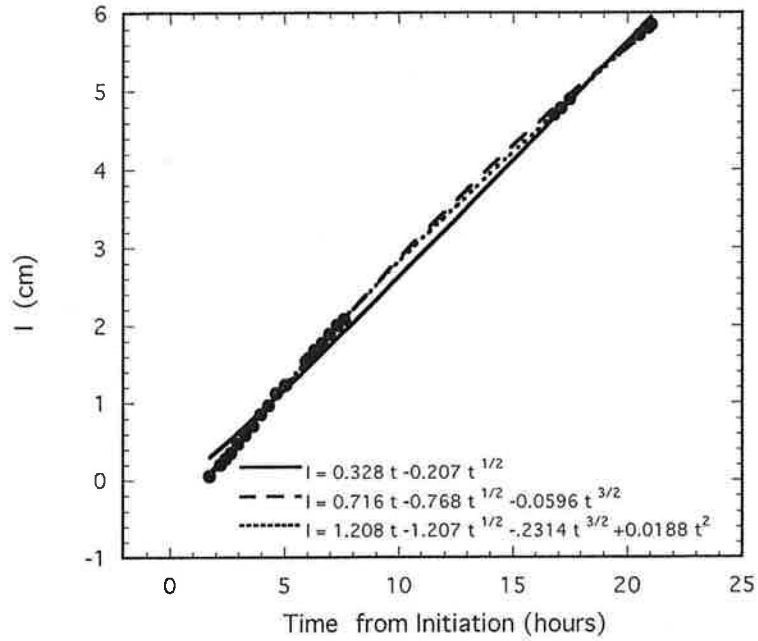

Figure I.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site I.

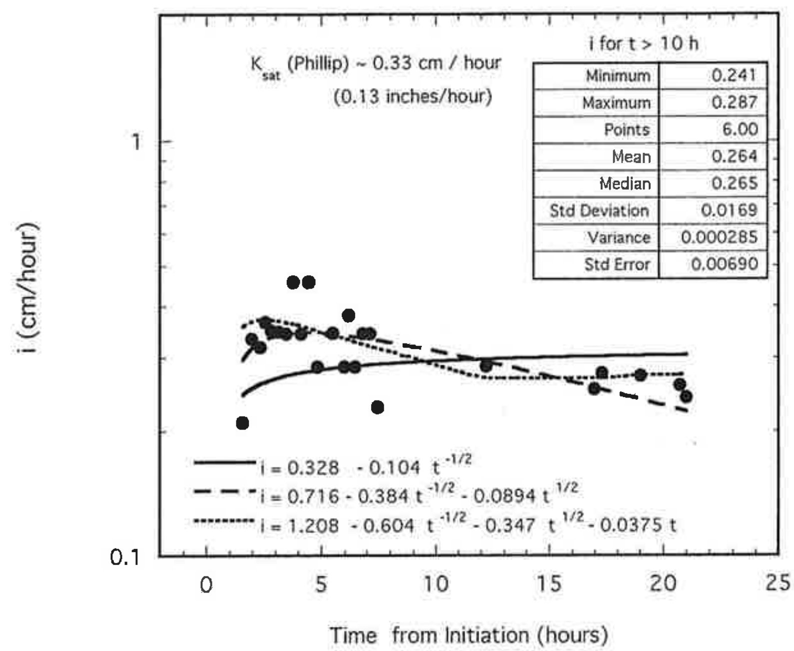

Figure I.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site I.

SITE J (Gardena Silt Loam : Coarse-silty, mixed, superactive, frigid Pachic Hapludoll)

Site J was located in a non-irrigated wheat field. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during August through October, 1985. Because of slow infiltration rate several days were required to fully wet the soil profile. Soil morphology, in-situ and laboratory soil moisture retention data, soil physical data, soil saturated paste extract water chemisry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Cline and Sweeney (1991), pages 247-264. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Infiltration on Site J (as on all Sites D-K) was measured within the area used for determining K(ψ) during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Site J, as for all of Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table J.1. Cumulative infiltration (I), and infiltration rate (i) for the surface of Site J (Gardena silt loam) measured near Oakes, ND.

T_I (H)	I (CM)	T_I (H)	I (CM/H)	T_I (H)	I (CM)	T_I (H)	I (CM/H)
0	0	0	0	0.987	17.8	0.962	6.13
0.012	1.72	0.006	62.1	1.04	18.1	1.013	5.75
0.018	2.33	0.017	84.5	1.096	18.4	1.068	5.46
0.022	2.63	0.02	84.5	1.274	19.3	1.213	5.07
0.026	2.94	0.024	84.5	1.335	19.7	1.304	4.97
0.029	3.24	0.027	84.5	1.465	20.3	1.432	5.17
0.033	3.55	0.031	78.4	1.515	20.6	1.49	5.34
0.037	3.85	0.035	78.4	1.612	21	1.564	3.93
0.041	4.16	0.039	73.2	1.681	21.3	1.646	5.02
0.045	4.46	0.043	73.2	1.753	21.5	1.717	2.62
0.055	5.07	0.053	57.8	1.842	21.8	1.798	3.43
0.061	5.38	0.058	57.8	1.932	22.1	1.887	3.38
0.067	5.68	0.064	47.7	2.169	23.4	2.051	5.48
0.081	6.29	0.077	37.9	2.336	23.9	2.253	2.97
0.089	6.6	0.085	39.2	2.429	24.2	2.383	3.28
0.109	7.21	0.103	28.2	2.532	24.5	2.481	3.15
0.121	7.51	0.115	24.4	2.748	25.1	2.64	2.73
0.149	8.12	0.141	21.1	2.97	25.7	2.859	2.75
0.181	8.79	0.165	20.7	3.082	26	3.026	2.73
0.194	9.4	0.19	42.2	3.324	26.7	3.203	2.67
0.215	10	0.204	28.2	3.543	27.2	3.434	2.61
0.244	10.6	0.236	19.3	4.323	29.1	3.933	2.35
0.261	10.9	0.252	18	4.628	30.1	4.475	3.51
0.297	11.5	0.279	16.5	5.569	32.1	5.098	2.11
0.34	12.1	0.329	13.6	6.126	33.2	5.848	1.92
0.369	12.5	0.354	13.5	6.998	34.6	6.562	1.59
0.414	13.1	0.4	11.3	7.314	35.3	7.156	2.2
0.441	13.4	0.427	11.3	8.001	36.6	7.657	2.01
0.472	13.7	0.456	9.89	8.679	37.6	8.34	1.43
0.541	14.3	0.524	8.85	10.01	40.1	9.346	1.87
0.575	14.6	0.558	9.07	14.61	46	12.31	1.28
0.69	15.7	0.67	12.1	20.02	51.9	17.32	1.09
0.713	16	0.702	13.2	27.17	61.6	23.6	1.36
0.839	16.9	0.794	6.8	28.14	63	27.66	1.43
0.887	17.2	0.863	6.27	31.52	67.1	29.83	1.23

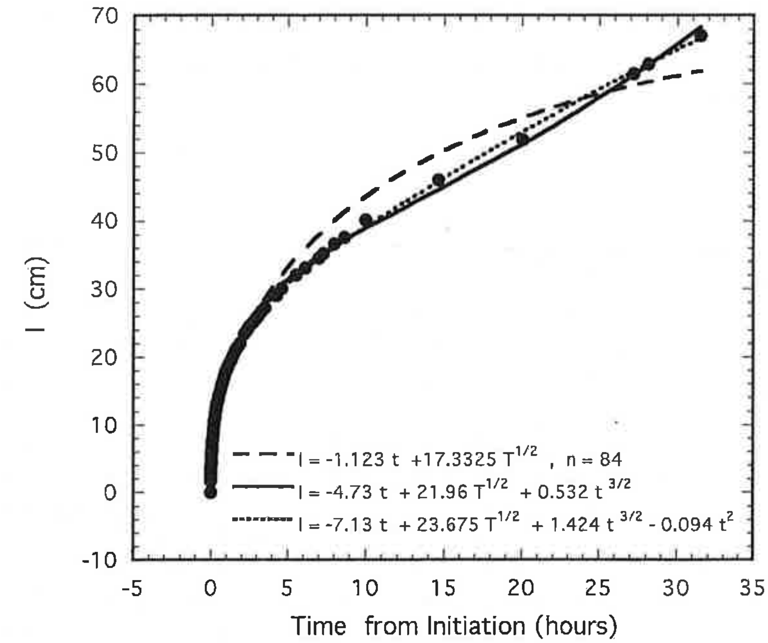

Figure J.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site J.

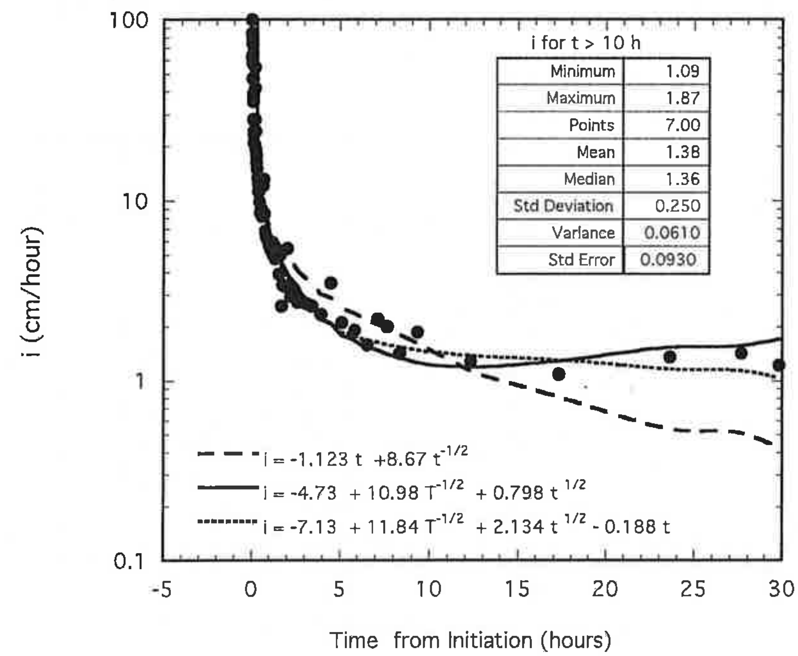

Figure J.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site J.

Table J.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137	152
Time (h)										
-0.08	-513	-529	-398	-152	-365	-273	-132	-47.4	-214	-191
0.19	-7.36	-116	-376	-63.6	-408	-250	-201	-43.4	-39.6	9.08
0.37	8.96	-34.9	-182	-127	-422	-247	-226	-40.3	63.4	-8.26
0.71	20.2	-16.5	-19.7	-215	-445	-249	-256	-40.3	20.6	-23.6
1.36	7.94	-15.5	-6.44	-51.3	-542	-173	-12.5	-35.2	22.6	-14.4
1.55	19.2	-10.4	-6.44	-12.6	-33.1	-67.8	-2.26	-32.1	21.6	-5.2
2.11	17.1	-12.5	-5.42	-10.5	-9.6	-7.66	5.9	-18.9	21.6	18.3
2.59	19.2	-13.5	-6.44	-10.5	-9.6	-4.6	9.98	-8.68	22.6	25.4
3.12	17.1	-13.5	-6.44	-10.5	-9.6	-2.56	14.1	1.52	24.7	25.4
3.59	19.2	-13.5	-6.44	-10.5	-9.6	-4.6	9.98	-8.68	22.6	25.4
5.57	17.1	-12.5	-5.42	-9.5	0.6	7.64	23.2	25	30.8	31.5
8.72	19.2	-8.38	0.7	10.9	17.9	19.9	34.5	19.9	7.34	170
20.1	19.2	-2.26	10.9	20.1	23	19.9	33.4	35.2	33.9	18.3
27.4	21.2	1.82	15	22.1	23	19.9	29.4	33.1	34.9	16.2
31.9	21.2	1.82	15	21.1	22	18.9	28.3	32.1	33.9	16.2
42.8	17.1	2.84	15	24.2	22	17.8	29.4	30.1	29.8	13.2
43.1	15.1	0.8	14	19.1	22	18.9	30.4	33.1	27.7	12.1

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	107	122	137	152
Time (h)										
1.36	16.1	4.88	12.9	-8.48	-77.9	-16.8	26.3	-119	-110	-163
1.55	16.1	3.86	10.9	-7.46	-46.3	-6.64	24.3	-88.2	-108	-160
2.14	16.1	3.86	9.88	-7.46	-15.7	1.52	24.3	-35.2	7.34	-148
2.59	16.1	3.86	10.9	-7.46	-4.5	4.58	27.3	-11.7	-62	-110
3.12	15.1	3.86	9.88	-8.48	0.6	8.66	40.6	7.64	-3.88	-8.26
3.59	16.1	3.86	9.88	-6.44	12.8	21.9	39.6	24	14.5	0.92
8.89	17.1	6.92	12.9	-2.36	20	25	48.7	26	13.5	3.98
14.6	19.2	8.96	17	5.8	29.2	30.1	53.8	16.8	15.5	5
20.1	21.2	17.1	19.1	10.9	32.2	33.1	54.9	15.8	10.4	3.98
27.3	24.3	25.3	27.2	18	37.3	35.2	55.9	11.7	12.4	5
32	22.2	20.2	25.2	20.1	37.3	35.2	60	7.64	12.4	3.98
42.9	15.1	9.98	20.1	21.1	27.1	32.1	50.8	4.58	8.36	2.96
43.1	15.1	12	21.1	23.1	31.2	33.1	51.8	8.66	13.5	6.02

Table J.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2	152.4
Time (h)										
0.86	0.443	0.393	0.375	0.362	0.394	0.394	0.33	0.368	0.436	0.47
2.32	0.433	0.4	0.362	0.365	0.444	0.43	0.406	0.431	0.307	0.486
3.87	0.582	0.534	0.493	0.48	0.598	0.561	0.536	0.587	0.64	0.648
5.89	0.435	0.394	0.376	0.366	0.434	0.418	0.404	0.439	0.459	0.478
8.22	0.423	0.396	0.366	0.367	0.44	0.421	0.404	0.436	0.462	0.469
14.9	0.441	0.402	0.38	0.366	0.455	0.433	0.41	0.443	0.466	0.473
20.4	0.45	0.407	0.384	0.376	0.459	0.437	0.424	0.455	0.47	0.483
27.5	0.452	0.413	0.39	0.373	0.465	0.437	0.418	0.45	0.472	0.493
32.1	0.447	0.414	0.383	0.384	0.458	0.434	0.418	0.454	0.475	0.479
43	0.462	0.427	0.392	0.395	0.463	0.453	0.433	0.463	0.476	0.482

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	76.2	91.4	106.7	121.9	137.2	152.4
Time (h)										
0.99	0.443	0.396	0.372	0.372	0.424	0.407	0.4	0.405	0.453	0.47
2.44	0.432	0.394	0.379	0.383	0.427	0.421	0.429	0.43	0.458	0.493
3.87	0.578	0.512	0.488	0.501	0.575	0.574	0.568	0.566	0.622	0.636
6.01	0.441	0.391	0.374	0.379	0.433	0.42	0.422	0.424	0.469	0.471
8.54	0.429	0.386	0.377	0.378	0.428	0.414	0.425	0.422	0.46	0.468

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

The rising gradient in the 0 to 15 cm layer indicates surface seal formation, resulting in an actual K change over time. The relatively large gradient at 15 to 30 cm indicates an impeding layer, possibly a plow pan. Decreasing gradient in that layer is caused by gradual wetting below the impeding layer. The small gradient at 91 to 106 cm with the large gradient in the 106 to 122 cm layer is likely caused by ponding above a transition to a finer texture layer as indicated by a higher sand-to-silt ratio (Schuh, Cline and Sweeney 1991, Tables J-1.2 and J-2.2). Below the textural change gradients approach 1. Most layers below 30 cm approach steady state after about 10 hours.

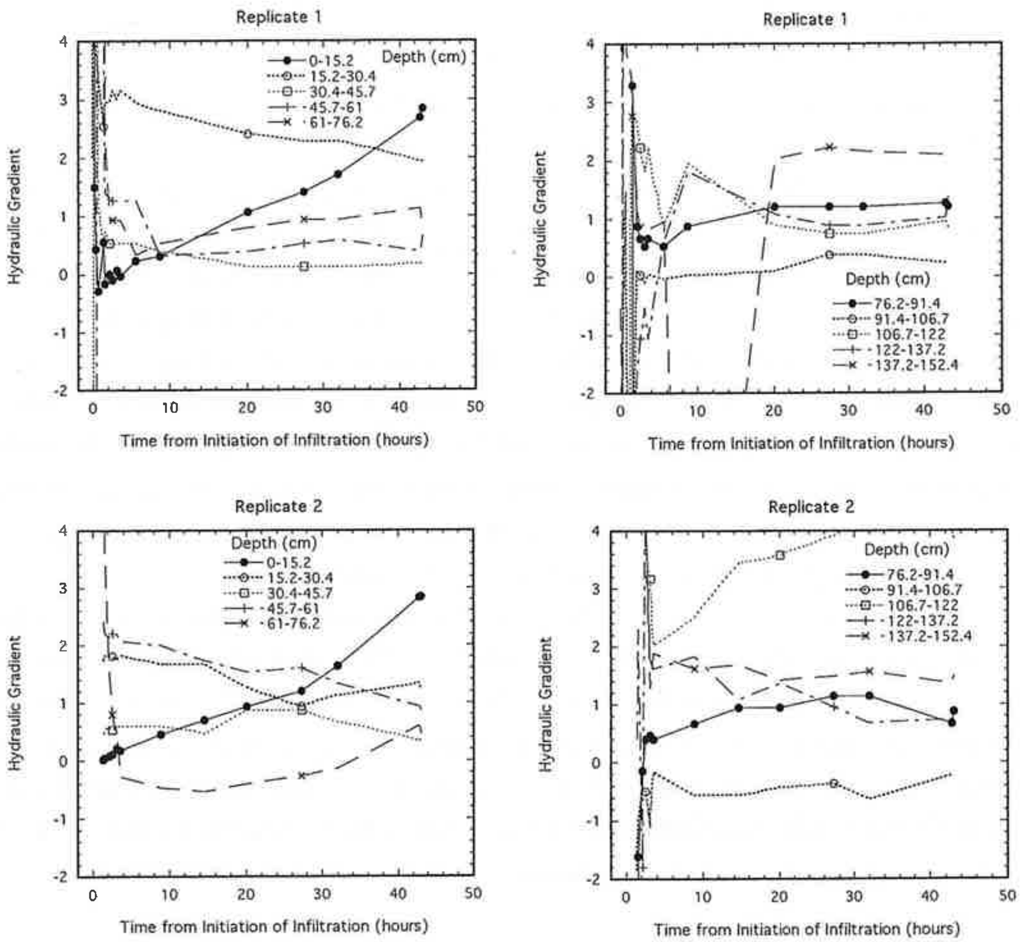

Figure J.3. Vertical hydraulic gradients during wetting and sorption of site J.

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site J are measured by matching the i vs. t function (Figure J.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table J.4. The measured K values may be saturated (K_{sat}) if the layer is fully saturated, or unsaturated [K(ψ)]. Fully saturated conditions generally occur when a soil profile saturates from the bottom up. Unsaturated conditions occur where an impeding layer causes perching of water and desaturation of the underlying soil. The saturation state (s for saturated) and corresponding matric potential (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included.

Table J.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption). Mean matric potential head (cm), corresponding to measured K for the depth interval, is in parentheses. (s) indicates saturation and ($-\psi$) is the corresponding matric potential expressed as cm of head.

Replicate 1

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-91.4	91.4-107	107-122	122-137	137-152
Time (h)									
1.36	*5.26*	9.27	-	-	-	-	-	-	-
1.55	*4.75*	-	-	-	-	-	-	-	-
2.11	*3.72*	298	-	-	-	-	-	-	-
2.59	*3.17*	-	-	-	-	-	-	-	-
3.12	*2.76*	34.9	-	-	-	-	-	-	-
3.59	*2.49*	-	-	-	-	-	-	-	-
5.57	*1.88*	7.81	-	-	-	-	-	-	-
8.72	*1.54*	*4.92*	-	-	-	-	-	-	-
20.1	*1.3*	*1.22*	*0.539*	*9.68*	3.28	1.61	1.08	12	1.47
27.4	*1.15*	*0.817*	*0.506*	*8.57*	*2.17*	*1.22*	*0.953*	*3.06*	*1.53*
31.9	*1.02*	*0.599*	*0.449*	*7.61*	*1.71*	*1.09*	*0.846*	*2.71*	*1.36*
42.8	*0.595*	*0.221*	*0.307*	*2.95*	*1.5*	*0.521*	*0.467*	*2.46*	*0.624*
43.1	*0.582*	*0.205*	*0.3*	*4.34*	*0.876*	*0.723*	*0.482*	*2.41*	*0.712*
mean	-	1.33 (s)	0.42 (s)	6.63 (s)	1.91 (s)	1.03 (s)	0.77 (s)	4.53 (s)	1.14 (s)
SE	-	0.735	0.0498	1.28	0.401	0.191	0.125	1.87	0.195
CV	-	0.553	0.265	0.432	0.471	0.413	0.364	0.924	0.382

Replicate 2

Depth (cm) >	0-15.2	15.2-30.5	30.5-45.7	45.7-61	61-76.2	76.2-91.4	91.4-107	107-122	122-137	137-152
Time (h)										
1.36	5.26	174	-	-	-	-	-	-	-	-
1.55	4.75	111	-	-	-	-	-	-	-	-
2.14	3.68	45.1	-	-	-	-	-	-	-	-
2.59	3.17	28.6	-	-	-	-	-	-	-	-
3.12	2.76	12.9	-	-	-	-	-	-	-	-
3.59	2.49	14.1	-	-	-	-	-	-	-	-
8.89	1.53	3.34	-	-	-	-	-	-	-	-
14.6	1.38	*1.96*	*0.824*	*2.93*	*0.792*	-	1.47	-	0.401	1.27
20.1	1.3	*1.4*	*1.02*	*1.49*	*0.845*	-	1.38	-	0.364	0.958
27.3	1.15	*0.964*	*1.24*	*1.32*	*0.72*	-	*1.01*	-	*0.296*	*1.21*
32	1.02	*0.619*	*0.898*	*1.52*	*0.763*	-	*0.893*	-	*0.229*	*1.49*
42.9	0.591	*0.209*	*0.443*	*1.76*	*0.634*	0.979	*0.881*	-	*0.146*	*0.787*
43.1	0.581	*0.205*	*0.484*	*1.44*	*0.672*	1.24	*0.667*	-	*0.151*	*0.85*
mean	-	0.89 (s)	0.82 (s)	1.7 (s)	0.74 (s)	1.1 (s)	1.1 (s)	-	0.26 (s)	0.82 (s)
SE	-	0.284	0.13	0.24	0.032	0.13	0.13	-	0.044	0.13
CV	-	0.318	0.38	0.34	0.11	0.17	0.3	-	0.41	0.38

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site H was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table J.5. Cumulative infiltration and infiltration rate are shown on Figures J.4 and J.5, with corresponding fitted functions using the method of Philip (1957, 1966).

Table J.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site J (Gardena silt loam) measured near Oakes, ND.

t_I (h)	I (cm)	t_i (h)	i (cm/h)		t_I (h)	I (cm)	t_i (h)	i (cm/h)
0	0	0	0		5.825	18.8	5.494	3.14
0.342	0.815	0.171	3.03		6.019	19.5	5.922	3.57
0.63	1.51	0.486	2.41		14.35	43.4	10.19	2.87
1.041	2.89	0.836	3.37		15.17	45.8	14.76	2.95
1.742	5.14	1.392	3.2		16.21	48.6	15.69	2.67
2.109	6.35	1.926	3.32		17.36	51.7	16.78	2.7
2.985	9.12	2.547	3.16		18.03	53.8	17.7	3.09
3.267	9.81	3.126	2.45		20.25	56.5	19.77	2.88
3.847	11.9	3.557	3.58		21.09	59.3	20.67	3.28
4.255	14	4.051	5.1		21.8	61.4	21.45	2.94
5.033	16.2	4.644	2.88		22.39	63.5	22.1	3.49
5.163	16.7	5.098	4.03		23.12	65.9	22.76	3.32

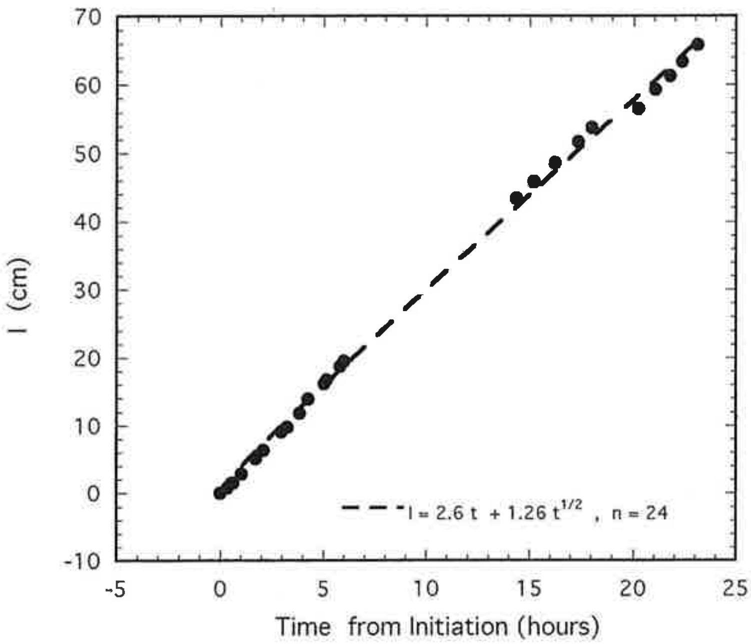

Figure J.4. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site J.

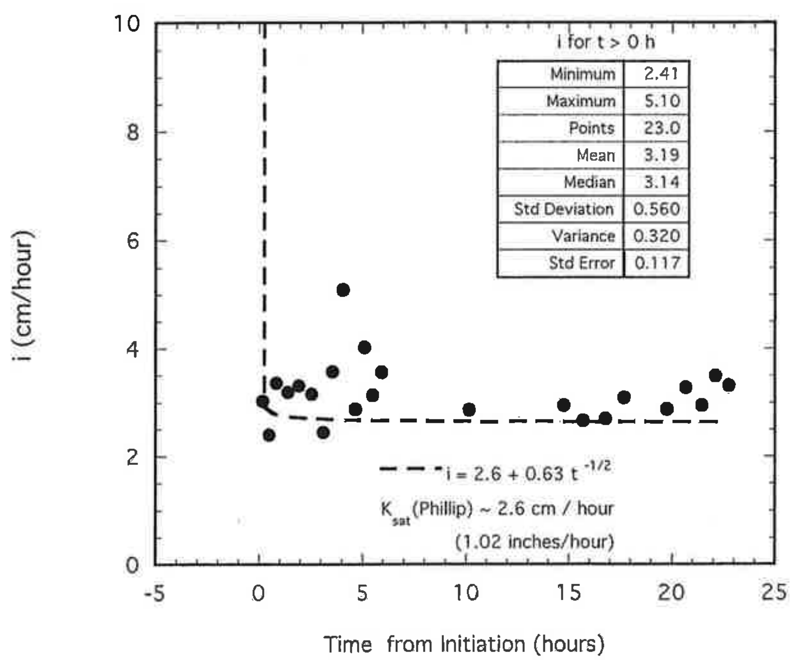

Figure J.5. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site J.

SITE K (Exline loam : fine, smectitic, frigid Leptic Natrudoll)

Site K was located in a nearly level, low hayfield near a sunflower field. The condition of the sunflowers, for which the soil was unsuited because of high sodium, was poor. The location and description are summarized on Table 1. In-situ hydraulic measurements and site descriptions were made during August through October, 1985. Because of slow infiltration rate several days were required to fully wet the soil profile. Soil morphology, in-situ and laboratory soil-moisture retention data, soil physical data, soil saturated paste extract water chemistry, and in-situ and laboratory unsaturated hydraulic-conductivity data were reported by Schuh, Cline and Sweeney (1991), pages 265-300. Soil hydraulic parameters for Brooks and Corey (1964) and Van Genuchten (1980, 1984) functional formats are in the same report in Appendices 1, 2 and 3. Comparative analyses of unsaturated flow parameters for these data in relation to soil textural data are discussed by Schuh and Cline (1991). Relationships between textural models and water-retention curves for these data are discussed in Schuh, Cline and Sweeney (1989).

Infiltration on Site K (as on all Sites D-K) was measured within the area used for determining $K(\psi)$ during drainage; and was measured concurrent with the initial sorption of the site, rather than after completion of field sampling. Also, on Site K, as for all of Sites D-K, infiltration rates were measured in the deep soil, after excavation for sampling and description of soil morphology.

Infiltration, Matric Potential (ψ), and Volumetric Water Content (θ) Data

Table K.1. Cumulative infiltration (I), and infiltration rate (i) for the soil surface of Site K (Exline loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		0.302	6.02	0.261	3.77
0.011	1.14	0.006	103		0.406	6.56	0.354	5.1
0.016	1.75	0.014	122		0.535	6.71	0.471	1.19
0.021	2.36	0.019	116		1.025	6.79	0.78	0.156
0.028	2.97	0.025	95.5		1.414	6.94	1.22	0.391
0.036	3.58	0.032	70.8		1.824	7.01	1.619	0.186
0.043	3.89	0.039	49.9		3.2	7.05	2.512	0.0277
0.064	4.5	0.053	28.9		6.9	7.11	5.05	0.0155
0.081	4.8	0.072	18		17.2	7.13	12.05	0.00185
0.107	5.11	0.094	11.6		137.6	7.15	131.6	0.0016
0.153	5.41	0.13	6.61		161.8	7.17	149.7	0.00079
0.221	5.72	0.187	4.5		262.8	7.19	212.3	0.00019

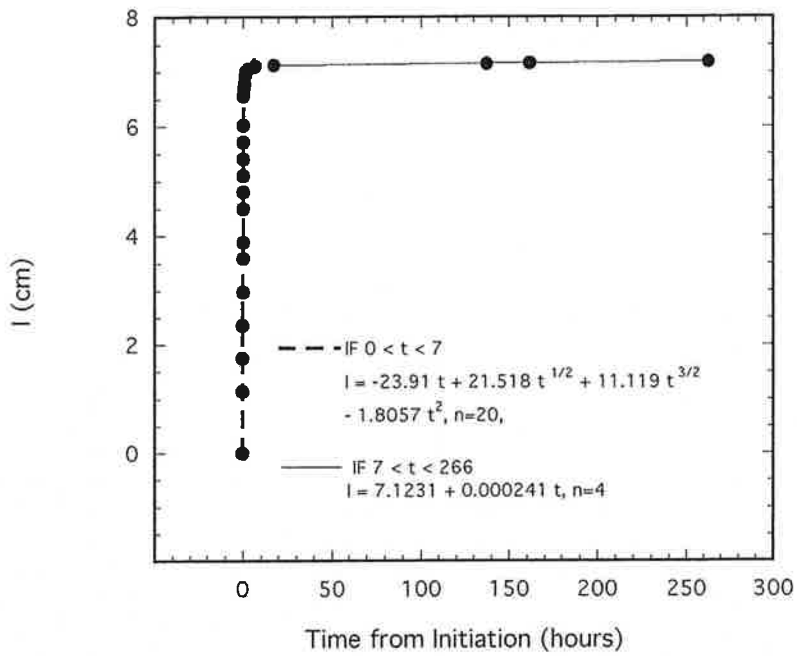

Figure K.1. Cumulative infiltration (I) and Philip (1957) parametric function for soil surface on Site K.

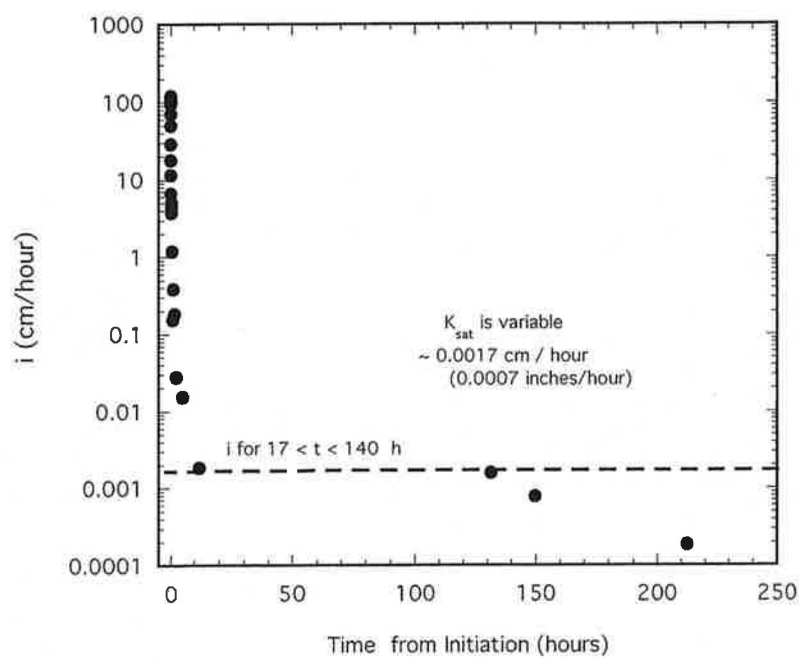

Figure K.2. Infiltration rate (i) and Philip (1957) parametric function for soil surface on Site K.

Table K.2. Soil water matric potential (in cm head units) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	122	152	183	213	\244
Time (h)										
-0.139	-483	-229	-415	-264	-430	64.8	-265	-123	68.4	67.4
0.494	-45.1	-242	-425	-277	-429	63.7	-260	-117	60.3	63.3
0.844	-77.7	-247	-197	-162	-383	-363	-439	-44.6	71.5	80.7
1.69	-33.9	-255	-482	-287	-418	80.1	-233	-93.5	65.4	65.4
3.34	-26.7	-274	-496	-313	-414	64.8	-203	-82.3	64.4	65.4
7.01	-42	-284	-515	-347	-413	57.6	-163	-64	61.3	65.4
17.3	-50.2	-221	-511	-363	-388	73.9	-124	-25.2	63.3	66.4
126	-58.4	-85.9	-235	-381	-302	62.7	-92.9	-4.8	61.3	62.3
138	-60.4	-100	-231	-394	-328	66.8	-97	-15	58.2	60.3
162	-59.8	-95.1	-183	-360	-346	39.3	-88.8	-11.9	62.3	64.4
263	-57.3	-71.6	-103	-137	-285	130	-66.4	2.34	67.4	63.3
283	-59.4	-83.9	-113	-130	-298	132	-72.5	-6.84	66.4	63.3
342	-64.5	-75.7	-87	-89.1	-243	124	-79.7	-8.88	65.4	61.3
477	-68.6	-94.1	-99.3	-85	-103	126	-81.7	-13	64.4	57.2
964	-64.5	-101	-106	-86	-42.8	-	-7.75	-20.1	57.7	54.2
1027	-61.4	-76.7	-76.8	-59.5	-21.9	-	7.04	-8.88	57.9	53.1
1152	-48.2		-64.6	-46.2	-6.64	-	34.6	-	58.2	-

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	122	152	183	213	244
Time (h)										
-0.139	-267	-236	-151	-167	-351	92.3	-457	-43.6	72.5	82.7
0.494	-131	-236	-182	-161	-377	-360	-450	-45.6	63.3	75.6
0.844	-31.8	-245	-478	-278	-423	72.9	-245	-107	66.4	66.4
1.69	-55.3	-271	-226	-185	-402	-369	-425	-41.5	72.5	82.7
3.34	-50.2	-313	-273	-227	-434	-379	-401	-40.5	73.5	79.7
7.01	-47.1	-373	-341	-285	-481	-377	-366	-30.3	73.5	133
17.3	-45.1	-406	-400	-347	-512	-353	-270	0.3	80.7	82.7
126	-52.2	-101	-279	-542	-503	128	-100	5.4	67.4	68.4
138	-152	-104	-250	-354	-521	123	-120	2.34	70.5	70.5
162	-50.2	-98.2	-179	-191	-506	81.1	-118	1.32	67.4	68.4
263	-48.2	-72.7	-76.8	-227	-438	128	-80.7	10.5	69.5	69.5
283	-47.1	-79.8	-80.9	-203	-441	100	-93.9	3.36	69.5	68.4
342	-51.2	-76.7	-68.7	-89.1	-379	132	-69.5	2.34	65.4	66.4
477	-49.2	-58.4	-50.3	-60.5	-364	132	-54.2	14.6	71.5	68.4
964	-60.4	-84.9	-75.8	-81.9	-173	-	-95	-6.84	60.3	58.2
1027	-28.3	-83.9	-71.2	-66.6	-28.6	-	-85.8	-8.88	58.7	59.3
1152	-57.3	-77.8	-64.1	-60	-20.4	-	-50.1	-2.25	59.8	60.3

Table K.3. Soil volumetric water content (θ) during infiltration (sorption).

Replicate 1

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8
Time (h)	0.4195	0.3848	0.3521	0.351	0.4147	0.4471	0.5136			
1.13	0.412	0.3853	0.3531	0.347	0.3999	0.4356	0.4979	-	-	-
2.03	0.4222	0.3905	0.3526	0.342	0.4136	0.4356	0.5124	-	-	-
7.21	0.4036	0.4189	0.3873	0.35	0.347	0.4088	0.434	0.5025	-	-
17.3	0.4362	0.3941	0.3703	0.3622	0.3765	0.4046	0.3495	0.4389	0.4858	0.5025
282	0.4335	0.3967	0.3744	0.3678	0.3926	0.4179	0.4157	0.4493	0.4961	0.5025
283	0.4163	0.3946	0.375	0.3673	0.3946	0.412	0.4099	0.4373	0.4841	0.4996
386	0.4254	0.3926	0.3755	0.3734	0.403	0.4147	0.4088	0.4494	0.499	0.499
432	0.4232	0.3926	0.3683	0.3714	0.4036	0.4041	0.3994	0.4413	0.4852	0.4996
477	0.4373	0.4009	0.3806	0.3688	0.4104	0.4291	0.411	0.337	0.4915	0.5066
964	0.4286	0.3967	0.3791	0.3734	0.4078	0.4222	0.4025	0.4329	0.4835	0.5042
1028	15.24	30.48	45.72	60.96	91.44	121.9	152.4	182.9	213.4	243.8

Replicate 2

Depth (cm) >	15.2	30.5	45.7	61	91.4	121.9	152.4	182.9	213.4	243.8
Time (h)	0.4195	0.3848	0.3521	0.351	0.4147	0.4471	0.5136			
1.29	0.4025	0.3729	0.3581	0.341	0.3905	0.4286	0.5037	-	-	-
2.14	0.3936	0.3714	0.3445	0.3315	0.4248	0.4319	0.5101	-	-	-
7.21	0.3744	0.348	0.345	0.4254	0.434	0.5124	-	-	-	-
17.3	0.4147	0.376	0.347	0.3415	0.4115	0.4254	0.5013		-	-
282	0.4238	0.3455	0.3637	0.3546	0.3786	0.4179	0.35	0.4227	0.4682	0.5013
283	0.4275	0.3858	0.3652	0.3586	0.3817	0.4152	0.4286	0.4281	0.4898	0.4961
386	0.4083	0.3863	0.3561	0.3536	0.376	0.42	0.411	0.4248	0.4727	0.499
432	0.4238	0.3915	0.3663	0.3617	0.3863	0.4136	0.4057	0.4173	0.4818	0.5066
477	0.4232	0.3853	0.3607	0.3642	0.3858	0.4216	0.3988	0.4168	0.475	0.5002
964	0.4216	0.3905	0.3331	0.3668	0.4083	0.4526	0.4163	0.4222	0.471	0.5031
1028	0.427	0.3827	0.3663	0.3683	0.4004	0.4576	0.412	0.4281	0.4677	0.499

Hydraulic Gradient Measurements

During sorption of an unsaturated soil layer hydraulic gradients can temporarily increase as moisture enters the upper boundary of the layer. They then decrease as the wetting front passes the bottom of the layer, and approach a constant value when steady-state conditions are approximated. For a homogeneous soil profile under unsaturated soil moisture conditions and where flux is limited by an overlying impeding layer, hydraulic gradients tend to approach a constant value near 1, and differences in flux are accommodated by changes in $K(\psi)$ with variation of saturation state. Where impeding boundaries occur steady-state gradients tend to be larger, while they tend to be somewhat lower just above the boundaries because of increased moisture near the lower boundaries. During steady-state conditions caused by surface infiltration gradients tend to be lower in deep soil profiles approaching the water table.

Because of its sodic characteristics sorption characteristics of this soil are highly complex. The surface layer is at steady state within 2 hours (Fig. K.3). However the next two layers (15 to 45 cm) are imbibing water for 100 to 200 hours, and continue to seal for the first 2 to 8 days. This is likely related to the sodium profile shown on Figure K.4. The high gradient at 122-152 cm is related to the interface between the overlying sodic loam and the underlying sand which seems to be causing ponding. Because of complex pressure relationships in expanding sodic smectite clay matrices, some of the interior gradients, particularly those indicating upward gradients, are not clearly understood.

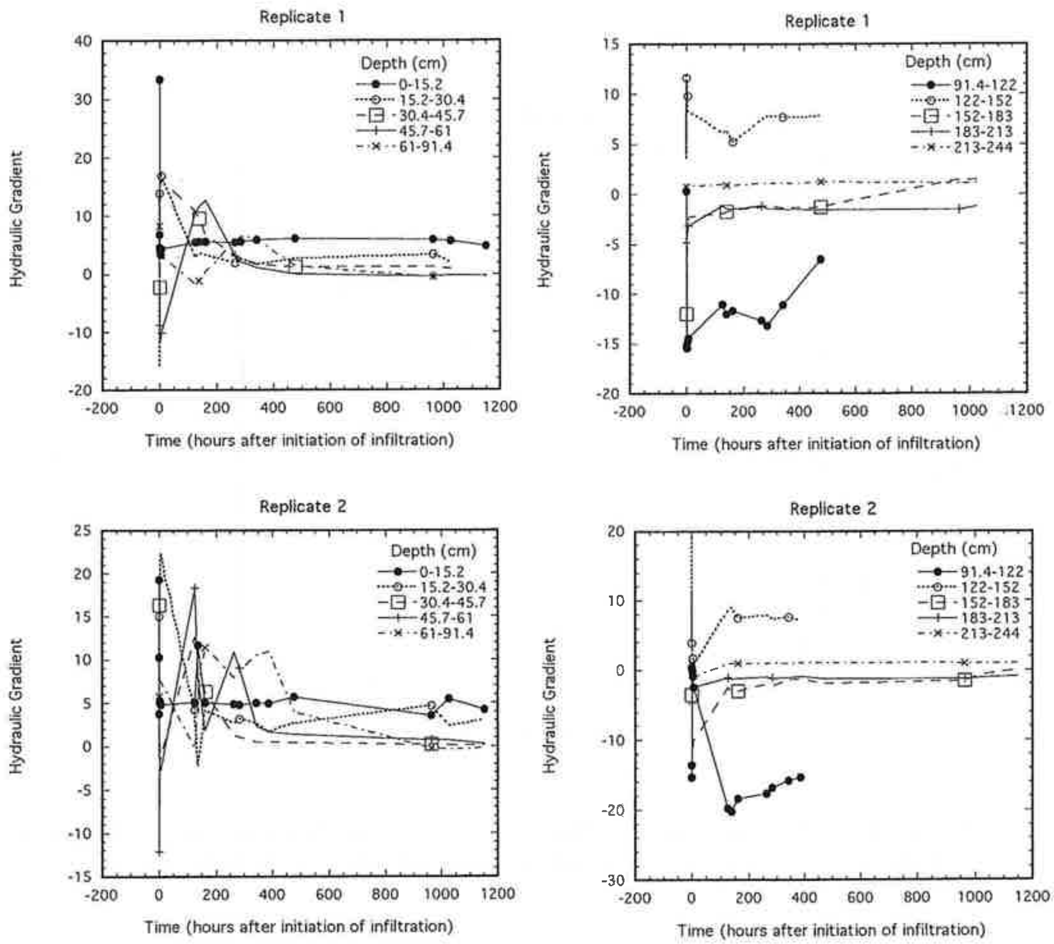

Figure K.3. Vertical hydraulic gradients during wetting and sorption of Site K.

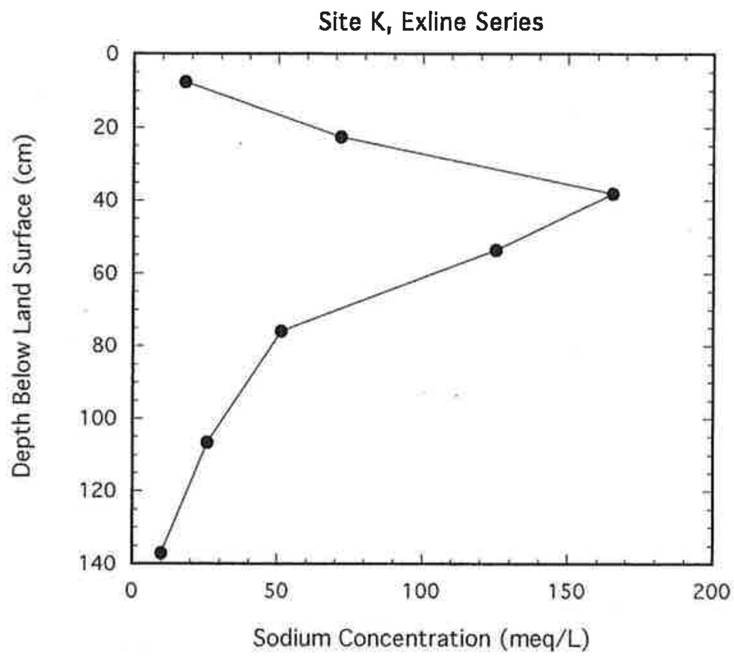

Figure K.4. Sodium concentrations for soil saturation extracts on Replicate 1 of Site K. (From Schuh, Cline and Sweeney, 1991, Table K-1.3).

Hydraulic Conductivity

Combined tensiometric data and infiltration rates can be used to calculate hydraulic conductivity for each layer during infiltration, provided flow through the measured layer is at steady state.

Hydraulic conductivity (K) on Site K are measured by matching the i vs. t function (Figure K.2) to the time sequence of the measured gradients. K(sat/ψ) are measured as i/grad at times when gradients appear to be at steady state for each specified layer. Time correspondence should not be a problem because i reaches steady state quickly.

K is a soil property and should be stable and consistent as long as the soil pore-structure and the air and fluid composition within it remains constant. Infiltration, however, is a highly complex process and K(sat/ψ) can change through modifying processes that include air entrapment ahead of or within the wetting front, purging of entrapped air, soil swelling, soil slaking or displacement during infiltration, particulate clogging, microbiological processes during long-term infiltration.

Steady-state K values are on Table K.4. The saturation state (s for saturated) and corresponding suction (ψ) for unsaturated values are included with mean K values. Standard error of the mean, and coefficient of variation are also included. The surface layer appears to be at steady state after 2 hours, but continues to seal so that K steadily decreases. K cannot ascertained in the middle layers because steady-state conditions cannot be ascertained during the process of imbibing water with clay expansion. Therefore, K is only estimated for the surface layer. Even in this layer, no reasonable statistical mean can be established because of constant change in the matrix during infiltration.

Table K.4. Vertical hydraulic conductivity (cm/h) during infiltration (sorption).

Replicate 1

Depth (cm) >	i	K at 0-15.2
Time (h)		
0.494	1	0.215
0.844	0.162	0.0238
1.69	0.177	0.0452
3.34	0.0224	0.0065
7.01	0.0109	0.00245
126	0.0018	0.000326
138	0.00133	0.000235
162	0.000499	8.88e-05

Replicate 2

Depth (cm) >	i	K at 0-15
Time (h)		
-0.139		
0.494	1	0.0972
0.911	0.162	0.0429
1.76	0.177	0.0333
3.34	0.0224	0.00449
7.01	0.0109	0.00228
126	0.0018	0.000351
138	0.00133	0.000114

Deep Subsoil Infiltration

After initial infiltration measurements and measurements of water content and tensiometric data for the draining profile, Site K was excavated for sampling and morphological description (Schuh, Cline and Sweeney 1991). At the bottom of the measured excavation, in the C horizon, infiltration was again measured using a double-ring infiltrometer. Results are in Table K.5. Cumulative infiltration and infiltration rate are shown on Figures K.5 and K.6, with corresponding fitted functions using the method of Philip (1957, 1966).

Table K.5. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site K (Exline loam) measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		3.486	39.1	3.367	11.6
0.034	0.462	0.017	41.2		3.673	41.8	3.58	14.8
0.161	1.67	0.097	9.49		4.599	52.9	4.136	12
0.274	3.06	0.218	12.2		5.612	65.4	5.106	12.3
0.404	4.44	0.339	10.7		5.904	68.1	5.758	9.49
0.53	5.83	0.467	11		6.212	70.9	6.058	8.98
0.667	7.21	0.599	10.1		6.759	77.1	6.486	11.4
0.806	8.6	0.737	9.97		7.681	87.5	7.22	11.3
0.927	9.98	0.867	11.5		7.825	88.9	7.753	9.66
1.162	12.7	1.045	11.8		8.526	97.2	8.175	11.8
1.382	14.8	1.272	9.42		8.637	98.6	8.581	12.5
1.558	16.9	1.47	11.8		9.242	107	8.94	13.7
1.937	21.1	1.747	11		9.49	110	9.366	11.2
2.179	23.8	2.058	11.5		9.724	112	9.607	11.8
2.426	26.6	2.302	11.2		14.03	147	11.88	8.08
2.652	29.4	2.539	12.2		16.21	171	15.12	11.1
3.248	36.3	2.95	11.6		18.18	193	17.19	11

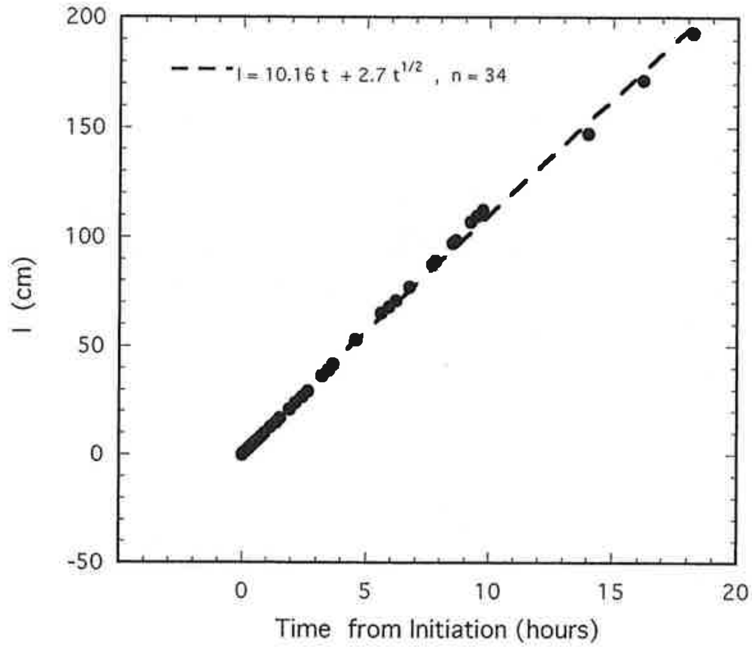

Figure K.5. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site K.

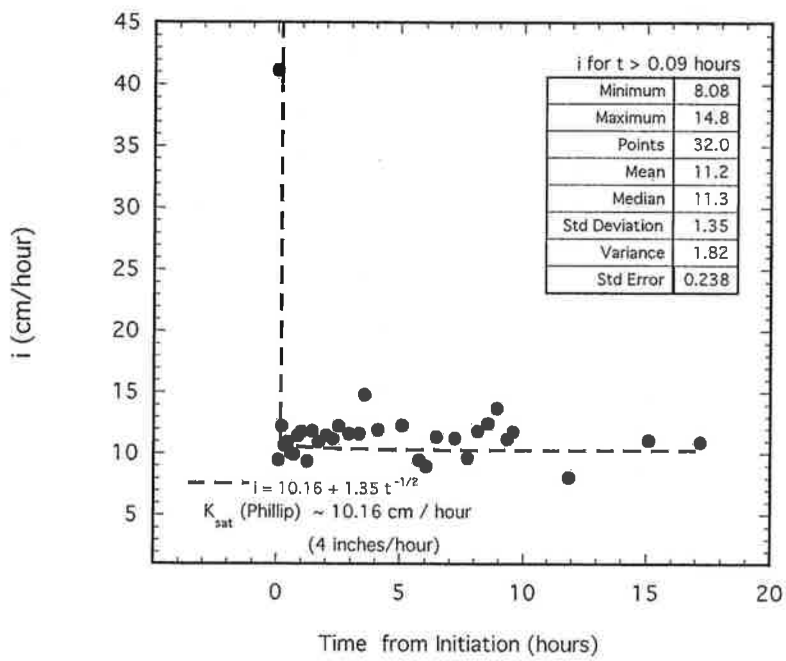

Figure K.6. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site K.

SUPPLEMENTAL DATA

Three additional infiltration tests (labeled RM1, RM2 and RM3) were conducted in the area of the Oakes aquifer in the Fall of 1985. These were measured in the C horizon at the bottom of excavated pits, as described for deep infiltration measurements on Sites D-K on page 5. The three additional measurements were conducted in conjunction with an investigation of the feasibility of artificial recharge. These data were reported in graphical form in North Dakota State Water Commission Water Resource Investigation No. 5 (Shaver and Schuh 1990), with accompanying soil profile descriptions and particle-size data in Supplement sections 1, 2, 3, and 10, 11, and 12.) For convenience, soil profile and particle-size data are republished in this supplement.

SITE RM1 (Parent materials beneath Embden Sandy Loam: Coarse-loamy, mixed, superactive, frigid Pachic Hapludoll)

Infiltration Site RM1 was located on pastureland, about 25 feet south of an observation well (Labeled 13005820AAB in the NDSWC database) located in the NW ¼, NE ¼ , NE ¼ of Section 20, T. 130 N., R. 58 W. Measurements were made on October 17 of 1985. Depth to the water table was 11.12 feet (3.4 m), measured at the adjacent observation well. The infiltration test was conducted in a pit excavated to a depth of 5.7 feet (1.73 m). Infiltration face preparation and measurements methods were described previously on page 5. Infiltration data are on Table RM1.1. Infiltration data with accompanying parametric functions using the form of Philip (1957) are shown on Fig. RM1.1. Description of the overlying soil horizons, and particle size data are on Tables RM1.2 and RM1.3.

Table RM1.1. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site RM1 measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		1.293	35.1	1.265	24.9
0.059	3.96	0.03	23.4		1.351	36.5	1.322	24
0.086	4.65	0.073	25.4		1.475	39.3	1.413	22.4
0.124	6.03	0.105	36.9		1.591	42	1.533	23.8
0.161	7.42	0.142	37.8		1.705	44.8	1.648	24.3
0.204	8.8	0.182	32.2		1.817	47.6	1.761	24.7
0.25	10.2	0.227	29.8		1.931	50.3	1.874	24.3
0.3	11.6	0.275	27.7		2.032	53.1	1.982	27.4
0.35	13	0.325	27.5		2.146	55.9	2.089	24.4
0.418	14.3	0.384	20.6		2.263	58.6	2.205	23.6
0.531	17.1	0.474	24.3		2.372	61.4	2.318	25.6
0.596	18.5	0.564	21.3		2.646	68.3	2.509	25.2
0.663	19.9	0.63	20.7		2.863	73.9	2.755	25.5
0.72	21.3	0.692	24.3		3.109	80.1	2.986	25.3
0.785	22.6	0.753	21.5		3.194	82.2	3.152	24.5
0.831	24	0.808	29.7		3.83	99.3	3.512	26.9
0.891	25.4	0.861	23.2		3.899	101	3.865	20
0.942	26.8	0.917	27.1		3.956	102	3.928	24.4
1.004	28.2	0.973	22.3		4.216	109	4.086	26.6
1.066	29.6	1.035	22.6		4.422	115	4.319	26.9
1.119	31	1.092	26.1		4.636	120	4.529	26
1.179	32.3	1.149	23.1		5.486	144	5.061	27.7
1.238	33.7	1.208	23.6					

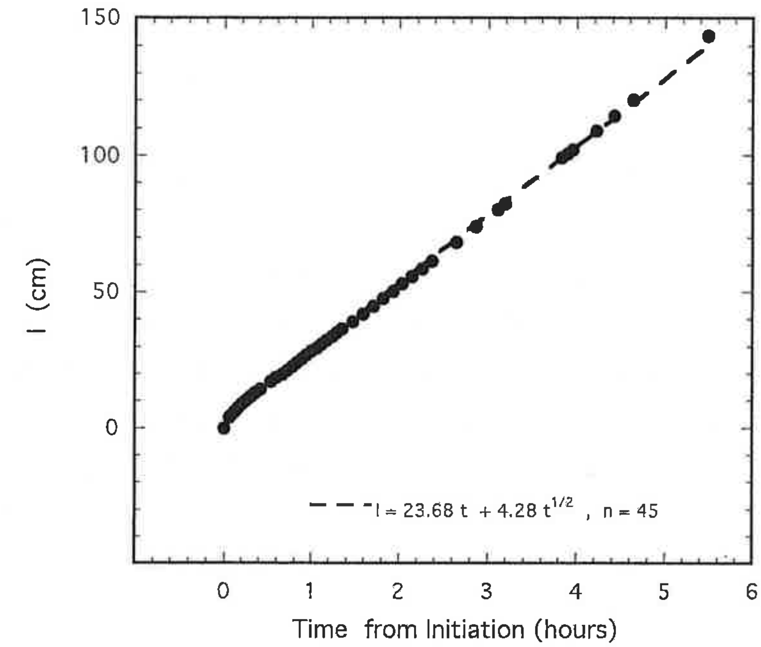

Figure RM1.1. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site RM1.

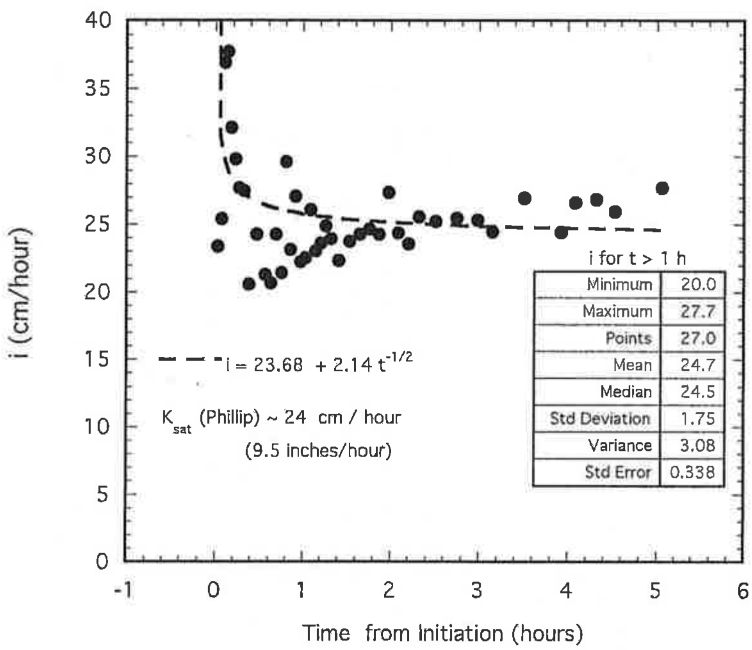

Figure RM1.2. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site RM1.

Table RM1.2. Description of the Embden soil profile at infiltration test Site RM1. (From p112, WRI 5, Shaver and Schuh, 1990). Profile description by Michael D. Sweeney.

Lithologic Description	Thickness Inch (cm)	Depth Inch (cm)
Dark-gray sandy loam	9 (23)	9 (23)
Grayish-brown sandy loam	8 (20)	17 (43)
Light-gray silty loam; violent effervescence because of lime accumulation	11 (28)	28 (71)
Light-brownish-gray fine sandy loam; strong effervescence because of lime accumulation	13 (25)	41 (104))
Light-brownish-gray fine sand; slight effervescence	25 (63)	66 ((168)
Light-brownish-gray fine sand; slight effervescence; few pebbles over 2 mm	30 (76)	96 (244)
Light-brownish-gray medium to coarse sand; slighyt effervescence; few pebbles over 2 mm.	12 (30)	108 (274)

Table RM1.3. Particle-size distribution for soil horizons on Site RM1. (From p121, WRI 5, Shaver and Schuh, 1990).

Soil Horizon	Depth to top Inches (cm)	Depth to bottom Inches (cm)	Depth to midpoint Inches (cm)	Sand % (2,000 to 50 μ)	Silt % (50 to 2 μ)	Clay % (< 2 μ)
A	0	9 (23)	4.5 (11)	68.1	24.4	7.4
Bw1	9 (23)	17 (43)	13 (33)	51.5	36.7	11.8
BCk	17 (43)	28 (71)	22.5 (57)	27.7	52.9	17.4
C1	28 (71)	41 (104))	34.5 (88)	53.3	32.2	14.5
C2	41 (104))	66 ((168)	53.5 (136)	90.1	7.5	2.4
C3	66 ((168)	96 (244)	81 (206)	91.5	7.5	.9
C4	96 (244)	108 (274)	102 (259)	86.9	9.6	3.5

SITE RM2: (Parent materials beneath Alymer Sand: Mixed, frigid Aquic Udipsamments)

Infiltration Site RM2 was located adjacent to a prairie trail about 50 feet east of an observation well (Labeled 13005831AAB in the NDSWC database) located in the NE ¼, NE ¼ , NE ¼ of Section 31, T. 130 N., R. 58 W. Measurements were made on October 17 of 1985. Depth to the water table was 9.3 feet (2.8 m), measured at the nearby observation well. The infiltration test was conducted in a pit excavated to a depth of 5 feet (1.52 m). Infiltration face preparation and measurements methods were described previously on page 5. Infiltration data are on Table RM2.1. Infiltration data with accompanying parametric functions using the form of Philip (1957) are shown on Fig. RM2.1. Description of the overlying soil horizons, and particle size data are on Tables RM2.2 and RM2.3.

Table RM2.1. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site RM2 measured near Oakes, ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		1.901	22.9	1.739	8.51
0.011	3.47	0.006	30.4		2.208	26.1	2.054	10.7
0.149	4.51	0.08	7.55		2.452	28.4	2.33	9.22
0.168	4.86	0.159	17.8		2.703	30.5	2.578	8.25
0.223	5.55	0.195	12.8		2.963	32.9	2.833	9.33
0.265	6.24	0.244	16.4		3.284	35.7	3.123	8.63
0.302	6.93	0.283	18.6		3.449	37	3.367	8.38
0.346	7.62	0.324	15.8		3.812	40.3	3.631	9.06
0.469	9.01	0.407	11.3		4.058	42.6	3.935	9.14
0.588	10.4	0.528	11.6		4.311	44.8	4.185	8.89
0.734	11.8	0.661	9.49		4.544	45.5	4.428	2.98
0.86	13.2	0.797	11		4.823	48.8	4.683	11.8
0.999	14.5	0.929	9.93		5.077	51.2	4.95	9.54
1.136	15.9	1.067	10.2		5.353	53.8	5.215	9.41
1.273	17.3	1.204	10.1		5.56	55.7	5.456	9.19
1.426	18.7	1.349	9.08		5.816	58.2	5.688	9.46
1.576	20.1	1.501	9.2					

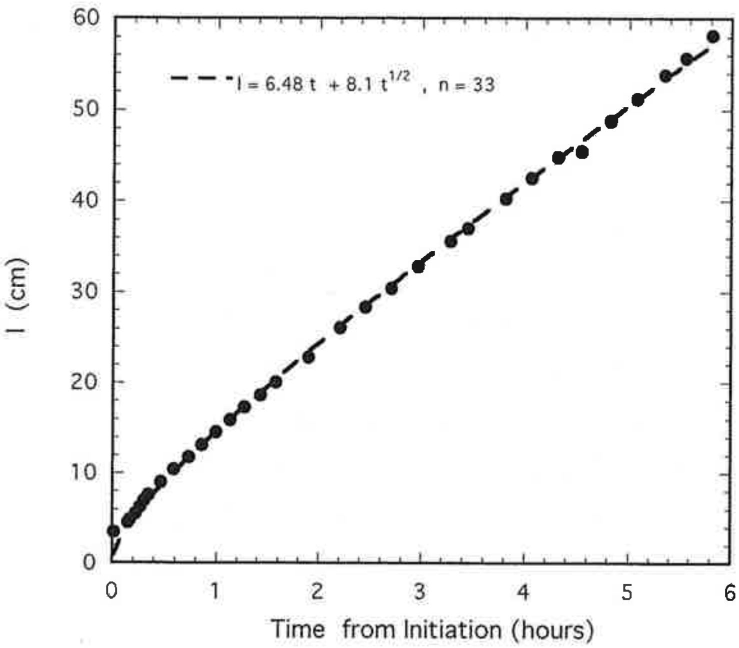

Figure RM2.1. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site RM2.

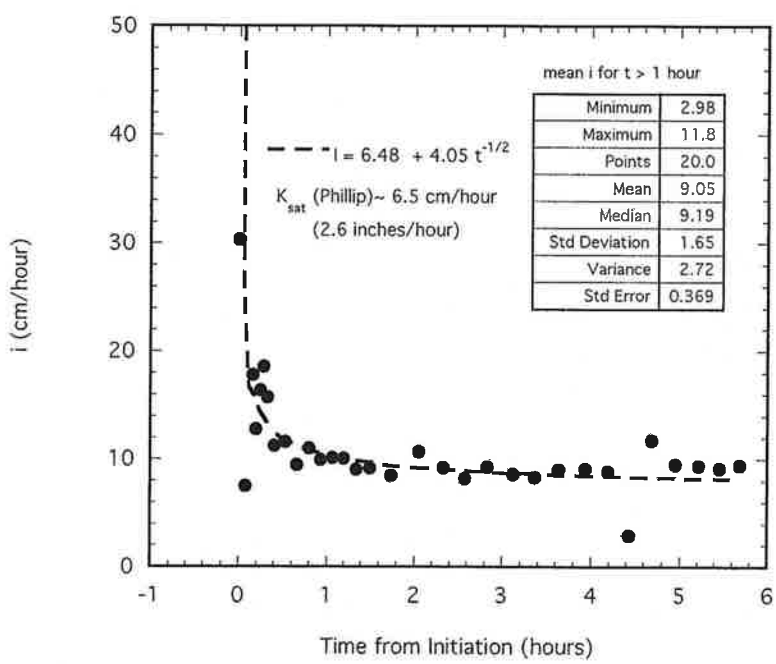

Figure RM2.2. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site RM2.

Table RM2.2. Description of the Alymer soil profile at infiltration test Site RM2. (From p113, WRI 5, Shaver and Schuh, 1990). Profile description by Michael D. Sweeney.

Lithologic Description	Thickness Inch (cm)	Depth Inch (cm)
Dark-gray fine to medium sand	10 (25)	10 (25)
Gray fine sand	8 (20)	18 (46)
Gray fine sand; iron mottles	8 (20)	26 (66)
Dark-gray fine to medium sand; buried A horizon	2 (5)	28 (71)
Gray fine to medium sand; iron mottles	17 (43)	45 (114)
Dark-gray loamy sand; buried A horizon	4 (10)	49 (124)
Gray fine to medium sand; faint iron mottles	7 (18)	56 (142)
Gray fine sand; slight effervescence; iron mottles	24 (61)	80 (203)
Gray sandy loam; strong effervescence; iron mottles	2 (5)	82 (208)
Gray fine to medium sand; slight effervescence; iron mottles	62 (157)	144 (366)
Very dark gray silty clay; slight effervescence	1 (3)	145 (368)
Gray fine to medium sand; slight effervescence; 1/4 -inch thick silty clay strata	13 (33)	158 (401)

Table RM2.3. Particle-size distribution for soil horizons on Site RM2. (From p122, WRI 5, Shaver and Schuh, 1990).

Soil Horizon	Depth to top Inches (cm)	Depth to bottom Inches (cm)	Depth to midpoint Inches (cm)	Sand % (2,000 to 50 μ)	Silt % (50 to 2 μ)	Clay % (< 2 μ)
A	0	10 (25)	5 (13)	97	2.4	0.6
C11	10 (25)	18 (46)	14 (36)	97.4	2.4	0.2
C2	18 (46)	26 (66)	22 (56)	97.7	2.1	0.2
2Ab	26 (66)	28 (71)	27 (69)	94.4	4	1.7
2C1	28 (71)	45 (114)	36.5 (93)	96.4	3.4	0.2
3Ab	45 (114)	49 (124)	47 (119)	69.1	27.3	3.6
3C1	49 (124)	56 (142)	52.5 (133)	91.6	6.7	1.7
3C2	56 (142)	80 (203)	68 (173)	93.9	4.5	1.7
3C3	80 (203)	82 (208)	81 (206)	77	13.7	9.3
3C4	82 (208)	110 (279)	96 (244)	91.4	5.1	3.5
3C5	110 (279)	144 (366)	127 (323)	91.1	5.4	3.5
3C6	144 (366)	145 (368)	144.5 (367)	54.5	26.4	19.1
3C7	145 (368)	158 (401)	151.5 (385)	87.4	8	4.6

SITE RM3: (Parent materials beneath overblown sand and buried soil: Unclassified)

Infiltration Site RM3 was located adjacent to a prairie trail about 50 feet southwest of an observation well (Labeled 12905924AAB in the NDSWC database) located in the NE ¼, NE ¼, NW ¼ of Section 24, T. 129 N., R. 59 W. Measurements were made on October 18 of 1985. Depth to the water table was 8.8 feet (2.7 m), measured at the nearby observation well. The infiltration test was conducted in a pit excavated to a depth of 5.25 feet (1.6 m). Infiltration face preparation and measurements methods were described previously on page 5. Infiltration data are on Table RM3.1. Infiltration data with accompanying parametric functions using the form of Philip (1957) are shown on Fig. RM3.1. Description of the overlying soil horizons, and particle size data are on Tables RM3.2 and RM3.3.

Table RM3.1. Cumulative infiltration (I), and infiltration rate (i) for the deep subsoil of Site RM3 measured near Oakes ND.

T (h)	I (cm)	t (hours)	i (cm/hour)		T (h)	I (cm)	t (hours)	i (cm/hour)
0	0	0	0		1.424	6.92	1.381	7.96
0.226	0.692	0.113	3.06		1.607	7.61	1.516	3.79
0.294	1.38	0.26	10.2		1.792	8.31	1.699	3.75
0.393	2.08	0.344	7.02		1.979	9	1.885	3.69
0.467	2.77	0.43	9.4		3.5	13.8	2.74	3.19
0.592	3.46	0.529	5.54		3.871	15.2	3.685	3.73
0.763	4.15	0.677	4.05		4.375	16.6	4.123	2.75
0.903	4.85	0.833	4.93		4.819	18	4.597	3.12
1.061	5.54	0.982	4.37		5.3	19.4	5.06	2.88
1.337	6.23	1.199	2.51		6.35	22.2	5.825	2.64

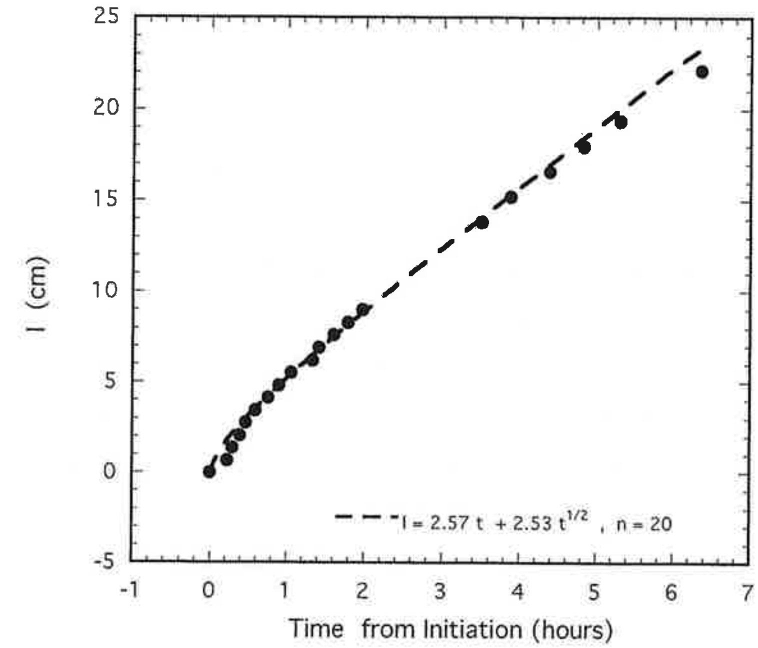

Figure RM3.1. Cumulative infiltration (I) and Philip (1957) parametric function for the deep subsoil on Site RM3.

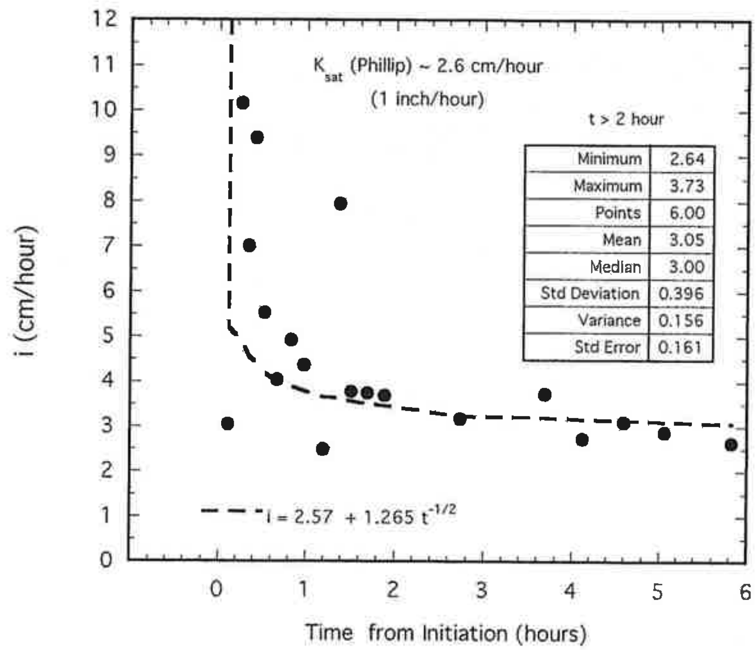

Figure RM3.2. Infiltration rate (i) and Philip (1957) parametric function for the deep subsoil on Site RM3.

Table RM3.2. Description of the "overblown sand and buried soil" profile at infiltration test Site RM3. (From p 114, WRI 5, Shaver and Schuh, 1990). Profile description by Michael D. Sweeney.

Lithologic Description	Thickness Inch (cm)	Depth Inch (cm)
Dark-gray fine sand	14 (36)	14 (36)
Dark-grayish-grown fine sand	16 (41)	30 (76)
Grayish-brown fine sand	6 (15)	36 (91)
Light-brownish-gray fine sandy loam; violent effervescence because of lime accumulation	16 (41)	52 (132)
Light-brownish-gray loamy fine sand; violent effervescence because of lime accumulation	20 (51)	72 (183)
Light-brownish-gray sandy loam; violent effervescence because of lime accumulation	8 (20)	80 (203)
Light-brownish-gray fine to medium sand; slight effervescence	16 (41)	96 (244)
Light-brownish-gray fine to medium sand; slight effervescence	9 (23)	105 (267)
Light-brownish-tray fine sand; iron mottles	9 (23)	114 (290)
Dark-gray fine sand	8 (20)	122 (310)

Table RM3.3. Particle-size distribution for soil horizons on Site RM3. (From p 123, WRI 5, Shaver and Schuh, 1990).

Soil Horizon	Depth to top Inches (cm)	Depth to bottom Inches (cm)	Depth to midpoint Inches (cm)	Sand % (2,000 to 50 m)	Silt % (50 to 2 m	Clay % (< 2 m
A1	0	14 (36)	7 (18)	91.8	5.8	2.4
A2	14 (36)	30 (76)	22 (56)	95.9	3.2	0.9
A3	30 (76)	36 (91)	33 (84)	96.3	3.1	0.6
Ak	36 (91)	52 (132)	44 (112)	74	12.2	13.7
ACk1	52 (132)	72 (183)	62 (157)	86.5	7.4	6.1
ACk2	72 (183)	80 (203)	76 (193)	71.6	15.4	12.9
C1	80 (203)	96 (244)	88 (224)	86.7	10.9	2.4
C2	96 (244)	105 (267)	101 (255)	78.7	12.3	9
C3	105 (267)	114 (290)	109 (278)	92.5	5.1	2.4
C4	114 (290)	122 (310)	118 (300)	95	2.3	2.7